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The International Network for Bamboo and Rattan (INBAR) is a broad-based, multi-disciplinary network that develops, provides and promotes appropriate technologies and other bamboo and rattan solutions to benefit people and the environment. A world-wide network, it connects governmental and non-governmental organizations and the private sector. INBAR provides leadership, coordination and support for research and development. Programs cover natural and cultivated raw materials; genetic resources; processing and utilization; economic and other social aspects; and supporting services. These programs aim to enhance the quality of life of poor and disadvantaged people in developing countries and make favourable impacts on forests and degraded environments.

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The Environmental Bamboo Foundation (EBF) is an Indonesian non-profit organization founded in 1993 in order to promote the wide scope of conservation and development values of bamboo throughout the world. EBF's main programs include agroforestry and watershed rehabilitation, education and training, design and marketing, research, information gathering and dissemination, and networking. The Foundation is based in Bali, Indonesia, and has affiliate non-profit organizations in the United States, the Netherlands and Australia.

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BAMBOO, PEOPLE AND THE ENVIRONMENT

Proceedings of the Vth International Bamboo Workshop
and the IV International Bamboo Congress
Ubud, Bali, Indonesia
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Engineering and Utilization

General Editors
I.V. Ramanuja Rao and Cherla B. Sastry

Volume Editors
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Contents

Foreword

The Vth INBAR International Bamboo Workshop was jointly held with the IV International Bamboo Congress from 19 to 22 June 1995 in Ubud, Bali. The Workshop was organized under the auspices of the International Network for Bamboo and Rattan (INBAR) and the Congress under the banner of the International Bamboo Association (IBA).

Over 600 people from different walks of life - scientists, engineers, architects, designers, crafts people, environmentalists, rural development experts, government officials and plain bamboo enthusiasts - congregated at Ubud to partake in the five-day event of the year. Several representatives of the Indonesian government, international organizations, diplomatic community, and local and foreign media attended the Bali Congress. A large number of scientists participated in the intensive and keen scientific discussions at the 15 scientific sessions.

That the event was such a huge success was largely due to the painstaking efforts put in by a number of people from the organizations involved, particularly by Dr Elizabeth Widjaja, Ms Linda Garland and their team at the Environmental Bamboo Foundation, which was the local host. It also made a great difference that the International Plant Genetic Resources Institute (IPGRI) and the Government of the Netherlands actively supported some of the scientific sessions. It would only be appropriate here to thank all of them.

The Bali Congress was held at a time when bamboo and other forest resources were being increasingly subjected to overexploitation and unsustainable use. This aspect was integral to the theme of the event - Bamboo, People and the Environment. Several papers and posters were presented at the Congress on subjects ranging from bamboo propagation techniques to anatomical studies on pachymorph bamboos, from the role of bamboo in rural development to use of bamboo in religious rituals, from bamboo conservation strategies to use of molecular markers, and from design input into bamboo crafts to bamboo building codes.

In compiling the proceedings, we decided to make a departure from the previous practice of gathering all the papers in one large volume. We felt that segregating the papers presented at the sessions into different subject areas would providea sharper focus, and presenting them as handy volumes would serve the readers better. Consequently, the proceedings are being published in four volumes: Propagation and Management, Biodiversity and Genetic Conservation, Engineering and Utilization, and Socio-economics and Culture. The last volume, Socio-economics and Culture, also contains the list of participants.

We have taken care to ensure that this publication imbibe the essence of the Bali Congress. Dr Elizabeth Widjaja, Dr P.M. Ganapathy, Dr Jules Janssen, Dr V. Ramanatha Rao, Mr. Brian Belcher and Prof. Trevor Williams have very kindly assisted with the technical editing of the papers, and we thank them for their time. We hope that you, as reader, would derive as much satisfaction as we did in bringing *Bamboo, People and the Environment* to you.

IV. Ramanuja Rao
Cherla B. Sastry
General Editors

Preface

This volume is the third of the four-volume series *Bamboo, People and the Environment,* which cover the proceedings of the Vth INBAR International Bamboo Workshop and the IVth International Bamboo Congress, jointly held in Indonesia from 19 to 22 June 1995. It contains papers covering physical and chemical properties, engineering, and utilization aspects of bamboo.

When a call for papers went out for the workshop and congress, more were offered in these subject areas than in any other. This marks a segment of bamboo interest which has expanded tremendously in the past decade and a half since the first international workshop in 1980 was sponsored by the International Development Research Centre of Canada. Then only four papers presented the utilization of bamboo, and they largely dealt with structure, properties and preservation.

The current volume spans interests in: traditional art material, handicrafts and furniture; use of bamboo in reinforcing concrete; as a raw material in paper industry; as well as use of bamboo either as a raw material or in processed form for construction and other uses. A substantial number of papers deal with the use of bamboo in construction.

Reading the presentations leads to several important observations. More important of these are that first, there still exist constraints to be overcome. Economical and eco-friendly preservation of bamboo, integrity of bonding in reinforcement, and stability of jointing are just a few such constraints. Second, building codes and other standards need to be developed and implemented speedily.

These observations provide a strategic agenda for the research community as well as for INBAR. The tremendous interest in low-cost housing -even in typhoon and earthquake areas – has led INBAR to refocus part of its research program to address this area.

P.M. Ganapathy
Jules A. Janssen
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Editors

Traditional Bamboo Housing in Asia: Present Status and Future Prospects

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Abstract

During the last three decades, several studies have been conducted on different aspects related to the structural use of bamboo. Some of these resulted in the development of various preservation methods to protect bamboo from biodeterioration and thereby improve its use, particularly in housing. Subsequently, several bamboo products have been developed for use in house construction.

Yet, many gaps in research still exist in areas such as strength properties and their interaction with other properties, standard testing methodology, and engineering designs with stronger jointing techniques. The need for a simple building code has also been felt for a long time. These issues need to be resolved before the full potential of bamboo as a building material can be realized.

Introduction

An archaeological discovery in Ecuador has traced back the use of bamboo for housing to the pre-ceramic period 9 500 years ago (Hidalgo **1992).** Although no such hard evidence is available in Asia, it is known that bamboo has been employed since several centuries for several purposes, including housing, in South, East and Southeast Asia. It is the single most important organic building material in these regions. It is used in over 70% of rural houses and extensively employed as informal shelter for the urban poor.

At present, there is an acute shortage of housing because of the scarcity of conventional materials coupled with rapid population growth. Some researchers have attempted to find new low-cost construction materials to substitute expensive steel (Ghavami and Fang 1984; Ghavami 1986).

Bamboo has great economic potential, especially in the developing countries, because it can be replenished within a very short time. A critical assessment of the present status and future prospects of bamboo housing would be helpful in exploiting that potential.

Present Status

Species

About 75 genera and 1 250 species of bamboo grow in differentparts of the world, especially in Asia. These range from small grasses to giant plants of over 40 m in height and 30 cm in diameter(Tewari 1992). With regard to economic importance, 19 taxa of bamboo have been accorded high priority and 18 taxa have been marked as important (Williams and Rae 1994), and most of these species are used for building construction, especially in Asia.

Traditional houses

Because of its easy availability, workability and low cost, bamboo is employed for columns, purlins, rafters, trusses, as well as walling and roofing. In Asia, traditional bamboo houses in villages are more or less similar in construction. Most rural houses of the low income group use bamboo for supporting the structure. Even when other materials are used, bamboo forms a major part of the unit. More than 50% of the roofs are a combination of bamboo and some form of thatch. Comparatively richer rural people and urban dwellers employ corrugated galvanized iron sheets for roofs. Some rural houses have walls of mud reinforced with bamboo.

Round bamboo is used for posts, beams, trusses and rafters for supporting and transmitting the roof load. Long, straight and thick-walled culms are selected for these purposes. The roof and wall are generally made of split and flattened culms from the thin-walled varieties. In hilly and coastal areas, the floor is often raised on stilts made of bamboo.

Till a few decades ago, traditional rural bamboo houses in the Indian sub-continent were constructed with emphasis on comfort and space. However, for most of the rural population, the once-cozy bamboo houses have now been reduced to small, flimsy structures, the maintenance of which is a constant drain from the meagre family income (Dunham 1994).

The importance of bamboo as a construction material, particularly for housing, has received renewed attention in recent years. A number of manuals have been prepared to provide guidance to the traditional methods of construction (Munandar 1985; Siopongco 1986). However, these manuals do not provide the requisite technical information for a practising engineer to design with confidence (Boughton 1990).

Physical and mechanical properties

The physical and mechanical properties have been evaluated for some priority/important bamboo species. The density of bamboo is found to vary from 500 to 800 kg/m^3, depending on the anatomical structure such as the quantity and distribution of fibres around the vascular bundles. Density increases from the centre to the periphery of the culm (Sekhar and Bhartari 1960; Sharma and Mehra 1970). It also increases from the base to the top of the culm. The maximum density is obtained in about three-year-old culms (Liese 1986; Sattar et al. 1990; Kabir et al. 1993; Espiloy 1994).

Bamboo possesses high moisture content which is influenced by age, season of felling and species (Kumar et al. 1994). Moisture is at its lowest in the dry season and reaches maximum during the monsoon. A higher content of parenchyma cells increases the water holding capacity (Liese and Grover 1961). Unlike wood, bamboo starts shrinking above the fibre saturation point (Rehman and Ishaq 1947). The shrinkage is in diameter as well as in wall thickness and appreciably higher than in wood. Because of the differences in anatomical structure and density, there is a large variation in tangential shrinkage from the interior to the outer-most portion of the wall (Sharma and Mehra 1970). This leads to drying defects, such as collapsing and splitting, and affects the behaviour of bamboo during pressure treatment.

Bamboo possesses excellent strength properties, especially tensile strength. Most of the properties depend on the species, and the climatic conditions under which they grow (Sekhar and Gulati 1973). Strength varies along the culm height. Compressive strength increases with height, while bending strength has the inverse trend (Sekhar and Bhartari 1960; Liese 1986; Espiloy 1987; Janssen 1987; Sattar et al. 1990; Kabir et al. 1991,1993). An increase in strength is reported to occur at 3-4 years, and thereafter it decreases (Liese 1986; Sattar et al. 1990; Kabir et al. 1993; Espiloy 1994). Thus, the maturity period of bamboo may be considered as 3-4 years with respect to density and strength. Maturity of culm is a prerequisite for the optimum utilization of bamboo in construction and other structural uses.

Strength data of some of the priority/important species along with two timber species are given in Table 1. It is evident from the table that bamboo is as strong as wood, and some species even exceed the strength of timber species like Tectomgrandis(teak) and *Shorea* robusta(sa1). Janssen (1988) has reported that the ratio between the ultimate compression and the mass per unit volume for dry bamboo is higher than that of dry wood. The reason is attributed to the higher cellulose content of about 55% in bamboo compared with about 50% in wood.

Some studies have been conducted on the relationship between anatomical structure and physical and mechanical properties on the one hand, and the technological characteristics, behaviour in processing and product quality on the other (Janssen 1981; Espiloy 1987,1992; Widjaja and Risyad 1987; Abd. Latif and Mohd. Zin 1992; Liese 1992). Density of bamboo is closely related to the relative proportion of vascular bundle and ground tissue, and plays an important role in influencing the mechanical properties. This explains the variation of strength along the culm height. Permeability, which is affected by the anatomical characteristics, influences moisture movement and thereby treatability. In wood, the chemical by-products polyphenol, resin and wax influence properties such as shrinkage, durability and gluability. Nothing in this regard is known for bamboo (Liese 1992).

The earliest tests on strength were conducted on *Dendrocalamus strictus* in India (Limaye 1952). Since then a need was felt for standardizing the testing methodology (Sekhar and Rawat 1956), and an Indian standard was later formulated for testing bamboos (Anonymous 1973). Since then, different countries have adopted different testing methods with widely varying conditions, leading to the present situation wherein most of the strength data reported from different countries cannot be compared.

Natural durability

The chemical constituents present in bamboo do not have enough toxicity to impart any natural resistance to fungal or insect attack. Furthermore, the presence of a large amount of starch makes it highly susceptible-to attack by staining fungi and powder post beetles (Gardener 1945; Mathew and Nair 1990; Gnanaharan et al. 1993). Thus, the natural durability of bamboos is very low and dependent on climatic conditions and nature of use.

Observations based on the performance of full-sized structures have indicated that untreated bamboos may last up to five years under covered

Table 1: Important strength properties of some bamboo species of different countries

Species	Country	SG	MC (%)	MOR (kg/cm²)	MOE (kg/cm²)	MCS (kg/cm²)	Reference
Bambusa bambos	India	0.65	15.5	674	65 000	483	Gulati & Singh 1989
B. bambos	Indonesia		15.5	905		421	Prawirohatmodjo 1990
B. bambos	Puerto Rico	0.58	10.0	918	120 000	367	Heck 1956
B. blumeana	Philippines	0.50	green	308	86 400	349	Espiloy 1985
B. blumeana	Malaysia	0.56	green	115	42 600	273	Abd. Latif & Mphd. Zin 1992
B. nutans	India	0.72	16.0	545	85000	508	Gulati & Singh 1989
B. nutans	Bangladesh	0.68	12.8	877	129 000	718	Sattar et al. 1995
B. polymorpha	India	0.66	13.9	355	44 000		Gulati & Singh 1989
B. polymorpha	Bangladesh	0.68	12.5	483	75 000	499	Sattar et al. 1992
B. tulda	India	0.71	14.9	506	82 650	615	Gulati & Singh 1989
B. tulda	Bangladesh	0.72	12.5	766	140 000	582	Sattar et al. 1992
B. vulgar-is	Bangladesh	0.68	12.5	762	146 000	458	Sattar et al. 1992
B. vulgaris	Indonesia		17.0	860	-	254	Prawirohatmodjo 1990
B. balcooa	Bangladesh	0.74	12.5	803	109 000	540	Sattar et al. 1992
Dendrocalamus asper	Indonesia		15.0	1050		322	Prawirohatmodjo 1990
D. strictus	India	0.72	10.7	1 184	159 490	645	Sekhar & Gulati 1973
D. strictus	Bangladesh	0.68	12.8	1002	148 000	631	Sattar et al. 1995
Melocanna baccifera	Bangladesh	0.66	12.0	723	232 000	498	Sattar et al. 1990
Tectona grandis	India	0.60	12.0	959	119 600	532	
T. grandis	Bangladesh	0.59	12.0	1008	131000	513	Yakub et al. 1978
Shorea robusta	India	0.71	12.0	1318	162 045	641	
S. robusta	Bangladesh	0.78	12.0	1037	128 000	532	Yakub & Bhattacharjee 1980

SG= Specific gravity, *MC* = Moisture content, MOR = Modulus of rupture, MOE = Modulus of eleasticity, MCS = Maximum crushing strength.

conditions (Tewari 1981). Data on natural durability under ground contact and exposed conditions are very limited. The grave-yard test on some Indian bamboos shows that the average life of untreated bamboos is less than two years (Purushotham et al 1954; Kumar et al 1994). Thus, bamboo falls in non-durable category.

Drying property

Green bamboo may contain 100-150% moisture. Because of the presence of hygroscopic materials in the parenchyma, bamboo takes a longer time to dry when compared with wood of similar density (Sekhar and Rawat 1964;Laxamana 1985). Kiln drying at high temperatures causes crack and collapse in round bamboos (Rehman and Ishaq 1947; Sattarand Bhattacharjee 1993). Air drying method is, however, suitable for drying round bamboos and may take 6-12 weeks, depending on the initial moisture, drying season and wall thickness. Defects such as collapse because of excessive and non-uniform culm shrinkage is a major problem in some species, especially in immature culms. It is thus recommended that only mature bamboos be used (Sharrna 1988). Split bamboos can be dried both by air and kiln drying methods without any difficulty.

Preservative treatment

Low durability is the major drawback of bamboo in structural use, and several methods have been developed to remedy this. Soaking bamboo in water is a traditional method widely practised in Indonesia, Vietnam, Bangladesh and other countries (Sulthoni 1987). Soaking leaches most of the starchy materials and makes bamboo resistant to borer, though not to termite and fungi. Chemical preservatives offer the best protection against termite and fungi. A comprehensive study on steeping, sap-displacement, diffusion, hot-cold bath and pressure processes has been conducted in India (Kurnar et al. 1994). The diffusion process and the Boucheri process are suitable for the treatment of green bamboos (Narayanmurti and Bist 1947; Singh and Tewari 1981; Abd. Latif et al. 1987). Dry bamboos can be treated using both non-pressure and pressure methods. A wide range of preservatives are available to suit different conditions.

The performance of treated bamboos depends mainly on the location of use and the preservative employed. Bamboo treated with copper-chrome-arsenic (CCA) shows some decay after 15 years in exposed conditions. The performance in partially exposed or covered conditions is much better.

A CCA-treated, low-cost bamboo house in India was found intact without any damage even after 40 years of service (Kumar et al. 1994). In Colombia, a bamboo house with ceiling and walls plastered with cement mortar is reported to have lasted more than 90 years (Hidalgo 1992). Preservatives can thus impart longevity to bamboo and thereby improve its performance in housing.

New products

Apart from the traditional uses in round and split forms, bamboo continues to find new uses in more exacting applications through high-quality products. Ply-bamboo is one such product which was first developed in China during the Second World War. Following further research, various types of panel/composite boards, laminated boards, particle boards, fibre boards, etc. have been produced in China (Zhu Huanming 1994). Bamboo mat board is being manufactured in China, India, Thailand and Vietnam. These products can be utilized in building construction. Woven bamboo mat, bamboo parquet, bamboo fibre reinforced plastic, etc. are also being studied for use in constructing houses. The manufacturing processes of such improved products, however, require expensive machinery and skilled labour. The socio-economic aspects of these products need further studies for their wide acceptance.

Future Prospects

The global shortage of housing materials, especially in the developing countries, is such that it warrants serious consideration. To keep pace with the population growth and to replace old houses, about 75 million units need to be constructed each year in Asia alone. The short supply of timber and other conventional construction materials accompanied by rising costs make it imperative to increasingly use bamboo for housing. In this regard, bamboo has the following advantages and disadvantages (Mathur 1981; Janssen 1987,1988,1990; Mishra 1990).

Advantages

- As bamboo grows very rapidly, it can be cultivated for quick and continuous return on capital.
- It can be planted easily in homesteads and harvested at the time of need without any additional expenditure.
- It possesses good mechanical properties and a high strength-to-weight

ratio. It can thus make lighter but stronger structural components for houses at comparatively low cost.

- Its surface is smooth, clean and hard, enabling easy use for specific purposes without much processing and consequently avoiding wastage.
- It can be dried with a simple method of air drying and treated with preservatives to enhance service life.
- Culms can easily be split into strips with simple tools even by workers with a low level of skill.
- Because of its lightness, bamboo house suffers very little damage from earthquake.
- Temporary and quick construction in disaster-prone areas is possible in cases of emergency.

Disadvantages

- Bamboo is not cylindrical throughout, but tapered.
- The hollow form makes jointing difficult.
- It is easily perishable and thus needs preservative treatment to obtain a reasonable life-span.
- When compared with wood, it has low parallel to shear strength and low resistance to splitting.
- In spite of many favourable qualities, bamboo is still considered by many housing experts as a short-life material suitable only for temporary shelters. In recent times, however, bamboo is beginning to receive international attention consistent with its centuries old heritage and widespread use. Although significant breakthroughs have been achieved in some respects, there are many gaps in research, especially regarding the structural use of bamboo.

Gaps in knowledge

- Lack of information on the strength properties of several species.
- Inadequate knowledge on the effects of anatomical structure, physical and chemical properties, growth factors, seasoning, and preservation on strength properties.
- Lack of a standard testing methodology for evaluating physical and mechanical properties.
- Dearth of engineering designs with stronger fastening devices for different types of construction.
- Absence of a code of practice that would enable engineers to design safe

and cost-effective structures with the same confidence as they would with recognized engineering materials such as steel and timber.

- Inadequate information on the economics of various aspects of processing, particularly preservation.
- Insufficient data on the economics of construction of different types of bamboo housing.

Conclusion

The gaps in knowledge mentioned above need to be filled before a fuller exploitation of bamboo for housing can be realized. To this end, regional projects, which allow sharing of facilities and knowledge, need to be formulated. An effective mechanism may be developed for the quick dissemination of research results to those who need them. To avoid duplication, this can be done through an international network. Rural-based housing entrepreneurship should be developed to take care of the technical aspects, particularly of preservation and engineering design, The cost of processing, including machinery and tools, may be subsidized to encourage the potential users as well as entrepreneurs. The question whether bamboo can play its deserved role in housing will be answered by the level of success achieved in these areas.

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Bamboo as a Building Material in Japan: Transition and Contemporary Use

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Abstract

This paper traces the intimate association of the Japanese with bamboo from time immemorial. Being easily available and requiring little processing, bamboo was the most widely used natural resource for a variety of uses-household and sporting articles, objects for religious purposes, housing, furniture, etc.

In Kyoto, bamboo was used in the wall foundation of the Horyuji temple, built about 1200 years ago. Old paintings in this town show that bamboo was used for walls, roofs and doors in the l6th-18th centuries. In the years just before World War II, use of bamboo diversified and it emerged as an important building material. Cultivation of bamboo and training the culms to various shapes became very popular. Bamboo reinforced concrete and bamboo boards also were developed during this period.

The paper notes the revival of interest in bamboo, mainly for houses and furniture, owing to the recognition of its environment friendliness. To sustain this interest, it is necessary to develop efficient preservative treatment methods and innovative designs.

Introduction

Bamboo is a plant that everyone in Japan is familiar with. There are several varieties of bamboo found throughout Japan-from Hokkaido, the northern-most prefecture, to Okinawa, the southern-most one.

Bamboo is easy to split vertically and is very elastic. Because of these characteristics, it is used for making household articles, toys and religious objects. It is not only used as an everyday material, but also worshipped as a religious object based on animism. The Japanese feel a strong bond with bamboo, as can be found in Japanese mythology. For example, according to myths, a goddess used a piece of bamboo when she cut the umbilical cord; this custom is still in practice in some parts of Japan. In the folklore of Kaguyahime, a princess was born from a bamboo culm. This story says something about the power of bamboo. The Japanese believed that a power existed inside the bamboo culm.

The Japanese still use bamboo on special occasions. For instance, on the night of 7 July when the Star Festival of Tanabata is held, bamboos are decorated with colourful paper, on which wishes are written down. During the New Year season, a bamboo flower vase *(kadomatsu)* is put in front of the house entrance to celebrate the *New* Year, *Kadomatsu,* made of a couple of pieces of bamboo that are cut into sharp angles, is supposed to be where God descends.

Since the Japanese have a close relationship with bamboo, both physically and spiritually, it is natural for them to use it as building material. This paper reports on the evolution of bamboo as a building material and its contemporary use in Japan.

Bamboo in Towns and Houses

Bamboo was originally used in local architecture mainly because it was readily available and did not require advanced tools and skills. Bamboo came to be used in various types of houses and various parts of houses. The traditional use of bamboo in Kyoto, Japan, is briefly described below.

Bamboo in towns

Old paintings of Kyoto town in the 16th-18th centuries show how bamboo was used in those days: for doors, walls and roofings, sometimes directly and sometimes mixed with other natural materials such as grass and wood. The paintings clearly indicate that bamboo was utilized with greater variety then than it is today.

Some parts of Kyoto still look as they did in the old days, but bamboo is not seen as frequently as before, although bamboo fences, walls and small windows in town are still well-managed by the residents.

Bamboo inside houses

Inside houses, one can see bamboo used for ceilings, floors, pillars, walls, windows and sliding doors. The climate in the country does not allow houses to be made of bamboo alone. Japanese houses have traditionally been made from a mixture of wood, mud, bamboo, grass and paper. Wood has softness and warmth, while bamboo is straight, cool and sensitive. Materials with such qualities were often preferred over manufactured materials such as steel and glass. Combinations of wood and bamboo bring forth remarkable spatial qualities: the room or house for tea ceremony being a good example.

In old Japan, natural beauty was more appreciated than the beauty created by human beings. People tried to enhance the natural beauty of bamboo by using it in various ways. In the 14th-15th centuries, some people such as Kamono Chomei and Jogakuu Syonin made elaborate bamboo houses that came to be looked upon as an expression of a new culture. These are the beginnings of tea houses and Sukiya style houses. The use of natural materials with elaborate skills and design had been popular until the 17th century, when the Western culture entered in Japan. Since then, most Japanese have not looked at natural resources as they did before.

At the time of World War II, there was a general resource crunch. Therefore, many studies were conducted to seek alternative natural resources, including bamboo. Bamboo-reinforced concrete was one result of these studies. After the war, however, utilization of bamboo and indigenous materials were neglected, and they were eventually replaced by industrial materials.

Today, majority of Japanese houses are in the so-called modern style, and the needs of people have changed. To meet people's preferences, bamboo companies have developed various articles, such as bamboo veneer boards. Bamboo itself is cheap; but the processing is so expensive that the cost of the final products are quite high.

History of Bamboo as a Building Material in Kyoto

Bamboo laths were used in the foundation of wall at Horyuji temple in Nara which was built 1 200 years ago. When the ruins at Nagaoka were investigated, bamboo used as drainpipes were discovered. The history of bamboo in Kyoto dates far back to the Heian period (8th-12th centuries) when bamboo came into use for several purposes. Bamboo's use as a building material came later. Below is a brief history of bamboo as a building material in Kyoto since the Meiji Era.

- The Meiji Era to the Taishoo Era (19th-20th centuries)
  - The bamboo mostly used as material was Phyllostuchys bambusoides Shieb. et Zucc. (Madake).

- The bamboo Phyllostachys pubescens Mazel ex Houzeae de Lehaie (Mousou-chiku), was grown mostly for its shoots.
- Bamboos with square culms were produced.

- Pre-World War days
  - High demand for *P. bambusoides* to make liquor barrels.
  - Production of *P.pubescens,* mainly for fishing materials, increased.
  - Design of building materials and manufacture for trial; production of bamboo with different culm shapes using templates, and establishment of a shop for bamboo building materials.
  - Bamboo-reinforced concrete studies were conducted because steel became expensive.
  - Bamboo board was developed.
- Post-World War days (1950s)
  - Most *P. bambusoides* stands came into bloom all at the same time and died.
  - Liquor barrels made of bamboo were replaced by glass containers.
  - Bamboo as a fishing material was replaced by fibreglass and plastic.
  - Increase in the production of bamboos with different culm shapes.
- After the 1950s
  - Increased demand for bamboo designed for traditional Japanese style houses, because of renewed interest of traditional culture.
  - Attempt to design new, modern Japanese style houses.
  - Several new bamboo boards developed.

Demand for bamboo as a building material saw an increase after the 1950s. The reason is that the development of new bamboo boards and the renewed interest in Japanese lifestyle took place simultaneously. The introduction of bamboo lamination technique and bamboo plywood also proved helpful. Nevertheless, the use of bamboo as a building material remained, and still remains, limited. One major reason for this is that bamboo materials are often damaged by insects, while another is the increase of western style houses and prefabricated houses.

Future Prospects for Bamboo as a Building Material

Although bamboo used to be a material that was indispensable for the Japanese, it has gradually disappeared from Japanese lifestyle asthe way of living changed. Nowadays, as far as ordinary houses are concerned, bamboo is not used any more. Even in everyday articles, plastic has replaced bamboo. It seems that prospects for bamboo are becoming less and less promising. According to the bamboo shop owners in Kyoto, however, although the demand for bamboo is not high, it is steady because bamboo is still used often in commercial buildings or high-class houses including tea houses, traditional style hotels, and restaurants where people prefer to feel a Japanese atmosphere.

Recently, environmental problems have become the concern of the world. This gives an opportunity to consider, or rather reconsider, housing based on environment-friendly systems. Traditional housing systems should again be revived, albeit in a way that suits modern needs. Bamboo is easy to raise and fast in growth. By considering uses that require "less processing", as still seen in other Asian countries, bamboo can be utilized as an ecologically safe material.

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Traditional Bamboo-based Walling/Flooring Systems in Buildings and Research Needs

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Abstract

This paper discusses various techniques of using bamboo in traditional wall construction – as whole culms, half round, split and interwoven into mats, and flattened and interwoven. They are used either directly or as a base for plaster. Their structural efficiency depends on how they are integrated and braced to the basic skeleton or frame of the structure. The jointing systems in bamboo walling as a whole must be improved to increase their resistance to strong winds and earthquakes. User and environment-friendly preservative techniques must be standardized and propagated in order to improve the durability of traditional bamboo walls against decay and insects.

Bamboo-based composites could be potential walling material, with scope to develop various walling systems as sheathing or skin. This requires development of economical, weather-resistant adhesives suitable for making composites.

Although bamboo is not as widely used for flooring as for walling, it has the potential for being used in the form of floor boards, decking and underlayment. Research is needed for developing bamboo board flooring materials.

Bamboo can also be used in urban/semi-urban construction as structural reinforcement in place of steel. Strategic research is required to find ways and means of improving the bonding of bamboo as reinforcement with cement concrete, cement mortar and soil cement.

Introduction

Shelter for the homeless continues to be a serious problem throughout the developing world. In India alone, it is estimated that there will be a shortage of 39 million dwelling units (Mathur 1987) by the end of this century. Tremendous growth in population has increased pressure on availability of conventional building materials. This has made the task of meeting housing shortage an uphill task. The depletion of forest resources and checks imposed on their harvesting have led to severe shortage of wood raw material and, in some countries, wood has gone beyond the reach of the poor for building construction. The rural housing sector in tropical developing countries still depends to a great extent on the availability of materials like unprocessed wood, mud, bamboo, thatch, etc. Using these materials, construction techniques have been developed over the years without depending upon high-energy materials like burnt bricks, cement, steel, quarried stone and processed wood. Among these, bamboo is an important material for low-rise rural and semi-urban housing in parts of India, Indonesia, China, Peru, Chile, Ecuador, Colombia and a few other countries.

Because of its inherent properties like renewability, easy workability and flexibility, bamboo is accepted as a versatile construction material. Unfortunately, however, it has not received the wider attention it deserves as a construction material and therefore, engineers tend to use high-cost materials like steel, cement, etc. to meet housing requirements. With the potential to increase bamboo resources brightening by improved propagation techniques, there is hope that the future demand for housing can be largely met by bamboo. Many researchers have, in addition, demonstrated the possibility to conserve bamboo resources through better utilization techniques. Against this background, the traditional methods of using bamboo in wailing and, to a limited extent, flooring are discussed here and suggestions made for future research.

Bamboo, either in round or split form, has been popular for traditional housing in several developing countries. It is normally used as a basic skeleton or as framing and walling along with materials like wood, brick and mud. It is particularly popular as a walling material, and used either directly or as base for plaster in low-rise buildings. As compared to brick or stone masonry wall, bamboo wall has the advantage of being lighter and therefore requiring nominal foundation. Further, it is eminently suited to resist forces of nature like earthquake and high winds. Bamboo houses are, therefore, particularly suitable for disaster areas and rehabilitation initiatives. Techniques for rational utilization of bamboo in housing have been developed over the years, depending upon the species of bamboo available, specific needs and the level of sophistication of local craft. There is, however, scope for further improvement in these techniques.

Bamboo is used in walls either directly or indirectly in almost all rural houses supporting light roof of thatch, or tiles as sheet roofing, In some types of houses, bamboo is also used for flooring, especially in stilt or raised type construction.

Traditional Bamboo Wall Construction Techniques

A wide variety of techniques is in existence for using bamboo in wall construction in different countries, developed mostly by rural craftspersons and tribal people. Such techniques in Latin American countries and India reflect a high class craftsmanship and understanding of the intrinsic properties of the material. These are discussed briefly here.

For bamboo wall construction, a basic skeleton is provided which consists of wood poles or sawn wood framework, or round bamboo posts which serve as support for wall in the form of infill or cladding. Very rarely, bamboo walls bear direct roof loads.

Bamboo is used extensively as walls, partitions, screens which may be broadly classified as permeable, semi-permeable and wattle walls. In permeable wall systems, bamboo is used directly in round, split or flattened form, or as a mat, or as combinations of these. In semi-permeable wall system, mesh work of split or matted bamboo serve as base for mud-stabilized lime plaster. It has also been used as reinforcement in rammed earth walls.

Most direct method of constructing a bamboo wall is by employing bamboo mat, plaited bamboo splits, flattened bamboo mats, etc. fixed to round bamboo culms or wooden frame work (Anonymous 1972): This is a dry type of construction, and the skill of craftspersons comes into play since various mat weave patterns and designs are possible. Thin or thick bamboo mats are used for this purpose. It is possible to prefabricate the wall cladding by weaving mat into split bamboo framework. Thin bamboo mats may be further stiffened with strip and bamboo beading. As the structure is light, the wall does not require any foundation, except for a raised basement to protect against moisture and insects. In Indonesia, bamboo boards *(pelpuh* or flattened bamboo) are used directly in vertical fashion, pinned to the wooden framework. Many tribal houses are built in India using different bamboo mat weave, sometimes interwoven or with split bamboos (Ranjan et al. 1986).

Other dry types of bamboo wall construction consist of whole bamboo culms placed side by side vertically, as in Thailand and Indonesia. Half round culms are also used by nailing the same either vertically or at 45° to the frames.

Unless protected by roof overhangings, bamboo mat or board walls deteriorate rapidly because of direct sunlight, weathering, and biological degradation caused by fungi and insects. Since bamboo mat or board walls serve only as cladding, there is the likelihood of its being blown by strong winds. On the other hand; dry bamboo construction being light, may be suitable for disaster areas and regions susceptible to earthquakes. They are also admirably suited as transit shelters.-It should be possible to increase their structural efficiency and life by suitable architectural/engineering design and preservative treatment.

An improved version of bamboo walling system, which can be considered semi-permeable, is the plastered bamboo mat or board wall. Plastering provides better insulation and protection against fire and weathering. Many variations have been attempted. Plaited bamboo splint can serve as base for mud plaster or stabilized mud, as practised in India. In Indonesia, thin bamboo mats are nailed on both sides of wooden posts or round bamboo poles driven into the soil. The mats are then finished with stabilized mud plaster, leaving an air space in between. Sometimes, instead of bamboo mats, bamboo boards (pelpuh) are pinned to horizontally placed round bamboo members at regular intervals which, in turn, are morticed into bamboo posts. They are made weatherproof by closely plaited matting, and the outer side plastered with stabilized mud.

In Colombia and Ecuador, split bamboo (estrilla) is widely used to connect to bamboo studs, spaced suitably and finished with plaster. Colombia has developed excellent techniques for stud wall construction similar to wood frame houses prevalent in USA (Hidalgo 1992). These houses consist of round bamboo studs, spaced at 45 cm c/c with bamboo or wood sole plates and bamboo wall plates. The studs are covered with flattened bamboo board on either side and finished with cement plaster. This is known as bamboo board wall. Air gaps are provided in between plastered bamboo board skins which serve as insulation. In other wall types, bamboo strips of 4 to 5 cm are fixed horizontally, spaced at 5 to 7 cm on both sides, and the space between the strips filled with mud and straw. Final finishing is with mud and plaster, This system is known as mud filler wall *(bajareque)*. In Colombia, since walls are made of fairly durable species like *Bambusa* guadula, the life of such houses is known to be long. This wall system, which is heavier than bamboo board wall, has bamboo boards or strips serving as sheathing in place of plywood or wooden board as in stud wall framing. When suitably braced, bamboo stud wall (either bamboo board or mud filler type) is very strong and capable of resisting high winds and earthquakes. Countries not endowed with rich bamboo resources cannot afford bamboo stud wall construction since bamboo requirement for unit area is rather high in this system. This type of construction also requires skills not generally available elsewhere.

Another distinct, traditional bamboo wall is the wattle wall, also known as wattle and daub, lath and plaster, etc. This type of construction is found in Peru, Chile (Quincha) and some parts of India. Unlike plastered bamboo mat wall, the wall consists of bamboo lath as a base for stabilized mud plaster with organic fibres, cow dung, etc. Plaster (stucco) is applied outside and finished with lime wash to give a typical stucco appearance. Bamboo lath consists of bamboo strips and round bamboo fixed to a load-bearing wooden frame work. Normally, the wooden frame is exposed and the wattle acts as the infill. Various designs of lath are in use: “sprung strip” and woven construction appear to be most popular type of lath. In India, whole culms or half culms are used as lattices known as jaffri, with rather larger interstices filled with mud and straw and finished with mud plaster. Wattle walls, unlike dry wall construction, provides protection against weather and insulates the house against fire. They have performed well against earthquakes.

Sometimes, bamboo has also been used as reinforcement for stabilized, rammed earth walls. The reinforcement may not be appropriate here as it is doubtful that adequate bond exists between mud and bamboo for any composite action.

Some Observations on Traditional Wall Systems

It is evident from the above review that traditional bamboo wall systems by themselves are not load-bearing, and that they do not transmit roof loads directly but merely serve as cladding or infill. No information is available on their ability to transmit transverse forces caused by earthquake and rocking by wind Performance of any bamboo wall - permeable, semi-permeable or wattle type - against wind or earthquake depends upon how they are integrated into the skeleton or frame, which ultimately transmits loads. In the case of permeable and semi-permeable walls such as mat board or mat/board plastered walls, forces resulting from wind pressure have to be transmitted through wall to the framework of posts and columns, or posts of round bamboo and poles. Similarly, structural performance of wattle wall depends on how it is attached to the framework. In the case of bamboo stud wall or bamboo board wall (as prevalent in Colombia), they can be described as fully load-bearing structural walls capable of transmitting forces from dead loads, wind and quakes. Of course, this depends on the size and species of bamboo, as well as on corner bracing. Hence, the detailing of traditional wall systems needs to be closely examined with regard to the cladding used, and how they are detailed and jointed with the basic skeleton system, in order to suggest improvements. Standardization and the gathering of feed-back on performance of various wall systems against wind and earthquake are essential.

Since traditional bamboo wall systems are light and flexible, one should expect that they perform reasonably well under earthquake conditions. However, it cannot be said that the same wall systems can resist wind loads efficiently as lightness and flexibility can be disadvantageous against strong winds. Hence, the performance depends on joints in the skeleton, method of securing walls to the skeleton, and how the skeleton itself is secured to earth/foundation and bracing.

On the whole, while there is a lot of information on wall construction techniques, very little information is available on their performance and behaviour under wind and earthquake forces. Architects and engineers, with a few exceptions, do not appear to have paid sufficient attention on these aspects. Nevertheless, performance of bamboo housing under high winds and typhoons has attracted attention of some researchers (Boughton and Chavez 1988), particularly regarding the efficiency of joints and types of failure. Information of bamboo jointing techniques, such as lashings (using rope) and pins, in relation to their load-bearing capacity is scarce. Janssen (1981) has made systematic survey of various jointing techniques with reference to bamboo trusses, covering traditional techniques like lashing, pinning, bolting etc. and their relative performance, and examining new jointing techniques. Some of these techniques should prove useful while working out improvements in traditional walling systems. Considering that bamboo has a tendency to split easily when nailed or pinned, more efficient ways of jointing bamboo for walling purposes require to be studied.

Another important aspect that needs attention for improving traditional bamboo walling system is treatment against decay, insects and other biological agents. With the exception of a few species, bamboo is highly perishable (Liese 1980). It is easily attacked by termites and insects, decays fast in humid atmosphere and wet conditions. Frame members, such as posts which come in direct contact with soil, in particular are highly susceptible to decay and termites. In such conditions, durability of the skeleton depends not only on natural durability of the material, but also on how well detailing of various elements has been worked out. If the detailing is done in such a manner that accumulates moisture and provides no scope for drying, the deterioration will be faster. In rural housing, especially in poor constructions, detailing is often neglected resulting in quick deterioration of walls. Wall claddings such as matting and boarding (unplastered or plastered) are vulnerable to termites and decay. Even wattle walls are susceptible to decay and termites. Although a wealth of information exists on the preservative treatment techniques of round or split bamboo (green or dry), the techniques have not been adopted widely in rural houses. This may be due to reasons such as high cost and non-availability of preservative chemicals locally, difficulty in treating at site and ignorance. Moreover, many of the preservative chemicals are too hazardous to be used in rural houses. Incorporating chemicals in mud plaster and soil could particularly be risky. Therefore, environment and user-friendly techniques particularly suitable for rural use need to be propagate-d. A uniform code on preservative chemicals for use in bamboo building construction could perhaps be developed.

Bamboo walling systems, like brick or stone masonry, can be plastered to impart fire resistance, while wood or wood-based materials need to be specially treated against fire. This is a major advantage and plastering techniques can be standardized for use in bamboo matting and boarding. If preservative-treated bamboo is economically available, there is no reason why plastered partitions or bamboo infill should not find wide use in urban housing to replace steel.

Different and specific techniques for constructing permeable/semi-permeable bamboo walls have been developed to suit particular needs of a region, based on the species of bamboo available locally. For instance, the type of woven or plaited mats for walls depends on such bamboo characteristics as wall thickness and internodal length. Hence, grading of bamboo should be attempted for wall construction, for matting and laths, and for wattle construction.

To sum up, the following aspects require attention for improving traditional bamboo walling systems:

- Structural behaviour and performance of different walling systems subjected to wind and earthquake forces;
- Standardization and improvement of jointing techniques;
- Standardization of preservative treatment techniques, keeping in view environment and user-friendliness;
- Developing grading rules for bamboo for their use as mat, board, lath, etc. in wall construction; and
- Developing standards on traditional walling systems.

Research Needs in Bamboo Wailing

Improvements and modification to traditional bamboo walling have attracted the attention of many researchers. In particular, several experimental low-cost houses have been constructed, incorporating improved bamboo walling systems. Experimental houses have also been designed and constructed to demonstrate enhanced durability, improved structural performance and efficient conservation of bamboo raw material. It has earlier been demonstrated that bamboo mesh-mud plaster walls are not only durable, but also require less bamboo raw material (Purushotham 1963, 1965). It has also been observed that treated bamboo as a base for mud plaster can last for more than 15 years (Tewari 1992) in dry conditions. However, there appears to be no information on the composite action of mud/bamboo mesh walls as a structural unit. They can best serve as infill walls. It has also been demonstrated that split bamboo can be combined with cement mortar or soil cement (Chadda 1956; Subramanyam 1984) to obtain a composite material suitable for structural and semi-structural purposes.

Similar to reinforcement, bamboo mesh has been used to reinforce cement mortar under the name 'Bamboocrete' (Sundararajan and Kacami 1979; Mansur and Aziz 1984). Systematic work is however, required in the area of bamboo reinforcement with cement mortar and soil cement for walling purpose. Special attention has to be paid on shrinkage/swelling of bamboo and its long-term behaviour as reinforcement. Techniques suggested for stabilizing bamboo by various coatings are rather superficial. No fundamental studies have been attempted on the stabilization of bamboo as reinforcement. There is, however, no doubt that the use of cement in place of mud for mortar will improve the weathering properties of bamboo cement mortar composites, which can be further enhanced by suitable surface coating and incorporation of water repellents.

Bamboo as reinforcement for cement concrete has always fascinated engineers. It has been demonstrated with varied degree of success that bamboo can replace steel in reinforced cement concrete for structural purposes like beams and slabs (Masani et al. 1977; Bajaj 1981; Ghavami and Hombeek 1981; Krishnamurthy 1990; Hidalgo 1992). Bamboo-reinforced cement concrete wall will be, however, expensive as compared with other traditional bamboo wall systems. It may find use as precast all-plank infill wall (Krishnamurthy 1990). Split bamboo appears to be better than whole bamboo culms as reinforcement. Bamboo-reinforced cement concrete wall may find use in urban housing, but will be beyond the reach of rural poor, as cement is an expensive material. Bamboo-reinforced concrete is yet to find extensive use and acceptance. Instability of bamboo owing to shrinkage and swelling leads to cracks and loss of bond, which in turn reduce the structural efficiency of the material. Various coatings and other means tried have not been altogether useful in overcoming this problem. Twisted bamboo strands from outer portions of the culm (Hidalgo 1992) have been suggested to improve bond between bamboo reinforcement and concrete. The fundamental aspects of stabilizing bamboo, the nature of bond between bamboo and concrete, and the durability of bamboo in a matrix of concrete in the long run need to be studied at length.

Bamboo Composites in Walling

As discussed earlier, bamboo finds use in walling either as whole culm or in split and woven mat form and, to a limited extent, as structural reinforcement. From the point of view of conservation of material, slivers, particles and chips can be converted into composite panel material similar to plywood, particle board and fibre board. Studies have shown that certain species of bamboo are suitable for manufacturing particle boards, including cement-bonded particle board. Particle boards and fibre boards have limitation as building material since their performance, like wood particle board, is limited under exposed conditions, especially when it is bonded with urea-formaldehyde resins (Jagadeesh 1994). It can at best be used in interior applications like partitions. Probably cement-bonded particle board may find use in exterior applications such as wall cladding. Bamboo mat, strip or curtain boards are used in China for making shutters (Zhang 1992).

Bamboo mat board is now manufactured in India, using woven mat based on a technology developed at the Indian Plywood Industries Research and Training Institute (IPIRTI) (Zoolagud 1990). It has been demonstrated that they can effectively be used for exterior applications like roofs and silos (Damodaran and Jagadeesh 1994). It can also be used for walling as cladding, structural sheathing or even stressed a skin panel similar to structural plywood. Unlike woven mat, mat board can be nailed to wood frame work or studs as sheathing skin in wooden frame house construction Because of the high shear modulus, mat boards will act as bracing to resist racking in the same manner as plywood. Further, it is also possible to use mat boards as skin in stressed skinwall construction, where mat boards can be glue-nailed to wooden frame work to act as a composite element which can resist bending and direct load. The high cost of mat board may be a deterrent in its wide use in housing. Further studies are required to standardize design of mat board for sheathed stressed skin type walls. Research is also required in finding low-cost adhesives which, at present, are based on petroleum resources. Studies are also required to find efficient ways of joining mat board to whole bamboo culms, if used as framing. In general, a composite material like bamboo mat board has scope as a structural material. It is particularly suited for prefabricated and dry type construction.

Bamboo as Flooring Material

Compared to the use of bamboo for walling, it is not widely used in flooring. However, in raised and stilt type constructions, whole bamboo culms have been used as principal and secondary floor rafters to support split bamboo (estrilza), bamboo mat or bamboo board. There is scope for improvement in this application since bamboo-based panel materials, such as bamboo mat board and particle board, can serve as floor decking. Such floor design will also add rigidity to frame construction. Bamboo reinforced concrete is another possibility for floor slabs.

Bamboo parquet flooring, where strips of bamboo are made into tiles (Abd. Latif 1988), can be an interesting area of study for developing value-added bamboo-based products.

Conclusion

Based on the information collected on traditional bamboo walling systems, it is clear that a bamboo wall acts as non-load bearing infill orcladding integrated with wood or bamboo skeleton. For durability, bamboo walls are plastered, with bamboo lath, board or plaited mat serving as the plaster base. The lightness of such walls makes them suitable for areas susceptible to earthquakes. Further, it appears that not much attention is paid to the durability of bamboo itself against degradation. It is also true that not much is known about the structural capacity of bamboo cladding/infill under racking forces. Here, there is major need to collect detailed information on existing detailing of bamboo wall in terms of type of bamboo species used, type of bamboo mat board, and their structural integrity against wind and earthquakes. There is also a need to pool together information on the preservative treatment of bamboo, and to bring out a Code of Practice for treatment of bamboo, entailing economical as well as environment and use-friendly systems.

Systematic work is also required in the area of composite wall construction, where bamboo mesh/strips act as reinforcement for cement mortar and soil cement. Such a composite wall construction should find wide use in low-cost housing. It is also necessary to find economical ways of stabilizing bamboo, and improve its bonding capacity with cement concrete or cement mortar.

Bamboo composite materials, particularly particle bamboo mat board and bamboo plywood, can be potential walling material in either sheathing or stressed skin construction of prefabricated houses. Studies are required in the development of economical exterior-type composite board and its structural efficiency in combination with wood or bamboo.

There is need to develop grading rules for bamboo for walling, matting and lath with regard to specific species and their physical characteristics. It will also be useful to develop standardized and optimum design for bamboo matting and lath suitable for walls as reinforcement or plaster base.

Further, a design manual needs to be developed to indicate the performance of various types of bamboo-based wall systems. Countries interested in the overall utilization of bamboo for housing should pool their resources to bring out general guidelines for utilization of various species of bamboo in housing. Systematic studies are also required on the development of flooring materials, especially floor board, parquet type tiles and floor-decks.

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The Importance of Bamboo and Housing Construction: a Case Study in Flores

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Abstract

Flores is one of the largest islands in Nusa Tenggara, Indonesia. It has a land area of 14 200 km^2 and a population of 1.4 million, most of whom live in rural areas as subsistence farmers. The island is located on the Eurasian plate along the boundary between the Indonesian and Australian plates, and potentially destructive earthquakes frequently occur in the area. Its location is in the active seismic zone classified as "very high risk" by the South East Asian Association of Seismology and Earthquake Engineering. The latest and the most major earthquake to hit Flores was on 12 December 1992, with the largest tremor reaching 7.5 on the Richter scale, causing considerable damage to buildings,

Traditionally bamboo has been used as a cheap and easily available local housing material by the Florinese communities. Since other construction materials such bricks and cement became available, there has been a tendency to move away from the use of bamboo. This tendency is associated with many social factors, which need to be examined before encouraging the communitiesto reverse this trend. Communities have recognized the comparative safety of bamboo houses in an earthquake zone, but for these communities the status of a bamboo house is not equal to that of a brick one.

Introduction

Flores is an island 33 km long and 14 200 km^2 in area, situated to the east of Bali in Indonesia. The population of 1.4 million has an average income of US$l50 per family per year which is earned mainly through subsistence farming, and other off-farm activities such as weaving involving mainly the women. For thousands of years, the Florinese communities have lived in simple bamboo houses.

There are many small NGOs in Flores which have been working on community development projects for many years, often through the catholic church. In 1964, a credit union organization (Badan Koordinasi Koperasi Kredit Daerah) was established in various parts of Flores. Its main activities encouraged the communities to save their money, and then permitted to borrow three times as much as they had saved. This organization proved to be very effective and there are many credit union groups now in the island still operating on this basis. In order to motivate and encourage full participation in its activities, the credit union promoted by lending small amounts the building of brick-and-mortar houses, considered safer and longer lasting. Gradually, the use of brick and mortar instead of bamboo became a trend in house construction, especially among the community members who had accumulated enough capital.

Despite their durability, these houses did not prove to be safer. This became evident to the communities on 12 December 1992, when an earthquake occurred, with the largest tremor reaching 7.5 on the Richter scale. The communities who had saved for years through their credit union groups to build brick-and-mortar houses lost their houses in a matter of seconds. Some members were still in the course of paying back the credit on a house that was instantly destroyed. Over 25 000 houses were destroyed during that earthquake (Table 1).

Table 1: Houses damaged in the Maumere Region of Flores during the December 1992 earthquake

Scale of Damage	Number of Houses
Totally Damaged	7 601
Partially Damaged	3 452
Marginally Damaged	2 953
Total Number of Houses Damaged	14 006

Note: The total number of houses in Maumere at the time of the earthquake was recorded as 44 399. Hence, 31.55% of the houses were damaged during the earthquake.

Trend Reversal: Concrete to Bamboo and Back to Concrete?

Following this disaster, the building material preference reversed yet again towards bamboo (Figure 1). This was, however, not because of the acceptance of bamboo as an earthquake-proof, permanent material but for reasons related to the economical situation of the communities at the time: bamboo was cheap and easily available. In this period, houses, schools, churches and offices were built from bamboo over the old foundations of brick houses, and often with the old tin roofs too.

Almost two years after the earthquake, it has become clear that the shift towards bamboo buildings was only temporary. Beautiful bamboo churches

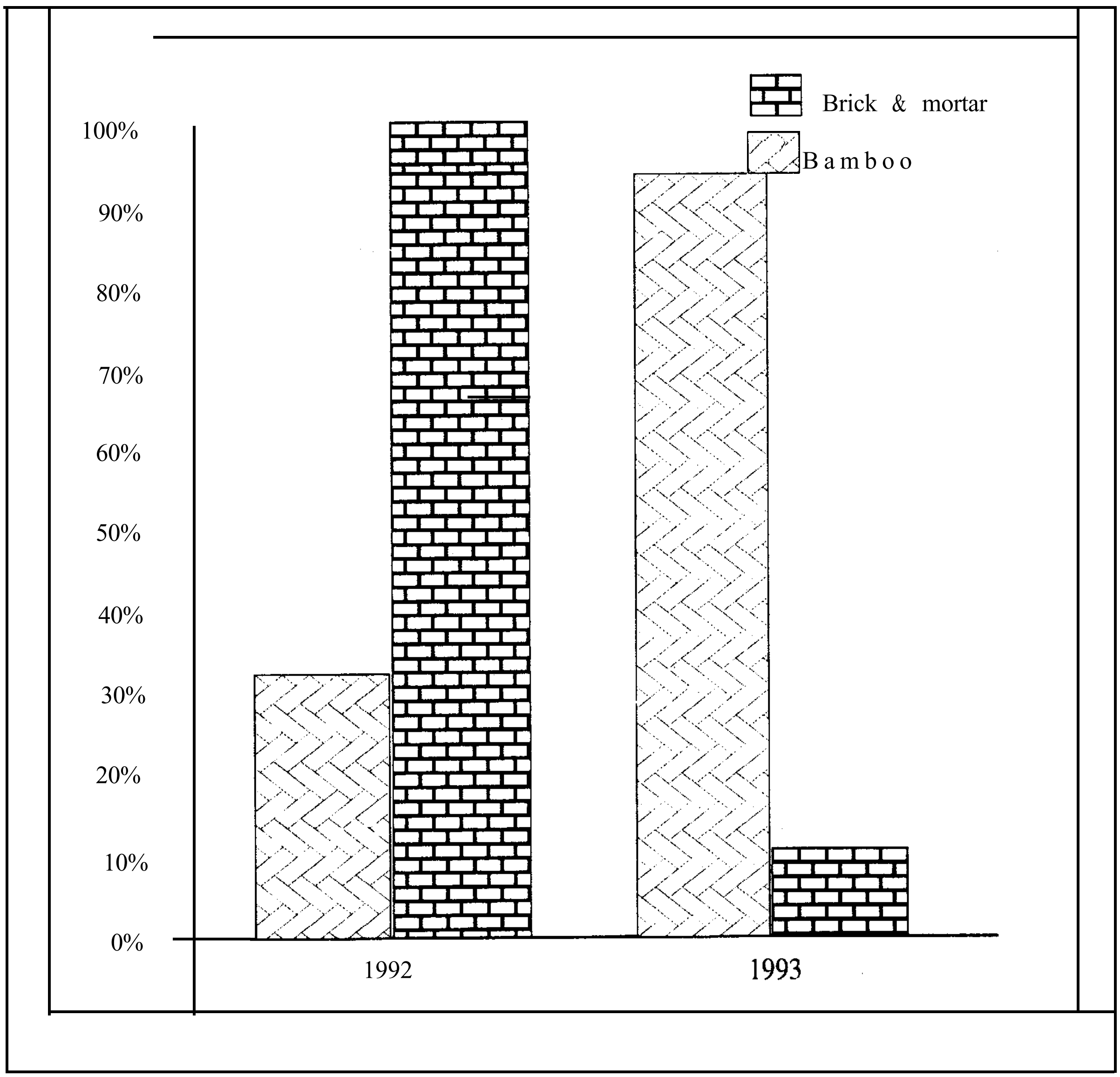

Fig. 1: A comparison of bamboo houses before (1992). and after the earthquake (1993)

are now being replaced by stone churches, and brick-and-mortar houses are slowly but surely springing up by the side of the bamboo houses. It can be observed that very few community members who constructed bamboo buildings after the earthquake considered them as permanent structures.

Disadvantages of Bamboo for Housing: a Florinese Perspective

From the point of view of the Florinese communities, bamboo still has many disadvantages including the following:

- The vulnerability of bamboo to pests such as beetles and termites which shortens the life-span of the house. The Florinese people living in bamboo houses have to replace their houses, on an average, every 10 years because of pest infestation weakening the structure. Communities living near the sea often soak the bamboo in sea water before construction in order to lengthen its life-span. However, this is not possible in most communities and so concrete houses are still seen as a long-term investment.
- The limited durability of the bamboo construction. Within the communities, there is a lack of architectural and construction skills. Consequently, the life of the building is limited. Examples of weakness in house constructions can often be seen in the villages. Bamboo houses, which were built just a year or two back, lean to one side because the main support structures were put straight into the ground, and the bamboo below the ground decayed. Other support structures such as roof support poles were often made from different lengths of culms joined together and consequently, the thatch roofs often caved in. These are some common examples of limited life of the construction which reinforces the communities' view that bamboo is only a material for temporary buildings.
- The status of bamboo as "the poor man's timber" is probably the most difficult to analyse and tackle as it involves social attitudes of the community. In general, communities are inclined to see bamboo houses as an indication of poverty. Concrete houses represent wealth and a higher status, even if poorly constructed and risky during earthquakes. This factor is extremely important when suggesting prioritization of bamboo in housing programs for Flores.

Possible Solutions and Recommendations

It is apparent that bamboo is an easily available local material which could be used as a comparatively safe building material in a "high-risk seismic zone" such as Flores. It is therefore important to encourage the communities to think about bamboo as a building material of permanent status, like brick and mortar, and emphasizing the advantages of bamboo in an earthquake area. Some suggestions to achieve this are presented below.

- Continued development and research into simple techniques for bamboo preservation. For example, the development of existing local preservation practices and comparative studies between techniques, with reference to effectiveness and cost.
- Building of prototype buildings using bamboo which would be considered appropriate and attractive by the communities. This would involve the target community, particularly the architects, from the beginning to help transfer the concepts into practice.
- Simple training courses at community level in construction technologies.
- Bamboo housing design and building competitions conducted at local level in order to promote bamboo and its status as a building material.

Conclusion

The properties of bamboo which make it suitable as a building material have been recognized for thousands of years by the Florinese communities who, at one time, lived only in bamboo houses. The communities can be encouraged to use bamboo as a material for permanent buildings through their own involvement in a community development housing program. There appears to be a large gap between the communities and the people who are involved in bamboo R&D. This gap needs to be bridged and communication between them improved. Flores needs field practitioners, development workers and bamboo construction experts to work together with the communities to develop and sustain bamboo constructions which will be safer for the people in another earthquake. However, the social attitudes towards bamboo will not make this task easy.

Bamboo Housing in Seismic-prone Areas

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Abstract

The paper discusses relevant data needed by the seismic engineer in order to assess the seismic response capacity of a building system, analysing the current information available and the testing techniques. The problem is examined in terms of the properties of bamboo as a material, and the behaviour of building systems where bamboo plays an important role is discussed. The research areas where more attention is needed are outlined.

Introduction

Bamboo construction has been a tradition for hundreds of years, especially in certain parts of Asia. Different cultures have found in this material a light, easily replaceable and economic way of building construction.

The techniques associated with bamboo construction stem from a variety of sources, and have been handed down the years from generation to generation. Traditional bamboo construction is an easy and straight forward combination of activities and tools, handy and available to the majority, including the young and the unskilled.

The performance of these traditional bamboo houses during earthquakes is neither fully documented in the literature, nor the theoretical basis for the analysis of such buildings available. This paper attempts to document some factors and criteria which might help to eventually incorporate some guidelines for the field practitioner.

Bamboo as a Building Material

There are several factors of interest in the response of a material to earthquake loads. It is important to clearly know the strength, flexibility and behaviour of the material under cyclic load. In the following sections, these factors are examined with regard to bamboo.

Strength

Many authors have measured the strength of bamboo under increasing or static loads, for different test conditions. A summary of some of the results can be found in Janssen (1991).

The major interest of the research so far has been to find a simple correlation between strength and a physical parameter, namely density, perhaps following the tradition that started with the study of other materials like wood and concrete. It is not easy to derive general conclusions about the properties of bamboo, because the testing procedures follow a wide variety of criteria. Furthermore, the main focus of the researcher has not necessarily been what a seismic specialist would regard as his or her major concern.

For the seismic engineer, the test itself plays a significant role, since he/she wants to know with as much precision as possible, not only what the strength is, but also what the stress-strain pattern is, because the latter will affect the response of the building to an earthquake.

In the above sense, the information available in literature is scanty for a seismic specialist. Furthermore, much of the available information is confusing in terms of what might be the yield point for bamboo, and the relation between this and the final strength (Arce 1990, 1992, 1993). Some of the concepts involved can be summarized as follows.

Compression strength

As has been pointed out by Meyer and Ekelund (1923), a great deal of problems arise because of the reinforcing effect that the testing machine has over the specimen in compression. This is true to a greater extent with other testing procedures also. It is possible that the common variance between bending and compression results can be explained, at least partially, by the negative effect of the testing procedure over the results. Contrary to what literature suggests, the author found enough indications to reject the idea of any correlation between density and compression strength, or between modulus of elasticity (MOE) and density. This calls for a rethinking on the efforts for devising an easy way to compute compression strength using a simple formula of compression as a function of density.

The main point to be stressed, perhaps, is that the measurement of compression strength of the culms is just an academic exercise with very little practical application. This is because the geometric properties of bamboo culms limit the height of the compression specimen and so, the culm lengths employed in tests have very little or no relation to the realities of construction application. Instead, the buckling strength of the culms assumes substantialimportance (Arce 1992). From another point of view, the testing of short specimens in compression gives no direct data of the compression strength of the material (not the culm), since it is a structure of limited length that is under test. As a summary, the compression strength of short specimens has very little application in understanding the seismic behaviour of bamboo buildings.

Stability of the culms

A study of the stability of the culms is of major importance in the understanding of the seismic response of bamboo structures. This being so, it is surprising that very little information is found in the literature on the buckling properties of bamboo culms.

The determination of the critical load on bamboo culms is difficult because of the variation along the culm axis of the MOE, thickness and diameter, and by the presence of nodes and the variations of the said factors in the nodal region. Lastly, the inherent crookedness of the culm induces early P-delta effects that must be taken into account. This P-delta effect has a very random nature, since it is mobilized not only by the lateral deformations of the structure under lateral loads, but also governed by the initial deformations of the culm.

As it can easily be deducted from the above, it is necessary to improve not only the testing procedures but also, what is perhaps more fundamental, the sampling criteria for the determination of buckling load on the culms. It will not be possible to experimentally determine the buckling load of each and every culm. Hence, there is need for establishing a method to gather the most important parameters for every species, every batch, plantation, period, area and country, so that the results obtained can be included in a code of practice.

In this sense, laboratory results on clear specimens can give a totally misleading indication of what is likely to be found in the field. Sampling criteria should be established regarding the actual or market conditions of the material. In turn, the market conditions should be controlled by an appropriate set of local grading rules for the culms. It is clear that this is only possible with the correct identification of proper grades. It has been observed by the author that storing conditions during the drying period may affect the shape of the culms. Grading of bamboo culms should be an important subject for future research, specially taking into account the amount of experience that timber engineers have gathered, even for tropical timber (Anthony et al. 1992; Leicester 1988).

Tensile strength

It is well known that the tensile strength of bamboo triples the compression strength and therefore, it will obviously be much larger than the buckling load of the culms. This takes tensile strength out of the critical path in relation to those properties that might be of interest for the structural and seismic engineers. Even then, the designer should bear in mind that in the case of trusses, some of the elements will have to sustain tensile forces. So, the strength mechanism of the culms under those forces should be analysed and understood. It is important that results of clear specimens are not directly transferred as those of full culms because, among other reasons, there will be a tendency of the culm to fail in the region of the nodes, the weakest link, and to develop high tensile parallel stresses, both factors being very much random in nature. Initial deformations of the culms would also lead to low rigidity at the beginning of the force deformation path.

Other properties

Although bending plays a major and significant role in certain applications, testing has shown that bending by itself is not a problem, since very rarely bamboo can, in an actual application, develop a condition where it will fail in bending. It is more likely that the failure would happen because of local buckling, longitudinal shear, local crushing under the loads, or a weak condition in the supporting areas. This means that effort by the designer should be concentrated on avoiding situations where these type of stresses can be critical. This is particularly important while dealing with joints (Arce 1990). In fact, joints play an extremely significant role in the behaviour of bamboo structures, and this is another field where very little data is available.

From the above discussion, it can be inferred that one of the most important parameters in the determination of bamboo strength under non-axial loads is the parallel shear strength of the culms. Besides, as mentioned before, it has been found that the weak link in the culm is the node. The number of nodes and their properties have a negative effect on the strength and elasticity of the culms, thus significantly influencing the response of a structure to earthquake loads. The study of nodes is of major interest in defining bamboo engineering properties. It is expected that nodes will prove to be a significant factor in any grading system of bamboo culms.

The Response of Bamboo Structures to Earthquake Loads

The material

As can be seen in Figure 1, bamboo is a brittle material. Under tensile and compressive stresses, it is generally elastic, keeping an almost perfectly linear relationship. It reaches the final load without entering first a receding or an elastic bhase.

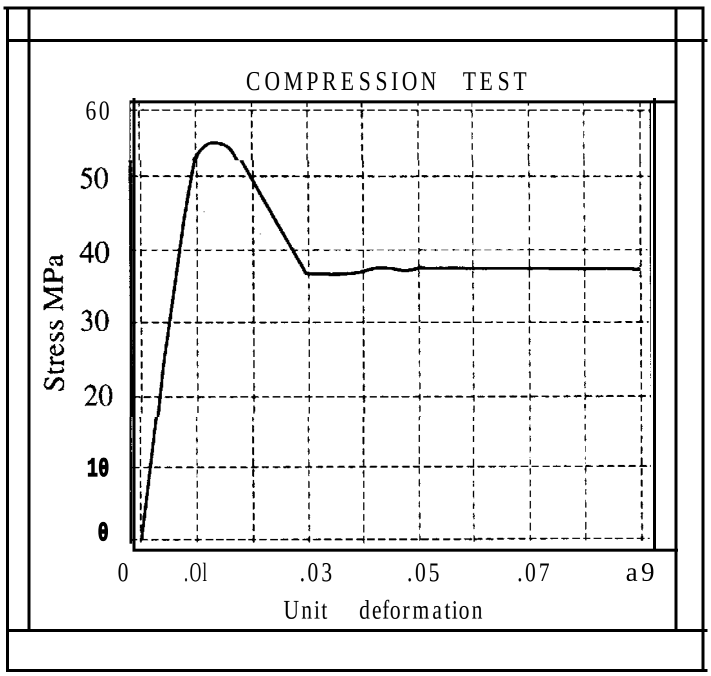

Fig. 1: Compression test on small rings

Failure occurs because separation of fibres occurs under high tangential stresses. Because of the orientation of the fibres and vessels, and as there are not radial cells, the transversal link is far weaker than the longitudinal observed strength. It is weakest no in the radial but the tangential direction, because of the fact that the amount of lignin increases towards the inner side of the culrn, creating unbalanced bending moments and consequent shear stresses. This type of failure can occureven during drying periods (Liese 1987). This is probably the source of the non-ductile behaviour of bamboo.

Building systems

The Seismology Committee of the Structural Engineers Association of California (SEAOC) defines an acceptable seismic performance as follows:

"Structures designed in conformity with these recommendations should, in general, be able to: 1) resist minor levels of earthquake ground motion without damage; 2) resist moderate levels of earthquake ground motion without structural damage, but possibly experience some non-structural damage; 3) resist a major level of earthquake ground motion having an intensity equal to the strongest either experienced or forecast for the building site, without collapse, but possibly with some structural as well as non structural damage”

It is interesting to look also at what is proposed as the basis for the design of wood structures by RILEM Committee 109-TSA (Blass et al. 1994):

" 2.6.2 Specific rules of timber structures

2.6.2.1 Basis of seismic design in timber structures.

As wooden members generally show brittle failure in tension, bending, buckling and shear, it is not expected that the wooden members would dissipate the seismic energy themselves, but the joints would dissipate the seismic energy due to plastic behaviour. Either of the following criteria should be applied according to the seismic property of the structure.

a) The structure should be designed so that the structural members and joints have adequate strength for the linear lateral force response caused by the severe earthquake motions. In this design, the damping of joints is taken into account, but ductility of joints is not expected.

b) The structure should be designed so that the structural members and joints have adequate strength for the non-linear lateral response caused by severe earthquake motion. In this design, the structure should have adequate ductility due to the plastic behaviour of joints or other dissipative systems.

The former criterion should be applied to non-dissipative structures such as arches, frames with glued joints, etc., and the latter criterion to dissipative structures such as frames with semi-rigid moment resisting joints, shear walls, etc.”

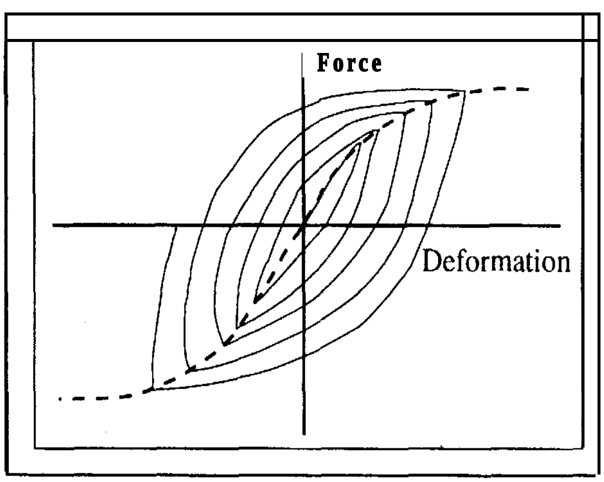

Fig. 2: Ideal seismic response

Actually, the ideal behaviour of a building system should be as it is illustrated in Figure 2. It can be observed that the major asset of this type of response is the building’s ability to sustain the load without significantly affecting its stiffness or strength. A direct result of this is the strength to deform so that energy is dissipated in every load cycle.

As stated before, bamboo culms fail in a brittle manner, thus having no post peak strength. The ductility of the material is nil. This implies that bamboo culms should be designed with appropriate factors so that it remain in the elastic limit. In this sense, the recommendations for wooden structures may equally suit bamboo, and perhaps should be taken as a good starting point for design recommendations.

This being the case, how should the designer deal with deformation energy in a bamboo building? Perhaps the answer can be found in two different approaches, depending upon the structural options.

First, let us examine the use of line type elements. In this type of structural option, deformations would be very large under lateral loads, and the response to earthquake loads would increase with deformation. Large bending deformations are developed in the nodal regions of the culms where a very low MOE exists, and also because of large P-delta effects in the columns of a frame. Culms rapidly deteriorate, exhibiting very thin load deformation loops under lateral loads (Figure 3, top). Actually, in some tested frames (Arce 1993, it was not possible to run a complete loop before failure occurred.

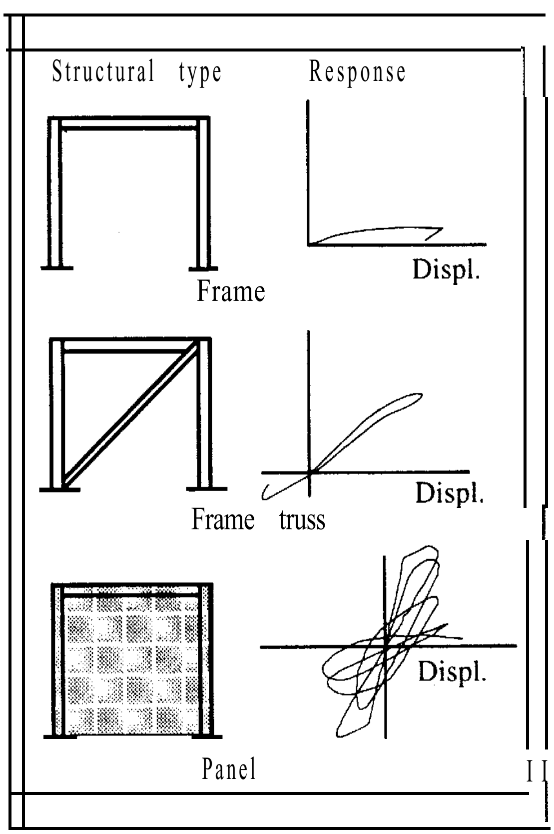

Fig. 3: Structural systems and their response

So it looks that a better design option would be the use of truss type structures, so that bending deformations can be kept under some degree of control (Figure 3, middle). In this, the strength of the structure would depend on the tensile and the buckling strength of the culms, both being brittle modes of failure unless plastic connections are used. Because of this fact, the proportioning of the culms should make them remain in the elastic range to avoid a general brittle failure.

But, bearing in mind that keeping stresses in the elastic range leads to zero energy dissipation, it would be convenient to look for ways of having a dissipation mechanism, so that the general behaviour can approach that in Figure 2. It is possible to produce a joint in which load slip rotation paths are determined and known, and are able to take plastic deformations, thus consuming energy and decreasing the response of the structure as a whole. From this point of view, joints can be regarded as the most important component in a bamboo truss, being either the source of a good dissipating mechanism, or the source of uncontrolled deformations leading to amplifications of the response of the building. Some steel fittings have been proposed for the fabrication of good and sound wood structural joints, and they might be a source of inspiration for bamboo designers. We have to bear in mind, however, that the cost of such fittings is normally high.

In the second place, it is worth looking at certain cladding applications of bamboo that have proved to be efficient solutions under real situations. Figure 4 shows a solution long used in Colombia, and introduced in Costa Rica some years ago by the Bamboo National Project of that country. Actually, this system was a sort of upper class fashion at the beginning of the century in Costa Rica. A wire mesh was however used instead of the bamboo mat, and a wooden frame was used instead of bamboo culm. Several houses built using this system in Costa Rica have recently survived high earthquake loads. Let us examine the possible causes of this desirable behavior. First, the system is light and the centre of mass of the building is close to the ground level (only one-storey houses have been built so far in Costa Rica), thus making use of a vital aspect in seismic engineering design. Second, it is clear that the frame of bamboo has a lateral rigidity far lower than the stiffness of the resulting

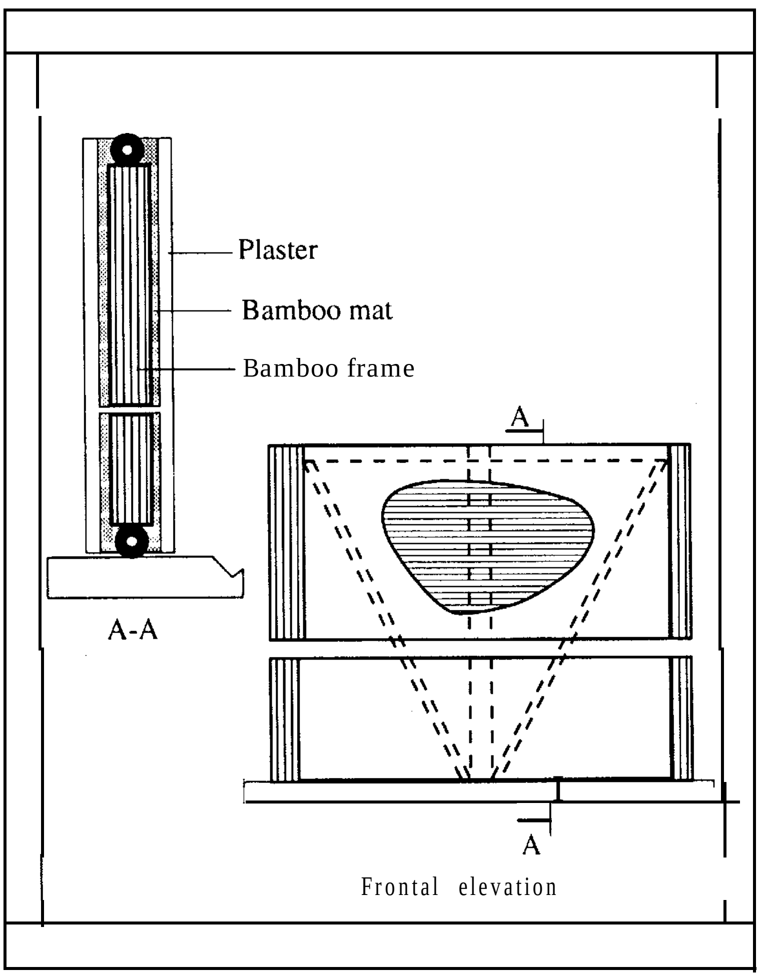

Fig. 4: Cladding system

cladding system., which becomes an integral part of the lateral load resisting system. This means that the lateral deformation is governed by the cladding and not by the bending of the culms. The low lateral deformations of the system lead to very low periods of vibration, as compared to those of the frame, generating a very low seismic response of the system as a whole. Third, the system overcomes of the problems which would otherwise arise from buckling of the culms, since lateral loads are taken primarily and mainly by shear in the cladding system, thus decreasing axial loads in the culms, which then play a low-profile role from the point of view of the response. Fourthly, the cladding itself might be regarded as a kind of ductile system because it would not collapse in a brittle way. After the first cracks appear, a friction mechanism would be of importance, as it has been found to be the case in, for example, some masonry systems. Even though this is not by far a perfectly ductile system, dissipating strength may prove to be enough, especially because of the low weight of the building (Figure 3, bottom).

Conclusion

The response of bamboo buildingsto earthquakes depend very much upon the quality of the design' itself. In this sense, bamboo is not different from other materials, since in all situations the design aspects of the building play the most significant role. It is the duty of the designer to make the best of every material. Materials may have advantages and drawbacks which must be carefully weighed. In the final design option, bamboo must be considered so that stresses are kept under control and elastic behaviour is assured.

Building systems can and have been developed where the best properties of bamboo are taken advantage of, and in a rational blend with other materials, structural systems with desirable behaviour are developed and built.

In dealing with frames and trusses, a bias towards the second must be encouraged, since open frames show large lateral deformations. In any case, ductility in this type of structural systems would totally depend on the quality of the joints.

When the structural system is such that the role of bamboo components in lateral deformations is kept to a low profile, a major advantage

1 The term "design" is employed here as the process of creation of shapes and systerns, or concepts, as different from crude calculation procedures.

appears since no major refinement is then needed in the determination of bamboo culm properties. It was pointed out in the first section of the paper that the determination of mechanical properties is not an easy task, and that sometimes concentration is not paid to those variables most relevant from the point of view of the seismic response of the material.

Following RILEM's recommendations, perhaps it should be possible to include in any bamboo building code the following recommendation, based on the above mentioned criteria.

"Basis of Seismic Design in Bamboo Structures:

As bamboo members show brittle failure in tension, bending, buckling and shear, it is not expected that these members would dissipate the seismic energy themselves, but the joints would dissipate the seismic energy if any plastic behaviour is provided for. The following criteria should be applied according to the seismic property of the structure.

The structure should be designed so that the structural members and joints have adequate strength for the linear lateral force response caused by the severe earthquake motions. In this design, the damping of joints is taken into account accordingly, with available experimental evidence, but ductility of joints would not be expected, unless shown otherwise by direct testing.

Designs based on frame systems should be avoided. Wall and truss-wall type systems should be preferred, so that lateral deformations can be kept under control, and secondary effects are minimal."

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Typhoon-resistant Bamboo Housing In the Philippines

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Abstract

Current construction practices and some structural defects in low-cost houses made of lightweight materials, such as bamboo, are described based on assessments of damages caused by two severe typhoons that hit the Philippines. The effect of inadequacies in design and construction on the housing backlog is discussed. Wind loads and pressure coefficients recommended by engineering design manuals and codes are evaluated with respect to typhoon-resistance of low-rise houses. It is suggested that, in order to build typhoon-resistant bamboo houses, wind loads, pressure coefficients and design methodology for low-rise buildings made of lightweight materials should be reviewed, and findings disseminated by means of a manual of construction for typhoon-resistant bamboo houses. Current research, as well as the direction of future research, on the use of bamboo for low-cost house construction at the Philippine Forest Products Research and Development Institute (FPRDI) are briefly outlined.

Introduction

In the 1980s, housing backlog in the Philippines was about 1.8 million units (Siopongco 1984). The latest projected demand for low-cost housing from 1993 to 1998 is 3.8 million units (Rebong 1995). The unabated backlog is due to increase in population, lack of financial resources, and damages to houses caused by natural and man-made disasters such as typhoons, earthquakes and fires.

Typhoons have contributed substantially to the housing backlog in the Philippines. Sufficient data have been gathered to show that storm surges are not rare in the Philippines and should therefore be given due consideration when building houses, specially those made of lightweight materials (Arafiles and Alcances 1977). During 1970-86, an average of 20 typhoons visited the Philippines annually (Soriano et al. 1987). Out of these, nine typhoons caused damages to houses, crops and other properties (Foliente 1986).

Figure 1 shows the number of tropical cyclones that caused damages to houses during 1990-94, as reported by the Weather Branch of the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). From 1993 to 1994, as many as 27 typhoons caused damages to houses, claiming at least 1 013 lives, and accounting for 448 injured, 1 677 missing and an estimated 20 trillion pesos worth of property loss.

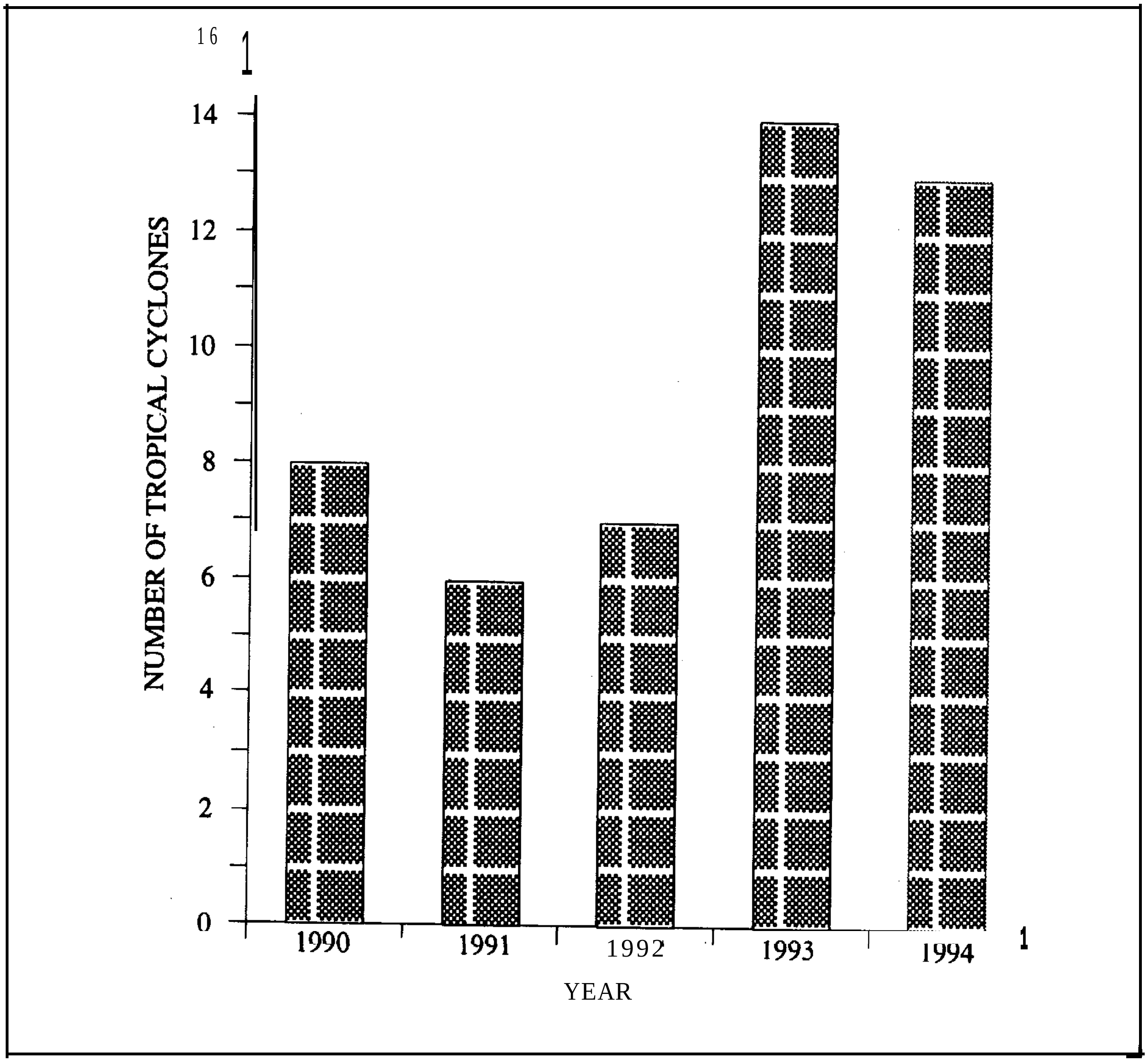

Fig. 1: Number of tropical cyclones which caused total/partial damage to houses during 1990-94 (Source: PAGASA Weather Branch)

Figure 2 shows the number of houses which were either partially or totally damaged by typhoons in the Philippines during 1990-94. In 1990 alone, a total of 223 535 houses were totally damaged and 636 742 houses partially damaged. Summing up the number of damaged houses in 1993 and 1994, a total of 222 576 houses were totally damaged and 669 954 partially damaged - about 23.5% of the total projected housing backlog from 1993 to 1998. Majority of the damaged houses were those with a projected lifetime of five 'years, such as those made of lightweight and indigenous materials (bamboo, nipa and anahaw), usually located in open and coastal areas. To prevent a further setback to the housing program, current design and construction practices using lightweight materials, specially bamboo, must be investigated and improved in order to make low-cost houses structurally resistant to typhoons.

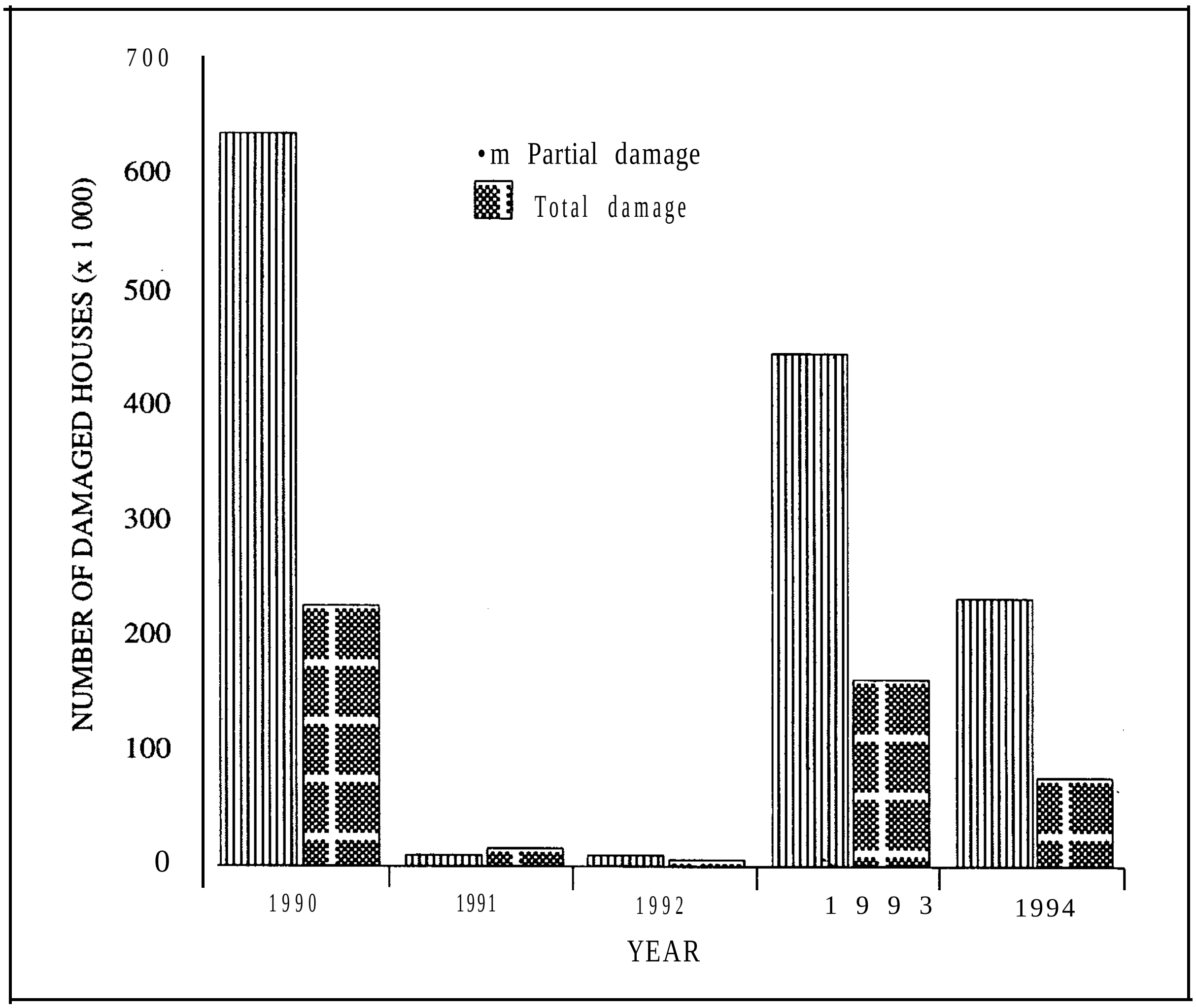

Fig. 2: Number of houses partially/totally damaged by typhoons during 1990-94 (Source: **PAGASA** Weather Branch)

Bamboo and Other Lightweight Indigenous Materials for Low-cost Rural Housing

Although a higher proportion of the population is concentrated in the rural areas, the demand for low-cost housing is currently greater in the urban areas, mainly because of migration from the rural to the urban areas. From 1989 to 1990, for example, urban population growth averaged about 4.56% annually compared to the rural population growth of about 1.58% (Rebong 1995). Low-income earners in the rural areas are attracted to the relatively faster pace of development in the urban areas, and their displacement entails additional housing in the urban areas, thus aggravating the housing backlog. Addressing the needs of the low-income group in the rural areas, one of the most basic of which is housing, is one way to discourage migration to the urban areas.

The projected total demand of 3.8 million housing units from 1993 to 1998 includes houses that need replacement because of substandard construction materials, as well as those that require major repair and rehabilitation. The National Shelter Program, in line with the Urban Development and Housing Act, aims to build 1.2 million homes from 1993 to 1998, reducing the total demand for housing within this period by about 31%. The Comprehensive and Integrated Shelter Finance Act has streamlined the government's efforts by directing housing projects to the lower 30% income group - the unprivileged and homeless, and the urban poor.

Among the housing units that are usually categorized as substandard and requiring major repair and rehabilitation are bamboo houses', most of which, based on typhoon damage assessments and observed construction practices, cannot withstand severe wind forces during typhoons. Damages in bamboo houses, particularly those in the rural areas, have been found to be initiated by structural failures of connections or joints between structural components (Reyes 1976, Siopongco 1984).

Low-cost housing for families belonging to the lower 30% income bracket in the rural areas is characterized by the use of lightweight and indigenous materials such as bamboo (or bamboo and wood), coconut timber, sticks, nipa, cogon, coconut leaves and anahaw. A house made of these materials has been dubbed as a poor man's house and may be unacceptable to some

In this report, "bamboo house" refers to a house having any of the structural components — such as posts, walls, roof trusses and floors - made of bamboo.

who are in need of low-cost housing because it is: (1) constructed using traditional techniques and thus does not need modern or sophisticated technology; (2) lightweight and thus likely to be temporary; and (3) not as safe as wood-and-concrete houses since it can be built without the services of an engineer or architect and is not covered by any building legislation or code (Pascua 1986).

The misconceptions mentioned above need to be removed in order to make bamboo houses acceptable to those in need of low-cost houses. People needs to be educated that in building houses, simple technologies are not necessarily inferior to complex ones. 'There is a need to stress that indigenous materials like bamboo, if properly joined and pre-treated, can make a house permanent and give it the advantage of relatively easier modification and replacement when compared with heavier and more expensive materials. Like any construction material, the adequacy of bamboo components and joints must always be assessed from an engineering point of view to ensure structural safety.

The Demand for Bamboo by the Construction Industry

In the construction industry, bamboo is used either as a non-structural, decorative material in commercial buildings or as a low-cost structural material.

Commercial buildings which house business establishments specializing in Filipino products and commodities usually prefer finishings utilizing indigenous materials such as bamboo (concrete hollow block walls and reinforced concrete posts covered with half bamboo culms, flush doors covered with bamboo strips, plywood ceiling covered with sawalior bamboo mat, etc.). Expensive finishings such as paints and varnishes are used to enhance the beauty of bamboo designs and patterns. Thus bamboo is used here for decorative and non-structural applications.

As a low-cost material, a small proportion of bamboo is used in construction as a scaffolding material for painting works of small buildings and houses. In the rural areas, although wood-and-concrete houses are increasingly being built, majority of the houses are still made wholly or partly of bamboo. Bamboo is used in almost all structural parts of a low-cost house, namely, as posts, girders, joists, trusses, floors, walls, ceilings, doors, windows and stairs. Nails, bolts and other hardware have limited use in bamboo house construction, specially where whole culms are involved. Traditional methods of fastening using different lashing materials such as rattan, abaca twine, nylon and, at times, galvanized iron wire have been observed in joints between bamboo structural components. The use of bamboo dowels combined with tying has proved to be an effective method of fastening whole bamboo culms to other components.

Statistics on the number of bamboo houses in the Philippines are not available; however, an analytical study conducted in Region 12 estimated that about 15% or 42 065 units are completely or partially made of light materials, with bamboo as a major component (Uriarte and Maligalig 1992).

Figure 3 shows the annual bamboo requirements by industry in Region 1 (Uriarte and Maligalig 1992), while Figure 4 shows the annual national demand by use (Tesoro 1984). In Region 1, the construction industry has the largest requirement at 210 325 culms annually, which is about 37.2% of the total requirement in the region. Furniture, handicraft, basket and fishing industries require 128 400,102 950,97 760 and 25 500 culms, respectively (Uriarte and Maligalig 1992).

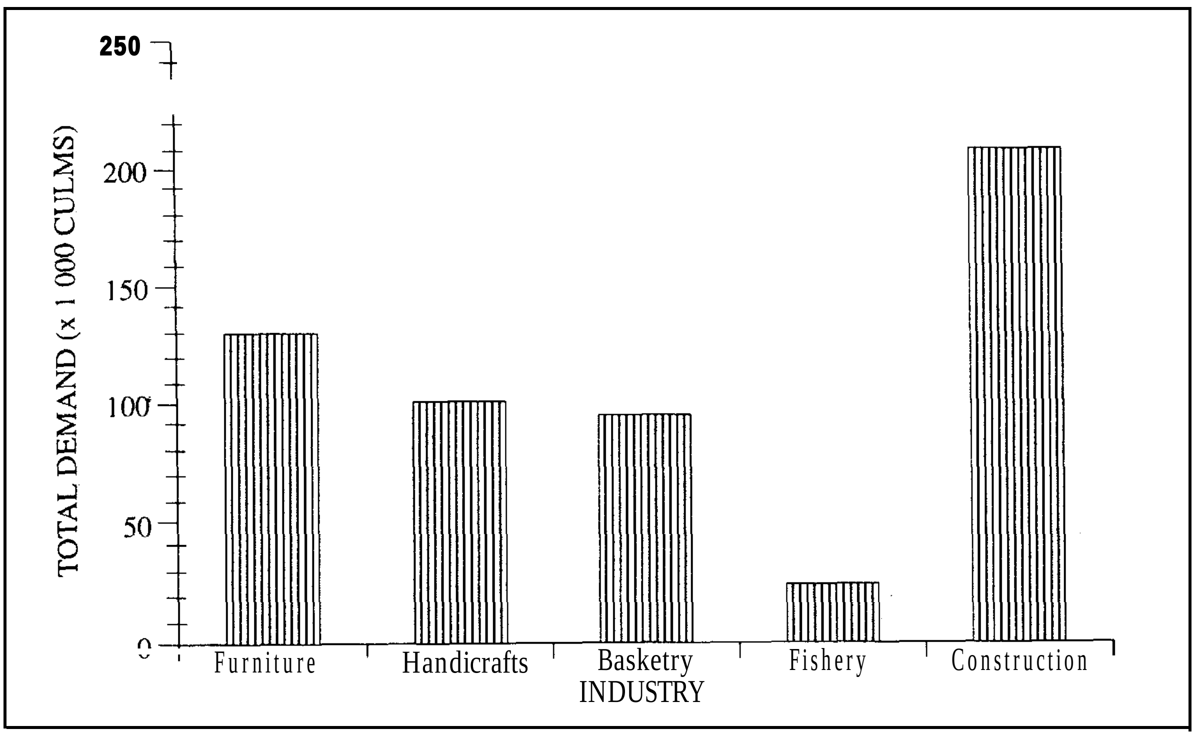

Fig. 3: Total bamboo requirements by industry in Region 1

2 The Philippines is composed of 15 political regions. Region 1 covers the Ilocos, which has a population of 3 551000 or about 5.9% of the national population as of 1990 (National Statistical Coordination Board 1991).

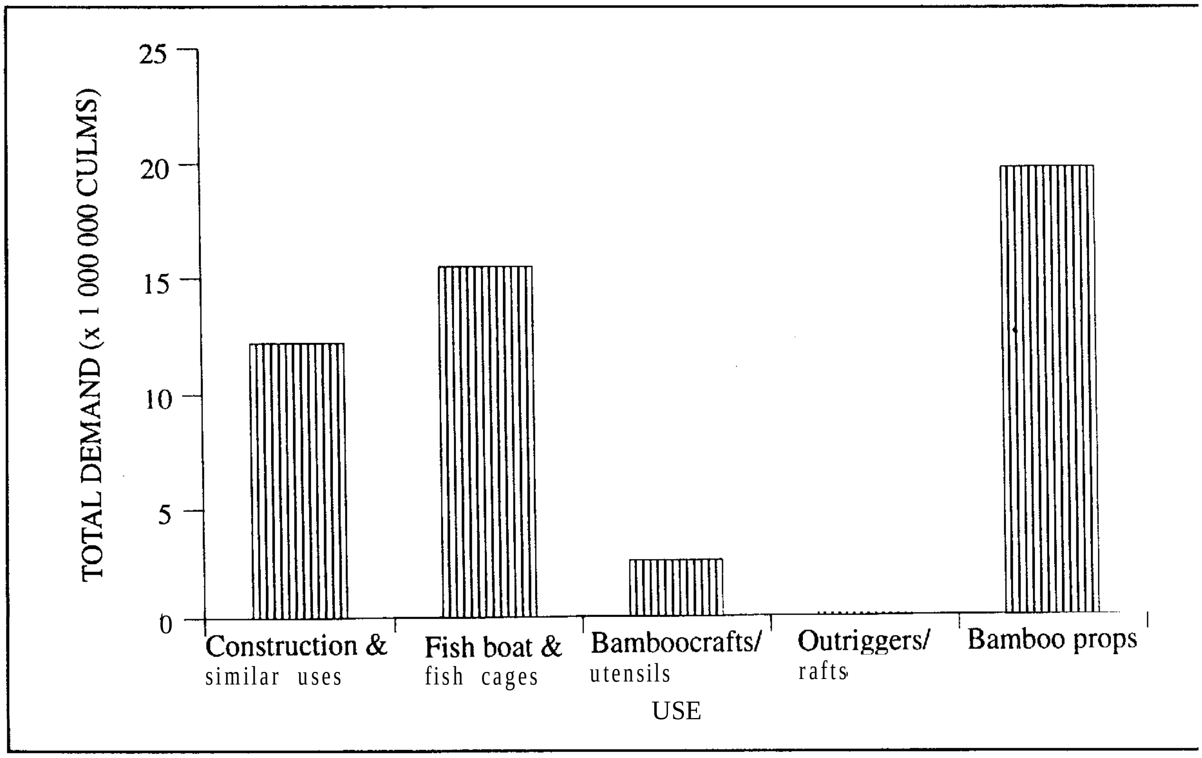

Fig. 4: Estimated annual demand for bamboo according to use

Figure 4 shows that the third highest demand, at **12.5** million culms or about 24.4% of the total demand for bamboo in the country, is for construction and other uses. The demand for bamboo used in fishpens, bamboo crafts, outriggers and banana props is 15.86 million, 2.7 million, 0.21 million and 20 million culms, respectively.

It is anticipated that the current massive bamboo propagation and production drive of both the government and the private sector (Anonymous 1995) will be matched by a corresponding increase in the demand for bamboo by the construction industry. This demand is brought about by an apparent recognition of the use of bamboo in low-cost house construction, as a result of the government's Shelter Upgrade Program. This program promotes the use of indigenous materials, and educates prospective house owners that houses made of lightweight materials can be structurally adequate and can easily be reconstructed in case of damages.

It must be emphasized, however, that low-cost houses employing bamboo and other indigenous materials will always be categorized as temporary structures if made using construction practices similar to those that resulted in structural failure during typhoons. In order to avoid this, structural failures in houses made of lightweight materials have been identified and analyzed by observing damages caused by typhoons.

Typhoon Damages in Houses Made of Lightweight Materials

Two typhoon damage assessments made in 1987 are presented here in order to describe the type and extent of damages which are to be expected during a severe typhoon. Assessments were conducted under a project of a United Nations-funded Regional Network, which was established in Asia in 1983 to facilitate information exchange on the development of low-cost housing in the area.

Fit, an extensive investigation of dmages in low-cost houses caused by the typhoon "Henning" was undertaken in August 1987 (Boughton 1987). Typhoon "Henning", with a central wind speed of 200 kph, was the seventh typhoon to be monitored in the Philippines within that year. About 100 damaged structures, most of which were houses and small school buildings made of lightweight materials, were inspected. Out of the small buildings observed, about 70% incorporated bamboo or a bamboo derivative in the structure and about60% had thatch roof materials.Three problems were generally highl ighted: (1) deterioration of timber; (2) inadequate fastening of lightweight roofing; and (3) inadequate bracing or poor performance of bracing.

Large-scale damages to buildings were caused by the failure of connections weakened by timber deterioration. Failure of this type was evident in posts and columns buried in soil. In some instances, borers and termites had caused total loss of timber below ground level. Timber deterioration from moisture accumulation was evident in connections between structural members such as at the wall top plate. The lack of ventilation around connections caused moisture to accumulate, thus allowing timber deterioration to accelerate. Failure of roof anchorage frequently resulted in the disconnection of the roof from the rest of the building.

It was observed that the most commonly used lightweight roof sheathings were of nipa and anahaw palms. Nipa palm shingles were fabricated by wrapping the palm leaves over split bamboo or nipa palm stalks. These were fastened to the roof frame by nailing and/or by tying with a lashing material such as nylon fishing line, abaca twine, or rattan or plastic strips. The performance of nipa was dependent on the aerodynamic form of the house and on the manner of fastening to the roof frame. Damaged nipa roofing was observed in houses with openings on the windward wall. The performance of nipa roofing was better where bamboo splits were tied to the roof structure at every cross-point, whereas failures were observed on roofs which had only two tied points on each tile.

Compared with nipa roofing, anahaw palm shingles made by fastening whole leaves to the roof frame performed better. Nylon or rattan was used to tie split bamboo on both the inside and the outside of the thatch, resulting in a consistently better performance than nipa, and also demonstrating the efficiency of tying to fasten split bamboo members in any structure.

Houses constructed from indigenous materials utilized bamboo wall cladding in the form of (1) bamboo splits tied or nailed to the wall frame, (2) woven bamboo *sawali* sandwiched between the wall frame and nailing strips on the outside, or (3) crushed bamboo sandwiched between the wall frame and the nailing strips. Failure of these walls were often because of racking caused by the lack of a bracing structure. Walls made of bamboo splits were severely damaged, frequently resulting in catastrophic failure or total loss. Walls made from *sawali* and crushed bamboo had small racking deflections, thus performing better and demonstrating superior stiffness compared with those made from bamboo splits. Whole bamboo culms, usually too slender to effectively withstand compressive forces, were used as external braces. These were rarely anchored to the ground, and their value appeared to be merely psychological in most cases. This also showed that the house owners were unaware of the fact that such braces can also be subjected to tensile aside from compressive forces during typhoons. Guy wires anchoring the house to the ground were also occasionally observed. This provision counteracts uplift forces or suctions of sufficient intensity to overcome the dead weight of the house.

The second damage assessment was conducted in November 1987, by a team composed of FPRDI researchers, after the 15th and most destructive typhoon of the year, “Sisang”, hit the Philippines (Gesmundo et al. 1987). Packing a maximum wind velocity of 205 kph at the centre, the typhoon left 32,000 houses either partially or totally damaged. Because of the inaccessibility of most affected rural areas, the assessment team covered only a limited area along the typhoon track. Nevertheless, detailed observations of 50 houses, most of which were made of lightweight materials, were considered adequate for the team to gather general observations about the structural inadequacies of low-cost houses in the rural areas. It was observed that the structural failures of the houses were often because of the poor joining of structural members and not because of the inadequacy of materials used. Failures of this type were characterized by disintegrated members and components with no evident failure in materials. In some instances, however, it cannot be discounted that although the joints might have been properly built, the green timber used resulted in joint failure. As the timber dries, its dimensional changes create internal stresses in the joint, causing distortion and eventual failure when severe wind loads are imposed on the structure (Soriano and Espiloy 1987).

About 40% of the houses suffered damages in roof structures owing to the slopes being too flat (<30°), poor connections between lightweight roof cladding materials and the roof frame or failure in joints between roof and wall, or a combination of these conditions. House owners who built their houses without adequate supervision, because of their desire to save on material cost, preferred flatter roof slopes thereby using shorter pieces of wood for trusses and shorter lengths of roof cladding. About 21% of the observed houses suffered damages in exterior walls and partitions because of poor connection details and lack of bracing, about 12% had uprooted posts and exposed foundations, and about 5% had damaged doors and windows.

Based on the above assessments, it can be generalized that there are two factors which test the structural resistance of houses during typhoons. First, the deleterious effect of moisture and rain, and second, the effect of severe winds. Although the damaging-effect of moisture can be gradual, catastrophic failure of weakened materials can occur from the combined effect of wind and water pressures during typhoons. The extent of damage caused by severe winds depends on the roof slope, permeability of structure, direction of wind, roughness of terrain, geometric shape of structure and the adequacy of joints.

Design Wind Load Considerations for Typhoon-resistant Bamboo House Construction

While a great deal ofresearch has been done on wind loading of tall buildings, very little attention has been devoted to buildings having heights less than 10 metres (Marshall 1975). Investigations of wind damage strongly suggest that coefficients contained in most current codes and standards do not adequately describe the wind characteristics near the ground and the pressure distributions on low-rise buildings[3].

The Structural Design Data and Specifications Handbook (Carillo 1980) and the National Structural Code for Buildings (Anonymous 1981), both of which are used by practising engineers and architects in the Philippines,

3 Low-rise buildings refer to those which have a maximum height of 10 metres.

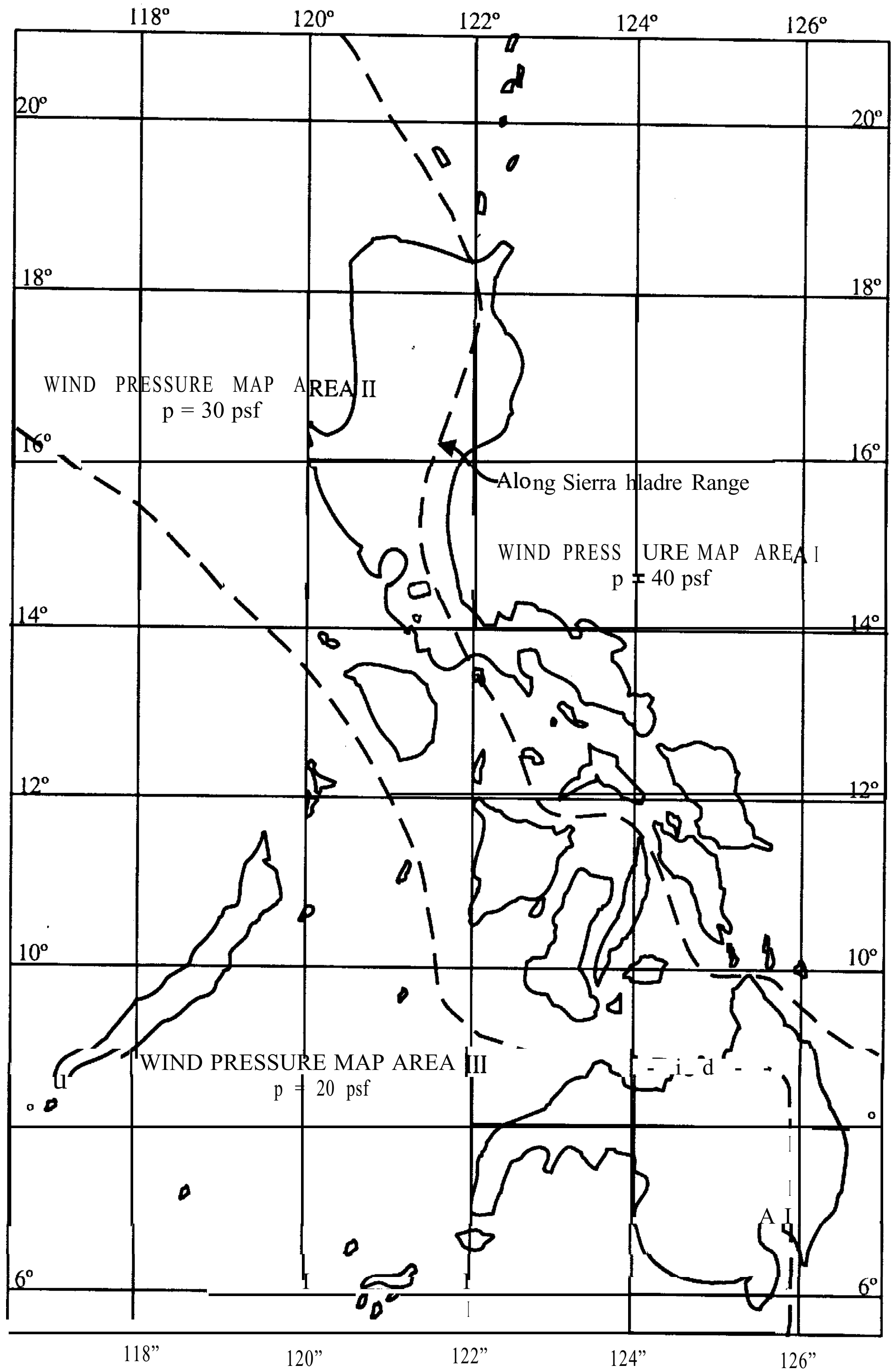

Fig. 5: Wind pressure map areas in the Philippines draw on the recommendations of a committee of the Association of Structural Engineers of the Philippines (ASEP) for the basic wind load values on structures. The committee derived the values from a study of the paths of remarkable typhoons in a 43-year period. The study resulted in the division of the country into three wind pressure areas (Figure 5). Table 1 shows the wind pressures for different height zones and wind pressure areas, with modifications for buildings higher than 100 metres as recommended by Carillo (1980).

Table 1: Basic wind pressures for different height zones above ground following uniform building code height zones and pressure variations (Carillo1980)

Height zone (ft)	Wind pressure (psf) map area		
	Area I	Area II	Area III
Less than 30	30	20	10
30 to 50	40	30	20
50 to 100	50	35	25
100 to 500	60	40	30
500 to 1200	70	45	30
over 1200	80	50	40

In 1975, a project titled "Design criteria and methodology for construction of low-rise buildings to better resist typhoons and hurricanes" was conducted based on the recommendations by the Agency for International Development (AID) and the National Bureau of Standards (NBS) of the United States that additional research on wind effects is needed to reduce property losses, human suffering, disruptions to productive activities and expenditures for disaster relief. The project involved direct measurements of wind loads on six low-rise buildings at three separate sites in the Philippines and wind tunnel studies using scale models of typical dwelling geometries.

The project included an estimation of extreme wind loads[4] in Philippine conditions, and conclusions were drawn based on wind speed data

4 Wind loads acting on the surfaces of buildings are expressed in terms of a dynamic pressure which is a function of basic wind speed and a pressure coefficient which accounts for terrain roughness, geometry and permeability of structure, wind speed direction and other design considerations.

recorded at various locations in the country (Simiu 1975). Significantly, the project recommended the redefinition of wind zones and improvement of design criteria in Zones I and II in the wind pressure map areas, and higher wind speed values in open and coastal areas in these zones. These recommendations, however, have not yet been verified or incorporated in design wind loads in currently used structural codes.

Damage assessments have shown that failures from strong wind pressures are often initiated at the connections or joints between structural members along the edges of roofs and walls. Separation of wind flows occur along-roof ridges and wall edges, thus developing forces that pull joints apart at these locations. Suction of extreme intensity on localized areas (Figure 6) and other building surfaces is the primary cause of failures in claddings and joints between structural components. For certain combinations of roof slopes and wind speed direction, a conical vortex can develop along the windward edges of the roof (Marshall 1975) (Figure 7). These point out the need to look into currently recommended slopes for particular roofing materials, and pressure coefficients for particular housing components.

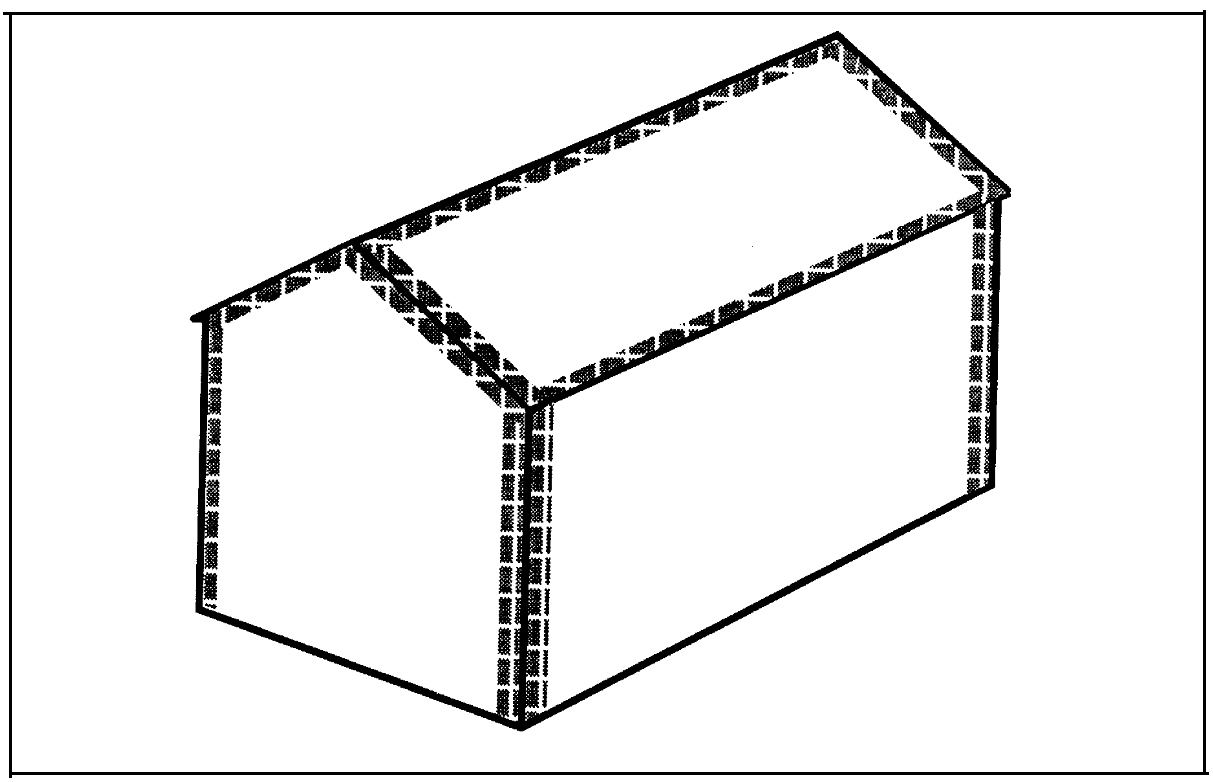

Fig. 6: Areas (shaded) of the house structure where high suctions must be allowed for cladding materials and joints connecting the elements

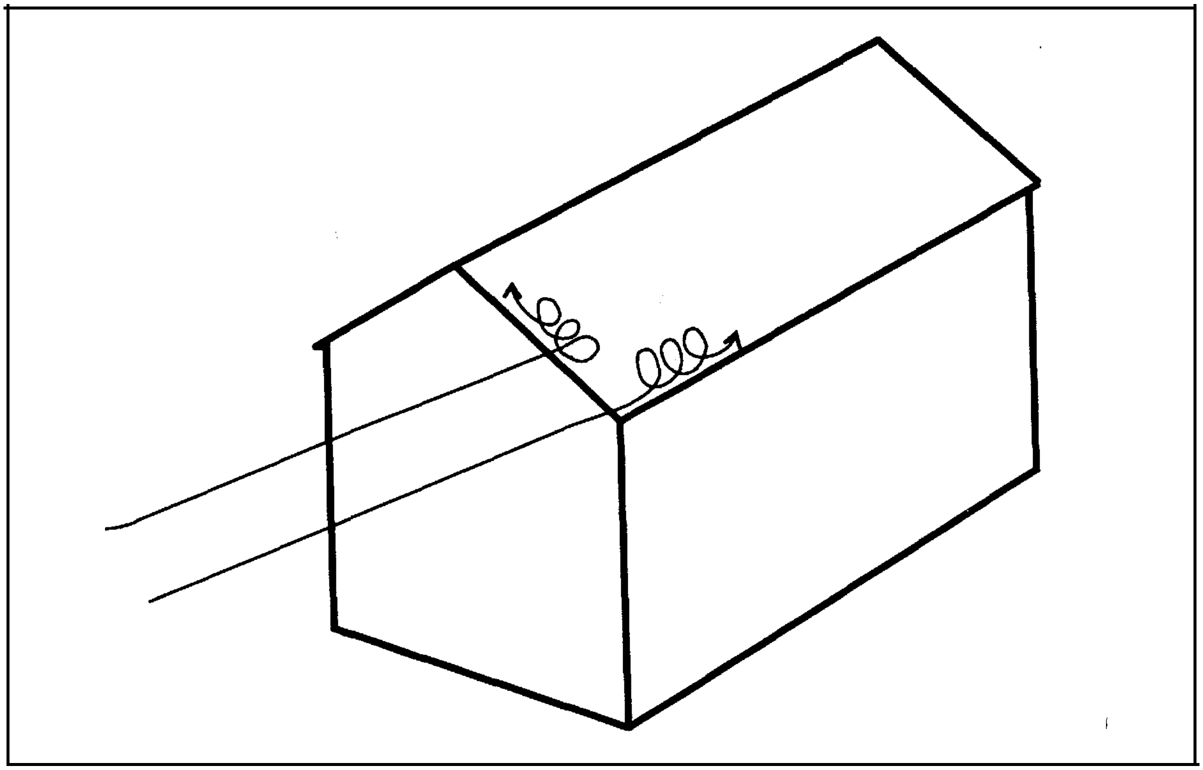

Fig. 7: "Rolling up" of high-speed wind flow into a helical pattern creating intense suction on the roof structure

Since walls, floors and roofs of houses made of bamboo and other light-traditional and current construction practices and architectural details in bamboo houses – must be supplemented with information on an acceptable engineering design criteria for bamboo houses, particularly those in open and coastal areas.

FPRDI Research on Bamboo as a House Construction Material

Current research

Studies on bamboo currently conducted at FPRDI are focused on the improvement of properties which are relevant in construction, and the design and development of bamboo housing components such as trusses, roofing and walls for low-cost housing. The studies include the following:

- Physical and mechanical properties of bamboos used in construction;
- Preservation of bamboo poles using the manually operated multi-cap HPSD;
- Full-scale testing of W-type trusses designed to withstand tropical storms and cyclones;
- Development/improvement of bamboo tied joints using two types of lashing materials;
- Development of corrugated roofing from bamboo sheets by physico-mechanical treatment; and
- Development of resin-bonded bamboo panels for curtain walls.

Future research

Aside from studies which will address problems encountered in current research, future research on bamboo as a construction material is geared towards the development and improvement of design criteria for typhoon-resistant low-cost bamboo house construction. The studies envisioned include the following:

- Standard strength test methods for bamboo and nondimensional timber;
- Crushed bamboo formed into timber- and panel-size building materials using a binder from waste plastics;
- Development of bamboo and non-dimensional timber joints considering the aerodynamics of low-rise buildings;
- Design of bamboo joints subjected to fluctuating wind pressures and separation of flows (at roof and wall edges);
- Wind tunnel studies involving scale models of bamboo structures incorporating new joint designs; and

- Development of a construction manual for a low-cost bamboo house with emphasis on design criteria for houses in extreme wind conditions.

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The Application of Bamboo for Earthquake-resistant Houses

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Abstract

In this paper, engineering details of earthquake-resistant bamboo buildings are discussed. The strength properties of bamboo culms employed and the allowances to be made for stress in the design are described, and the jointing with ijuk rope is illustrated. The paper concludes that Ioad bearing capacity is dependent more on lateral resistance than on compression and tensile strengths of the material. The importance of efficient jointing to prevent collapse of the building has therefore been stressed.

Introduction

Bamboo is one of the oldest materials used in building construction, especially in rural areas As a building material, it is a good substitute for timber. It is also light, easy to work with and readily available in villages practically at no or very little cost. In regions where earthquakes and tremors occur frequently, bamboo frame houses survives and remain serviceable longer than other types of houses.

In house construction, bamboo can be used for walls, framework, floors, doors, window and door frames and roofing. Because it is hollow, jointing of two or more members is a problem, and different types and methods of jointing and fastening are required. Furthermore, bamboo has a tendency to split easily and therefore cannot be nailed without pre-boring. Ijuk rope is used in Indonesia for jointing the culms in bamboo houses. According to experience gained, this material is highly suitable for this purpose.

Mechanical Properties

The mechanical properties of bamboo were studied using the culm of a bamboo which was more than three years old. The following results were obtained:

Tensile strength	:	1000 - 4 000 kg/cm^2
Compression strength	:	250 - 1 000 kg/cm^2
Bending strength	:	700 - 3 000 kg/cm^2
Modulus of elasticity	:	100 000 - 300 000 kg/cm^2

The following observations were made during pressure tests:

At 4 atm, perspiration at nodes occurs;
At 5 atm, severe leaking begins; and
At 10 atm, bursting occurs.

For design purposes, the following stress values can be allowed:

Tensile stress	:	300 kg/cm2
Compression stress	:	80 kg/cm2
Bending stress	:	100 kg/cm2
Modulus of elasticity	:	100 000 kg/cm2

Structure

Foundation

The building (36 m^2) was constructed using mostly bamboo materials (Table 1). For foundation, 30-mm concrete pipes were used, and for connection between upper and lower structures, l0-mm steel bars were employed. The concrete foundation was kept 50 cm above soil level (Figures la, b, 2).

Floor

Bamboo matting was used extensively for flooring (Figure 3). A matting was made from split sections of Gigantochloa apus and placed as the bottom layer and mortar is applied on top to complete the flooring.

Wall

Traditionally, several types of plastered bamboo mats are used for walls. The most important ones are:

1. *Bilik, kepang* or *gedek* This bamboo mat consists of strips having a thickness greater than 2 mm and a width of 2-5 cm (mats made from smaller strips are used for ceilings). The mats are placed on both sides of a timber or bamboo frame and nailed down.

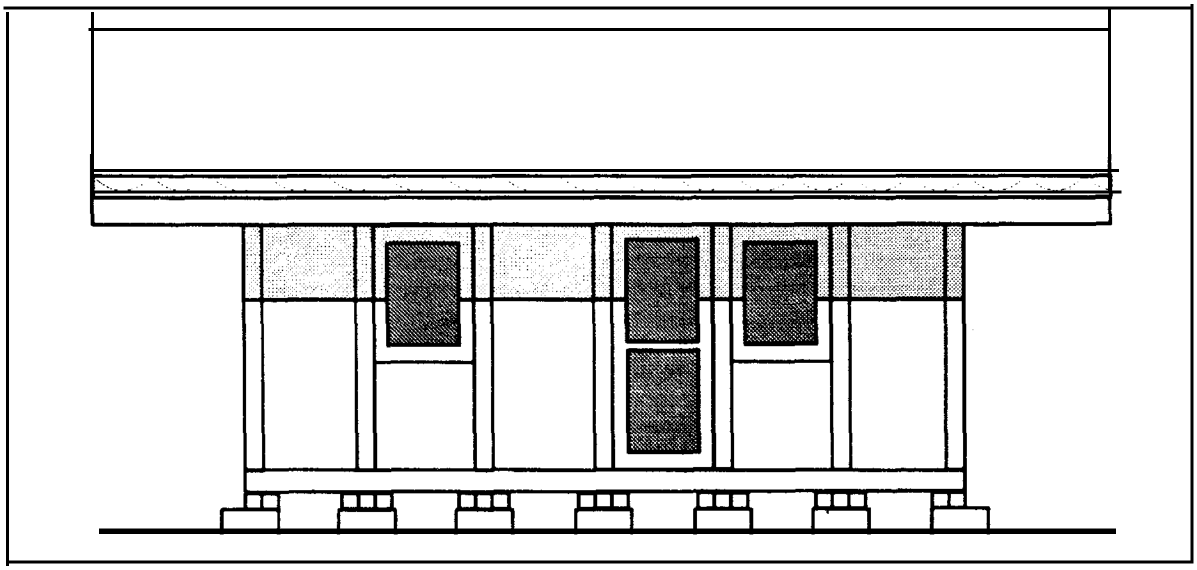


Fig. la: Front view of bamboo house

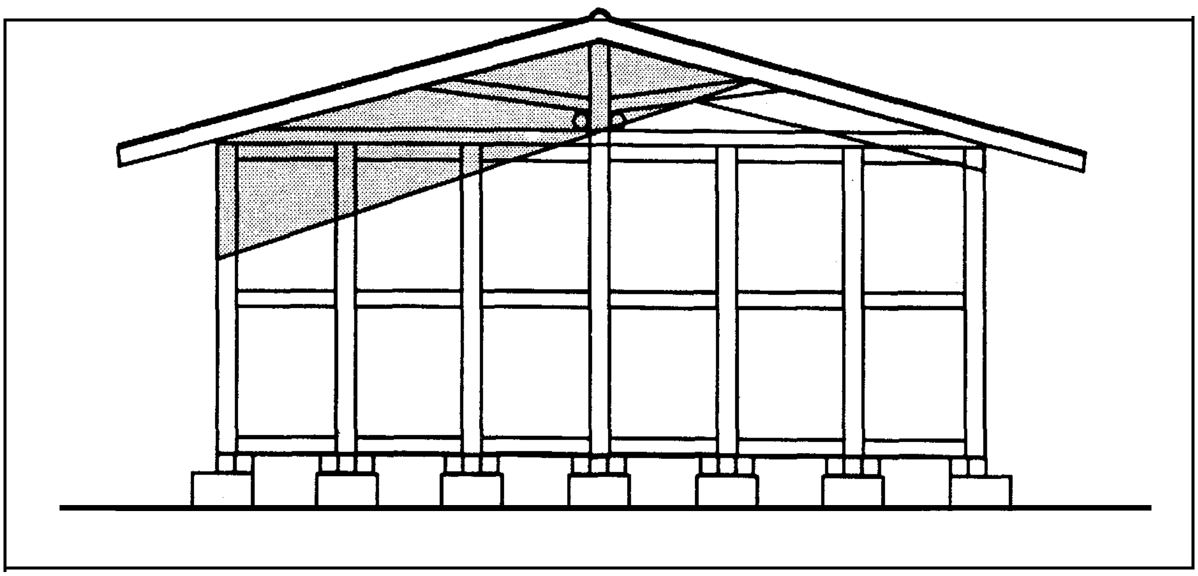


Fig. lb: Side view of bamboo house

2. *Sasak orsesak* This mat is made from unsplit sections of G. *apus,* and is stronger than *bilik.*
3. Bamboo boards: Plaited bamboo boards with stretched vertical steel wires are plastered over and used for walls in areas that experience frequent and heavy earthquakes.

A series of laboratory tests conducted on plastered bamboo mats showed plaster made of Portland cement and sand to be suitable for use in plastered bamboo mat walls. Walls are best made with bamboo board, and plaster made of Portland cement and sand in the ratio 1:5 (by volume) (Figure 3).

Table 1: Building costs

Material	Quantity (Rp.)	Unit Price (Rp.)	Total cost (Rp.)
Foundation			
- concrete pipe (30 mm dia.)	16.5 **pcs**	200003	30 000
- mortar + sand	1.20m^3	125000	a50 000
Sub total			480000
Walling			
bamboo culm (l0-12 mm dia.)	35 pcs (6-m)	1500	52500
- bamboo mats	87 m^2	**1000**	87000
- plaster (cement + sand)	87 m^2	2000	174000
- finishing (cement paste)	174 m^2	1000	174000
Sub total			487500
Flooring			
- bamboo culm (l0-12 mm dia.)	12 **pcs** (6-m)	1500	18000
- bamboo split (10 mm dia.)	120 pcs (6-m)	8009	6000
- mortar	36 m^2	2000	72000
Sub total			186000
Roofing			
- bamboo (l0-mm dia. trusses)	12 pcs (6-m)	15001	8000
- corrugated zinc sheet	45 pcs	9000	405000
- plain zinc sheet	8m^2	2800	22400
Sub total			445400
Doom and windows			
- door + glass	4 pcs	25000	100 000
- window + glass	4pcs	17500	70000
Sub total			125000
Accessories			
- locks, nails, anchor bar, etc.			50000
- ijukrope			75000
Finishing			
- wall paint	205 m^2	800	164000
- wood paint	47 m^2	750	32250
Sub total			199250
Wages	25 workers	20 931.50	523287
TOTAL BUILDING COST			2 616 437
BUILDING COST/M^2	2 616 437/36 m^2		72678.80

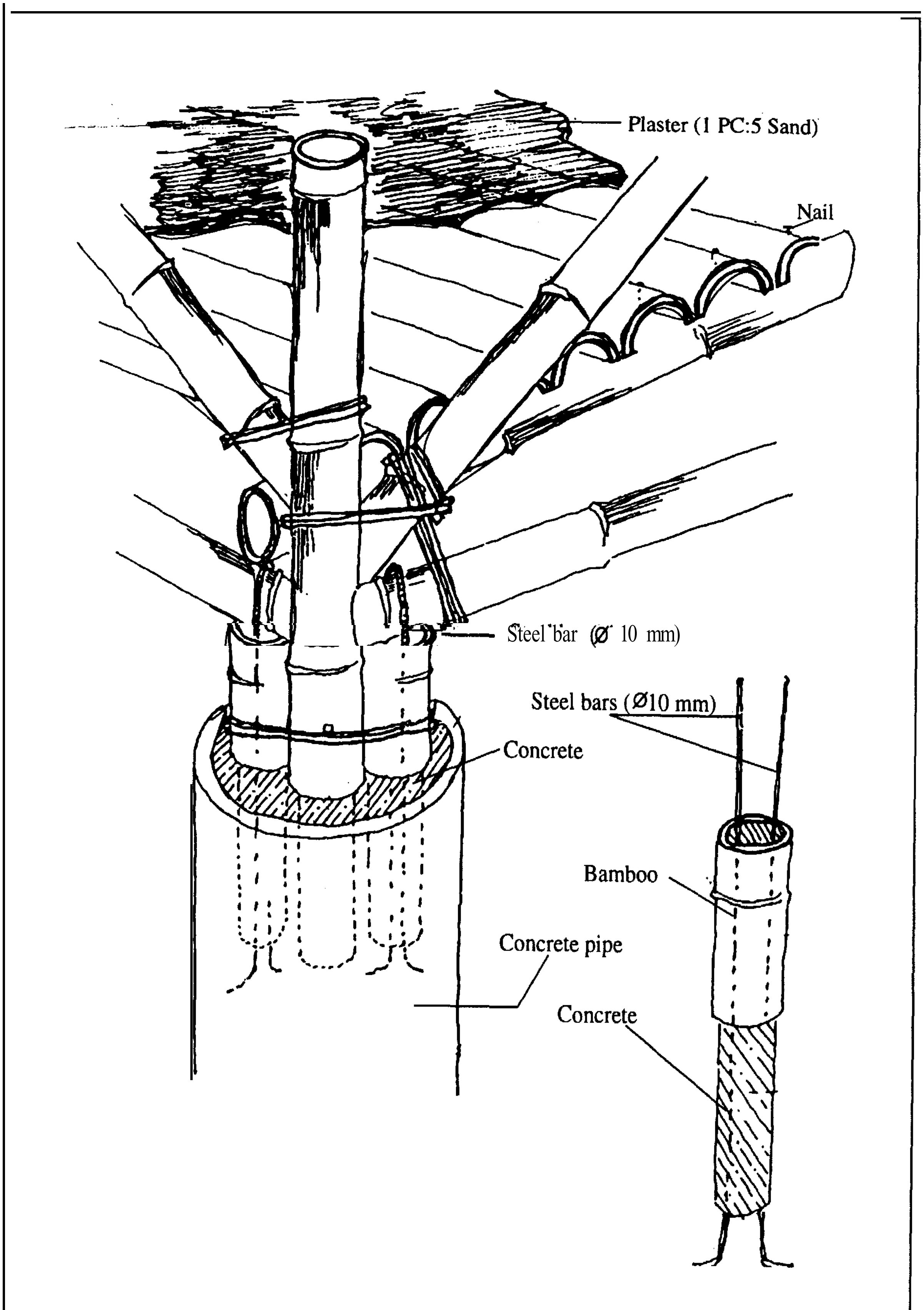


Fig. 2: Structure of the foundation

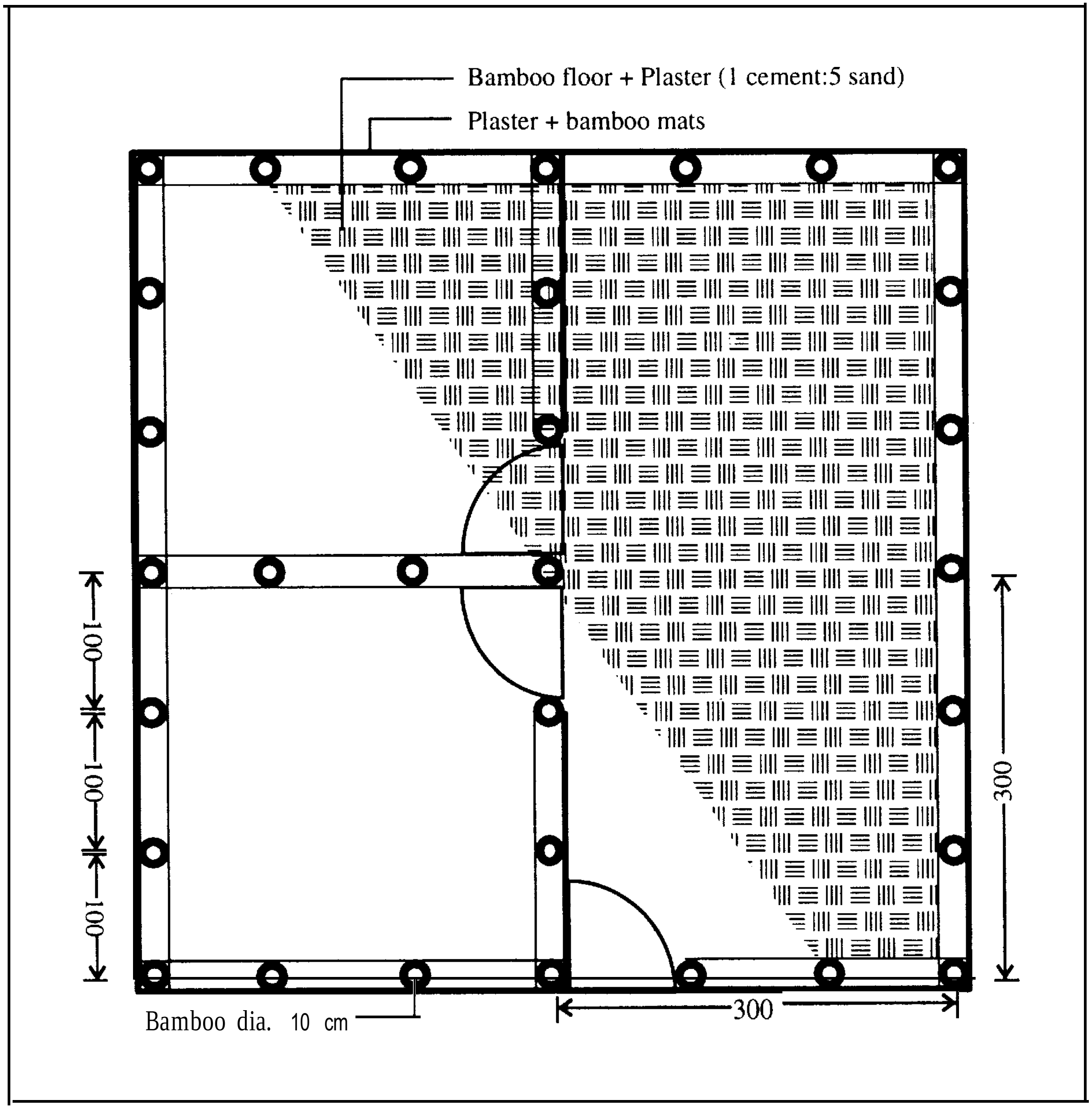


Fig. 3: Floor plan (using plastered bamboo mat)

Roof trusses

Bamboo roof trusses are usually fabricated on-site, and they are easy to erect. Several types of bamboo joints with *ijuk* rope and bamboo pins are illustrated in Figures 6a-d. *Ijuk* rope has a maximum tensile strength of 1000 kg/cm^2.

The roof truss tested were of king post type (Figure 5), and the structural elements were connected using *ijuk* rope and bamboo pins (Figures 6a-d). The diameter of the *ijuk* rope was 6 mm, and the loading test was

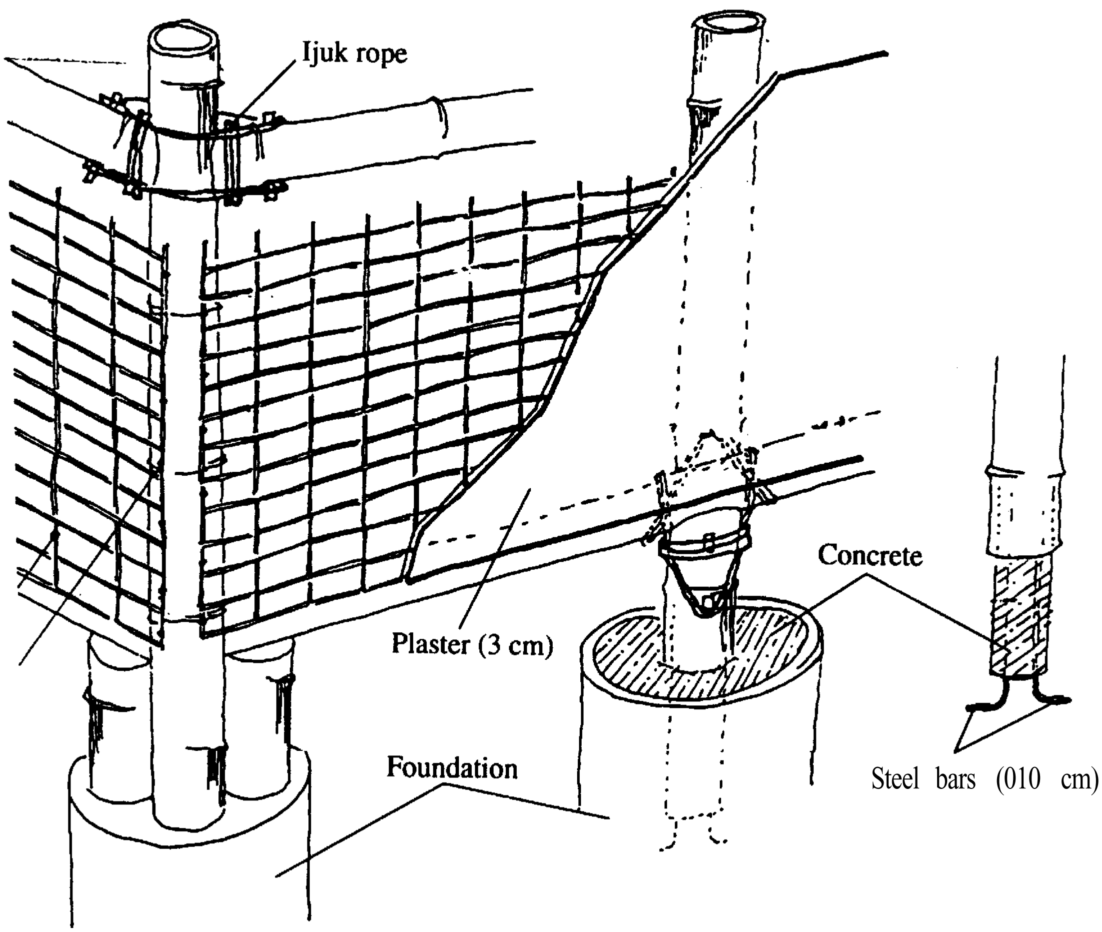


Fig. 4: Structure of wall

carried out using the "screwed hook" testing method (a screwed hook connected to spring dynometers with a maximum capacity of 1000 kg). The load was applied at the three upper joints in two stages: first, up to the nominal load; second, up to failure.

Conclusion

1. The load bearing capacity of bamboo structural elements depended mainly on its lateral resistance and less on its compression and tensile sttengths;
2. Collapse of the structure occurred mainly because of yielding of the joints on account of the insufficient radial resistance of the structural members;

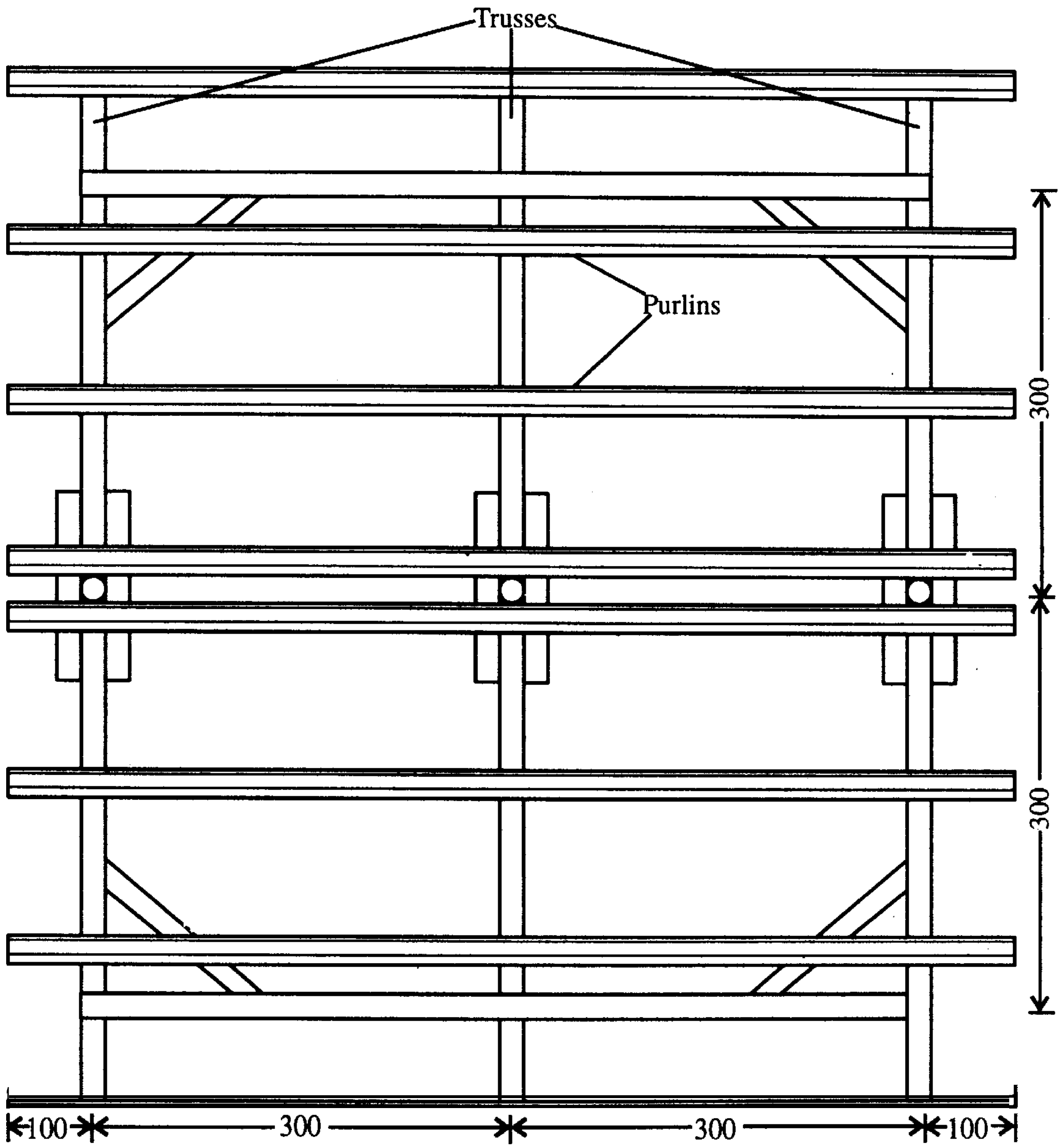
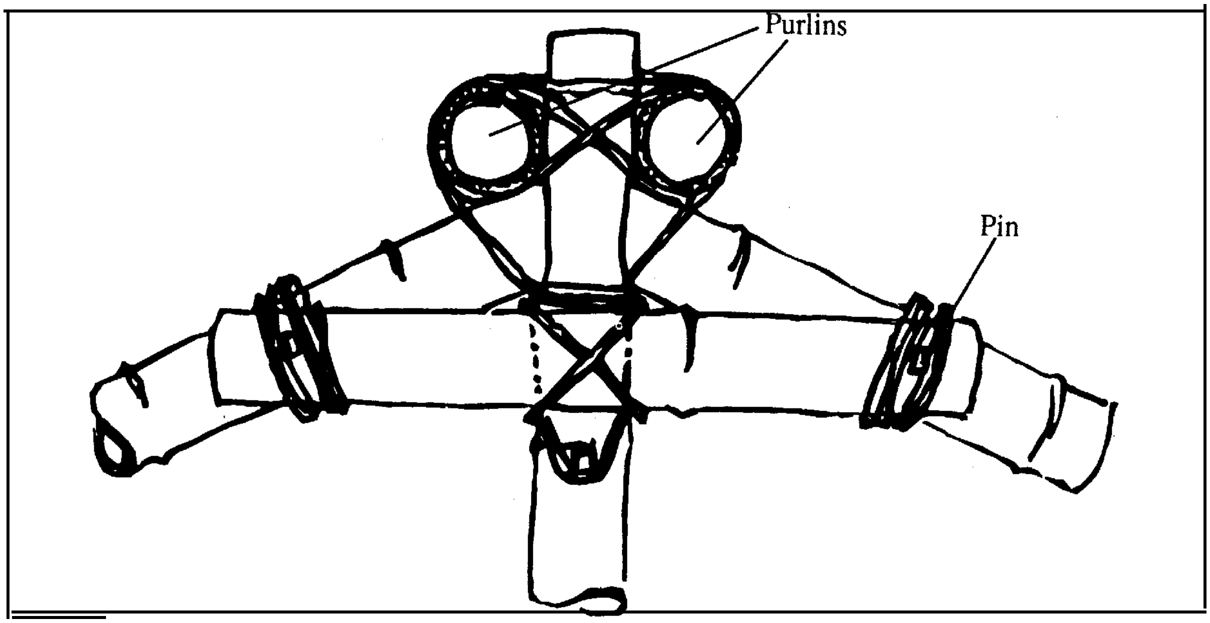


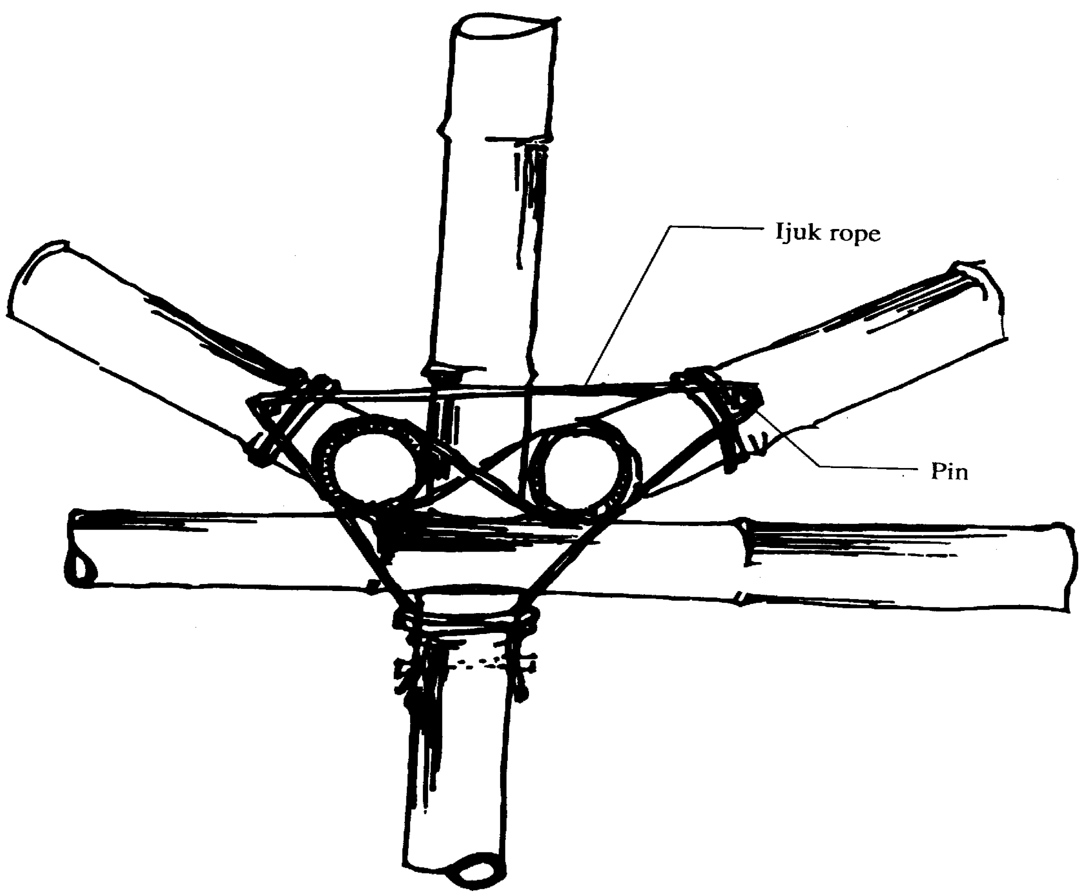
Fig. 5: Roof plan

3. Vertical deflections measured were considerably larger than calculated values;
4. Location of the joints at the nodes increased the load bearing capacity of the structure; and
5. Safety factor in relation to the maximum load could not be ascertained because many defects were observed on the structural members before the maximum load was reached.

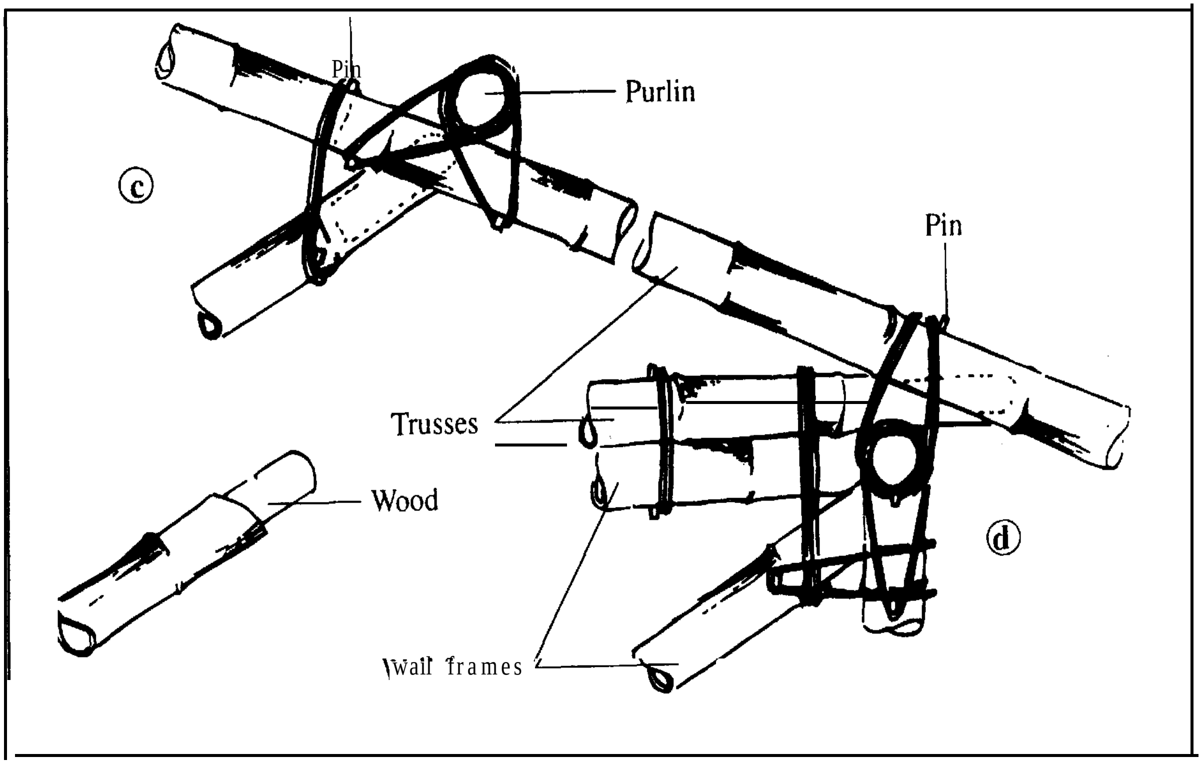
As elastic instability of the structure as a whole was always accompanied by failure of the joints, it is recommended that the behaviour of joints under load be studied.



Figs. 6a: Jointing of various structural elements



Figs. 6b: Jointing of various structural elements



Figs. 6c, d: Jointing of various structural elements

Study of Mechanical Properties of Bamboo and its Use as Concrete Reinforcement: Problems and Solutions

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Abstract

When the possibility of using bamboo as reinforcement in concrete was first demonstrated, it generated considerable excitement. It was, however, short-lived as bond integrity between bamboo and concrete was found to be low and unstable, resulting in the collapse of structures which used such reinforcement. Since then, attempts have been made to overcome this problem, but with little success.

This paper, after analysing the relation between mechanical properties and position in the culm, proposes that in respect of tensile and bending strengths, as well as water absorption (which is responsible for shrinkage, swelling and weakening of the bond), the outer 30% of the culm is far superior to the inner 70% in its suitability as a reinforcement material. By making "cables" by twisting or braiding strands from the outer portion of the culm, and utilizing the same for reinforcement, stable bonding is possible. Thus, bamboo can successfully be used as reinforcement in concrete.

Introduction

The history of bamboo's use as reinforcement in concrete goes back to 1914, when H.C. Chow worked out the first experiment in this field at the Massachusetts Institute of Technology. Since then, many investigations have been done in this field in several countries. The most outstanding of these works was in 1950, by H.E. Glen at the Clemson Agricultural College, South Carolina, USA. As part of his research, he built several buildings using bamboo splints and small-diameter culms as reinforcement in concrete structures, though with very poor results. This experiment and others made in Vietnam for military purposes (Figure 1), form the best demonstration of the fact that the traditional use of small-diameter bamboo culms and splints taken from the culm of giant bamboos (Figure 2) is not recommended for reinforcement in concrete (Figure 3).

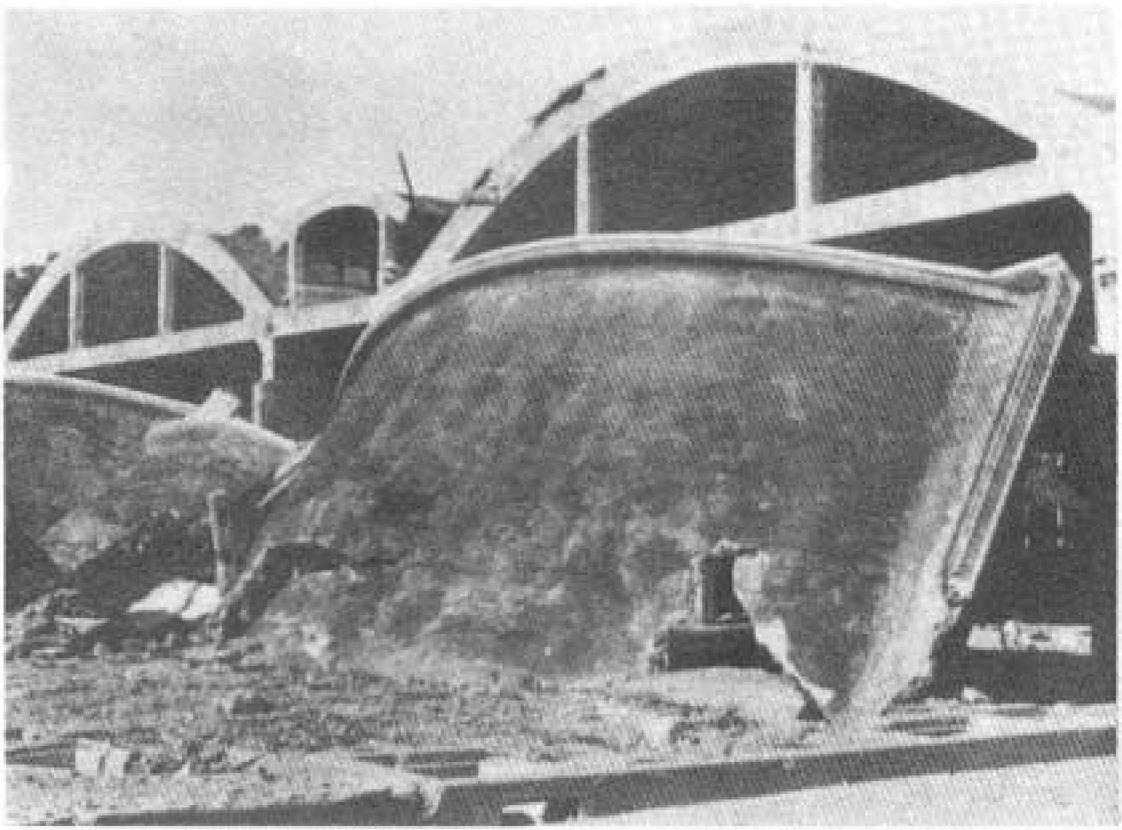

Fig. 1: The lack of adherence between bamboo splints/bamboo culms of small diameter and concrete can have catastrophic results as can be seen in this building made in Vietnam

The reason for the failure of concrete structures reinforced in this traditional way is that the interior, softer part of the culm (Figure 4) absorbs water in the concrete and swells. On drying, it shrinks and loses its adherence to the concrete and consequently, its function as reinforcement. In order to solve this problem, researchers have suggested a number of solutions. Some of these are so impractical and uneconomical that one can clearly see that they have failed take into account the end-users, who are mostly peasants living near forests, where it is difficult or impossible to get or transport, forinstance, long steel bars. Some are fairly simple. For example, Glenn (l944) recommended a coat of asphaltic emulsion on the bamboo reinforcement as the cheapest remedy. Most are sophisticated, like the

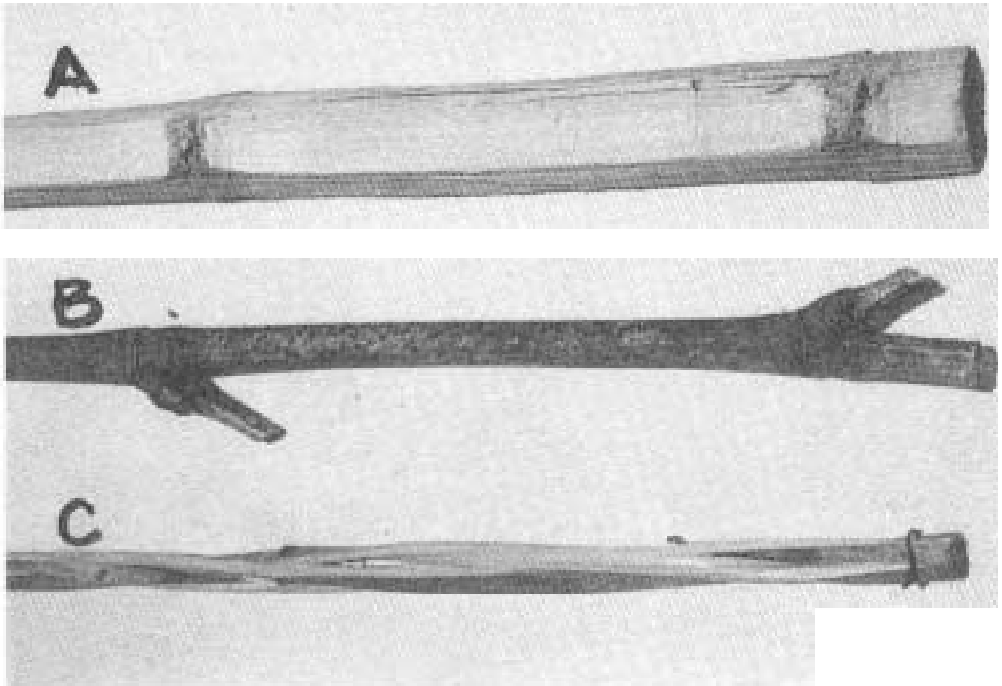

Fig. 2: (A) Splint of bamboo and(B) small-diameter bamboo culm (or branches) used traditionally in reinforcing of concrete; (C) Bamboo cable made with strands of the outer part of the culm wall

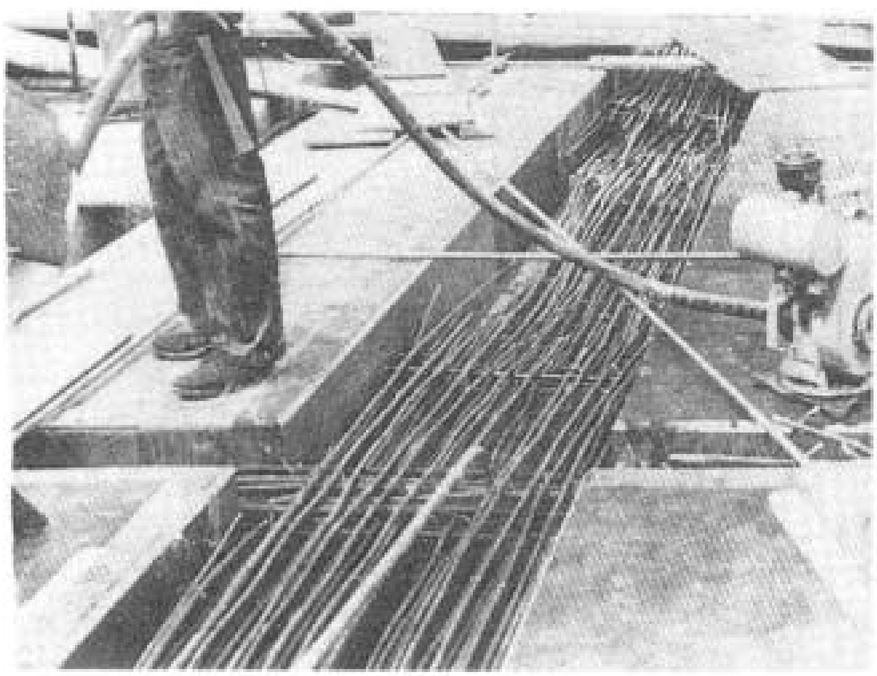

Fig. 3: One of rhe concrete structures built by Glen in 1950 using as reinforcement small-diameter bamboo culms that had very poor results

suggestion of Pama et al. (1976) to immerse the bamboo material in 2% zinc chloride, or in a Neoprene adhesive mixed with sand. But products such as zinc chloride and Neoprene are not easily available in rural settings. Kowalski (1974) advised the use of polyester resins or epoxy adhesives and silica powder as part of the treatment; a treatment which is so expensive that a month's earnings of a peasant will not be able to cover the cost of resin necessary for a three-metre bamboo piece. Probably the most uneconomical recommendation was by Fang et al. (1976): to apply first a sandblasting treatment, and then a sulphur and sand treatment

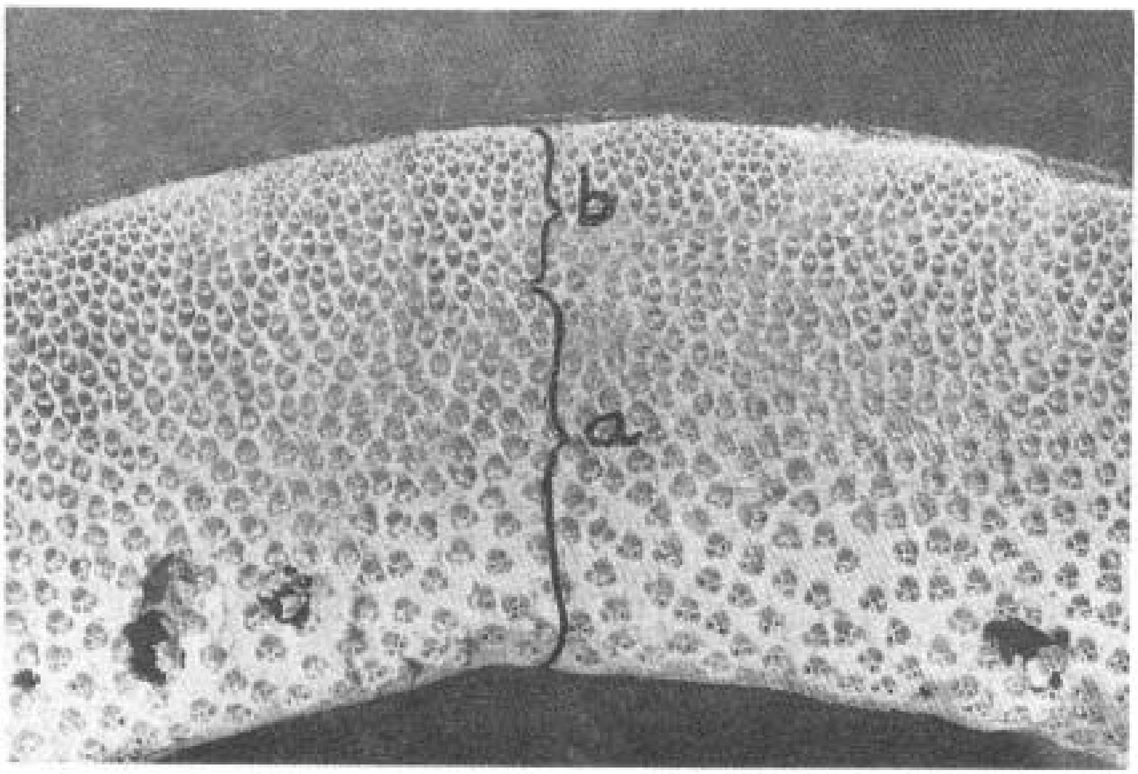

Fig. 4: Cross section of the internode in the culm wall: the vascular bundles, and the densest zone (a) and the sofrest zone (b) which is most attacked by insects can be seen

It was this situation that prompted the establishment in 1974 of the Bamboo Research Centre (CIBAM) at the National University of Colombia, to look for a new, practical and safe technology for the use of bamboo as reinforcement in concrete.

The purpose of this paper is to show how, using bamboo cables as the reinforcing material, the problem of adherence and swelling of bamboo when it absorbs water was solved. A new testing method for bamboo is also proposed in order to obtain more accurate information on its physical and mechanical characteristics.

Testing Bamboo for Compression and other Mechanical Properties

The first study at CIBAM was on the physical and mechanical characteristics of the species known by the common name "guadua de castilla", one of the most important species in Colombia. The study followed the recommendations of the research by H.E. Glenn (1350) which, at that time, was considered the best and most complete done in America on the physical and mechanical properties of bamboo species, and on their use as reinforcements in cpncrete.

In 1976, while working at the Smithsonian Institution in Washington, the author came across a publication by Walter Liese on the anatomy of bamboo which alerted him on the procedural mistakes in the study undertaken at CIBAM on the physical and mechanical properties of bamboo. The case is similar with most studies carried out up to the present time on the mechanical properties of bamboo, for the following reasons:

1. The information developed by researchers of Asia, America and Europe on the strength characteristics of bamboo is based on inadequate data obtained using different testing methods, and widely varying dimensions and shapes of test specimens. This'is the result of the erroneous belief that bamboo and timber have the same anatomical structure and consequently, the same structural behaviour. This is the reason why most researchers utilize the standard test procedures for wood laid down by the American Standard for Testing Materials (ASTM) in their experiments on bamboo. Most researchers ignore the fact that bamboo does not have radial cells which, in the case of wood, increases its shear strength. The absence of radial cells is one of the reasons why bamboo has a low resistance to shear strength parallel to the axis, which is an advantage for purposes such as the basketry but a disadvantage for researchers when trying to make from bamboo the same type of specimens used for testing timber. Bamboo specimens generally break very easily in the direction parallel to the axis. Hence, it is necessary to develop a different type of bamboo specimen for laboratory tests. There are some other researchers who are not familiar with the Standards and invent their own test methodologies,

2. Most studies on the mechanical properties of bamboo to date have been theses of students from different engineering faculties, supervised by professors who, in some cases, do not have any experience in bamboo construction and/or any knowledge of the plant. In the Americas, where

12 giant species of the genus *Guadua* are distributed from Mexico to Argentina, the problem is worse since most researchers are not familiar with ***Guadua*** species. Ignorance of their scientific names and the confusion on their common names, which vary from country to country, add to the problem. For example, there are six different native species of giant bamboos in Colombia that are used in construction. All the six are erroneously considered to belong to the same species that goes by the common name of "guadua", and to have the same scientific name of Guadua *angustifolia.* This situation has prompted most studies researched in Colombia to have titles such as "The mechanical properties of guadua" when meaning a specific bamboo species, or "The mechanical properties of *Guadua angustifolia* Kunth" when the species investigated might be a different species altogether. It is often not possible to know which of the six species was/were used in the experiments, and there are cases in which several species were used in the belief that they are all the same species.

3. As propose (and stated by researchers in the introductionoftheirreports), the final goal of these studies on the mechanical properties of bamboo is to establish standards concerning the appropriate use of each species in the field of construction. However, most research up to the present time show only a list of values of the mechanical properties in Newtons or kg/cm^2. These are practically useless and inapplicable because they do not make it possible to establish standards for the appropriate use of bamboo in construction. For example, if a study gives the maximum compression strength of a bamboo as 400 kg/cm^2 and we need to use this bamboo in columns 2.5 m high, we can only calculate the parameters of the column as ifit were a straight steel tube. In practical terms, however, what one needs to know for using the material in construction is the relation between the strength to compression of the whole internode, or by linear metre the lower, middle and top sections and its relation to the diameter, the thickness of the wall, length of the internode, and the area of the vascular bundles in sq. mm.

This is the reason why no one uses in construction any of the studies that have so far been done on the mechanical properties of bamboo. Those are consulted only by people who are starting a new research work, while. we continue using bamboo by trial and error.

To sum up, studies that can only be understood by engineers but not used by them are of no value. It is necessary to develop simple and practical methods or standards that can be utilized in construction by any bamboo builder, even though he/she does not understand values in Newtons or kg/cm^2. This is the basis for this paper.

New Basis for Testing Bamboos

From the anatomical studies on bamboo conducted by Walter Liese, we know that the nodes play an important role in the physical and mechanical properties of bamboo, and that the fibre length increases from the nodes to the centre of the internodes and from the periphery to the centre. This means that any section taken from any part of the internode will give different values of compression strength. From this, we can conclude that the whole internode has to work as a unit. The first researcher who tested whole internodes was Bauman in 1912. It is very important to test internodes with the nodes, and sections of 1-2-3 metres composed of several internodes taken from the bottom, middle and top sections of the culm. At CIBAM, we tested sections of 1,2 and 3 metres of guadua de castilla. The following information obtained from the tests can possibly act as the principles for establishing a new methodology for testing bamboo for construction purposes.

- **One-metre-long sections**

Maximum compression stress = 23 650 kg; diameter - 133 mm; age - 5 years; wall thickness - 15.5 mm; number of nodes - 4.

Minimum compression stress = 7 350 kg; diameter - 83.9 mm; age - 1 to 3 years; wall thickness - 17.3 mm; number of nodes - 3.

- **Two-metre-long sections**

Maximum compression stress = 22 500 kg; diameter - 143.3 mm; age - 5 years; wall thickness - 16.2 mm; number of nodes - 7.

Minimum compression stress = 3 830 kg; diameter - 78.6 mm; age 1 to 3 years; wall thickness - 7.1 mm; number of nodes - 6.

Three-metre-long sections

Maximum compression stress = 16 600 kg; diameter - 130.9 mm; age 5 years; wall thickness - 19.2 mm; number of nodes - 13.

Minimum compression stress = 2 740 kg; diameter - 94.4 mm; age 1 to 3 years; wall thickness - 9.7 mm; number of nodes - 10.

The above information is related only to the bottom section of the culm. If similar data can be obtained also from the middle and top parts of the culm, it would be the complete information on the mechanical characteristics of the whole culm. It would also give an idea on the different uses that each part have in the construction of a building, particularly regarding the members that are structurally under compression.

It is very important to bear in mind that physical and mechanical properties vary from one species to another and even within the same species, depending on the habitat of the species, and also on whether the species is cultivated on flat or sloping ground. For example, in Colombia, Guadua angustifolia grows between 1200 and 1800 metres above sea level, and is stronger than the same species that grows in Ecuador at less than 500 metres above sea level. Mechanical characteristics such as tensile and bending strengths of culms have to be tested according to the dimensions used. For example, tensile strength has to be tested using strips with the length of the internode, including the nodes, and also using strips one-two-three metres long.

Another important point to bear in mind, particularly when the researcher ignores the scientific name of the species, is to take frontal and lateral photographs of the branch complement or base of the mid-culm branch, and also of the sheath. These are used in the identification of the species, and the information can help avoid confusion of species.

Use of Bamboo Cables as Reinforcement in Concrete

In a transverse section of the cuim two zones can be seen (Figure 4):

a) The inner, softer part which accounts for about 70% of the culm wall. This zone is the one that swells as it absorbs water in concrete. This part of the culm was tested for tensile strength and gave a maximum value of only 706 kg/cm^2.

b) The outer part of the culm comprises 30% of the culm wall and is the denser zone. Consequently, it absorbs only a minimum amount of water. This zone was tested for tensile strength and gave a maximum value of 2 052 kg/cm^2.

This means that the outer part of the culm is almost three times stronger than the inner part. From the same section of the culm from which strips for the above experiments were taken, a strip containing both zones was taken and tested. It gave a maximum value of 1 175 kg/cm^2, which is the combined strength of the two zones. This means that if the inner part is removed from the strip, the strength of the strip will increase. At the same time, it would also solve the problem of swelling of bamboo strips used as reinforcingconcrete. In order to increase the adherence of strips from the outer portion to the concrete, bamboo “cables” of small diameter were made from stnnds by braiding (Figure 5) or twisting (Figures 6-8), in the same way as the Chinese manufacture bamboo cables of 30 cm diameter which they use in the construction of suspension bridges of up to 120 metres long. (Figure 11).

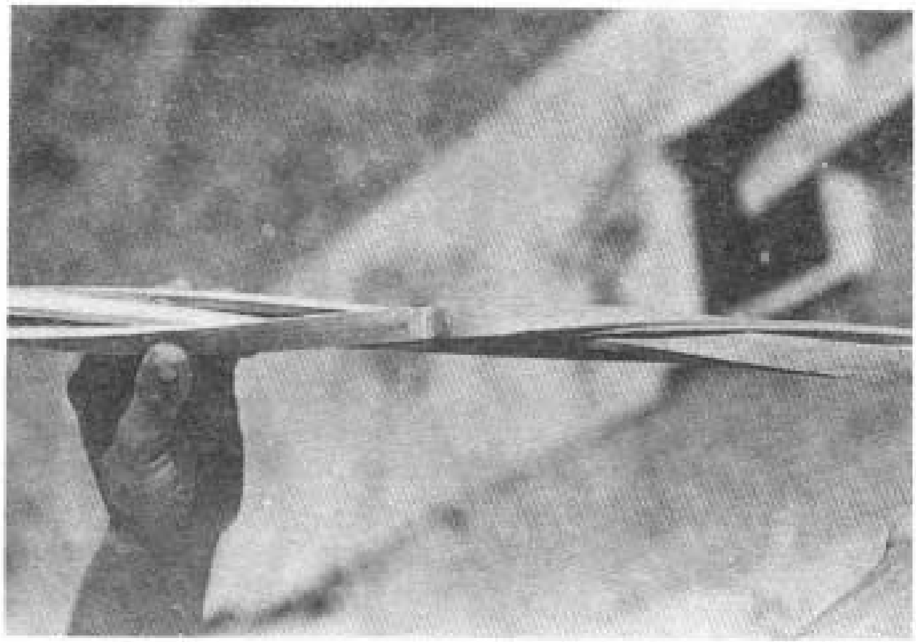

Fig. 5: The first experiments were made with cables composed of three braided strands, with satisfactory results

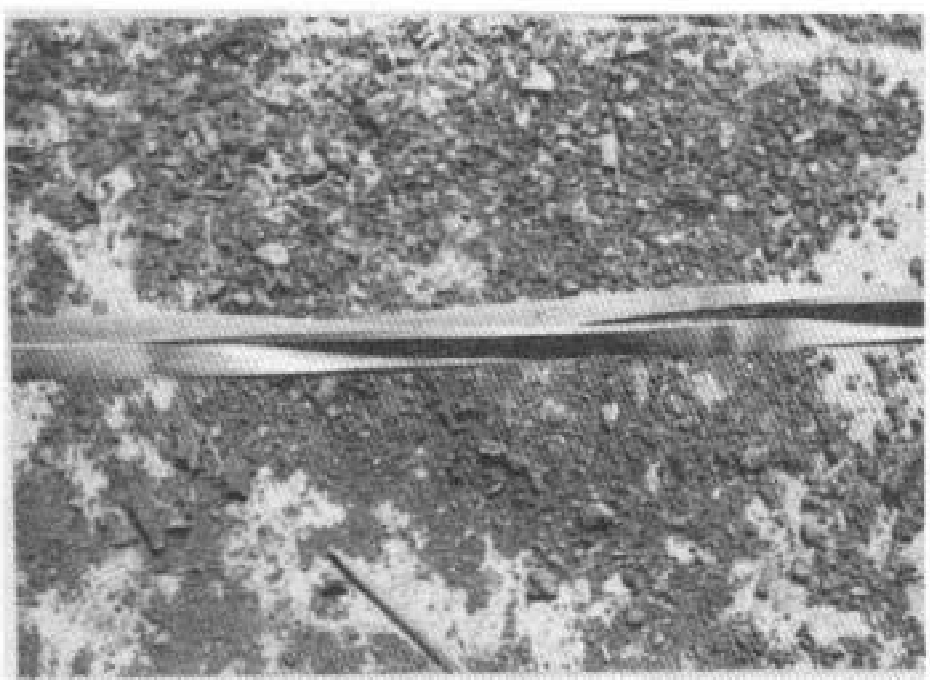

Fig. 6: Most of the experiments were made with bamboo cables made by twisting three or more strands

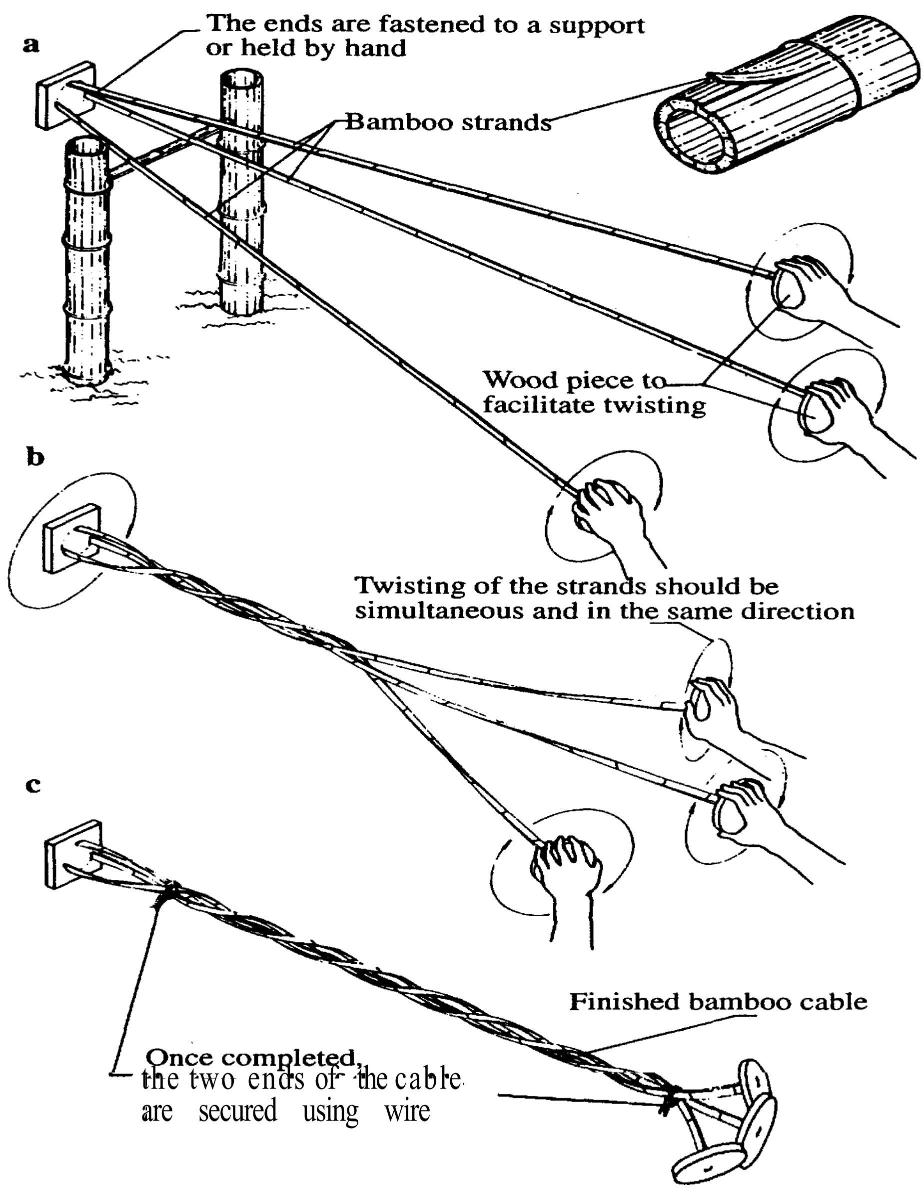

Fig. 7: Production of cables using bamboo strands

Fig. 8: Bamboo strands king twisted into cables

A total of 163 bamboostrips-each 500mm long, 100mm wideand 3 mm thick from different culms of different ages-were tested for tensile strength. The maximum value was between 3 000 and 3 213 kg/cm^2. Some values as high as 3 018 and 3 206 were obtained from bamboos that were one year old.

Advantages of Bamboo Cables Used as Reinforcement

1. The strips are made out of the outer part since its dimensional changes are minimal and it does not require waterproofing.
2. The strips from the outer portion of bamboo is the strongest part of the culm wall. If the cross-sectional area of the inner part of the wall (70% of the wall) is replaced using the outer part, the integrity of reinforcement will increase five to six times.
3. The adherence of bamboo cables is greater than that of splints and small-diameter bamboos because of the helical form of the cable (Figures 6, 7). Tests showed that the adherence of splints and small-diameter bamboos was about 5.09 kg/cm^2 and that for the cable 18.22 kg/cm^2.

The method for manufacturing a cable with three or more strands can be seen in Figures 6-9. The stirrups are made using strips of bamboo culms

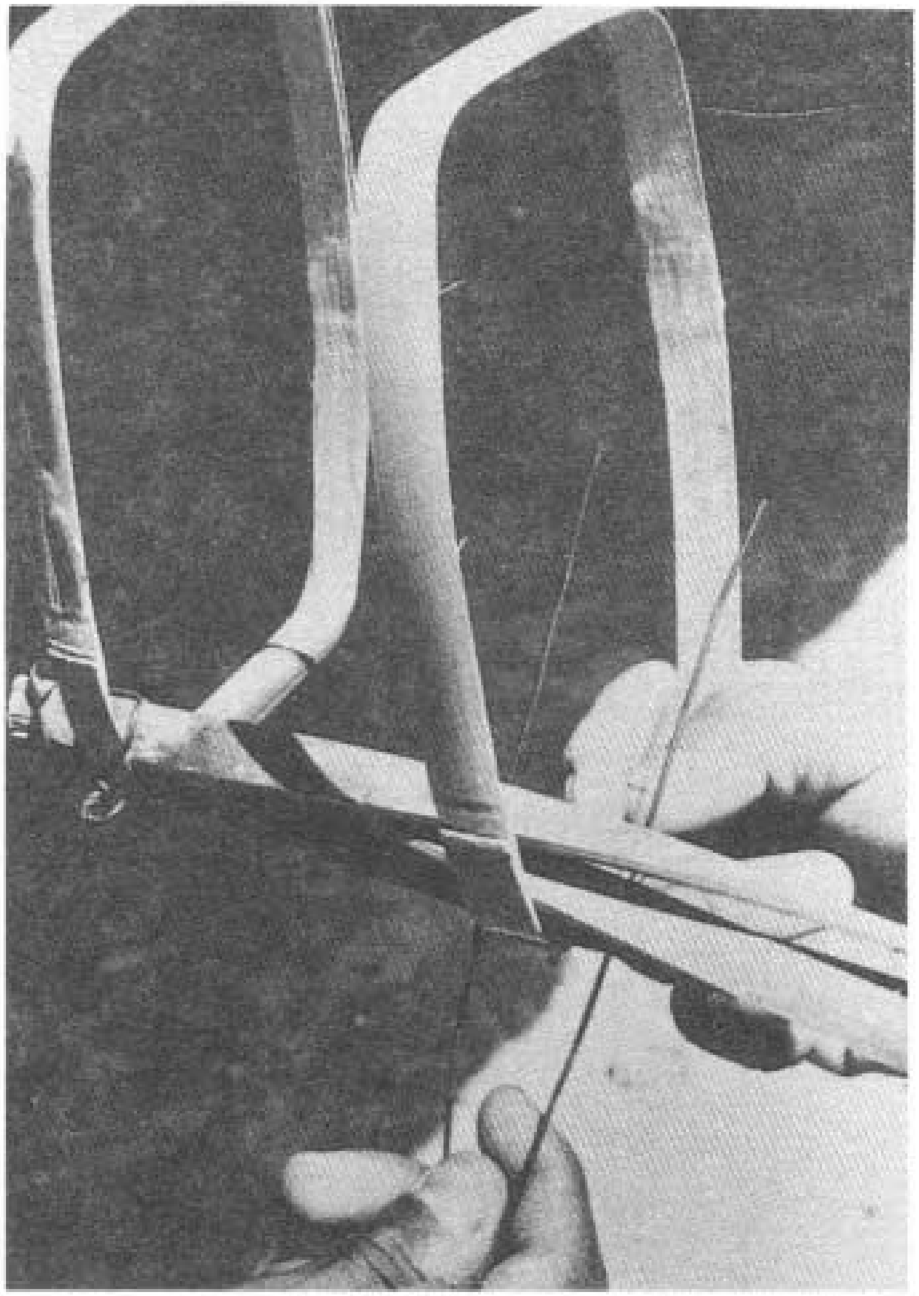

Fig. 9: In the manufacture of the stirrups, strips of nine-month-old bamboo were used since they are more flexible

that are nine months old since they are more flexible than older bamboos (Figure 9).

About 24 concrete beams, each 2.45 m long, were tested in groups of three (Figure 10). In one group, the bamboo strips were used vertically, while in the second group, they were used horizontally. In the third group, bamboo cables were employed. Each group had the same area of reinforcement. The tests proved bamboo cables to be the most efficient.

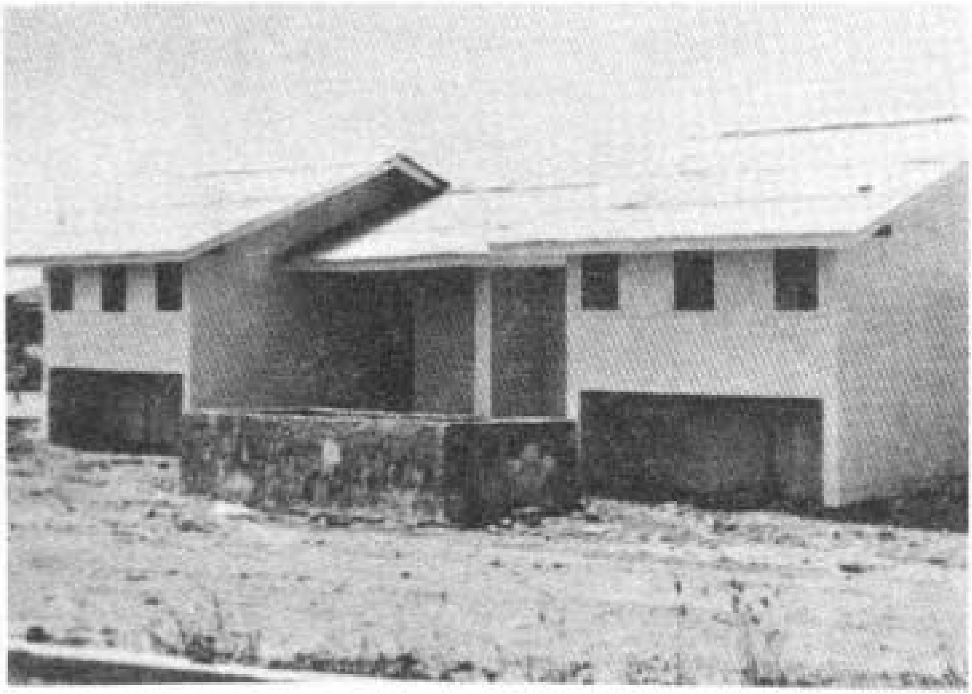

Fig. 10: About 24 concrete beams were tested, reinforced with cables

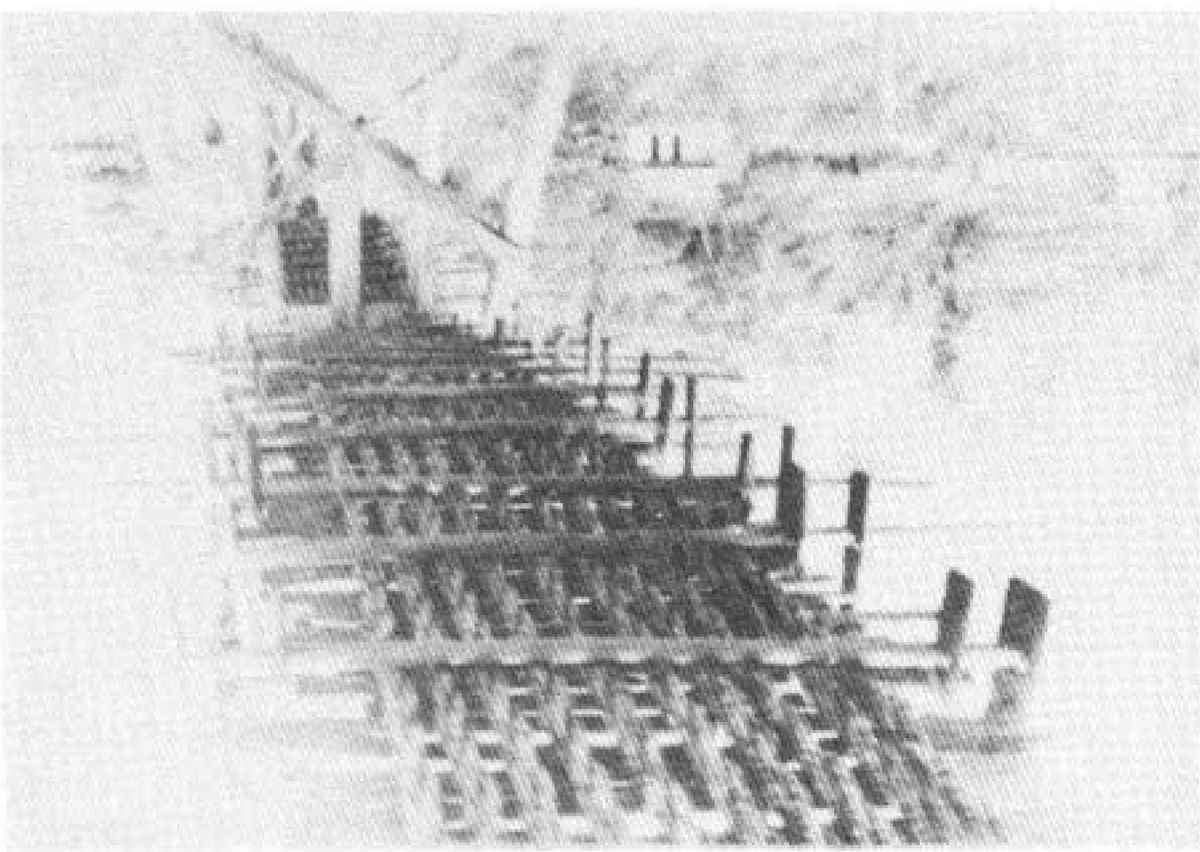

Fig. 11: Chinese suspension bridge made with bamboo cables (can be seen in the lower pan)

Uses of Bamboo Cables in Foundations

This technology was used in Ecuador to reinforce slab foundations for a prefabricated housing program in Guayaquil city. The cables were used as reinforcement in the peripheral beams (Figure 12). The slabs were reinforced with a mesh made of bamboo strips. In one of the slabs the mesh covered the entire area (Figure 13), and in another slab only 60-cm wide mesh was used below the base of the central walls (Figure 14). Ten years after the construction, the houses with slab foundation did not show any crack (Figures 15, 16).

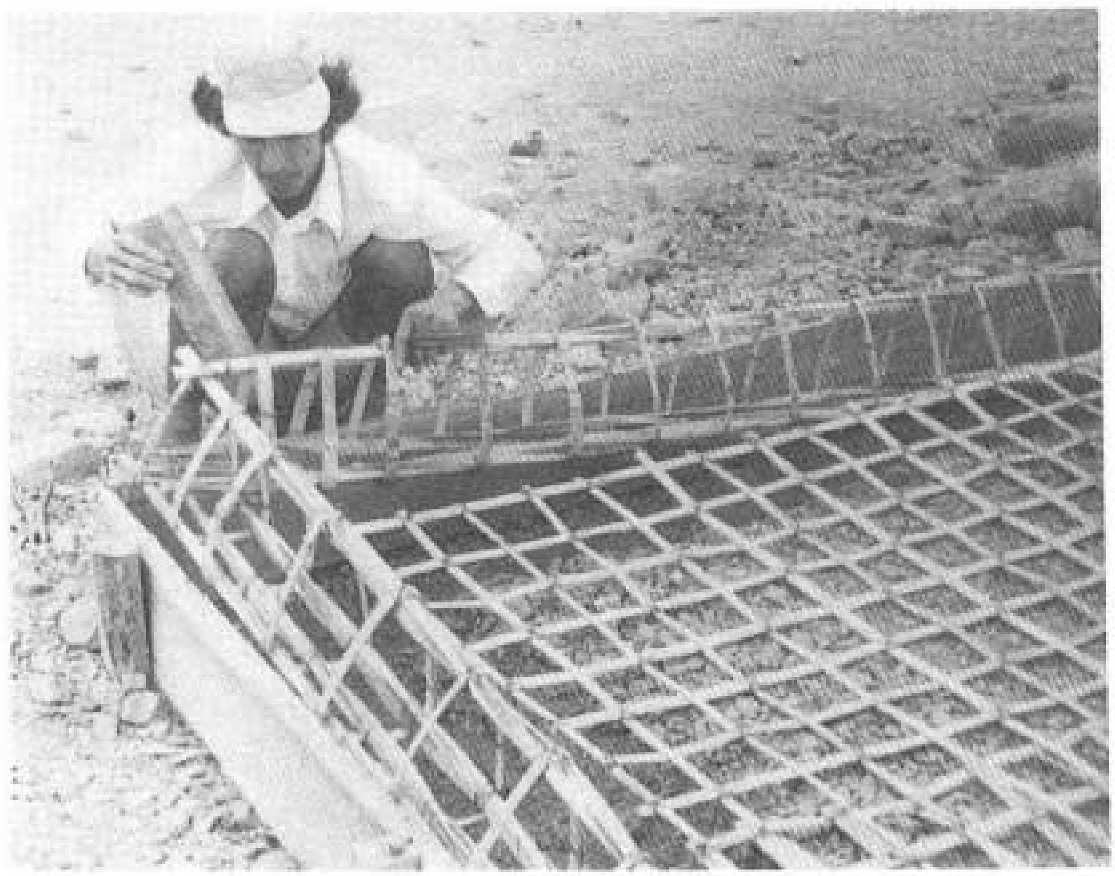

Fig. 12: Peripheral beams of the slab foundation were reinforced with bamboo cables, with satisfactory results

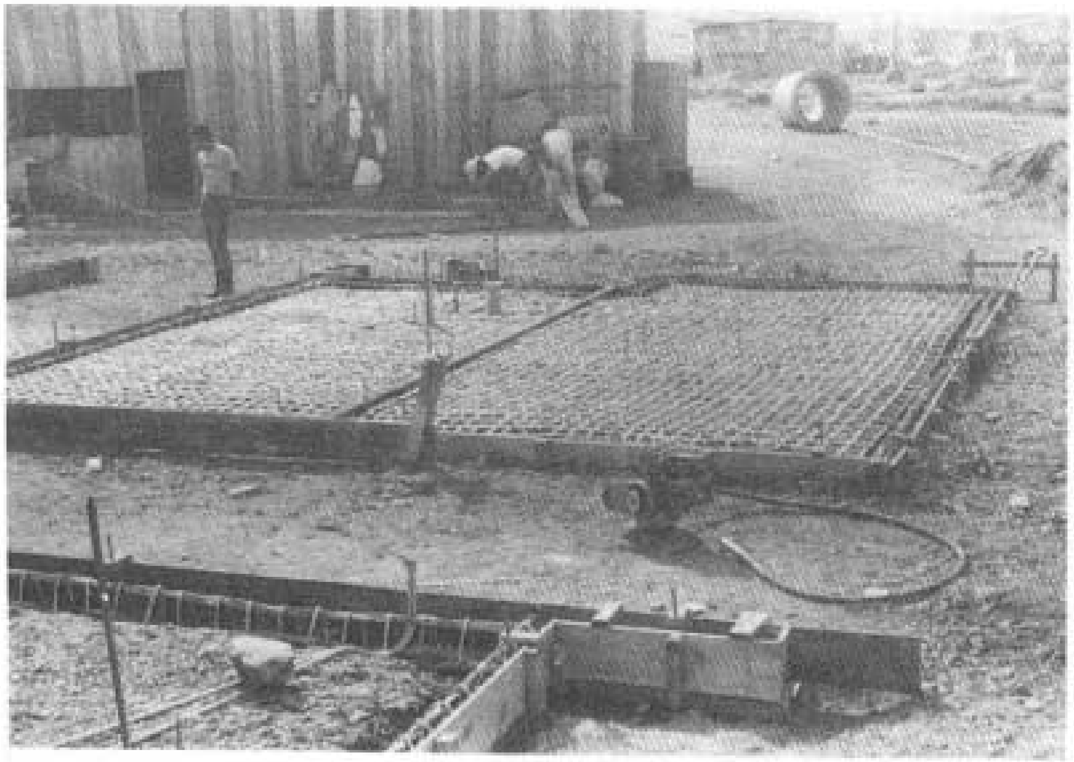

Fig. 13: Experiment with a bamboo mesh covering the whole slab in order to improve its resistance to earthquakes

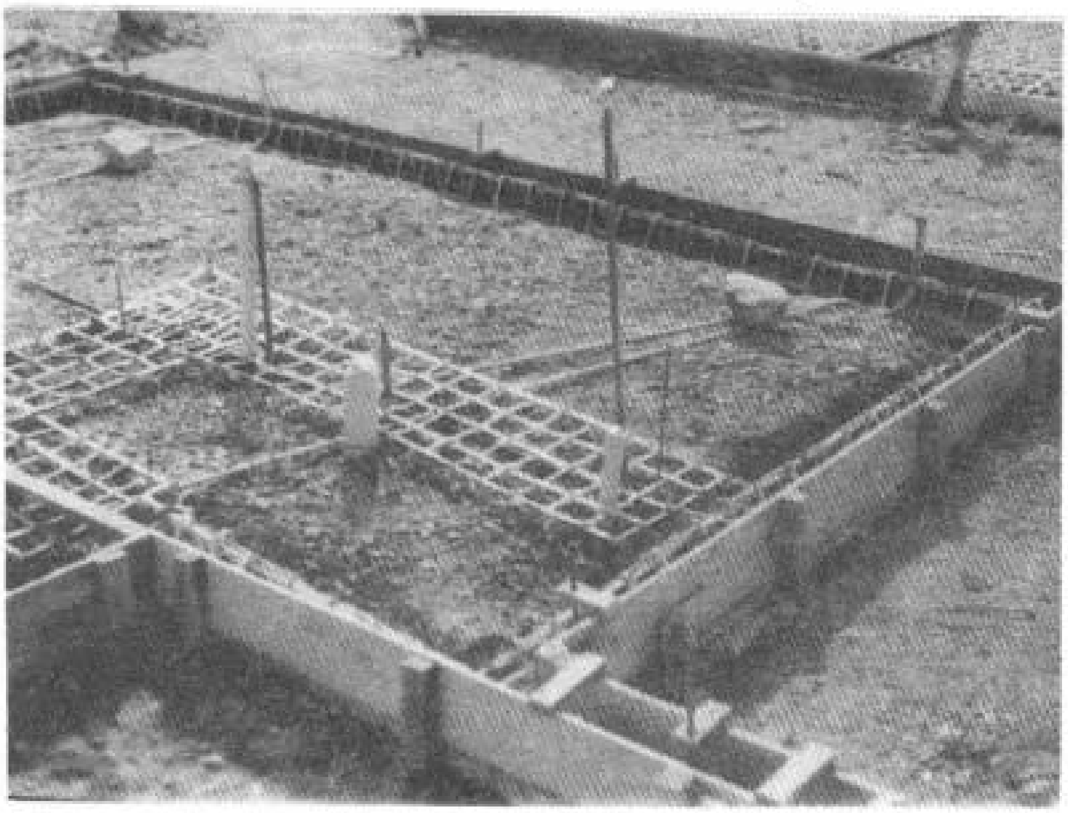

Fig. 14: In some slabs only a 60-cm wide mesh located in the base of the walls was used

Fig. 15: The slab foundations, reinforced with bamboo cables and mesh and built 10 years ago, have no cracks

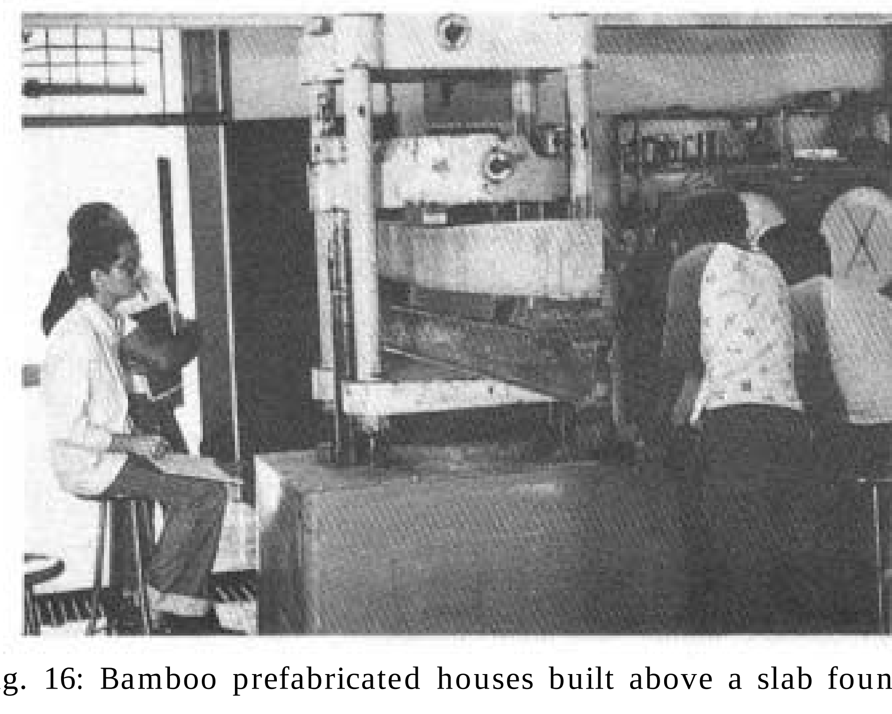

Fig. 16: Bamboo prefabricated houses built above a slab foundation

A Study on *Dendrocalamus asper* as Concrete Reinforcement

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Abstract

A study of Dendrocalams asperas concrete reinforcement has been conducted. It covered the physical and mechanical properties, the effects of some chemical treatments and concrete types on the quality of bonding between concrete and bamboo; and the effect of bamboo profile on the strength of concrete reinforcement.

Based on the superior physical and mechanical properties, *D. asper* has a good prospect to be utilized for concrete reinforcement. Among thechemical treatments, varnish coating on the surface of the culms was the most successful in increasing the bonding strength (surface shear between bamboo and concrete). Better quality concrete also increased strength value of concrete with bamboo reinforcement. The maximum strength was achieved by increasing the width of the rectangular bamboo profile by 30%.

Introduction

The overexploitation and depletion of the forests in tropical areas, especially in Indonesia, has led to severe timber shortage, which has made many people realize the great potential of bamboo as a timber substitute. *Dendrocalamusasper(Betung)* is a large bamboo with culms reaching 20-30 m in height. The internodes are 20-45 cm long with a diameter of 8-20 cm, and the walls are relatively thick (11-35 mm) but thinner towards top of the plant. *D. asper* is one of the most useful bamboos for construction in rural communities, mainly because of the strength and durability of its culms.

Depending on their abundance, cost and favourable strength properties, round bamboo culms are used for houses, bridges, ladders, etc. They are also used, either round or split, for reinforcing mud walls in rural and semi-urban areas. Bamboo-reinforced concrete (BRC) is also used for making small water tanks, grain silos, short-span beams, lintels, slabs and platforms, with a cost reduction of 30-40% over steel reinforced concrete structures of the same size and shape (Mishra and Sanyal 1991).

Based on the tensile strength (100-400 N/mm[2]), bamboo strip is the best known alternative for steel as concrete reinforcement (Yap 1967). The possibility of using Indonesian bamboo as concrete reinforcement material was investigated by Surjokusumo and Nugroho (1993,1994), using several bamboo species such as *Gigantochloa* apus(Tali), G. vetiicillata(Andong) and *D.* asper(Betung). *D.* asperwith its straight culms has the highest value in terms of tensile strength and modulus of rupture (MOR).

Materials and Methods

D. asper was collected from a village grove of Leuwiliang, Bogor (West Java). Twelve mature culms (three years and above in age) from one or more clumps from two different localities (humid soil and dry soil) were considered for each investigation. Physical and mechanical properties – density, moisture content, shrinkage characteristics, static bending, shear strength, maximum crushing strength and tension parallel to gain – were determined for samples with both internodes and nodes. The standard test procedure of ASTM (1990) for small, clear specimens of timber was followed as far as practicable.

A box of size 100 x 100 x 50 cm was used for dipping the culm strips in water for three months to reduce the starch content. For dimensional stability, three kinds of chemicals (paraffin, varnish and a water repellent) were applied. Three types of strip profiles (square, rectangular and trapezoid) and three sizes of strip width (0.3 mm, 0.6 mm and 0.9 mm) were used as concrete reinforcement material. Concrete was produced by mixing Portland cement, sand, gravel and water in the ratio of 1 : 3.365 : 4.062 : 0.663, to obtain the minimum concrete quality (>K-125).

Results and Discussion

It can be observed in Table 1 that the moisture content of *D. asper* grown in humid soil was higher than that from dry soil. Bamboo from dry soil had better dimensional stability because the shrinkage percentage from green to air-dried was lower than that of the bamboo from humid soil. This may be related to the lower moisture content. The density of dry soil bamboo was also found to be higher than the one from humid soil, and this may be attributed to the presence of a higher proportion of sclerenchyma tissue/ fibrovascular bundles at in culms from the species grown in dry soil. The mechanical properties – modulus of rupture (MOR), modulus of elasticity (MOE), compression, tension and shear – varied significantly between two locations. Values of all mechanical properties were higher for D. asperfrom dry soil than for the same from humid soil.

The presence of nodes is a disadvantage for using bamboo as a reinforcement material. It is evident from Table 2 that the internode of D. asper was the strongest in MOR, MOE, compression and tension than the node (ratio lower than 1), but not in shear. Shrinkage showed a similar trend, while moisture content and density had a ratio of more than 1.

Lowering the starch content of bamboo is crucial for the prevention of attack by powder post beetle. One of the traditional, non-chemical methods for bamboo preservation is to steep the bamboo culm in stagnant water for about three months, whereby the starch content can be decreased from 1.64% to 0.92%. This treatment brings about a change in the mechanical properties of the culm, in ratios varying from 0.93 to 1.15, which are statistically insignificant (Table 3).

Table 1: Physical and mechanical properties of *D.* asper internode from different locations

Properties	Location	
	Humid soil	Dry soil
Moisture content (%)	15.65	12.36
Density	0.56	0.65
Shrinkage : green to air-dried (%)		
a. Volumetric	12.02	9.27
b. Width (tan.)	4.83	4.66
c. Depth (rad.)	3.87	3.27
Static bending		
a. MOR (N/mm2)	134.43	149.62
b. MOE (x1000 N/mm2)	19.18	21.21
Compression (N/mm2)	54.26	59.99
Tension (N/mm2)	213.22	227.34
Shear (N/mm2)	11.20	12.52

Table 2: Physical and mechanical properties of *D.* asper internode and node.

Properties	Position		
	Internode	Node	Ratio
Moisture content (%)	14.00	15.30	1.09
Density	0.61	0.70	1.15
Shrinkage : green to air-dried (%)			
a. Volumetric	10.64	10.55	0.99
b. Width (tan.)	4.74	3.49	0.74
c. Depth (rad.)	3.57	3.15	0.88
Static bending			
a. MOR (N/mm^2)	142.03	121.47	0.85
b. MOE (x 1000 N/mm^2)	20.20	16.78	0.83
Compression (N/mm^2)	57.13	52.42	0.92
Tension (N/mm^2)	220.28	138.03	0.63
Shear (N/mm^2)	11.86	12.62	1.06

Table 3: The effects of three-month steeping in water on the mechanical properties of ***D. asper***

Properties	Treatment		Ratio
	Control	Water-steeped	
Static bending			
a. MOR (N/mm^2)	177.03	167.83	0.95
b. MOE (x 1000 N/mm^2)	18.93	21.21	1.15
Compression (N/mm^2)	67.56	70.19	1.04
Tension (N/mm^2)	307.27	285.94	0.93

The effects of three months of steeping in water on ***D. asper*** for bamboo concrete reinforcement are presented in Table 4. The results indicate no significant differences in mechanical properties as compared to the control.

Table 4: The effect of three-month steeping in water of D. asp for bamboo concrete reinforcement

Properties	Treatment	
	Control	Water-steeped
Tension (N/mm*)	20.80	19.94
Surface shear (N/mm*) of bamboo-concrete	0.447	0.446

Table 5: The effect of chemical treatments on D. asper strip for bamboo concrete reinforcement

Properties	Chemical treatment			
	Control	Paraffin	Water repellent	Varnish
Static bending				
a. MOR (N/mm^2)	1.06	1.84	2.05	7.49
b. MOE (x 1000 N/mm^2)	0.89	3.30	12.27	4.86
Compression (N/mm^2)	17.90	**11.10**	15.87	117.60
Tension (N/mm^2)	0.13	0.08	0.12	0.87

Table 5 shows the effects of chemical treatments on the culm surface of ***D.*** asper for concrete reinforcement. The results indicate that surface coating with varnish has the highest value of MOR, tension, and surface shear between bamboo and the concrete. This means that bamboo strip with varnish surface coating is the best alternative for steel in concrete reinforcement.

Increasing the width of bamboo strips of different shapes resulted in the values of all mechanical properties getting increased (Table 6). The maximum strength for rectangular bamboo strips was reached by increasing the width to 0.9 mm. The average values of MOR, MOE, and surface shear between bamboo and concrete were 8.08 N/mm^2, 9.65 N/mm^2 and 4.01 N/mm^2, respectively. The trapezoidal profile with 0.9 mm width showed the highest average tension parallel to grain of 111.40 N/mm^2

Table 6: The effects of shape and width of bamboo profile on the mechanical properties of concrete reinforcement

Profile shape	Width increase (mm)	Mechanical properties (N/mm^2) MOR	MOE (x103)	Tension	Shear
Square (control)	0.0	5.46	3.54	75.03	2.50
Rectangular	0.3	8.08	9.65	109.87	4.01
	0.6	7.11	5.75	94.25	3.14
	0.9	5.50	5.95	109.53	3.64
Trapezoid	0.3	6.03	9.56	93.73	3.12
	0.6	7.02	7.99	93.73	3.12
	0.9	6.93	7.86	111.40	3.71

Conclusions

Because of the high values of physical and mechanical properties, ***D. asper*** has good prospect of being utilized for concrete reinforcement. It was noticed that better quality of concrete increases the strength value of concrete with bamboo reinforcement. Varnish coating on the surface of the bamboo strip increases bonding strength and enhances other mechanical properties as well. The maximum strength for the reinforcing bamboo can be reached by increasing the width of the rectangular bamboo profile by 30% at the nodes. Long-term, in-service observations and testing for bond integrity will be necessary before definite conclusions can be drawn.

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The Use of Bamboo for Reinforcement in Light-frame Construction System

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Abstract

This paper deals with the development of bamboo-reinforced sheathing to be used in lightweight construction, employing coconut wood for frame and pozzolana cement mixed with lime and sand for mortar.

Experiments were carried out by: placing bamboo strips, with or without surface coating, in different directions; nail-jointing coconut wood; and various alternatives to the expensive cement-based mortar. The tests conducted for shear resistance'showed that sheathing made of coconut wood frame, diagonally placed and varnished bamboo strips, and pozzolana cement-based mortar was suitable for lightweight construction.

Introduction

Bamboo is an indigenous material used extensively as a building material in Indonesia, especially in rural areas, because it is relatively cheap, easy to work with and readily available. It is used for framework, walls, floors, doors and windows, roofing, ceiling, and as scaffolding material. Some researchers have reported that bamboo has relatively high tensile and flexural strengths and that it can be used as concrete reinforcement.

Improved economic conditions have prompted people to prefer masonry houses. But masonry houses usually suffer damage during most earthquakes. On the other hand, bamboo houses have demonstrated their superior ability to resist earthquakes. This makes bamboo the building material of choice in areas which suffer from frequent earthquakes and tremors.

Appropriate technology for supporting housing programs needs to not only conform to the needs of the target people, but also be technically standardized and use locally available raw materials to the extent possible. Although wood falls in this category, quality wood has at present become an expensive material in some areas in Indonesia Coconut wood, available abundantly in the country, can be used as a substitute material in some wood applications.

Another building material that has become expensive is Portland cement. Researchers in Indonesia have addressed this issue by developing alternative binding materials, such as pozzolana-lime cement and Portland-pozzolana cement, which can be effectively used in housing construction.

In view of the above, this study set two objectives: (1) to provide an appropriate technology for the production of suitable building materials for low-income people, especially in the earthquake zones in remote areas; and (2) to find out a way to utilize local raw materials for panels for a light-frame construction system.

Materials and Methods

Materials

1. The frames were made of more than 15 years old, unproductive coconut trees. In view of the inherent properties of coconut wood, especially the density distribution and hardness of the vascular bundles, the trunks were cut using special cutting systems.
2. The reinforcement was made of 2-mm thick *Gigantochloa apus* strips.
3. Two types of mortar were prepared for this research: first, pozzolana-lime binder mixed with fine aggregate; second, soil-Portland cement mixture.

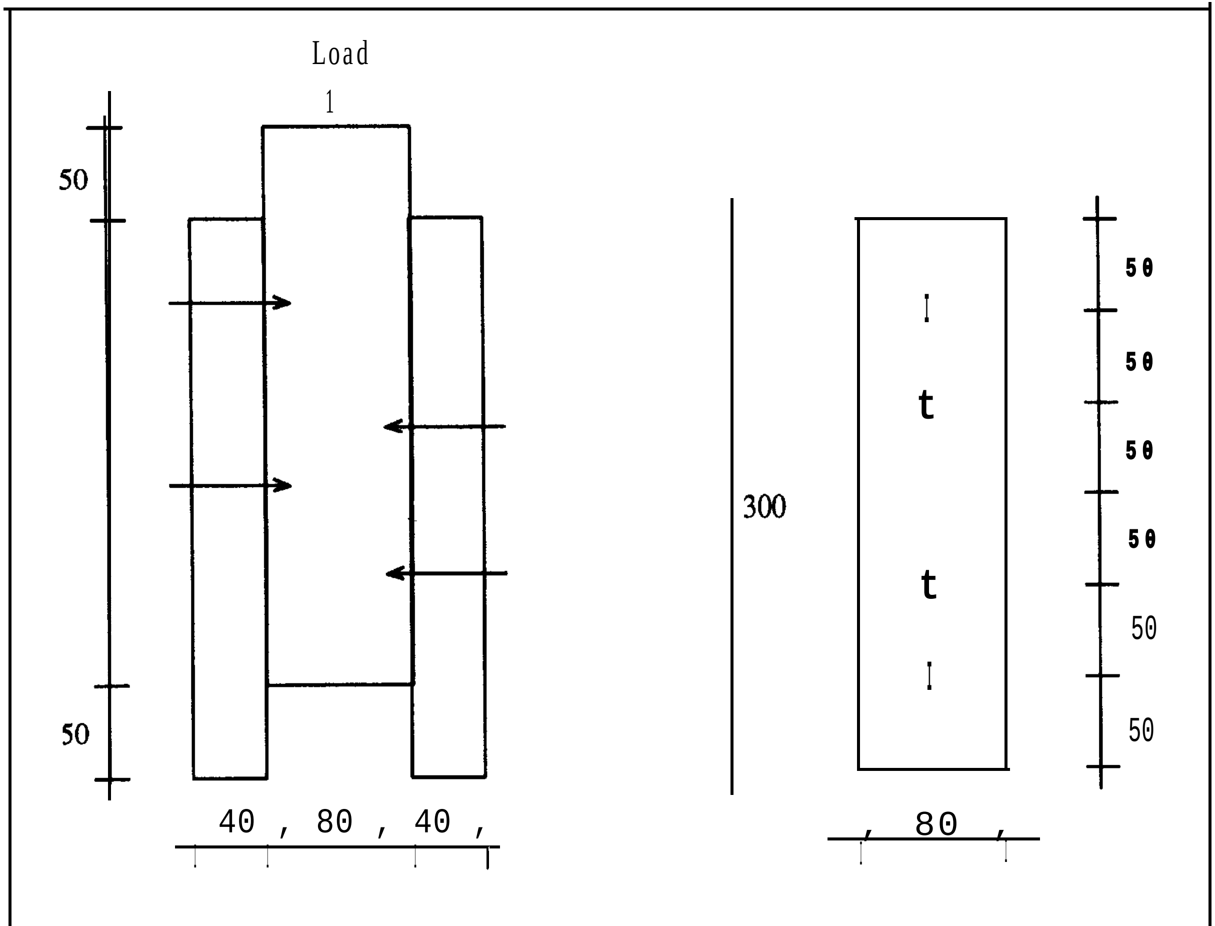
Testing method

Physical properties of coconut wood

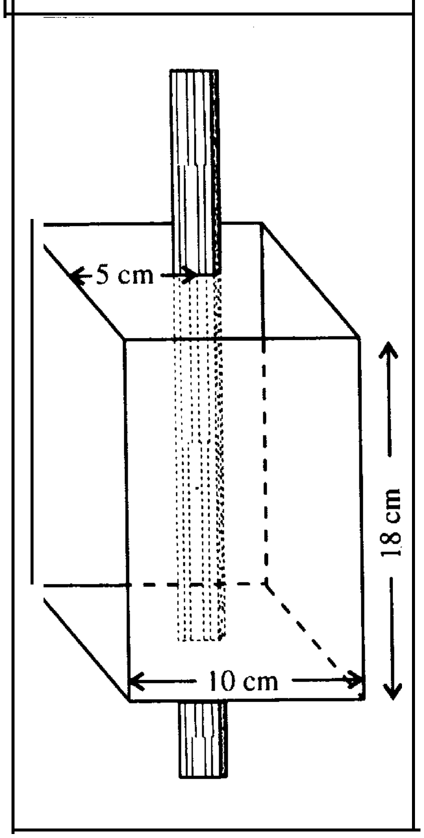
Test specimens were 50 x 50 x 50 mm. Each coconut trunk was divided into three parts – the lower, middle and upper. Test specimens were tested based on ASTM D-143 procedure.

Nail jointing of coconut wood

The sample-for testing was prepared as shown in Figure 1. The diameter of the nails were 3 and 4 mm and their length 76 mm. Test specimens were in dry condition. Deformation was measured with a dial gauge and



Fig, 1: Specimens for testing nail jointing of coconut wood



the ioad was checked when deflection was 1 and 2 rnm. Load was continuously applied till failure occurred.

Mortar

In the case of pozzolana-lime-sand (SPK) mixture, the test specimens used were cubes of 70 x 70 x 70 mm. The ratios of pozzolana-lime to sand tested were 1: 3,1: 5 and 1:7. Mortar was tested after conditioning for 28 days.

In the case of stabilized soil, the specimens were cylinders with a length of 200 mm and a

Fig. 2: Sample for testing bonding strength between bamboo and mortar

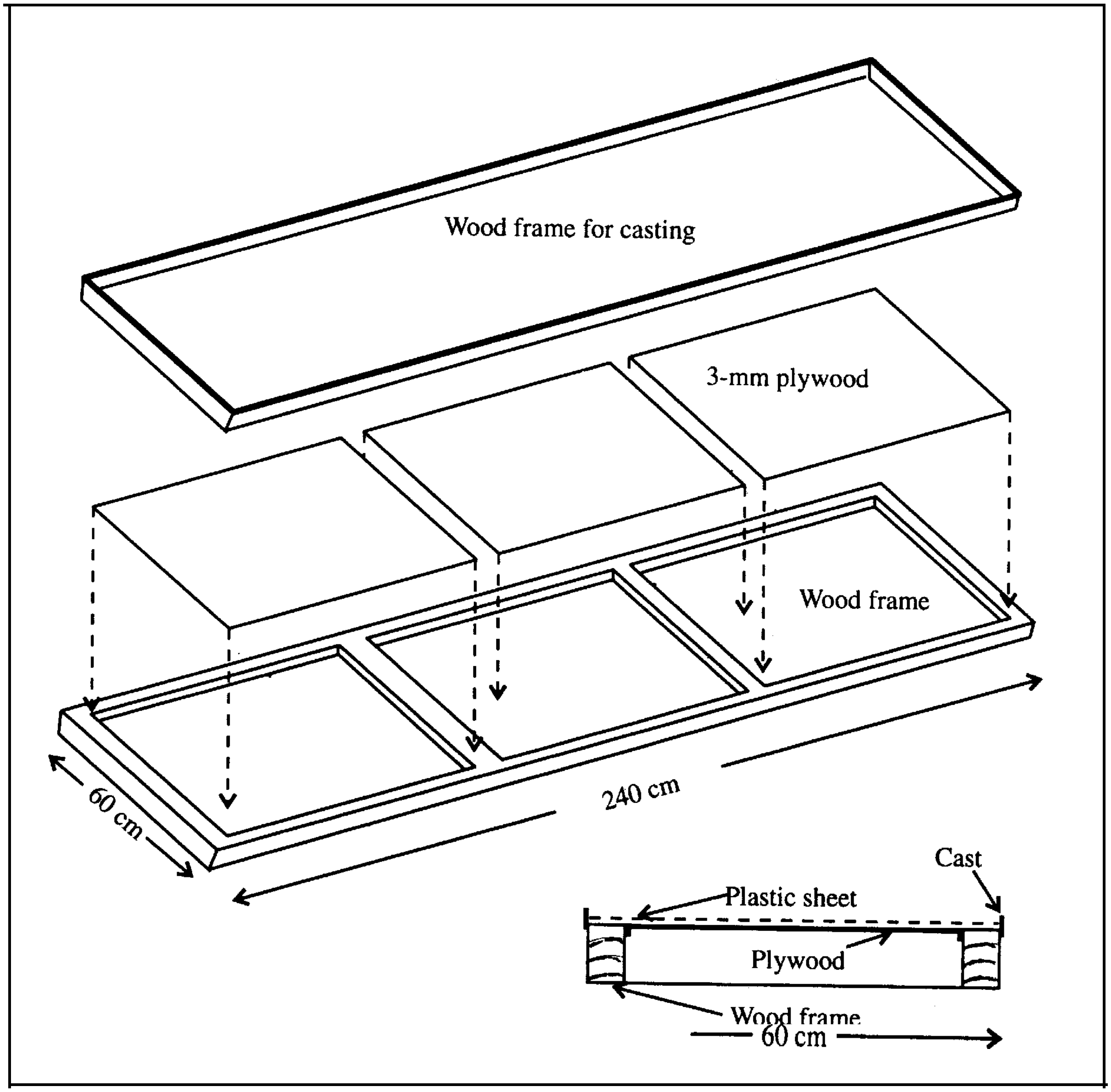


Fig. 3a: Making the panels (top) and cast (bottom, cross-section view)

diameter of 100 mm. The soil to cement proportions tested were l00:0, 97:3, 95:5, 93:7 and 91:9. Thespecimens were tested after conditioning for 28 days.

Bonding strength between bamboo and mortar

The specimens were prepared as shown in Figure 2. The specimens were of two types: in one the bamboo strips were coated with varnish, while in the other the strips had no coating. They were tested after 28 days of conditioning, and the test involved application of longitudinal tension force.

Cast

The frame was made using 40 x 80 mm coconut timber (Figure 3a). The size of the panels were 60 x 240 mm. For reinforcement, bamboo mats were applied horizontally and diagonally (Figures 3b, 3c). The cast was made of 10 x 50 mm coconut wood, 3-mm plywood and plastic sheet. After casting materials were applied, mortar was applied to 10 mm

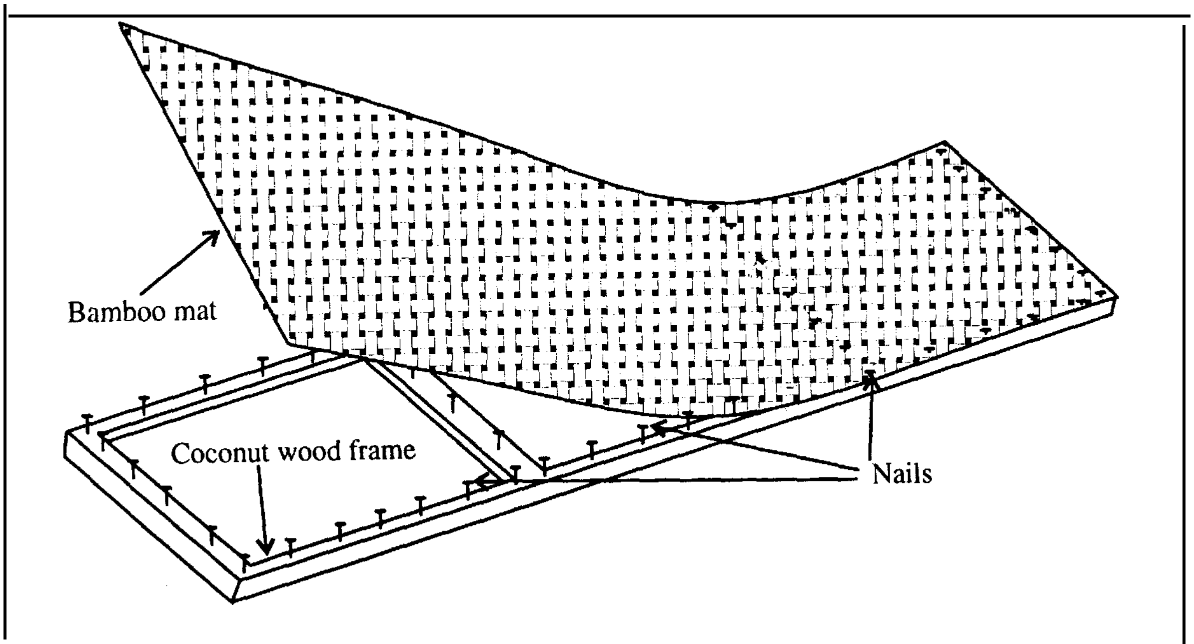


Fig. 3b: Coconut wood frame with horizontal-vertical bamboo mat reinforcement

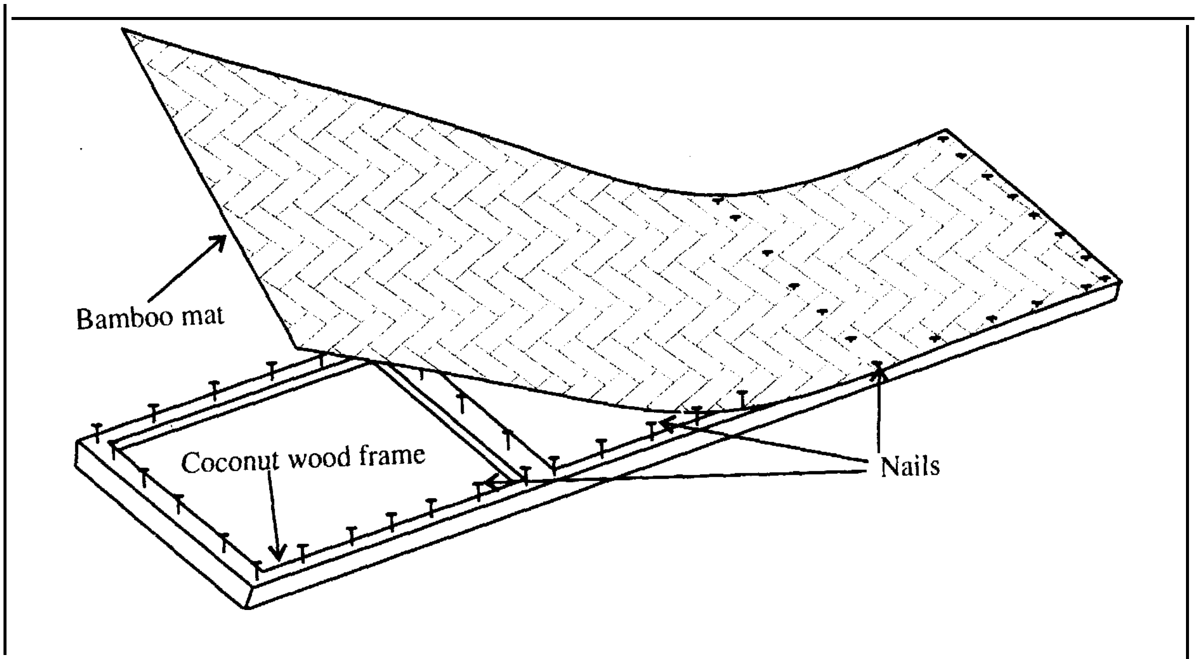


Fig. 3c: Coconut wood frame with diagonal bamboo mat reinforcement

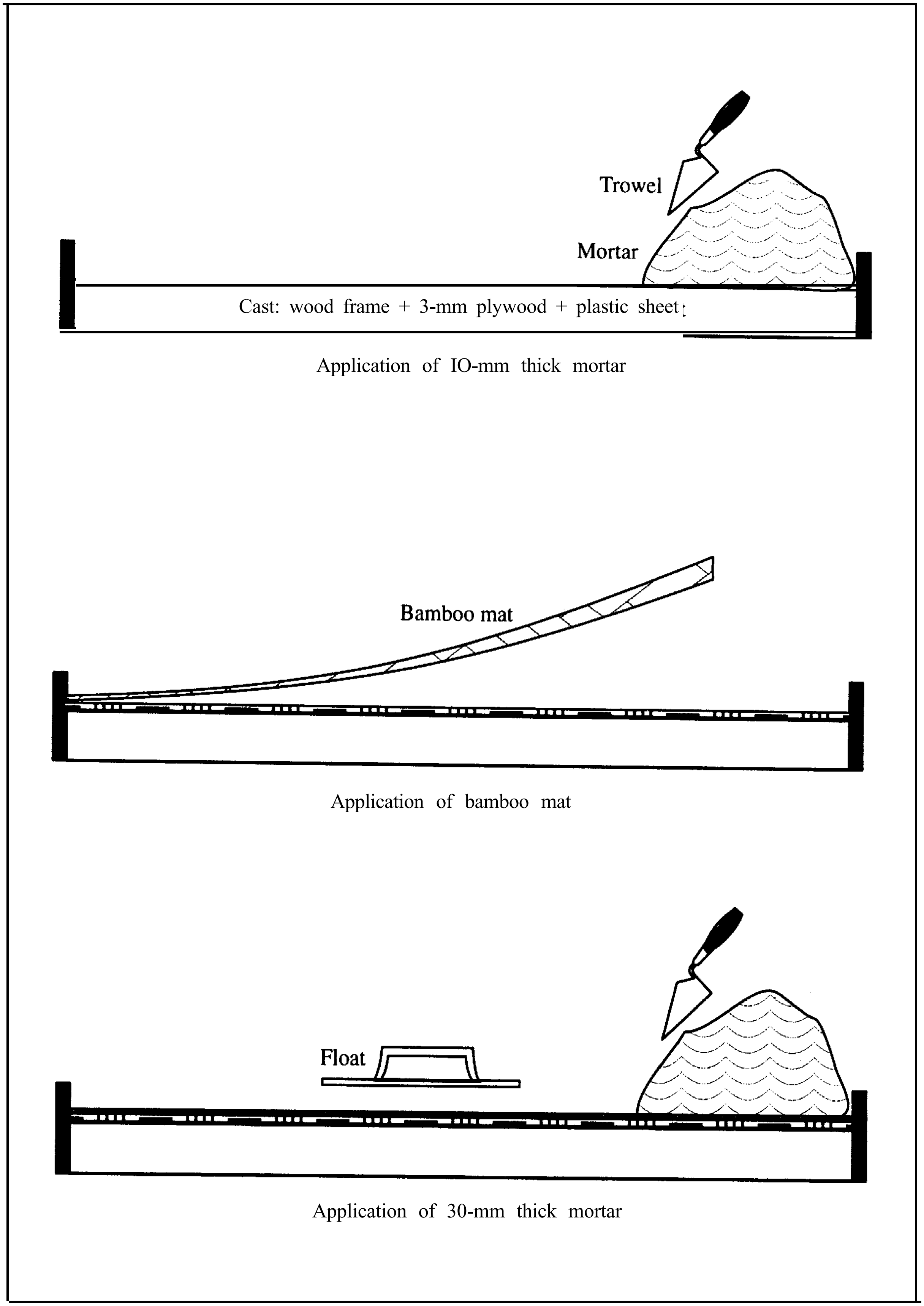
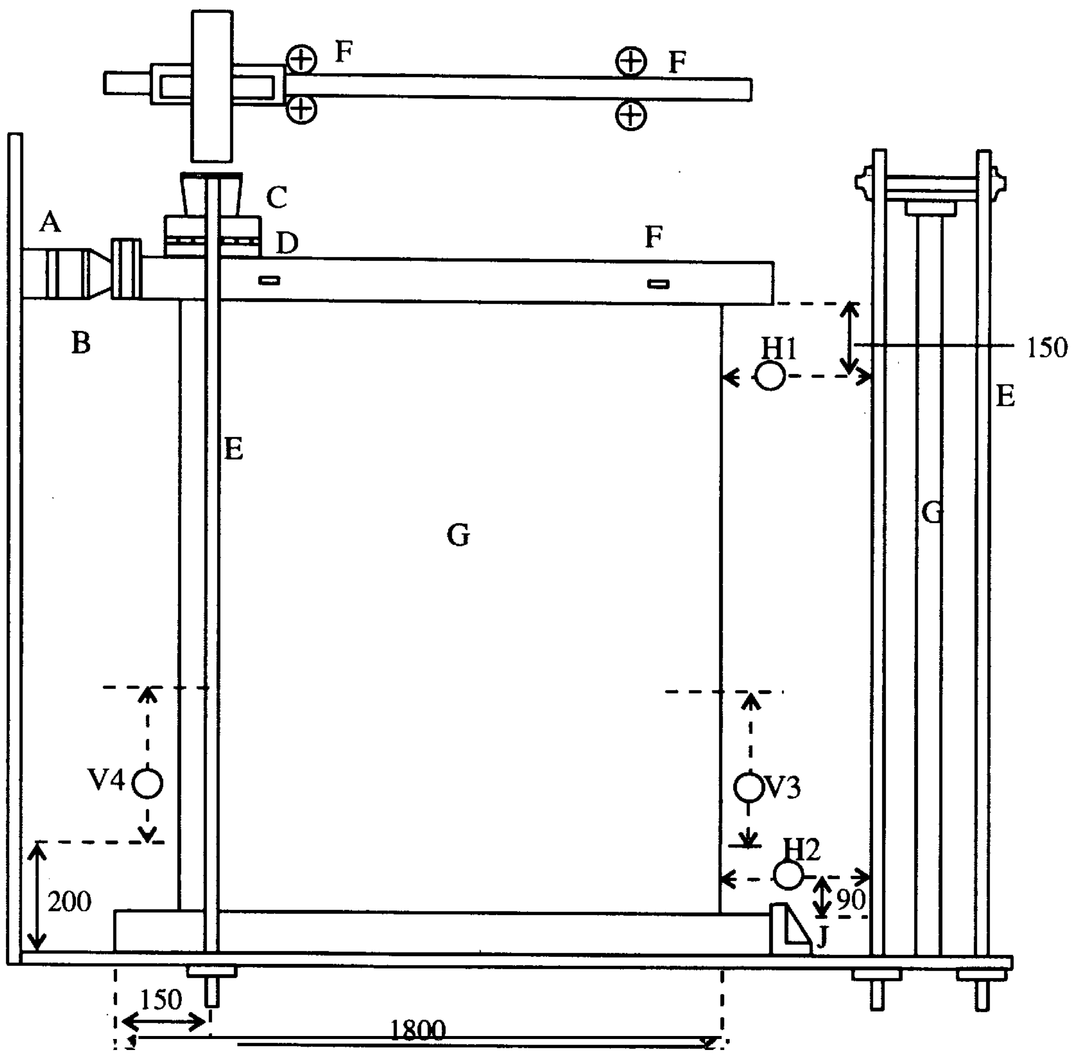


Fig. 4: Casting (mortar application) thickness (Figure 4). The surface was then finished as smooth as possible. The panels were conditioned for 28 days before testing.

Shear resistance of wood frame component

The specimens were made exactly as the ones used in the field. Each test had three replications. The procedure employed was as follows (Figure 5):



A: Hydraulic jack B: Load cell
C: Plate D: Roller
E: Tie rod F: Lateral guide
G: Specimen J: Stopper
H 1, H2: Indicating dial for horizontal shift
V3, V4: Indicating dial for vertical shift

Fig. 5: Shear test for panel

- load was applied to the specimen through a 90 x 90 mm high-strength timber piece firmly bolted to the upper surface;
- indicator dials were provided for measuring the displacement of different parts of the frame;
- load was applied and the drifts of the specimen in horizontal and vertical directions were measured.
- application of load was continued to the maximum limit.

Results and Discussion

Density of coconut wood

The density of coconut wood for the lower, middle and upper parts were as in Table 1.

Table 1: Density of coconut wood

Specimen no.	Lower	Middle	Upper
1	0.75	0.59	0.29
2	0.81	0.62	0.31
3	0.69	0.52	0.23
4	0.77	0.57	0.27
5	0.73	0.57	0.26
Mean	0.75	0.57	0.27

Based on the above data, only lower and middle parts of the trunk were utilized for making the frame of the panels. The lower part was utilized for sides of the frame and the middle part for the inner part of the frame.

Moisture content

Moisture content of coconut wood is given in Table 2. The tested materials were in air-dry condition after two months of seasoning. In this condition, the moisture content of the lower part of coconut wood was relatively similar to the middle and upper parts. Defects were found to be more on the upper part.

Nailed coconut wood joint

Joint is the weakest part in construction. Nail-jointed coconut wood was tested and the results were as shown in Table 3.

Table 2: Moisture content of coconut wood

Specimen no.	Lower	Middle	Upper
1	14.79	13.69	14.29
2	13.82	14.86	14.31
3	12.69	13.98	14.53
4	14.78	14.57	14.27
5	14.63	14.27	14.26
Mean	14.14	14.27	14.33

Table 3: Test results of nail-jointed coconut wood

Specimen number	Load value when deformation is l mm (kgf)	Load value when deformation is 2 mm (kgf)	Maximum load (kgf)
1	812	961	1736
2	725	923	1300
3	750	975	1410
4	650	780	1262
5	789	890	1 324
6	600	700	1 205
7	655	850	1370
8	625	816	1 278
Mean	700.7	862.1	1606

With the safety factor of 2.75 as mentioned in the Indonesian Standard for wood Construction, the test results showed that the joint system could be used in frame construction.

Mortar

Pozzolana-lime-sand

The compression strength of pozzolana-lime and sand mortar is given in Table 4. For making panels, mortar of pozzolana-lime and sand in 1:3 ratio was employed.

Table 4: Compression strength of pozzolana-lime-sand mortar

Mix no.	Compression strength (kgf/cm^2)
1 (l:3)	
1	61.9
2	62.2
3	64.4
Mean	62.8
II (1:5)	
1	40.2
2	41.7
3	39.8
Mean	40.6
III (1:7)	
1	11.2
2	10.9
3	13.1
Mean	11.7

Stabilized soil

The test results of thestabilized soil are as shown in Table 5. The data shows that the compression strength of mortar of stabilized soil was lower than pozzolana-lime-sand mortar. For the full-scale specimens and bonding test specimens, only pozzolana-lime-sand mortar was used.

Bonding strength of mortar and bamboo

The bonding strength of mortar and bamboo, both treated with varnish and untreated, are shown in Table 6. Varnish treatment increased the bonding strength. In wet condition, bamboo being a hygroscopic material, absorbs water from the mortar. When the mortar dries, bamboo releases water making the bond weak. Varnish, as a water repellent, prevent bamboo from absorbing or releasing water.

Table 5: Test results of stabilized soil mortar

Specimen	Shrinkage (%)	Compression strength (kgf/cm^2)
100:0		
1	0.701	11.49
2	0.691	12.10
3	0.712	11.21
Mean	0.701	11.60
97:13		
1	0.520	14.86
2	0.544	14.26
3	0.490	15.10
Mean	0.518	14.74
95:5		
1	0.270	18.79
2	0.265	17.88
3	0.286	19.24
Mean	0.273	18.63
93:7		
1	0.020	22.16
2	0.024	21.71
3	0.018	23.12
Mean	0.021	22.33
91:1		
1	0.100	27.76
2	0.009	28.12
3	0.011	27.45
Mean	0.010	27.77

Table 6: Bonding strength between mortar and bamboo

Specimen number	Load at failure (kgf)	Shear area (cm^2)	Bonding strength (kgf/cm^2)
Al	240	91.60	2.62
A2	230	92.37	2.49
A3	228	91.20	2.50
Mean			2.54
Bl	184	93.40	1.97
B2	172	93.99	1.83
B3	196	95.14	2.06
Mean			1.95

A: Bamboo treated with varnish B: Untreated bamboo

Shear resistance of wooden frame components

The shear resistance of wooden components used with bamboo reinforcement, in both horizontal-vertical and diagonal directions, are given in Table 7. The data show that the diagonal bamboo reinforcement gives higher shear resistance than the horizontal-vertical reinforcement. Fewer number of mortar cracking on the surface were noticed in panels which had bamboo treated with varnish. As shown in bonding strength tests, varnish treatment improved bonding between bamboo and mortar. The highest shear resistance was obtained with diagonal bamboo reinforcement treated with varnish and the lowest for horizontal-vertical bamboo reinforcement without varnish treatment.

The allowable load of shear resistance Pa may be calculated using the formula:

Pa = 3/4 x P1/250 x a, where

P1/250 = mean value of shear loads when the value of shear drift ratio is l/250 kg/m,

a = ratio reduction factor in relation to the performance and workmanship.

Table 7: Shear resistance of wood frame components

Specimen number	Load at shear drift ratio 1/250 (kg/m)	Shear drift ratio at maximum	Maximum load (kg)
A1	72	0.025100	206
A2	60	0.021692	186
A3	78	0.026948	208
Mean	70	0.024580	200
B1	50	0.019568	167
B2	54	0.020115	173
B3	61	0.022011	186
Mean	55	0.020565	175.3
C1	44	0.019811	158
C2	39	0.03 8282	143
C3	37	0.016850	139
Mean	40	0.018314	146.7
D1	28	0.014312	121
D2	30	0.014985	132
D3	20	0.011072	119
Mean	26	0.013456	124

A: Diagonal bamboo reinforcement with varnish treatment
B: Diagonal bamboo reinforcement without varnish treatment
C: Horizontal-vertical bamboo reinforcement with varnish treatment
D: Horizontal-vertical bamboo reinforcement without varnish treatment

Conclusion

1. Coconut wood is a good alternative material for wood frame;
2. Nailed coconut wood joint conforms to the Indonesian Wood Construction Standard **(PKKI-1961);**

3. Mortar made of pozzolana-lime and sand in 1:3 ratio can be used for sheathing;
4. Varnish treatment increases the bonding between bamboo and mortar; and
5. For the wood frame wall component, diagonal bamboo reinforcement with varnish treatment gives the highest shear resistance.

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Strength of Filled 'Bamboo Joint

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Abstract

Tensile strength of bamboo is quite high, but its benefit has not been exploited optimally because bamboo structural members are often connected to each other by conventional methods, making the joints very weak.

A study was conducted to devise a strong joint for assembling bamboo structural members. A method of joining bamboo members with bolts, steel gusset plates, and cement mortar or wood filling was tested. The strength of the joint was tested using a steel loading frame and a hydraulic jack.

The research results showed that the strength of the joint varied from F40 kN to 90 kN. Although these values are higher than those for conventional joints, efforts to further increase the strength are required, to derive in full measure the benefit of bamboo's strength properties.

Introduction

The pressure of burgeoning human population in the world has posed the challenge of maintaining and managing natural resources to meet the present as well the future needs. The growth of human population and its prosperity are bound to cause even greater demand on timber for housing. In the process, serious problems of over-exploitation and destruction of tropical forests may occur. In order. to protect forests from degradation and shrinkage, one needs to search for substitute materials for timber.

Bamboos grow rapidly, can be cultivated easily, have good mechanical properties (Janssen 1990) and can be preserved employing simple techniques (Liese 1980; Sulthoni 1990). However, bamboo jointing has posed structural problems. It is often accomplished using conventional methods with pins and ropes, resulting in very weak joints. Bamboos are widely used for light structures, such as rafters, purlins, roof girders, walls, ceiling and fences. Since the tensile strength of bamboo is very high, we may conclude that the use of bamboo as substitute material for timber is limited only because of a lack of knowledge on how to make strong joints.

To derive optimal benefit from bamboo in construction and thus give it a bigger role in building construction, it is essential to devise strong joints for structural members.

Strength of Filled Bamboo Joint

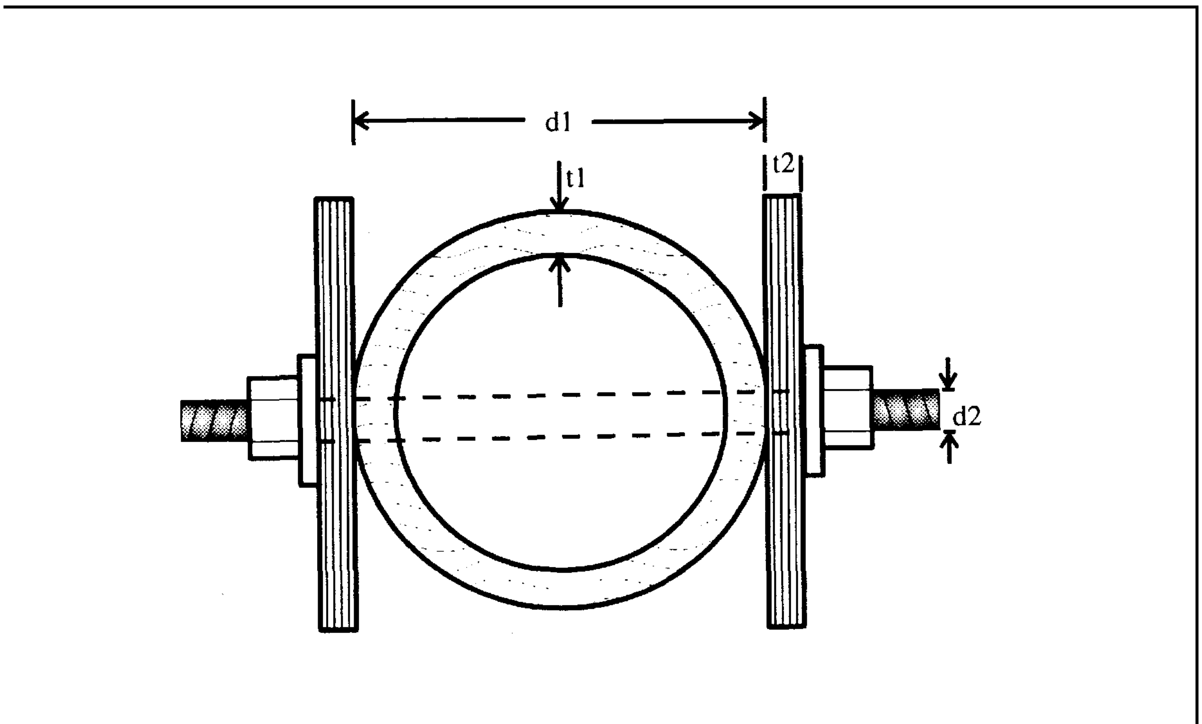

Fig. 1: Bolted bamboo joint

Consider a filled bamboo joint as shown in Figure 1, in which the bearing pressure is assumed to be uniform. There are three failure possibilities which can be described as follows:

a) Assuming that the bolts are stiff and the bearing pressure is above the ultimate stress of the materials, the jointing strength may be expressed as:

$P = (d_1 - 2t_1)\, d_2 f_c + 2 t_1 d_2 f_b$ where, (1)

P = joint strength

d_1 = diameter of culm

t_1 = thickness of culm

d_2 = diameter of bolt
f_c = ultimate bearing stress of filling material
f_b = ultimate bearing stress of bamboo

b) Assuming that the bolts are stiff and failure occurs at bolts or gusset plates, the joint strength can be computed using the following equation:

$P = 2\, t_2\, d_2\, f_s$ where, (2)

t_2 = gusset plate thickness
f_s = ultimate bearing strength of steel

c) Considering that the bolts are not strong and yield stress occurs at bolts, the elasticity M_p of bolts can be determined using the equation:

$$M_p = \frac{Pd_1}{16} \qquad (3)$$

If the yield stress of bolts is f_y, the bolts' elasticity M_P can be computed using the equation:

$M_P = Z\, f_y$ where (4)

z = bolts' modulus of elasticity.

The bolts' modulus of elasticity Z can be expressed by the equation:

$$Z = \frac{d_2}{6} \qquad (5)$$

Combining equations 3,4 and 5, the joint strength can be given by the following equation:

$$P = \frac{8d_2^3 f_y}{3d_1} \qquad (6)$$

The joint strength is the minimum value of P obtained from the equations 1,2 and 6.

Materials and Methods

The study was conducted using *Bambusa blumeana* Schultz (Ori), *Gigantochloa atter* Munro (Wulung) and *Bambusa vdgaris* Schrad (Tutul). The jointing method was intended to meet the level of rural technology, and accordingly no complicated tools were used in assembling the joint.

The method of jointing bamboo members with cement mortar filling is described below. Several holes were made on culms for bolts and cement mortar filling. The bolts were fiied and cement mortar filled into the internode space where the joint was to be made. Four weeks later, gusset plates and nuts were assembled.

Bamboo joint with wood filling was done first by scraping the inner side of the internode, where the joint was to be made, with a steel wire brush to provide a rough surface. Resin was poured into the internode, followed by the wood filling. The resin functioned as glue for the filling and as a filler. One day later, the filling was dry and the joint ready to be assembled with holes drilled on the culm.

The gusset was made out of 6-mm thick steel plate with 540 MPa yield strength. This extra thick plate was used to ensure that failure would not occur because of it, and that it could be used several times. A 3-mm steel plate, or 25-mm hard wood board with 60 MPa bearing strength could also be used, as suggested by Mishra (1990).

The joint strength tests were conducted on individual member connection as shown in Figure 2. A special bamboo truss was made to demonstrate the joint strength. It was loaded with a concrete block of 40 kN weight as shown in Figure 3. A 10-m span bamboo bridge is shown in Figure 4. The bridge's truss is constructed with bamboo members of diameter 7-8 cm.

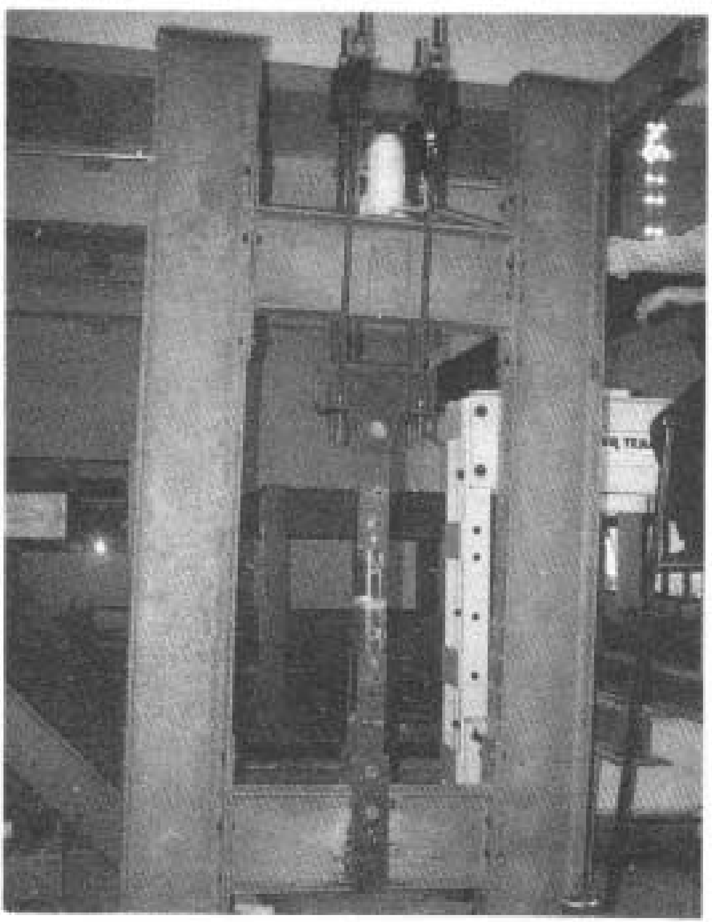

Fig. 2: Individual joint test

Results and Discussion

Mechanical tests on bamboo showed that the compression strengths of B. *blumeana*, *G. atter* and *B.* vulgari were61.440MPa, 47.969 MPa and 42.041 MPa, respectively. The average yield stress of bolts obtained

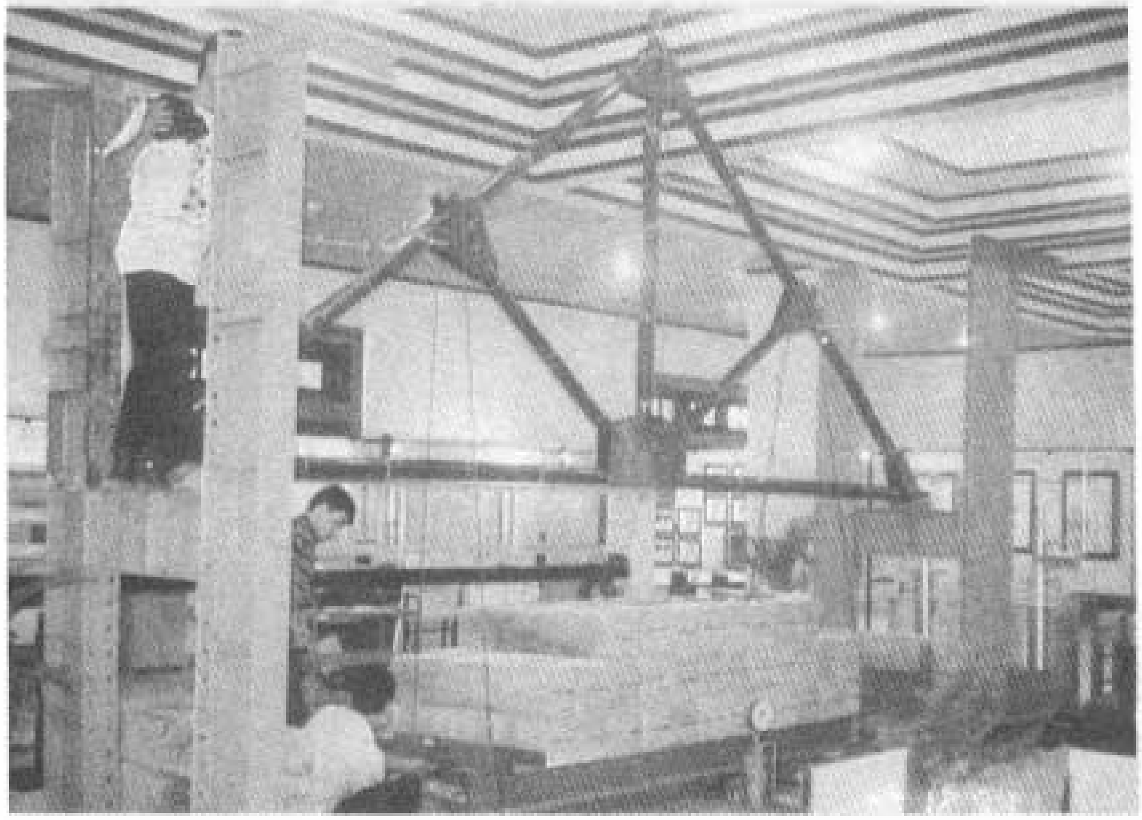

Fig. 3: A bamboo truss with 40 kN load

from material tests was 540 MPa. These results were adopted in determining theoretical joint strength, using equations 1, 2 and 6, with a net bolt diameter of 13 mm.

The theoretical strength and that obtained in experiments of filled bamboo joints are presented in Table 1. It can be seen that the experimental joint strength varied between 40 kN and 90 kN. These results were higher than those obtained with conventional jointing method. The average ratio between theoretical and experimental results was 100.24%, with a standard deviation of 14.53%. Thus, the theoretical values were in close agreement with the experimental results. The standard deviation was significant since it pointed to variation in quality of construction resulting from the method of assembling which used only simple tools. In fact, filling cement mortar into the bamboo proved difficult.

Tension tests on bamboos showed that the specimens without nodes were stronger than those with nodes. This meant that bamboo members' tensile strengths should be determined by taking the ultimate strength of specimens with nodes. The tests of specimens with nodes gave the ultimate strength of *B.* blumeana, G. atter and B. vulgaris as 138.506 MPa, 116.006 MPa and 81.456 MPa, respectively. Considering these results, the

Fig. 4: A bamboo bridge of 10 m span

tensile strength of bamboo culms of 80 mm diameter and 7 mm thickness will vary between 68 kN and 116 kN. Since the experimental joint strength varies between 40 kN and 90 kN (Table 1), it can be concluded that efforts are still needed to increase the joint strength, so that optimum use can be made of bamboo's strength.

Table 1: Strength of filled bamboo joint (Number of bolts used = 2)

Diameter (mm)	Thickness (mm)	Bamboo strength (MPa)	Filling material	Filling strength (MPa)	Theoretical joint strength (kN)	Experi-mental (kN)	Theoretical Experimental ratio (%)
78.02	12.07	61.440	Mortar	22.00	69.379	77.5	89.52
75.28	8.89	61.440	Mortar	22.00	61.279	67.5	90.78
76.15	7.70	61.440	Mortar	22.00	59.339	55.0	107.89
73.14	11.51	61.440	Mortar	22.00	65.431	62.5	104.69
76.21	9.18	61.440	Mortar	22.00	62.406	55.0	113.47
76.91	8.27	61.440	Mortar	22.00	60.940	50.0	121.88
67.96	13.19	61.440	Mortar	22.00	65.921	80.0	82.40
69.92	10.34	61.440	Mortar	22.00	61.200	75.0	81.60
70.93	9.14	61.440	Mortar	22.00	59.317	70.0	84.74
91.15	14.12	61.440	Timber	43.31	69.417	62.5	111.07
87.29	11.26	61.440	Timber	43.31	72.847	60.0	120.81
89.80	7.30	47.696	Timber	43.31	70.461	62.5	112.74
87.90	6.50	47.696	Timber	43.31	71.984	87.5	82.87
104.24	13.25	42.041	Mortar	17.00	60.703	70.0	86.72
93.96	8.71	42.041	Mortar	17.00	52.872	42.5	124.40
113.12	13.67	42.041	Mortar	17.00	55.937	57.5	97.28
110.17	11.37	42.041	Mortar	17.00	57.435	60.0	95.73
104.06	9.30	42.041	Mortar	17.00	58.104	55.0	105.64
99.40	11.17	42.041	Mortar	17.00	58.473	52.5	111.38
92.74	9.87	42.041	Mortar	17.00	53.874	67.5	79.75

Mean = 100.24%

Standard deviation = 14.53%

Conclusion

The theoretical values were close to the experimental results. The standard deviation was significant because the quality of construction varied owing to the simple tools used.

Tensile strength of bamboo should be determined with the ultimate strength of specimens with nodes.

Although the experimental joint strength values, which varied between 40 kN and 90 kN, were higher than those obtained using conventional methods, efforts are still required to increase this in order to make optimum use of the inherent strength of bamboo.

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Bamboo Preservation at the Costa Rican National Bamboo Project

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Abstract

Bamboo is becoming an important raw material in Costa Rica helping to mitigate the increasing demand for materials for building houses, and making furniture and other articles essential to improve quality of life. Since the natural durability of cut bamboo culm is generally low in the tropical environment, it is necessary to protect and preserve it from decay and insect attack. This paper presents the experience of the Costa Rican National Bamboo Project in preservation methods and quality control measures, and analyses observations on the perfomlance of treated bamboo as a building material for houses.

Introduction

Bamboo preservation has been accorded great importance at the Costa Rican National Bamboo Project (CRNBP) ever since it started to build houses using *Guadua* spp. about seven years ago, offering strong (earthquake-resistant), economical good-quality dwellings for low-income people.

Considering that there was no experience in Costa Rica in bamboo preservation and, in general, little experience in wood preservation, it was decided that an intensive research program on bamboo preservation should be started. This paper describes the technical and economical aspects of bamboo preservation at CRNBP, and the results obtained.

Bamboo Preservation Research

At the beginning, the methods and preservatives which couId be employed to treat bamboo in the rural areas of the country were analysed. It was necessary to treat bamboo culms as well as "esterilla" (bamboo culms split open with an axe and flattened into a board) and "regillas" (small boards or laths obtained by sawed bamboo culms). After various tests, and technical and economical analyses, it was possible to find a good and relatively low-cost preservative, and adapt and develop a simple and effective preservation system to treat the material.

For treating culms, amodified sap displacement method was preferred, and for treating esterilla and regilla an immersion/diffusion treatment was selected. The sap displacement method for culm treatment gives the best results in terms of penetration, distribution and preservative retention. Although it is possible to obtain good distribution and preservative retention with other kinds of treatments such as immersion, the treatment time is very long. Another advantage of modified sap displacement method is that the equipment used is simple, low-cost and can be built anywhere with easily available materials. Furthermore, it can be built in different scales, from a portable equipment to treat a few culms to a large-scale, permanent plant to treat hundreds of culms per day.

The treatment plant

The sap diffusion plant, which employs modified boucherie process, is depicted in Figure **1.** The preservative liquid contained in the tank (B) is introduced into one end of the culm through plastic hoses connected to a centrifugal pump. The liquid pressure is maintained at 80-120 kPa (0.8 to 1.2 kg/cm^2). Through diffusion process, bamboo sap is replaced by the preservative solution. The time taken for the completion of the process will depend on the size of the culms. In a few days' time, the culms will be fully impregnated with the preservative. The liquid emerging from the free ends of the culm is stored in another tank (C), and later filtered and r-nixed with fresh preservative for reuse. In this way, it is possible to recycle practically all the chemicals used in the treatment.

In the experiment, a boron solution (disodium octoborate tetrahydrate) was used as the preservative. Several tests were performed in order to know the possible flow paths that the preservative would take while diffusing through the culm. Since the preservative solution was colourless, 0.1% red aniline was added to it as a marker. Analysis of different parts of the treated material revealed that the colourant (marker) was present only in the conducting vessels, and that too mostly in the larger vessels near the inner part of the culm. This observation confirmed that the flow was mainly through the vessels. Other elements, even the ones near the vessels, did not show any trace of the colourant. However, a penetration analysis after the

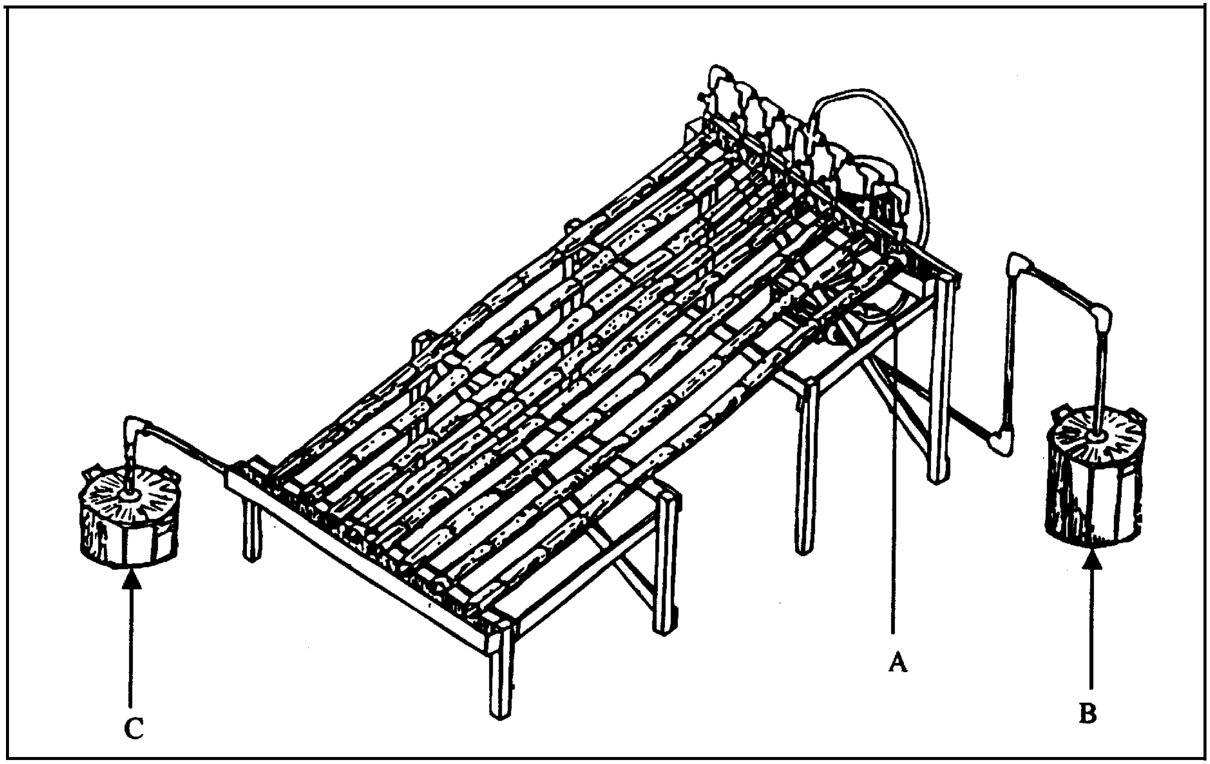

Fig. 1: Modified boucherie process for bamboo culms

treatment, made using curcumine reagent, showed that the boron in the preservative had apparently diffused into other elements – parenchyma and fibres -also.The distribution was irregular, presentingamore intensive red colouration in tissues near the internal culm wall. This is a favourable indication since the inner part is more vulnerable to fungal and insect attack. It was also observed that all parts of bamboo culms, including the inner epidermis tissue and diaphragms, were totally impregnated with boron.

Permeability determination

Permeability is a physical property which indicates the rate of flow of a liquid or gas through a porous material, under the influence of a pressure gradient.

In order to determine the permeability of *Guadua atlanticoculms* treated with boron preservative, it was assumed that the flow of liquid through bamboo culms obeys Darcy's Law, in the same way liquid flows through wood (Hudson and shelton 1969; Siau 1971; Gonzalez and Siau 1978). Under this assumption, the flow of liquid per unit area through bamboo culms is proportional to the gradient of pressure per longitudinal unit in the direction of the flow.

In Figure 2, the variation of liquid preservative flow with the treatment time for two Guadua culms is shown. It was apparent that there was a tendency for increased flow at the beginning of the treatment, followed by a gradual decrease during the rest of the treatment period. This might have been due to an obstruction produced by air bubbles blocking the liquid flow through the small conducting vessels. Nevertheless, since the flow variation was not significant during the first 30 minutes of the treatment, the process was considered steady for calculating permeability using the equation:

K = V L p/t A (dP), where

K = specific permeability, Darcy

V = volume of liquid, ml

t = time, s

A = transverse area perpendicular to the flow direction, cm^2

dP = pressure drop through the culm, atm

L = length of the culm, cm

u = viscosity, dyne $.s/cm^2$.

In Table 1, the specific permeability, the moisture content before treatment, and some morphological measurements of the three groups of Guadua culms treated are given. The three tested groups were: (a) culms treated few hours after harvest (fresh); (b) culms soaked in water for one day before treatment; and (c) culms stored in air under cover for one or two days before treatment.

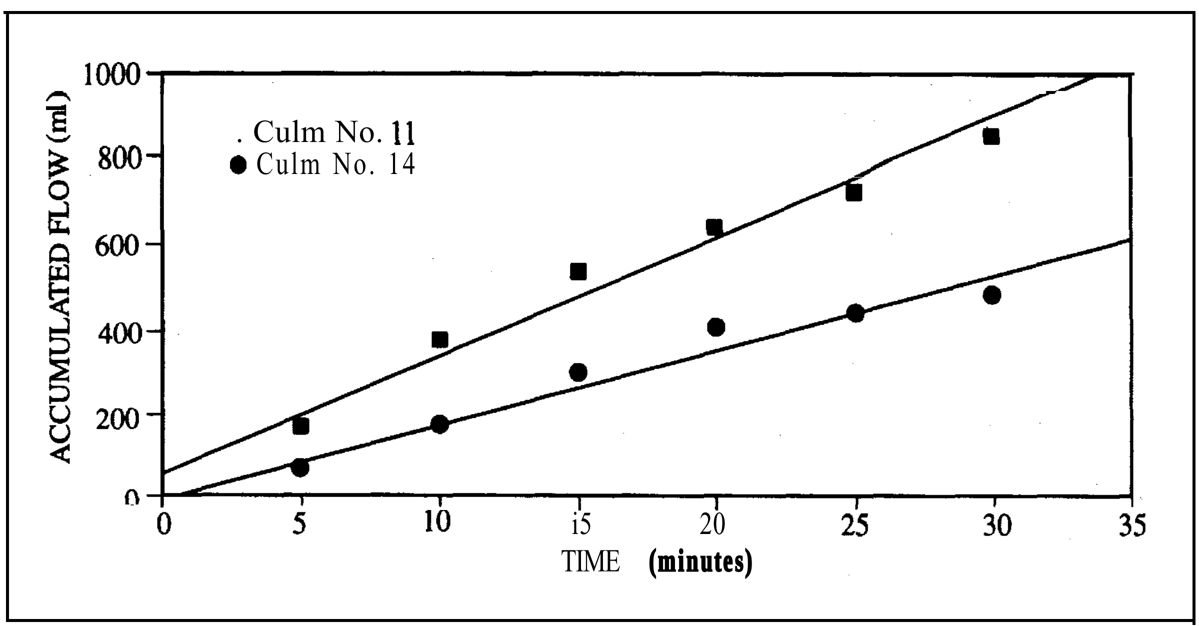

Fig. 2: Longitudinal flow of boron preservative through ***Guadua*** culms

As can be seen from Table 1, the permeability calculated for culms that were stored under water before treatment was about twice the permeability of fresh culms. It is possible that during the immersion period, part of the air captured by conducting vessels of the culms diffused into the soaking water, thus facilitating the flow of the preservative and sap. On the other hand, the permeability of the culms that were stored in air was about 4 and 8 times less than the permeability of fresh culms and the culms stored in water, respectively.

Table 1: Specific permeability of treated Guadua culms

Parameters	Fresh culms	Culms stored in water	Culms stored in air
Length (cm)	311.0	301.0	311.0
Average circumference (cm)	32.2	32.3	34.0
Wall thickness (cm)	0.94	1.06	0.87
Moisture content (%)	90.0	84.0	110.0
Specific permeability (Darcy)	2.9	6.5	0.83

Note: Data given are the' average values of 5 to 7 treated culms.

Chemical analysis

In Table 2, the retention and distribution of boron in six of the treated culms are given. Retention was calculated using atomic absorption spectrophotometry (Liese 1990b). Liese (1990b) determined the percentage of area of vessels for *Guadua atluntico* to be between 5.2% and 9.4%, with an average of 8% for the middle part of the culms. Taking this into consideration, the treatment time was taken as completed at the moment when the volume of the liquid emerging from the free end of the culm was equal to 5-10% of the solid volume of the culm. In practice, it was found that such a quantity of liquid was reached between 5 and 35 minutes since the start of the treatment, with an average of 23 minutes.

In Table 2, two preservative concentrations are given: inflow concentration is that of the preservative being fed under pressure into the culm, while outflow concentration is the concentration of preservative in the liquid (sap and preservative) that emerge out of the culm Three concentrations were used for the inflow preservative: 1%, 2% and 3% w/w of boron salt in water. From the results of the chemical analyses of the different parts (Table 2) it can be seen that retention.was usually above 0.7 mgWg (about 0.35% by weight of the preservative chemical used), a quantity considered as minimum for protecting bamboo from Dinoderus. The quantity of boron retained in the upper part of some of the culms tested, however, was below the minimum level required. It is believed that this was due to the difficulty experienced in ejecting the air from the pressure cap, which led to the accumulation of air in the upper part of the culm and prevented the liquid flow in that zone.

Table 2: Retention and distribution of boron in ***Guadua*** culms

Parameters	Culm number					
	8	9	10	18	11	12
Preservative concentration						
- Inflow (% B)	0.98	0.98	2.03	2.03	3.12	3.26
- Outflow (% B)	0.78	0.55	2.13	0.90	3.08	1.05
Outflow liquid volume (% of culm volume)	10.70	6.20	10.50	5.50	10.70	5.00
Retention (mg B/g)						
- Inlet part of culm						
- upper zone	0.85	0.51	1.51	0.78	0.90	0.65
- middle zone	0.87	0.87	1.59	1.58	0.92	1.03
- lower zone	0.91	0.91	1.72	1.19	0.96	1.09
- Middle part of culm						
- upper zone	0.68	0.59	1.12	0.79	1.16	0.57
- middle zone	0.75	0.75	1.56	1.39	1.17	0.75
- lower zone	0.98	0.98	1.62	1.28	1.27	1.09
- Outlet part of culm						
- upper zone	0.62	0.54	0.59	0.54	1.02	0.50
- middle zone	0.72	0.72	0.79	1.25	1.24	1.03
- lower zone	0.76	0.76	0.96	1.14	1.02	1.41

Chemical analyses also showed that, in general, the treated culms, irrespective of the concentration of the preservative solution used, exhibited a top-to-bottom reduction in the quantity of the chemical retained. That is, the inlet part (top) of the culms had the highest concentration of the chemical, followed by the middle part, and the outlet part (bottom) had the lowest concentration. The same behaviour was observed in other bamboo species and with other preservatives: for example, the results presented by Purushottam(1954) on the treatment of Bambusapolymorpha and B. nutans, utilizing modified boucherie process and zinc chloride as the preservative. The tendency was also observed by Slob et al. (1987) when treating *Arundinaria alpha* with modified boucherie process and CCA as the preservative.

Durability of treated and untreated Guadua culms

With the purpose of testing the resistance of *Guadua* bamboos to insect attacks, mainly by *Dinoderus* sp., treated and untreated culm samples were stored outside in a rack under a roof, at the National Bamboo Project facilities in Cristo Rey, San Jose. The results of this test are shown in Table **3.**

Table 3. Results of long-term exposure of ***Guadua*** culms

Type	Number of samples	Exposure (months)	Effects of *Dinodems* attack		
			Light	Severe	Destroyed
Preserved	**21**	**15**	**14**	7	0
Unpreserved	15	**15**	2	**1**	12

After **15** months of observation, it was found that most of the untreated samples were destroyed, while none of the treated ones suffered destruction. Some of the treated samples, however, experienced severe attack in the upper zone of the transverse section, where low retention of the preservative chemical was observed (Table 2).

It was also observed that even the walls and diaphragms in the zones that had showed good retention and penetration of the preservative were perforated by *Dinoderus.* But when these specimens were split open after six months of exposure, the insects which managed to perforate the walls and the diaphragms were all found dead inside the internode since they were unable to have any biological activity.

Conclusion

From the test results discussed above, it is possible to make the following observations and recommendations:

- The modified boucherie process used for the tests on' *Guadua* culms ca'n be well-adapted for the preservative treatment of *Guadua* culms.
- Mature, healthy, fresh culms are the ones that can be better treated. A system of standardization and selection before treatment is recommended.

- Permeability of *Guadua* culms can be maintained and even increased by soaking in water before preservative treatment. Permeability is an important property that helps understand aspects that affect the treatability of bamboo culms. It is recommended that further research be carried out to study this property.
- Boron preservatives are indicated for treating bamboos, mainly for their effective preservative property against insect attacks, and good diffusion, retention and migration characteristics. They are also non-toxic to humans, and have a low pollution potential.
- It is necessary to prevent air blockage of the conducting vessels so that high retention and easy migration of the preservative can be ensured, leading to an improved preservation system.

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Building Codes for Bamboo Housing

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Abstract

This paper deals with the need for an international model for national building codes for bamboo. The pros and cons of building codes are explained, as well as the role of an international model for such codes. The contents of the proposed model are described in detail, followed by a description of the procedures involved in the creation of an acceptable international code.

What is a Building Code?

The building code is a national regulation for the building industry, regarding materials, workmanship and structures. A more common name is "standards". Kaplinsky (1992) gives a comprehensive overview of the various aspects of standards.

Unfortunately, in many cases standards or regulations are formulated specifically for housing for the middle class and consequently, the housing for the lower classes of the society is often substandard and liable for collapse since it does not meet the "minimum acceptable standards" required. On the other hand, good standards do not harm the lower income families, but protect consumers, workers and the environment, and promote economic growth. So the issue is not whether standards should be implemented, but how they are formulated.

Standards generally protect the rich; and if they are meant to protect the poor (for example, ensuring their safety at work), they often go unimplemented. Though standards are known to be a part of developmental problems, they can become a part-of developmental solutions.

Good standards should meet the following requirements:

- Protection of the consumer - substandard items are a loss of money, and even a danger to the consumer;

- Protection of the environment - effluent disposal and other forms of pollution are kept within acceptable limits;
- Reduction of production cost - standards can eliminate most of the scrap, and improve quality without raising production cost;
- Minimum standards of work - for instance, health, safety, no child labour, etc.;
- Safety of the inhabitants - for example, in earthquake-prone areas high-rise structures built with substandard cement may not be safe, or in hurricane-prone areas houses built without adequate safety measures may be dangerous; and
- Market requirements - a product made according to standards can more easily penetrate the markets, especially in the case of export.

We are living in an increasingly regulated world which urges developing countries to cooperate in their efforts for standards that meet their specific requirements. The central issue is that standards regarding production and consumption must recognize the envirdnments in developing countries. Standards have to be defined in the South, by the South, for the needs of the South, and using the resources of the South.

Schilderman (1992), looking more specifically at housing, gives a useful summary. To start with, standards define a minimum level of quality of housing, mainly to prevent disasters or to reduce health risks. In the South, however, standards apply to urban areas only. Furthermore, standards are, in many cases, inappropriate because they:

- are imposed or imported;
- are not in line with local traditions;
- do not recognize that building is an incremental process;
- do not take into account the needs of the masses; and
- cater to the requirements of the upper class only.

The problems are compounded since:

- funds are not available to meet the requirements of the standards:
- people's priorities are different;
- imported standards do not use local materials;
- standards often mean bureaucracy;
- standards destroy a lot of housing resources; and
- standards increase overcrowding.

In view of the above, it is clear that one needs a different approach. One has to meet the basic needs of the masses, starting with an absolute minimum and showing the way for gradual improvement. The absolute minimum should ensure, for example, that houses do not collapse over the inhabitants. Standards should not be prescriptive ("walls should be 50 mm thick"), but indicate a performance, such as being able to withstand a hurricane or an earthquake. In the case of building with bamboo, the standards should show the way to achieve a desired level ofperformance using bamboo, and give adequate examples. They should make use of the opportunities provided by bamboo to help people to solve their problems, starting at a low level and growing to a higher level.

Such a bamboo standard can become a boon instead of a burden. It can stimulate the use of bamboo, and provide recognition for the material by wider and better use. A UNIDO report (Anonymous 1991) says about wood: "In most developing countries, building legislation is inappropriate and does not recognize wood as a durable construction material. This has prevented banks and other financial institutions from supporting the use of wood in construction." The remark is valid also for bamboo also. In the future we should think in terms of a system of certification.

A considerable part of a bamboo standard should be based on observations, such as which type of housing did survive the disaster? which houses are more durable or need less maintenance? etc. A bamboo standard should teach valuable lessons. The standard currently being developed for mud (Anonymous 1992) is an example of such an approach.

An International Model

This lengthy introduction gives an overview of the opportunities that standards provide, and what is wrong with the current practice with standards. Our main problem. however, is that bamboo does'not appear in national building codes. This hampers recognition and, sometimes, may even be interpreted that the material is "forbidden", though this risk is only in urban areas since bureaucrats rarely visit rural areas. Anyhow, it is a constraint for the progress of bamboo as an engineering and building material in developing countries. National standards that rectifies this problem can open the way for engineers and designers to work with bamboo.

If the development of national bamboo standards is left to the national authorities, one can expect a wide diversity among the different national standards. Take the case of timber, for example. Standards have been prepared and accepted in the USA, Europe and Australia; but they will never agree on a world standard any more. If, on the contrary, an international model for national standards is developed, then we will be strengthening the position of bamboo considerably. For us, the opportunity for a world bamboo standard is open, and if we succeed we are half a century ahead of our colleagues involved with timber.

The International Standards Organization (ISO) defines standards as "technical specifications or rules, based on consensus, and approved by a recognized standardizing body." The "consensus" is our task, and we have to submit our proposal to the IS0 to gain due authority for the product of our labour.

Other arguments in favour of such an international model have been described by Boughton (1990a). Many countries are facing a huge shortage of housing. Therefore, governments are willing to consider bamboo as a contribution to the solution. But bamboo still has the stigma of being the poor man's timber, and is not considered a modern material. A building code would be the solution to this problem as it would help formalize the position of bamboo.

Advantages of codified design with bamboo can be summarized as follows:

- Engineering recognition. A code will stimulate engineers to use bamboo. "Engineers and architects prefer to work with the determinacy of a well-known system or material, supported by solid knowledge of its properties, backed by the existence of a minimum of code specifications on which they can base their judgement and design decisions" (Arce 1993);
- Contractual advantages. A code makes contractual arrangements much easier;
- Trade advantages. A code facilitates quality control of products; and
- Increased use of bamboo. Codification leads to better social acceptance, and to innovation found more regularly in designs than in other aspects.

Are We Willing and Able to Do This?

Given the advantages of an international model for national bamboo building codes, we should undertake the job to prepare such a model. But the question is: can we do it? Arce in a letter to Boughton said, "At the time other codes started their development, there was already a great deal of documented experience...in the case of bamboo, we do not have that important advantage."

In the opinion of the author this is an interminable discussion between scientists and engineers. The scientists among us are right: we do not know enough about bamboo to design such an international model for standards. But the eternal fate of the engineer is to give an answer, and a reliable at that, based even on inadequate data. From this point of view, the author's opinion and strong advise is that we must start right away.

The topic has already been discussed at the Second International Bamboo Workshop (1988), Cochin, India, in the papers presented by Janssen (1990) and Boughton (1990a), as well as in the meeting of the Sub-group on Building and Engineering with Bamboo (Workshop proceedings, p. 383). In several meetings of the CIB-W18B committee, the issue was raised, for instance, by Boughton. At the Fourth International Bamboo Workshop (1991) in Chiangmai. Thailand, too the subject was discussed, mainly in the meeting of the same Sub-group, and the minutes distributed to the participants. Unfortunately, progress has been slow, largely because of the lack of funds. At present, funding is rather sure for small, short-tenn activities of, for example, three months and a budget of US$l00 000. We must, hence, look for a group of volunteers who would be able to work at their institutes and with their know-how at no cost, though for working sessions we can expect funding.

The Content of an International Model

Evidently this will need thorough discussions, and the following is meant only as an opener (Boughton 1989a; Ghavami).

Philosophy

A similarity with timber codes will be an advantage for the users to get accustomed to it, and for us to write it. This applies also to the use of nomenclature, symbols and terminology. Some parts our bamboo code (for instance, torsion or lateral buckling) will be simpler than that for timber, while some other parts (for example, connections) will be more complicated. Items to be included are: scope and relation of bamboo code to other relevant codes, and organization and use of the code. The model will have two characteristics: for some chapters it will be a complete code; while for others it will give only a guideline for the national codes.

Structural safety and sound design

These will be as in timber codes, but taking into account the specific properties of bamboo (for example, the thin walls as compared with the massive cross-section of timber). Basis of design will include the fundamental requirements and general design concepts. We can rely heavily on timber standards here; but we have to take into account the differences between timber and bamboo, such as the elasticity of bamboo till failure and the way bamboo fails by losing its cross-section only.

Materials testing and properties

Description of the properties of bamboo and how to determine them in the laboratory; similar to the ASTM standards for wood. The thesis by Arce provides adequate information on these problems. Description of materials used for connections – rattan, twine, natural fibres, nylon line, polypropylene, nails, bolts, glue, etc. – maybe given in an annex. Field information, such as how the houses perform in practice during an earthquake or during a typhoon, may also be included.

The chapter has to have a full code for both lab and field tests since evaluation reports from the field guidelines have to be given, We should keep in mind that only a few properties are relevant for the prediction of failure loads (Arce in the same letter to Boughton).

From lab tests to data for calculations

We have to decide whether we will use the system of an overall safety factor or the modem system of partial safety factors. Will we define guidelines, or a full code? Rajput and others **(1992)** have published a very interesting article on this subject. The author does not agree with every item in this publication, but as a whole this is exactly the type of studies we need.

Beams and columns

A full calculation code, as well as basic lessons like "do not concentrate forces" and "spread load over a number of elements", buckling -allow for movements, tolerances – no two pieces are identical, etc.

Joints and trusses

Only guidelines for national codes. Boughton (1989b) provides a classification:

- Complete joint alternative. The joint for a given load is fully specified, including the description of all fastening elements;
- Component capacities alternative. The components have been described, and the designer can design the joint based on this information (more flexibility and more design effort); and

- Design principles alternative. Basic mechanics of joints and materials are specified.

Topics like hurricanes and earthquakes

Guidelines for national codes, and for evaluation reports from the field. For example, which houses and which details perform well in practice?

A grading system

Important for market development and export. Only guidelines are needed See the article by Rajput and others (1992).

Reinforcement in concrete

Lifetime of bamboo in this alkaline environment. Only guidelines are required.

Durability and preservation

Detailed information on how to improve the life of bamboos, maintenance and design for maintenance. Preservation should include information on the proper selection of bamboos. Safety of the workers and the inhabitants, and pollution and the environment are the other topics to be covered. Only guidelines for national codes.

Handbooks on building with bamboo

Guidelines for producing these publications. In general, our model should give only regulations. However, it is a wise practice to publish also a series of handbooks with adequate sketches and details. These handbooks should conform to the model or to the standard, which means they should allow regular upgrading.

Export items from bamboo

Export items made of bamboo can already be seen on the market, and it would be good for the economic development of the South if bamboo products are developed specifically for export to the North. For this, product development standards are needed. To quote from the UNIDO report (1991):. "A number of participants said that standards could act as barriers to the import of products from developing countries. The interest of developing countries should be protected and their views represented at international gatherings dealing with standards harmonization in the European market." Although the statement does not specifically mention housing or building standards, its relevance to bamboo standards cannot be ignored.

Apparently, many aspects of the standards mentioned above have to be discussed. Still, to take the matter a step ahead, what should be included or excluded? Boughton (1990b) proposes to include buildings like schools, medical centres, and privately owned buildings such as warehouses, commercial structures and tourist facilities, and to exclude housing. Again, there is enough here to warrant serious discussion. The most important point, however, is: how do we take the results of our work to an extent where they work in favour of the people whose problems with standards have been described in the first paragraph of this paper? Will our idea of taking the standards to the ISO and from that level to the different national standard organizations suffice?

Procedure

An international model for national building standards should be designed with the participation of an international volunteer group of leading experts. This should be done in close cooperation with the CIB-W18B committee. In the meetings of this committee in Singapore (1988) and Seattle (1989), some outlines had been presented (Boughton 1989a, b). Sound project management will be essential.

To make the model official, and acceptable to national authorities, it should become an IS0 standard. This is in line with the IS0 Development Program to promote the establishment of international standards needed by developing. countries. The task involves technical and procedural aspects.

The technical aspects involve the preparation of documents, based on the results of tests and research carried out in several countries, and representing the state of the art as proven and accepted by the majority of experts in the given field. These documents should cover testing of physical and mechanical properties, strength grading, preservation, and a design code for bamboo structures. A handbook on the mechanical properties of bamboo is already available (Janssen 1991).

The procedural aspects involve a proposal to the relevant IS0 technical body for a new work item in this area and its follow-up. The appropriate technical body in this case seems to be ISO Technical Committee (TC) 165 on Timber Structures. According to ISO directives, the proposal for the new work item can be made by one of the ISO-member bodies or a liaison organization, and should be approved by vote by a majority of the participating members (P-members) of the TC, or a subcommittee within that TC. It should be pointed out that among the bamboo-growing countries, only China and India are P-members of the TC 165 (out of a total of 19 P-members).

Once the IS0 technical body accepts the proposal to include a project on bamboo in its program, the next step is the formation of a Working Group headed by a Convener in order to prepare a Committee Draft which hopefully develops into an International Standard to be voted on by IS0 members.

Experience has shown this to be a lengthy exercise. It is advisable that a group of technical experts begin preparing some pre-standards at the time the formal procedure via IS0 members in the interested countries is initiated. In this way, by the time the proposal is accepted, documents will be ready for discussion and approval.

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Bamboo-based Boards in China: an Introduction

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Abstract

This paper gives an introduction to the structure and application of bamboo mat plywood, bamboo strip plywood, bamboo-laminated board, bamboo particle board, thin bamboo veneer, bamboo-timber composite board and bamboo parquet. The paper also briefly introduces other bamboo-based panels, which have been developed successfully but not yet put into commercial production – such as bamboo fibreboard, cement-bonded particle board, bamboo-plaster particle board, etc. Some examples of research conducted in recent years on bamboo composite boards, and the socio-economic benefits involved in their production are examined. The paper also suggests measures for the development of bamboo resources and bamboo-based panels, and discusses the steps required for opening up the market for the same.

Brief account of bamboo resources

The rapid decrease of world forest resources and wood supplies with the development of industry and the increase of population has made bamboo plantations a crucial part of social forestry in many developing countries. Research, development and utilization of bamboo are getting greater attention now on account of dwindling wood supplies.

Bamboo, with its 1250 species under 75 genera, occupies globally about 14 million hectares, distributed mainly in the tropical and subtropical zones. Asia accounts for the largest share (12 million ha), followed by South and North Americas, Africa, Oceania and the Pacific Islands. The bamboo resources are mainly in developing countries: China, India, Burma, Thailand, Bangladesh, Malaysia, Vietnam, Japan, Indonesia in Asia, and Mexico, Guatemala, Honduras, Colombia, Venezuela and Brazil in South America.

In Africa, bamboos occur in a relatively small area in the narrow zone of rainforest and mixed forest of broad-leaf trees, ranging from Senegal on the west coast to Madagascar off the east coast. Most bamboo forests in the world are not managed intensively and are characterized by low productivity.

Bamboo is traditionally utilized for houses, rafts, farm implements, food, and several other goods for daily use and entertainment. The global yield of bamboo is estimated at 16 million tonnes, and non-industrial uses (such as farm implements, household articles, handicraft items, construction, etc.) account for about 70% of this. Only 30% of the yield goes for industrial use, mainly for pulp making. In most bamboo-producing countries, the techniques for bamboo processing are primitive and the products low in quality. Although bamboo has many advantages such as fast ‘growth, short rotation, excellent physical and mechanical properties, etc., its utilization is somewhat limited by its hollow stem and relatively small diameter.

Research on Bamboo-based Panel/Composite Board

In the past 10 years, many countries, particularly China, has attached great importance to better processing and utilization of bamboo resources. Apart from universities, government research centres and some enterprises which have been carrying out research and development work, some specialized institutions have been set up to conduct bamboo research. The scope of research has been wide-ranging, covering the structure and physical and mechanical properties, development of new technologies and products, relationship between various properties and product quality, and development of processing machines and ancillary materials such as adhesives. The underlying aims of these research are further lowering of production costs, waste reduction, and development of more and better products.

Properties of bamboo

The research on the structure, physical, mechanical and chemical properties of bamboo is mostly conducted by research institutions and universities. Such research has laid the foundation for processing, utilization and preservation of bamboo. Some examples are:

- The relation between the microstructure and physical and mechanical property of bamboo;
- Electron microscopy studies on carbonized bamboo;

- Conductivity;
- Chemical properties and calorific values;
- Defects and their evaluation;
- Surface wettability; and
- Effect of nodes on the strength properties.

Development of new board products

Research on bamboo-based panel/composite board has been extensive. The products that have gone into commercial production include mat plywood, slivers board, bamboo-based particle board, composite board with wood, paper-overlaid mat corrugated board and parquet. Other board products developed, but not yet commercialized, include:

- Hardboard and MDF. Technologies for making hardboard (wet process) and MDF (dry and wet process) from *Phyllostuchys pubescens* have been developed, though the research has shown that fibre separation from bamboo is comparatively more difficult than in wood. The production process is under study for effecting necessary modifications.
- Cement particle board. The product is made using needle-shaped bamboo particles and common silicate cement, with calcium chloride as the solidifying agent. Research results indicate the need for pretreatment of bamboo particles.
- Plaster particle board. The board is made with residues obtained from the processing of *P.pubescens* and a small, wild bamboo species that grows in the mountain region. Other materials used are plaster of paris powder and an additive. All major properties of the board are comparable to those of wood-based plaster particle board available in the market. The research has shown that the size of bamboo particles has a significant effect on the properties of the board, the optimum ratio being 50% coarse particles, 30% medium particles and 20% fine particles.
- Arc-shaped board. Used for decoration, the product is made from the inner part of the culm (with its natural bend) left after the outer parts is stripped for other boards. Bonding is with a wood or bamboo-based substrate.
- Net board. It is a light board, quite similar to honeycomb plywood, made by hot pressing bamboo slivers (core layer) and bamboo strips or resin-impregnated paper (facing and backing).
- Densified bamboo. A macromolecular chemical (intensifier) is used to saturate the vascular bundles in the culm. The process involves vacuum impregnation under high temperature, and condensation and heat setting

of the hydroxyl group chemicals brought about by the glucose of the cellulose molecules. The densified bamboo is already being used to make weaving shuttles for silk fabrics, and research on the development of shuttles for cotton weaving is now under progress.

- Bamboo-wood composite oriented particle board. This product resulted from the research carried out to overcome the high density of bamboo-based particle board. The bamboo-wood composite oriented particle board has bamboo particles as facing and poplar wood particles as core. The strength-weight ratio of the board is 60 as compared with 29.9 for bamboo-based particle board.

Relation between product cost and quality, and technological process and parameters

This is the area where research has not only been voluminous but also more thorough and subject to constant improvement. The main purpose of most of these efforts is to lower the production costs, improve productivity and product quality, make optimum use of the bamboo resources available, and to derive maximum socio-economic benefits. For example, the earlier technology for bamboo sliver laminated board had all the resin-impregnated slivers in the blank oriented in the same direction. This caused the board to warp and deform when force was applied transversally, thereby limiting its application. Further research led to the addition of a transverse layer of slivers, solving the specific problem and greatly improving the overall strength of the board.

Adhesives, preservation, bleaching and dyeing

Adhesives

Urea-formaldehyde (UF) and phenol-formaldehyde (PF) adhesives are widely used for bamboo-based panels/composite boards. Since the structure, and the physical and mechanical properties of bamboo are different from wood, and because the poor wettability of bamboo/makes bonding difficult, the adhesive used for wood cannot be used for bamboo without modifying the formulation. Hence, the researchers have developed adhesives that suit the properties of bamboo, the UF adhesive formulation for bamboo mat concrete being one example. Another study aimed at reducing the cost of adhesive (to offset the high volume of adhesive required) resulted in the use of tannin extract to substitute 60% of phenol in PF resin adhesive. The Indian Plywood Industries Research and Training Institute has developed a PF resin formulation for impregnating bamboo mat which has reduced by two-thirds the quantity of resin required for pressing bamboo mat board.

Bamboo is treated by physical and chemical means to protect against degradation and decay caused by fungi (staining and rotting), insects (termite, borer, beetle) and natural elements (water and fire). Physical treatment methods developed include water soaking and exposure to high temperature, and infrared andmicrowave radiations. Chemical treatment methods include painting, cooking, fumigating and pressure injection using a variety of chemicals.

A method developed for defatting of bamboo culms involves boiling of culms in an aqueous solution of sodium hydroxide for one to two hours. The fat is then wiped away from the culms.

Bleaching of culms to impart better colour has been the subject of several studies. The procedures developed include: (1) soaking in a 10% solution of hydrogen peroxide for 5-10 minutes; (2) soaking in an aqueous 1% solution of bleaching powder for one hour, and boiling in 5% acetic acid solution for 30 minutes; (3) treating with sulphur dioxide in a sealed container; and treating with sodium hypochlorate solution for 30 minutes.

Some products require dyeing of bamboo for improved aesthetic appeal. One dyeing process developed involves boiling of bamboo-in a 2% sodium hydroxide or sodium carbonate solution for 3-5 minutes, and then boiling in a solution of alkali dye for 30 minutes. Another method is to scrape the culm surface, paint the surface with a thin solution of sulphuric acid (for black colour) or nitric acid (for light brown colour), baking it immediately.

Machinery and equipment

As the variety and complexity of board products increased, so did the need for specialized machinery and equipment. R&D in this field has, among others led to the development of:

- Steam/electrically heated softening box : for softening by heat the arc-shaped sections of split bamboo;
- Stripping machine : used to extract, under high temperature and pressure, strips from softened bamboo sections;
- Planing machine : for planing the bamboo strips to a desired, even thickness;
- Drying and setting machine : for drying the strips to the required moisture content, and to ensure smooth and uniform strips;

- Oblique planing machine : employed for bevelling the ends of strips, so that they can be jointed with one another to make long strips;
- Bamboo cutter : a machine for splitting bamboo culms;
- Sizing machine : used for obtaining strips of a set width (20,15,10 or 5 mm) and thickness (7 - 14 mm);
- Sliver cutter: for cutting slivers (30 mm maximum width, 0.5 mm minimum thickness);
- Bamboo curtain weaving machine : weaves per minute 300 mmof bamboo curtain (from strips) of 1.8, 2.1 or 2.4 metres width.

Bamboo-based Board Manufacture

The bamboo-based panel manufacture in China started in the mid-1970s, with the productionof bamboo mat plywood. Since then, continuous research on the physical and mechanical properties of bamboo, as well as a better understanding of the structure of bamboo wall, have given rise to a number of bamboo-based panel products with special properties. The following is a brief introduction to these products, some information on the industry that makes these products, and an outline of the socio-economic benefits derived from bamboo composite board industry.

Types of bamboo boards and their end uses

Bamboo mat plywood

The production of bamboo mat plywood involves cutting of bamboo slivers, mat weaving, drying, coating with adhesive (UF/PF resin) and hot pressing. The thin bamboo mat plywood is used only for packing and light building construction. The thick boards find use as structural material in concrete buildings and for making wagon platforms. The surface of the plain bamboo mat plywood is sometimes decorated to make a value-added board, useful in making furniture and wall panels.

China has formulated a National Standard (GB13123-91) for bamboo mat plywood with effect from April 1992. The Standard stipulates, among others, the moisture content, modulus of rupture and ageing resistance, as well as the amount of formaldehyde released into the surroundings.

Bamboo sliver laminated board

This board also is made from bamboo slivers, through drying, gluing, redrying, laying up, hot pressing and bonding. The board with the slivers laid up longitudinally is called single-direction structural board, while the one with the slivers running criss-cross is called non-single-direction structural board. Bamboo sliver laminated board exhibits a high longitudinal strength and hence, can be used as platform for trucks, gangplank at construction sites, etc. It requires comparatively low capital investment and less mechanization.

Bamboo strip plywood

For making bamboo strip plywood, bamboo culm is cut into sections, split, nodes removed, and made into strips of desired width and thickness by softening at high temperature, followed by flattening and planing. The strips are then dried, set, painted with glue, laid up and hot pressed into plywood. The main difference of bamboo strip plywood with bamboo mat plywood and bamboo slivers laminated board is that in the former, softening and flattening are used to get bamboo strips of desired width and thickness.

There are at present over 20 bamboo strip plywood factories in China, with a total production capacity of 50 000 m^3 per year. The plywood is used extensively in car and train manufacture. Reprocessed bamboo strip plywood (surface overlaid with resin-impregnated paper) is used in place of wood and steel for form works in concrete building construction, thus providing immense economic benefits.

Bamboo curtain plywood

In this bamboo-based panel, instead of individual strips, a curtain made of bamboo slivers is used. The manufacturing process involves drying, adhesive application, pre-drying, laying up and hot pressing. Usually, bamboo curtain plywood has a three-layer structure, with alternating vertical and horizontal curtains. PF resin-impregnated Kraft paper, veneer or bamboo mat are sometimes overlaid on the outside surfaces for use in concrete form work and wagon panels.

Bamboo-based particle board

Bamboo particle board is made using bamboos wastes, and the process consists of roll pressing, cutting, milling to form particles, adhesive spraying, spreading, forming and hot pressing. The surface of bamboo particle board is flat and smooth, which make it suitable for use in furniture.

Rotary cut veneer

Straight, round and thick-walled culms of *Pbyllostuchys pubescens* is used for manufacturing rotary cut veneer. The production process involves cutting, cooking, rotary cutting and drying. The veneers, after bleaching, dyeing and surface modification, can be used for decorating high-grade furniture, walls, ceilings, partition screens, etc. It also finds use in handicraft items.

Paper-overlaid bamboo mat corrugated board

The board has four layers of bamboo mat as the substrate, on which PF-resin impregnated, reprocessed paper is overlaid, and finally hot pressed with corrugation. It is used as roofing material owing to its resistance to ageing and corrosion, elasticity and strength. In China, paper-overlaid bamboo mat corrugated board is cheaper than asbestos or fibreglass corrugated sheets.

Bamboo-based composite boards

Bamboo-based composite board is inade of either bamboo and one or more other materials (such as wood), or of two or more different bamboo materials (such as bamboo mat and bamboo particles). Generally, the manufacture of all such composite boards involves application of adhesive, forming of blanks and hot pressing. Currently, there are four types of bamboo-based composite boards in use in China:

- Bamboo mat-particle composite board. The surface layer is made of bamboo mat, while bamboo particles form the core. Mainly used for flooring, panelling and partitioning in railway coaches.
- Wood veneer-bamboo strips-particle composite board. Wood veneer is used as the surface layers. Bamboo strips and particles bonded with PF resin form the core.
- Bamboo mat-bamboo curtain composite board. The board has bamboo mat as the surface layers, and bamboo curtain impregnated with PF resin as the core. In order to improve the surface finish and wear, the face layers are overlaid with one or two layers of PF resin-impregnated Kraft paper. This type of composite board is mainly used for concrete form work.
- Wood veneer-bamboo curtain composite board. This bamboo-wood board has wood veneer as the facing and backing layers, and resin-impregnated bamboo curtain at the core. The production process is the same as the one employed for plywood production.

The tensile strength of bamboo fibre is twice that of wood, and its hardness 100 times more. Therefore, bamboo plywood/composite board can be used for concrete form work in place of wood, steel and other materials. If the surface is overlaid with resin-impregnated Kraft paper, its physical and mechanical properties can be further improved to make it suitable for different uses in building construction. Bamboo plywood and composite board are lighter than steel or wood and hence, require less labour for loading and unloading. Furthermore, they have a high degree of safety, long service life and the potential to save steel and timber.

A wide range of bamboo-based boards are useful in concrete form work. These include bamboo mat plywood, bamboo strip plywood, bamboo curtain plywood, bamboo particle board, bamboo mat-curtain composite board and bamboo-wood composite board. Surface modifications – with resin-impregnated Kraft paper and/or wood veneer – can also be made to suit the requirements of specific applications.

Bamboo-wood composite board

This is a comparatively new product, yet to be commercialized. It is made with strips from *P. pubescens* and veneer of *Pinus* ***massoniana.*** PF resin application, laying up and hot pressing are the main production steps. The surface of the board can be coated with PF resin to give it resistance to water and rot. The board may also be subjected to chemical preservative treatment to prevent insect attack.

Other products

Two important bamboo products, through not belonging to the category of board, are moulded weaving shuttle and parquet. The shuttle is made from culm wool through drying, resin impregnation, redrying, spreading, and hot pressing in the mould. When compared with wooden shuttle, the moulded bamboo shuttle has higher wear resistance, smoother surface and better dimensional stability.

Bamboo parquet, which usually has three layers, is made essentially in the same manner as bamboo strip plywood. At the end of the process, however, the hot pressed strips are sanded and varnished to make parquet. Bamboo-wood composite parquet has wood veneer at the core.

The industry

On an average, a bamboo board factory in China has 120-200 employees and an annual production capacity of 2 000-4 000 m^3. Most of them have 120-l 50 employees and annual production of 2 000 m^3, which seems to be the ideal size. Production at a smaller scale may increase the production costs and correspondingly decrease the profit, while a larger factory may find local raw material supply to be inadequate and be forced to obtain bamboo from distant places, thus increasing the production costs and reducing the profit margin.

Economic and social benefits of bamboo board production

Since the mid **1970s** when the production of bamboo mat plywood began, production of bamboo-based panel/composite board has steadily gone up. In the last seven or eight years, the increase in production has been by leaps and bounds, especially in the bamboo-rich provinces such as Hunan, Fujian, Zhejiang, Jiangxi and Sichuan. Almost all counties in these provinces have at least one bamboo-based board factory. According to a 1988 estimation, there were over 100 such factories in China, with a total installed capacity of about 100 000 m^3 per year. More recent, but incomplete, statistics put the figure at 200, of which 100 make bamboo mat plywood, 25 produce bamboo strip plywood, 20 manufacture bamboo curtain plywood, and 20 are bamboo particle board factories. The total annual capacity is estimated at 300 000 m^3, while the annual production is 150 000-200 000 m^3. Still, the bamboo-based panel/board industry in China is considered to be in its infancy when compared with industries that handle other forest products. The general trends noticed in recent years are:

- increase in product variety, with new products emerging in large numbers;
- improvement in product quality;
- more intense market competition; and
- increase in mechanization and corresponding decrease in manual operations.

The bamboo-based panel/board production has brought in several direct socio-economic benefits to the producers as well as the users:

Monetary benefit

The normal profit margin of a bamboo-based panel manufacturer is l0-15%. For a factory that produces 2 000 m^3 panels a year, the annual profit would be about 500 000 yuan RMB. The customers also have accrued monetary benefits from bamboo-based panel production. For instance, the Nanjing Car Factory made a saving of 220 yuan RMB (1988 price) per truck when it substituted the pine-based board platform with bamboo-based plywood platform, and this saving was passed on to the customers. At an annual production of 16 000 trucks, the amount saved adds up to a phenomenal 3.52 million yuan RMB. Another example is in the construction industry, where bamboo-based concrete form work has significantly brought down the costs, to the direct benefit of the customers. Bamboo-based frame work costs only 43% of the steel-based form work and 60% of the wood-based one.

Employment

As mentioned earlier, a bamboo particle board factory with an annual production of 150 000 m^3 employs up to 120 people, while a bamboo plywood factory with an annual production of 200 000 m^3 gives employment to 150 people. This means that the 200 factories in China provides employment to about 26 000 people.

Wood substitution

Wood substitution is a major benefit of all bamboo-based products. For example, at the Nanjing Car Factory, each truck produced used to consume 0.35 m^3 of pine wood. Substitution of pine wood with bamboo for making truck platforms reduced this to 0.125 m^3 of wood; that is, each cubic metre of bamboo plywood saved 2.8 m^3 of wood.

If half of the *R.pubescens* harvested per year (150 000 culms) is used, the annual production of bamboo plywood would be 833 000 m^3. If this is used to substitute wood, about 2.33 million m^3 of wood would be saved every year. If the particle boards produced per year (690 000 m^3) is added up, the annual saving in wood would reach 4.26 million m^3, or even 5 million m^3 if the factory wastes can also be put into use.

Rural economy

Factories manufacturing bamboo-based panels are mostly built in rural areas or nearby, where bamboo resources are available. Bamboo farmers in rural China, who used to sell raw bamboo earlier, have now started making bamboo slivers, curtains and mats, and selling them to the factories. Moreover, seeing an opportunity in the factories' steady requirement for bamboo, they have also started bamboo planting and management more enthusiastically. It has been noticed that in rural areas where bamboo forests grow, centres have sprouted with bamboo development and utilization as the activity. This has proved to have a stimulating effect on the economy as a whole also. Thus, the development of rural economy has benefited significantly from bamboo-based panel production.

Problems and Solutions

Current problems

- *Insufficient development, utilization andprotection of bamboo resources.* As mentioned earlier, the world's bamboo resources are concentrated mostly in some developing countries in Asia, Africa and Latin America. In all these countries, reckless harvesting, low productivity and poor management have done immense damage to the bamboo resources. Even in countries where bamboo is better utilized, more attention is paid to harvesting of bamboo than to its development and protection, resulting in a general decline of the resources.
- *Developmental imbalance in bamboo-based board production.* The resource, industrial and technical levels are higher in Asia than in Africa and Latin America, and this has brought about an imbalance in the global develop ment of bamboo-based boards. China has achieved, especially in the last two decades, rapid development in this industry; but even then, pockets of unequal development exist in the country. P.pubescens is the species used mostly, and the factories are largely confined to the eastern and central provinces.
- *Technology and equipment require further improvement.* The physical and mechanical properties of bamboo differ from those of wood; bamboo has a higher density, lower wettability and water permeability, etc. The production of bamboo-based boards is technically more problematic than the production of wood-based boards: the raw material consumption and productivity are comparatively lower, and the resin consumption, product density and power consumption are higher. An important reason for this is that the machinery and equipment used for producing bamboo-based boards are the ones originally designed for wood processing and hence, cannot fully meet the requirement of bamboo processing.
- *Product useand markets need furtberdevelopment.* In comparison with wood-based boards, the current use and market share of bamboo-based boards are rather limited. For example, bamboo-based boards find use only in concrete form work, packaging, and as floor for vehicles and houses. But there are several firms making these same products and competing for the same limited market.
- *Full socio-economicpotential yet to be realized.* Because of the problems mentioned above, the actual production of bamboo-based board is much less than the installed capacity. This results in its full socio-economic potential not being realized.

Solutions

In spite of the differences that exist among the countries in terms of resources, industrial and technological levels, there are some universally applicable measures to remedy the above-mentioned problems.

- ***Bamboo resource development.*** The first and foremost effort must be to protect the existing bamboo forests through curtailing unsustainable harvest. Second, the productivity of the bamboo stands must be increased; sound management can triple the productivity of bamboo stands. Third, it would be an effective measure to establish bamboo plantations on a commercial scale. Fourth, specialized agencies need to be created for intensifying bamboo production management.
- ***Development of newproducts.*** The manufacturers and technologists should not only encourage the development of new quality products that the market needs, but also provide training and organize activities towards that end. Emphasis must be placed on the effective use of sympodial bamboos, the main bamboo resource in the world. Research and development efforts should focus on bettering technology and equipment, raw material utilization, productivity and product quality, and on lowering power and resin consumption and overall production costs.

Market exploitation

Since it takes some time before a new product is accepted by the market, an active marketing drive would be required. It is also important that the product marketed meets the relevant national/international standard. The quality of products reaching the market can be maintained at. a high level if there is a mechanism that compels compliance to such standards.

Education and international cooperation

It would be worthwhile to include bamboo science and technology as part of forestry education. Courses such as “bamboo cultivation”, “bamboo utilization” and “bamboo economy and management” deserve to be introduced into forestry college curriculum. Similarly, training courses on bamboo-related topics would be very helpful in mobilizing the technical personnel required for bamboo research and development.

It is also important that greater efforts be made for furthering international exchanges in bamboo science and technology. Organizations such as the International Network for Bamboo and Rattan (INBAR) could provide an impetus to this through activities such as symposiums, training courses, technical information exchange, regional/international research and development projects, etc.

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Development of Semi-fibre Bamboo Board Processing Technology: Shortening the Press Cycle

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Abstract

Utilization of bamboos as an alternative raw material in wood panel industry is being promoted in Indonesia because of their easy availability and the high mechanical strength. This laboratory-scale experinient was aimed at shortening the press cycle in the processing technology for semi-fibre bamboo board made from *Gigautocbloa apus*. Specifications in the Japanese Industrial Standard (JIS) A-5908 was taken as the reference for physical and mechanical properties of the boards. Results of the experiment showed that semi-fibre ply-bamboo (zephyr board) conforming to JIS standardusing UF adhesive can be made employing a pressing cycle of 20 minutes, and PF bonded board conforming to the same standard can be made employing pressure for less than 6 minutes after pre-drying treatment. Further experiments are needed on the utilization of bamboo for single-layer and single-fibre orientation board for building construction applications.

Introduction

In Indonesia, demand for wood is increasing with the increase in construction activities and export of wood-based products. On the other hand, the quantity and quality of wood resources from tropical forests have been steadily declining. This situation has necessitated the utilization of other renewable and sustainable resources, such as bamboo, for wood substitution. Using bamboo as the main raw material, bamboo panels can be developed and used to substitute wood-based panels. However, one problem in the production of bamboo panels (such as ply-bamboo, bamboo laminated lumber) by bonding is that the epidermal layer of bamboo culm, with its high wax and silica content, is resistant to bonding. In the experiment carried out, this problem was overcome by crushing the culm to form strands (zephyr).

This paper discusses the means for shortening the press cycle of the processing technology for zephyr bamboo boards made from *Gigantockloa apus,* using urea formaldehyde (UF) and phenol formaldehyde (PF) resin adhesives.

Materials and Methods

A fresh *Giguntochlou upus* bamboo culm was cut to 25-cm lengths, split and crushed using a bamboo crusher to make zephyr, which was then dried in an oven to oven-dry moisture content. The zephyr was dipped in liquid adhesive for 10 minutes, subjected to a spinning cycle to reduce the adhesive content, and formed into a three-layer mat with fibre orientation at right angles, similar to plywood. UF and PF resins were the adhesives used. The mat was then hot-pressed (130°C for UF and 160°C for PF) to make 250 x 250 mm boards of 10 mm thickness. Pressing time was varied to 8, 10, 12, 16 and 20 minutes. In the case of PF adhesive, the mat was formed in single layer with single-fibre orientation. The mat was dipped in PF adhesive for 10 minutes, and placed in an oven at 80°C for 10,20 and 30 minutes. The pressing time was varied to 6,8 and 10 minutes.

Specimens cut from both types of boards were tested after conditioning for two weeks. Internal bond (IB) strength, thickness swelling (TS) and bending strength were tested in accordance with the provisions of Japanese Industrial Standard (JIS). A-5908.

Results and Discussion

Figures 1 and 2 show the modulus of rupture (MOR) and modulus of elasticity (MOE) of boards using UF and PF adhesives, and pressed for varying time periods. In the longitudinal direction, MOR and MOE increased with increase in pressing time. In the lateral direction, MOR and MOE values did not show any significant change with pressing time of more than 10 minutes, but began to decrease at a pressing time of 8 minutes. During the measurement of MOR and MOE; shear failure was noticed. The results indicated that type 250-90 overlaid board, as per JIS specifications, can be obtained for PF and UF bonded boards with a pressing time of more than 10 minutes.

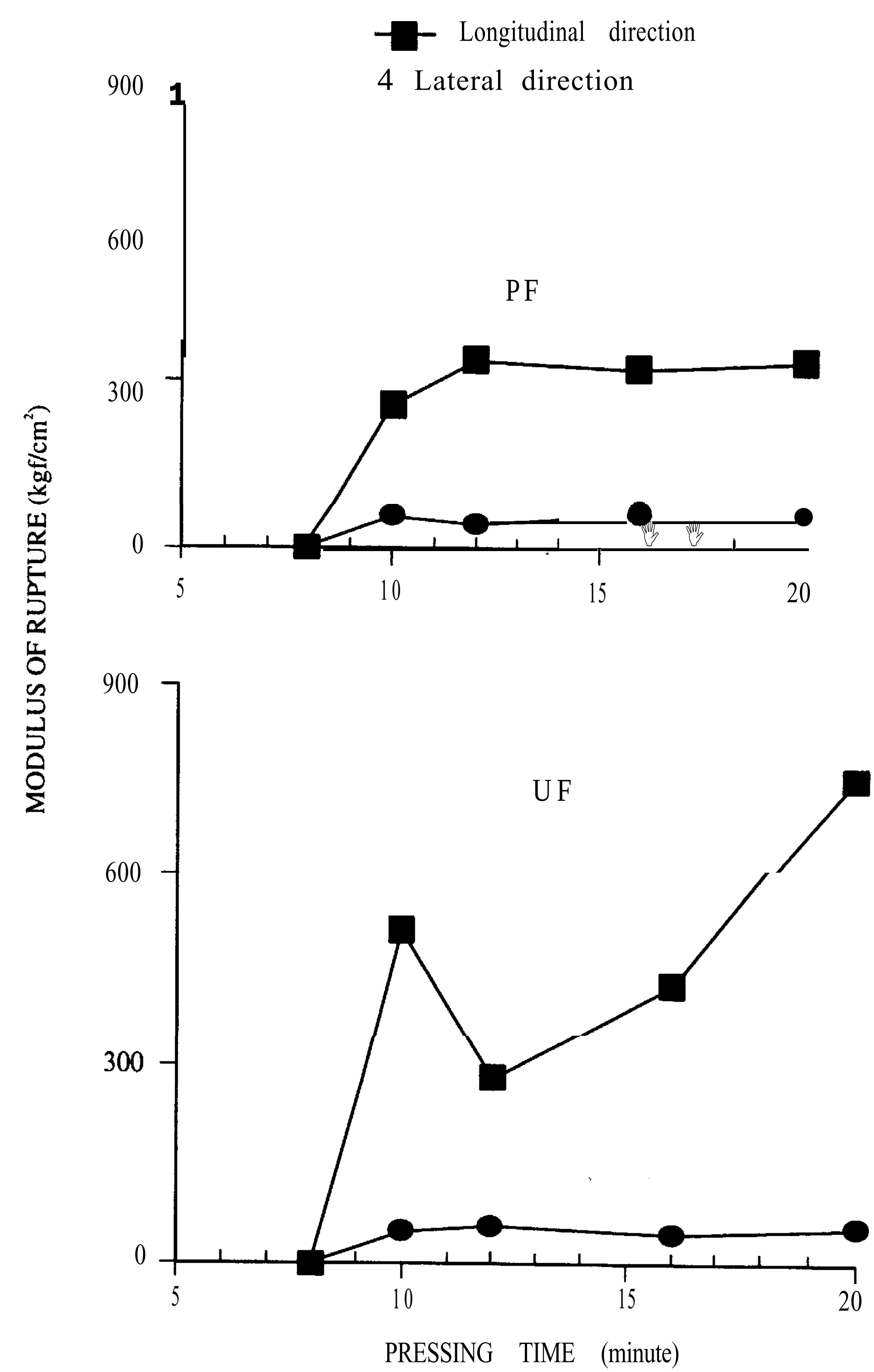

Fig. 1: Effect of pressing time on MOR of UF/PF-bonded zephyr board

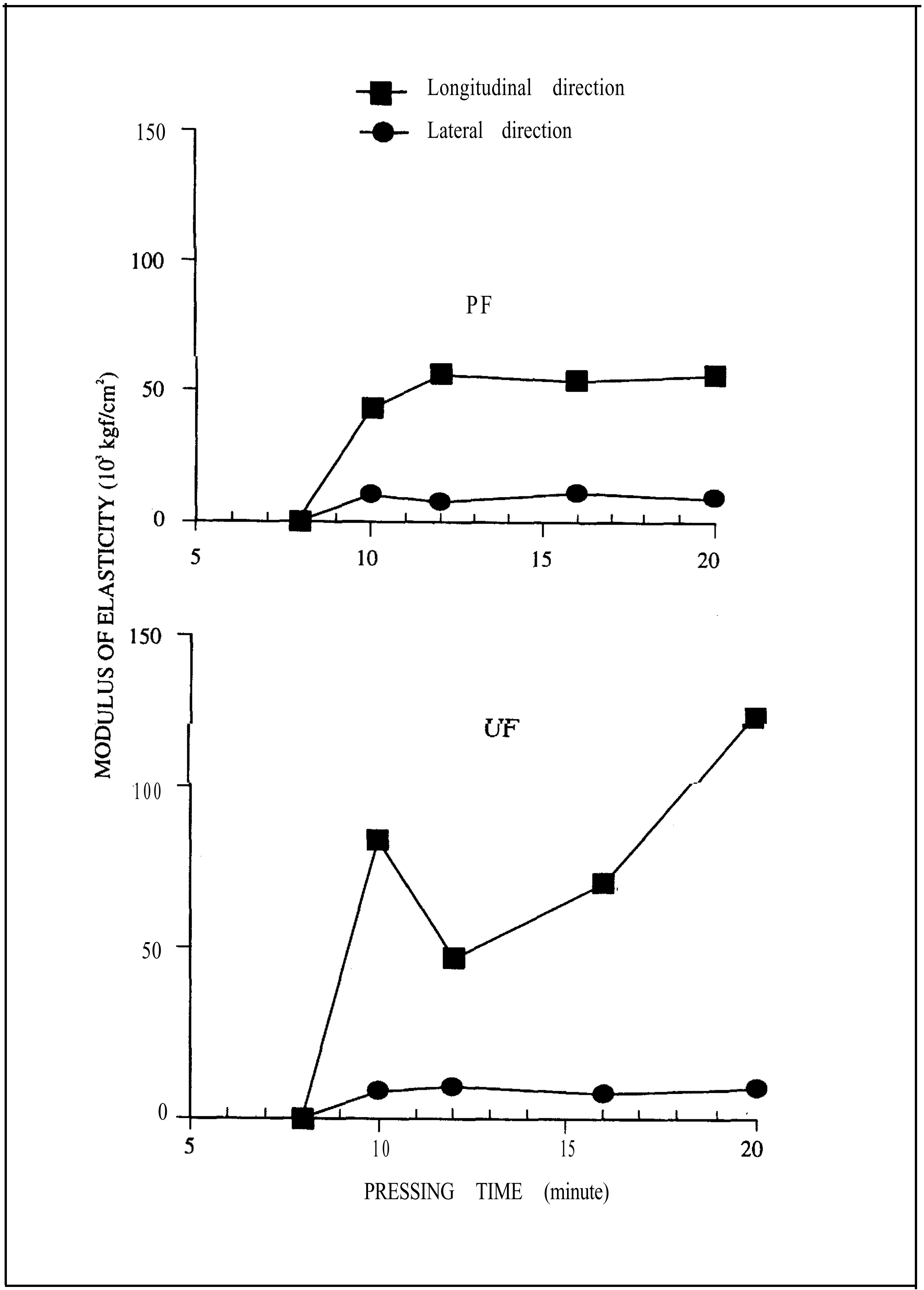

Fig. 2: Effect of pressing time on MOE of UF/PF-bonded zephyr board

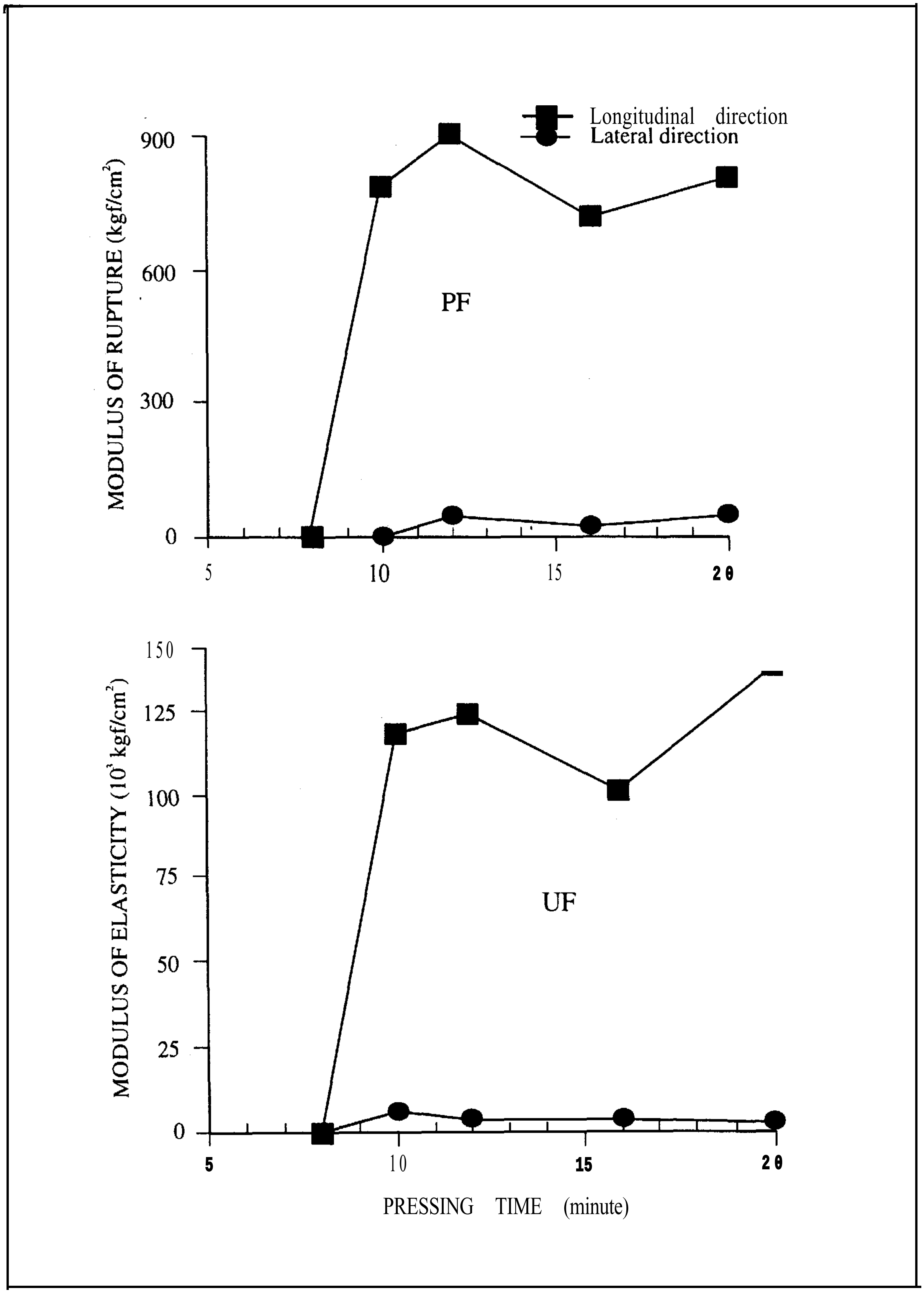

Fig. 3: Effect of pressing time on MOR and MOE of UF/PF-bonded zephyr board

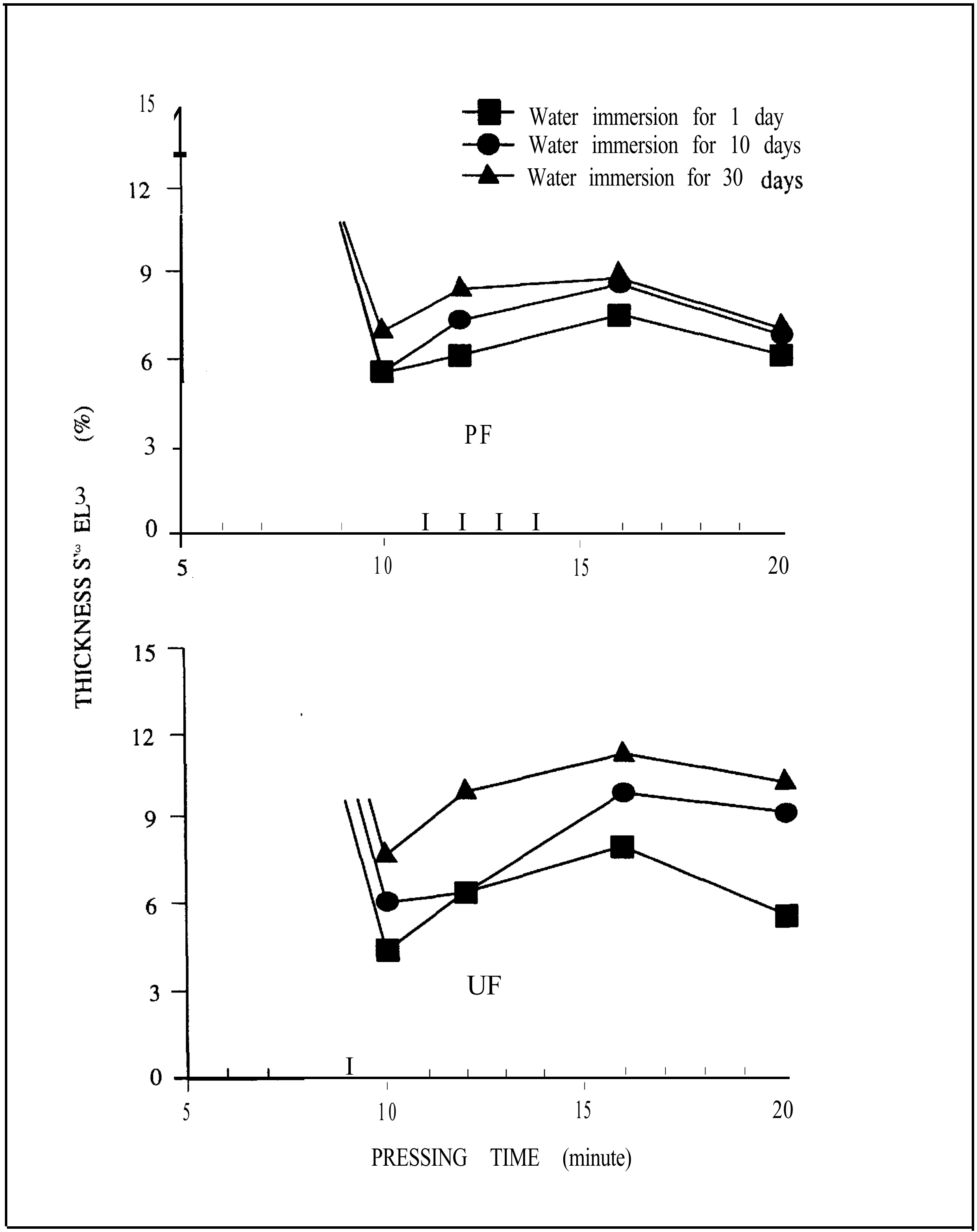

Fig. 4: Effect of pressing time on thickness swelling of UF/PF-bonded zephyr board

Figure 3 shows MOR and MOE of zephyr board of single layer and single-fibre orientation, bonded with UF/PF resin adhesives and subjected to different pressing times. The trends of MOR and MOE were similar to those of the three-layer zephyr board. However, the values of MOR and MOE in the lateral direction were observed to be lower than those of three-layer zephyr board. On the other hand, MOR and MOE in the longitudinal direction showed higher values. Shear failure was noticed during these measurements also. The experiment showed that type 250-90 overlaid board, conforming to JIS specifications, can be obtained with a pressing time of more than 10 minutes.

Figure 4 shows the thickness swelling (TS) of zephyr board bonded with UF/PF resin adhesives undervarying pressing times. UF-bonded board had a higher TS than PF-bonded board. This corresponded to the results for a wood-based panel obtained by Mallari et al. (1986), who reported that the hydrolytic degradation of UF resin adhesive, which involves the severance of cross-linking in the cured resin by water molecules, resulted in increased swelling of the boards.

Figure 5 shows internal bond (IB) strength of UF/PF-bonded zephyr board made using at different pressing times. The IB strength of boards is a measure of bonding integrity. For boards bonded with PF adhesive, the IB strength did not decrease when the pressing time was shortened to 10

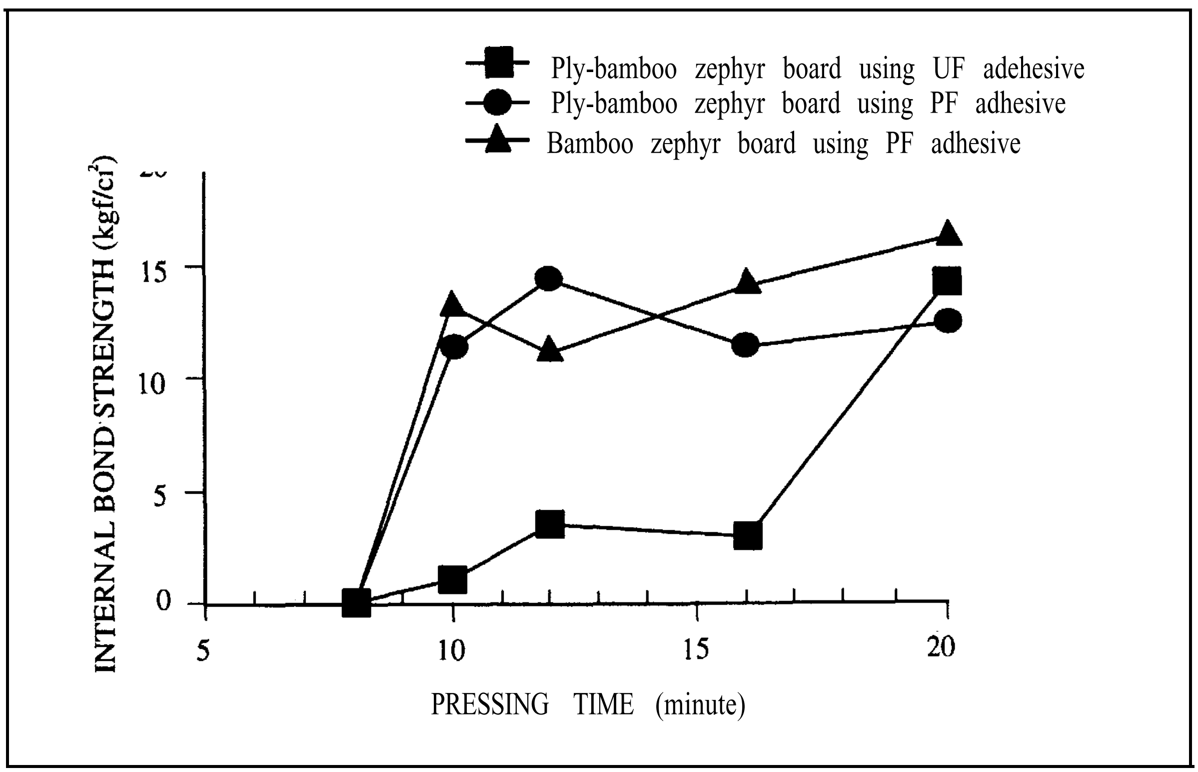

Fig. 5: Effect of pressing time on internal bond strength of UF/PF-bonded zephyr board

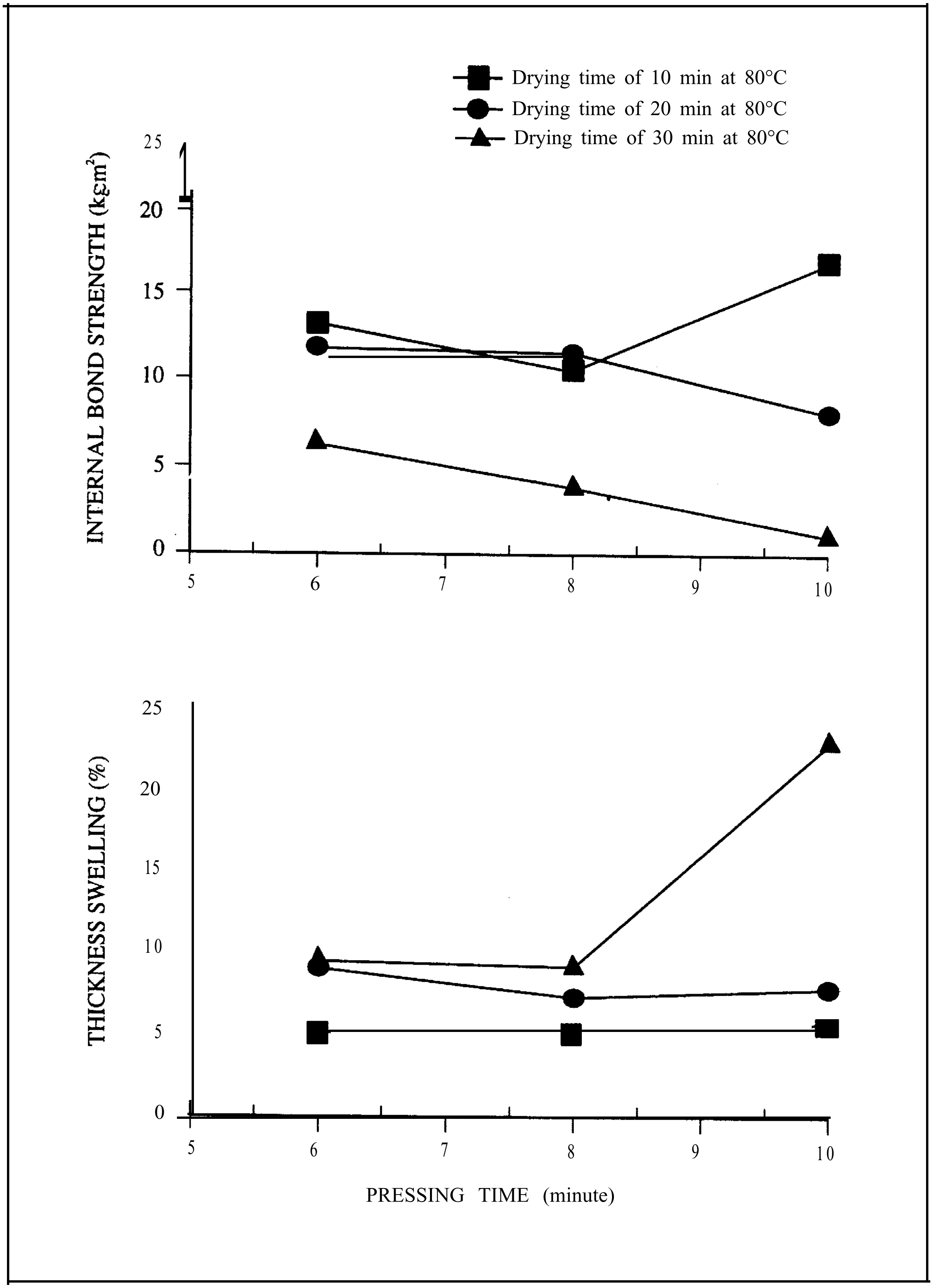

Fig. 6: Effect of pressing time (after pre-drying) on internal bond strength and thickness swelling of PF-bonded zephyr board minutes; but it began to decrease when the pressing time was reduced to 8 minutes. On the pther hand, boards bonded with UF adhesive showed the highest IB strength when pressed for 20 minutes and drastically decreased when pressing time was less than 16 minutes.

Another experiment was conducted to reduce the pressing time of 10 minutes obtained for PF-bonded boards conforming to JIS specifications. It involved the reduction of moisture content of fibre strands after dipping in PF resin adhesive. With a lower moisture content, a shorter pressing time was expected. The strand layer was pre-dried in oven at a temperature of 80°C for 10,20 and 30 minutes, and pressing times of 6,8 and 10 minutes were employed. The same pre-drying technique (20 minutes at 80-85°C) was used by Zoolagud and Rangaraju (1994) to make bamboo mat board.

Figure 6 shows the IB strength and TS of zephyr board using PF adhesives, and subjected to pre-drying treatment and various pressing times. Longer pre-drying treatment caused decrease in IB with increase in the pressing time. Type 200 overlaid board according to JIS specifications can be obtained using a pre-drying time of 10 minutes and a pressing time of 6 minutes. With regard to TS, a similar trend was observed. Pre-drying for 30 minutes at 80°C and pressing for 10 minutes did not yield boards conforming to JIS. However, pre-drying for 6,8 and 10 minutes did produce boards that met the specifications.

Conclusion

Results of the laboratory-scale experiments showed that UF-bonded zephyr board conforming to JIS can be made with a pressing cycle of under 20 minutes. In the case of PF-bonded board, a pressing time of 6 minutes could be achieved with a pre-drying treatment of 10 minutes at 80°C. However, further experimentation on the utilization of bamboo for single-layer and single-fibre orientation zephyr board is necessary,

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An Economical Bamboo Particle Board

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Abstract

Bamboo composites offer strategic advantages in promoting use of bamboo as an alternative to wood and other construction materials. This paper addresses some concerns of the development of bamboo composite products, and introduces an economical bamboo particle board that matches the mechanical performance of waferboard (a wood-based structural panel product common in North America) and medium density fibreboard (MDF) commonly used in furniture industries.

Introduction

Why bamboo?

There is an increasing demand for wood and wood products throughout the world (Anonymous 1991). Because of the decreasing supply of economical wood raw material (Anonymous 1993), attention has been given to bamboo in recent years although there are fundamental differences between bamboo and wood products.

There are many benefits of bamboo as recognized by numerous publications (see past INBAR workshop proceedings, etc.). For applications in construction, bamboo has a very high strength measured macroscopically (Montero 1991) and microscopically (Liese 1985), and a unique geometrical disposition that makes it favourable for applications as post and beam.

As a resource, bamboo yields are high per unit area (Liese 1985; Shi Quan-tai et al. 1987), and it can be easily propagated allowing for the reforestation of denuded areas and the development of plantations.

Composite materials

The greatest obstacle to increased use of bamboo is the difficulty in connecting members because of the unique shape of individual bamboo culm. Janssen (1981) and Arce (1993) have focused on this concern, in the interest of developing easily replicable joints that have quantifiable strengths for inclusion in building codes in bamboo regions. The overall aim in this process is to remove the uncertainty of material performance by engineering the joining process.

This concept can be applied to the material itself. Because of the presence of nodes, variances in wall thickness and cross-section, bamboo culms suffer from a large amount of variability which ultimately leads to overdesign in order to ensure safe construction. By breaking bamboo into the lowest common denominator – fibres or particles – a new product can be engineered and created.

The process of engineering products from particles is well-suited to bamboo because of the complexity of each culm's cross-section and the high fibre strength. Moreover, there are greater benefits that can be obtained. A composite material can be made into almost any shape. This allows for the creation of bamboo products that are strong, and meet internationally accepted standards, shapes and sizes.

In any manufacturing process, there are numerous factors that affect the product performance, and all have an impact on the final product cost. Therefore, research and development of products must consider the following:

- What product shape is desired (panel size and thickness, lumber length and cross-section)?
- What product performance is critical (MOE, MOR, water resistance, density, nail holding capability, etc.)?
- What are the costs of manufacturing (electricity, coal, resin, equipment, labour, etc.)?

Bamboo particle board

Working with the Costa Rican Building Research Centre (CIVCO) and Forintek Canada Corp., an economical bamboo particle board was developed. The product was intended as an alternative to plywood in several structural applications, such as packaging containers, furniture and sheathing.

Other bamboo products were considered, but particle board was selected as it does not involve a labour intensive process, an essential factor in the application of the technology in countries such as Costa Rica with its (relatively) high labour costs.

Given the high humidity in some Central American regions, a water resistant product was required. Phenol formaldehyde (PF) resin offers water resistance and good bonding with bamboo, but often leads to high-cost products because PF resin is expensive, and it requires long press times, thereby decreasing the production capacity of a given manufacturing installation. The research program endeavoured to develop a bamboo particle board that would address all of the concerns stated above.

Materials and Method

Guadua bamboo from Costa Rica was used in this study. Both the lower and upper sections were used. Core resin contents of 3%, 4% and 5% by mass were used on test panels, ranging in target density from 700 to 900 kg/m^3. Face resin contents were increased by 1% over core resin contents. All test panels were 610 x 510 mm, with a target thickness of 16 mm.

The bamboo was crushed using a hammermill. The particles were then sieved into coarse and fine material. The particles were blended with the PF resin and wax (1%) in a rotary blender. Mats were hand-formed in three layers, with the product mass being divided 40% : 60% between the faces (fine material) and the core (coarse material), respectively. All panels were pressed for three minutes, using steam injection at a press temperature of 215°C.

The panels were trimmed and cut for testing according to Canadian Standards Association (CSA) standard CAN/CSA 043.1 Test ***methods for strandboard and waferboard.*** Product density was measured. Although numerous tests can be performed on any product, three tests critical in determining product performance were identified and performed:

1. A three-point bending test to get data on the modulus of rupture (MOR) and modulus of elasticity (MOE);
2. Internal bond (IB) test; and
3. A 24-hour water soak test to determine thickness swelling (TS) and water absorption.

Results and Discussion

As shown in the following charts, the MOR (Figure 1) and MOE (Figure 2) increased with greater product density, and with increasing resin content. As these are two critical factors in cost analysis of composite manufacture, it is important to note that at a density of 750 kg/m^3 and a resin content ofapproximately 4%, the values set by waferboard standards were met: the MOE and MOR standards for waferboard were achieved (3 100 MPa and 17.2 MPa, respectively), the TS value of the bamboo composite

(Figure 3) was less than the 20% required, and the IB (Figure 4) was greater than 345 kPa.

In determining the manufacturing cost of the bamboo particle board introduced above, there were two concerns that needed to be addressed:

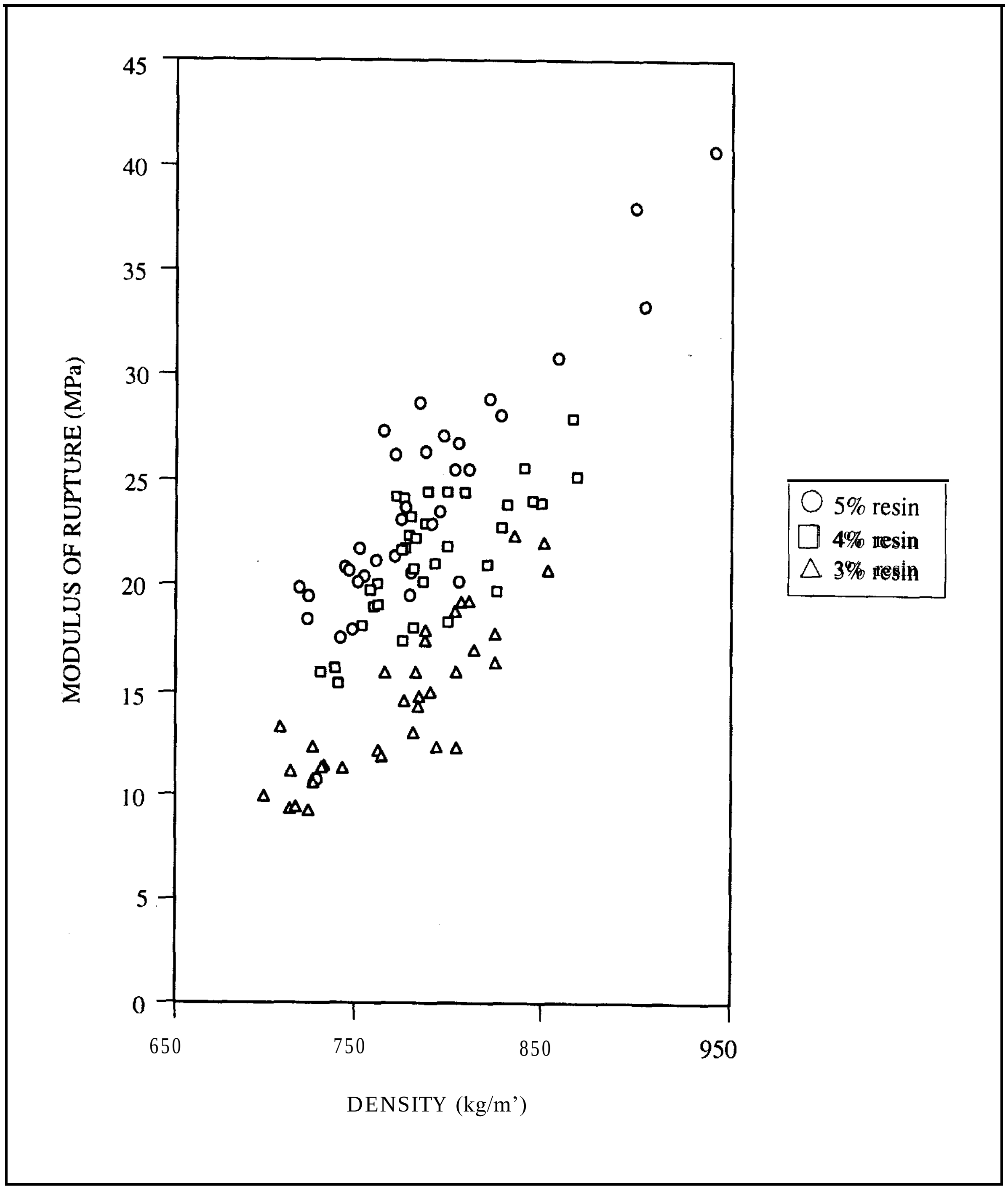

Fig. **1:** Relation between MOR and density

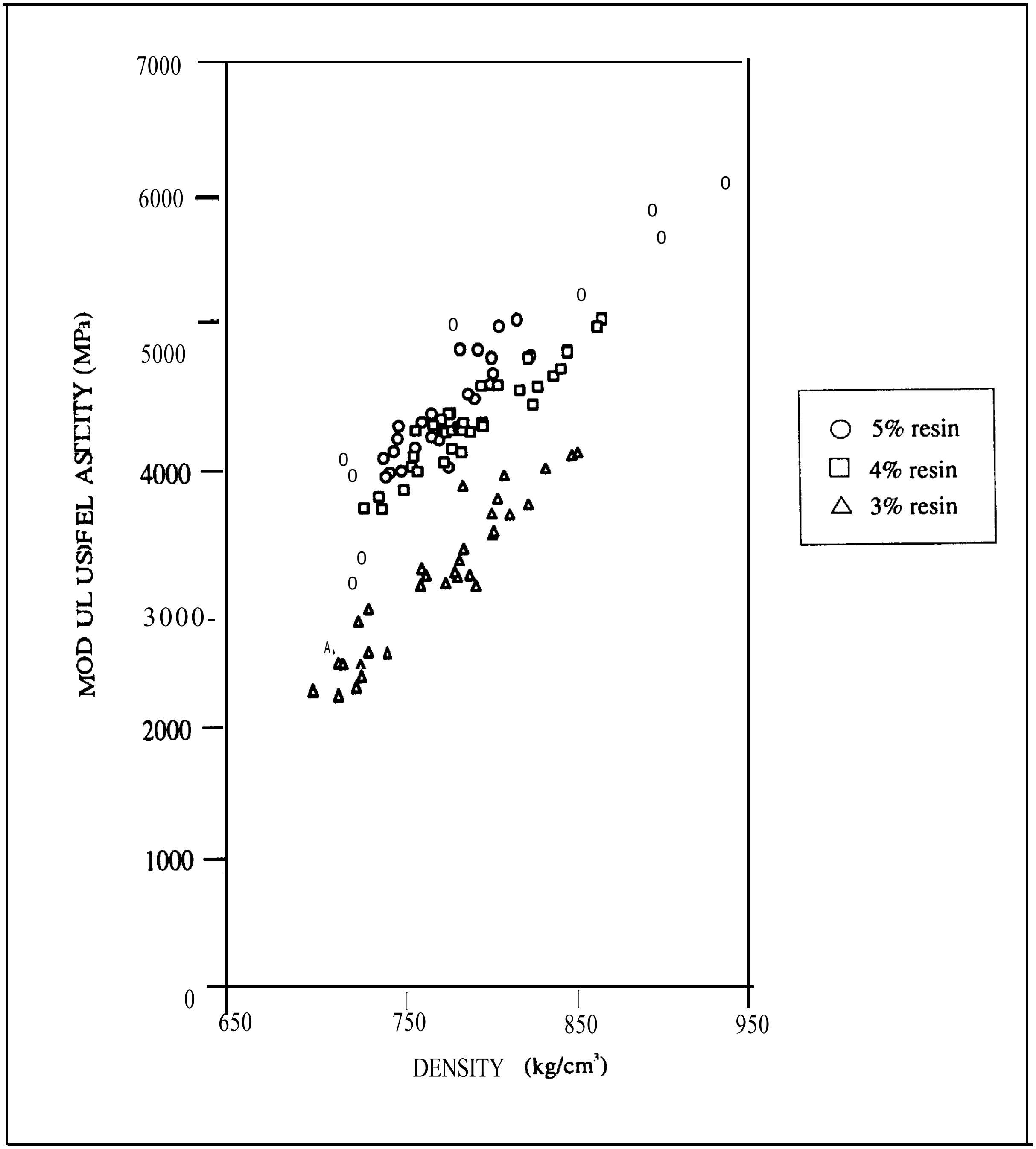

Fig. 2: Relation between MOE and density

variable costs (cost per unit) and fixed costs (including administrative overhead and equipment).

Because of the low press time of three minutes, the productivity was very high. It is common for roughly one-third of the capital invested on equipment in a composite factory to be spent on the hot press. Maximizing the effkiency (that is, decreasing the press time) is the best method for increasing the factory efficiency, and therefore the return on capital investment.

It is important to note that a press time of three minutes is very fast for PF-bonded particle board. Particle boards (of comparable thickness) bonded with PF developed in China require a press time of 10 minutes (Xu 1995).

The bamboo particle board used PF resin, which can be up to 100% more expensive than urea formaldehyde (UF), but is used in much smaller quantities. Chew et al. (1994) used 8% UF in the development of bamboo

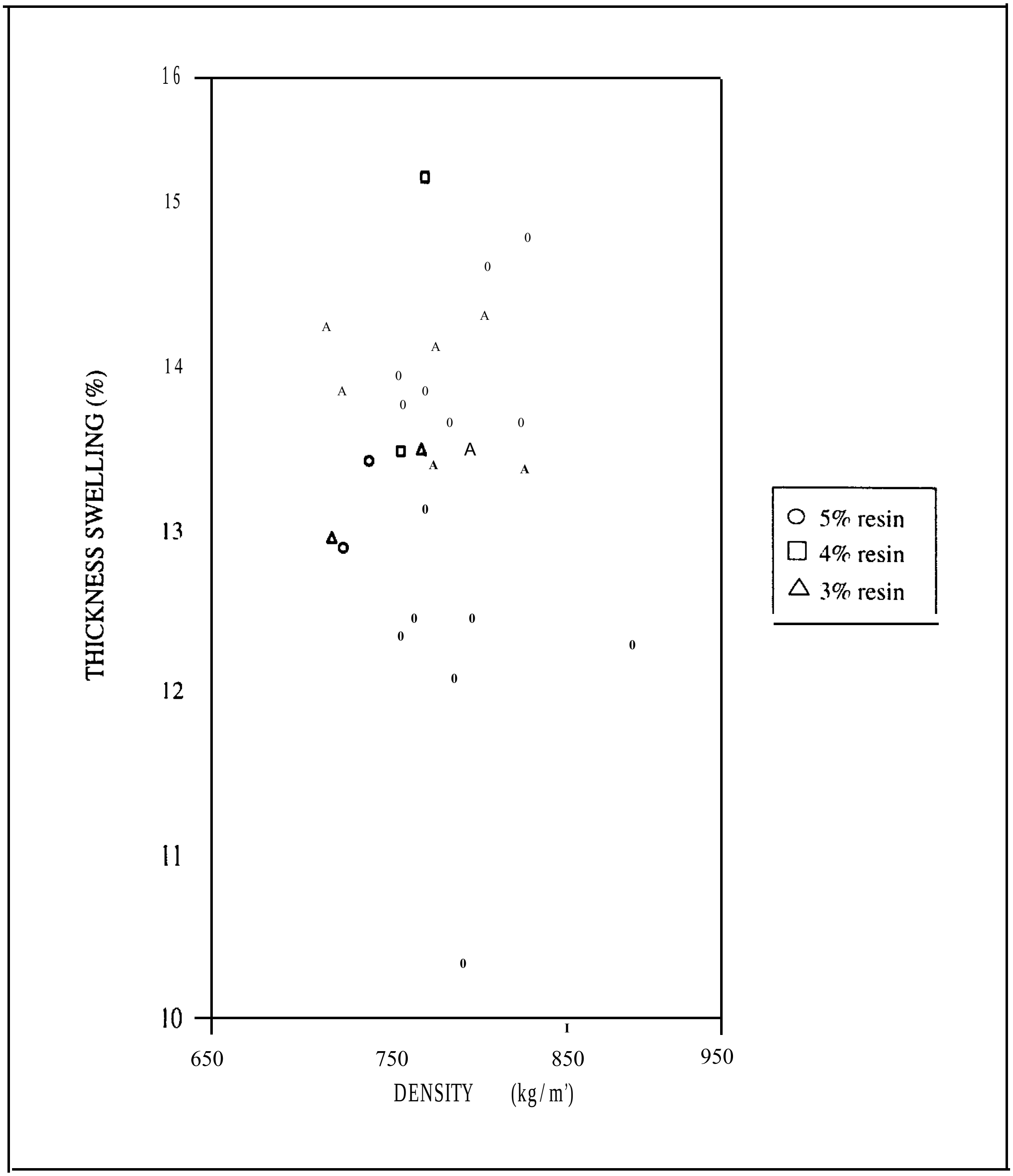

Fig. 3: Relation between thickness swelling and density

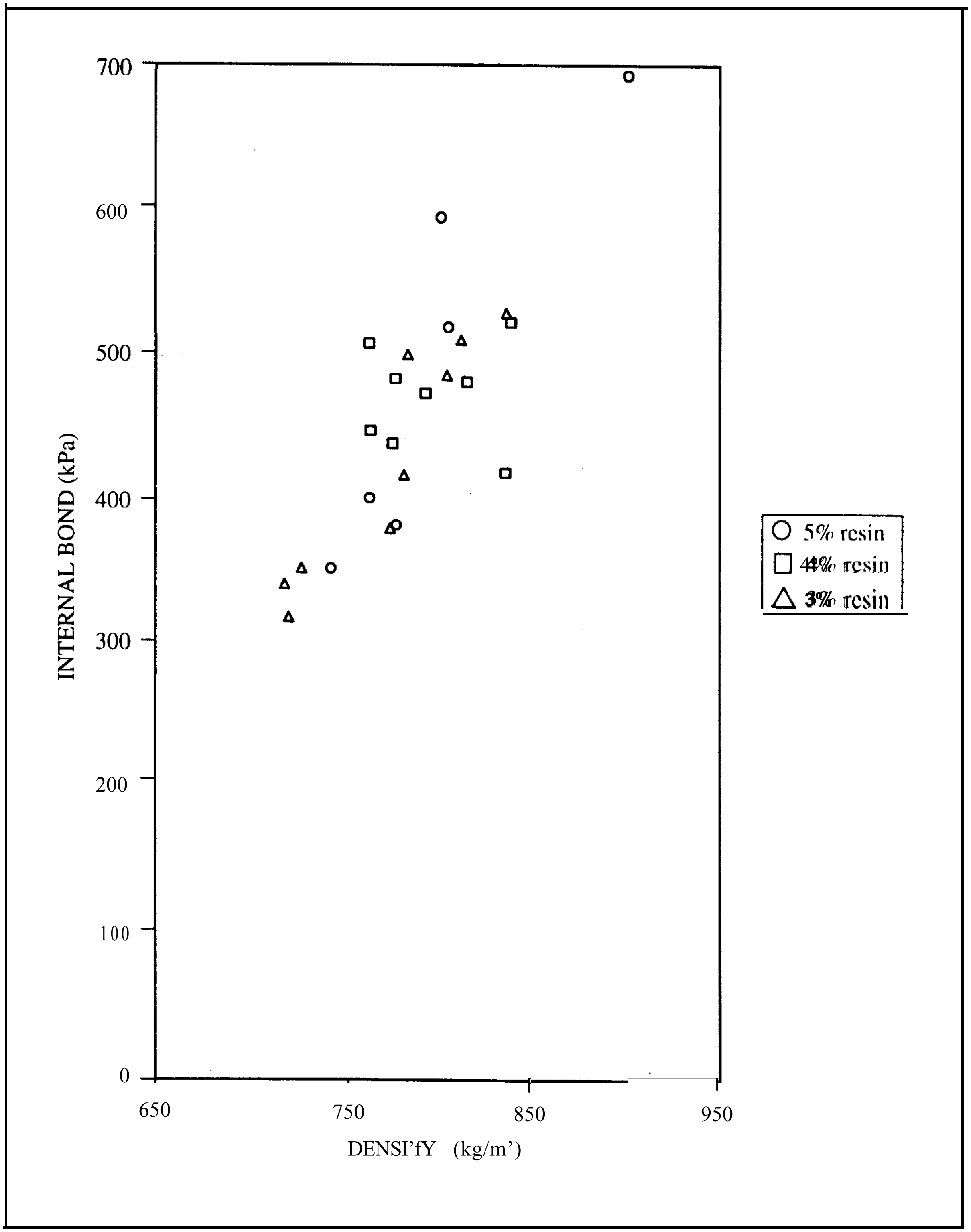

Fig. 1: Relation between internal bond and density

In summary, the bamboo particle board presented here is efficient in the use of resin, and efficient in the use of the hot press. 'Therefore, the cost of the raw material remains the greatest concern. As bamboo is not yet traded globally as a commodity, it is very difficult to determine a price for the raw material. Current manufacturing projects (India, China, etc.) often benefit from government subsidies, which artificially decrease the raw material cost to the manufacturer.

If bamboo is to be truly useful and widely available material, it will have to compete on a large scale with wood and wood products. At present, bamboo is often purchased on a price per culm basis, as it is used in small quantities. These prices cannot be extrapolated to determine the cost of large, bulk shipments of bamboo for industrial use.

Conclusion

Bamboo composites offer strategic advantages in the advancement of bamboo as an alternative to wood and other construction materials. Through this study, a bamboo product was developed to meet international structural panel (waferboard) standards which can be used for construction, packaging and furniture. Through prudent engineering design governing product density and resin content, and by utilizing innovative pressing technology that decreased press times, an economically viable manufacturing method was developed for bamboo particle board.

Future technical work will be focused at developing other bamboo composites to meet specific product demands, such as concrete form strength, weathering extremes and density considerations. In addition, the development of numerical methods to model bamboo composites would assist in understanding the complex micro and macroscopic mechanical properties of products, and help decrease expensive laboratory costs.

The study above and the future work outlined are applicable to panel products, but will also provide the basis for the development of lumber alternatives. The creation of standardized bamboo composite lumber will greatly assist bamboo in becoming a true alternative to wood.

Only when large volumes of bamboo are available at prices comparable to wood will bamboo become an important material for industrial production. There exists, therefore, a great need to determine the true costs of bamboo harvesting, and for the establishment of bamboo plantations on a large scale. The marriage of technical product development and raw material economics is critical in the development of bamboo as an industrial material, and it is recommended that future work continue with these two important consideration.

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Properties of Particle Board Made from *Bambusa vulgaris*

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Abstract

The properties of particle board produced from 1, 2, 3 and 4-year-old *Bambusa* vulgaris Schrad, the most common cultivated bamboo in Malaysia, were ascertained. Three particle boards with the density of 561,641 and 721 kg/m^3 were produced using urea-formaldehyde resin as binder with resin contents of 6, 8 and 10%, and a pressing time of 6 minutes at a temperature of 160°C All boards tested passed the minimum requirements of British Standards BS5906-1989, thus indicating the sustainability of this' lignocellulosic material for the manufacture of particle board.

Introduction

The development of particle board has largely been based on the use of softwood species. The advancement of technology, however, has enabled hardwood and agricultural residues, as well as other industrial by-products, to be utilized in the manufacture of particle board in Malaysia. Since rubber wood, at present extensively used for particle board, is also a highly sought after material for the development. of furniture industry, other lignocellulosic materials have to be found to overcome the probable insufficiency of this material in the near future. Bamboo seems to be the best alternative.

Of the 50 bamboo species found in peninsular Malaysia, 13 are widely utilized. *Bambusu vulgar-is* is the most common cultivated species, planted for its shoots or culms. Although ***B.*** *vulgar-is* is found in plenty, the properties of this species are yet to be researched in detail. This paper investigates the effect of age of B. *vulgaris* on the properties of particle board made from the species in order to optimize the potential applications.

Materials and Methods

Ten B. vulgaris culms each from the age groups of 1,2, 3 and 4 years were collected within the vicinity of Forest Research Institute Malaysia (FRIM) Forest Reserve in August 1993. All the culms were then longitudinally split before being fed into a Palmann drum chipper. The chips produced were then flaked in a Palmann knife-ring flaker set at 0.6 mm. Since the flakes were of the desired sizes, no further processing was carried out. The flakes were later screened to 0.5, 1,2 and 3 mm sizes before being oven-dried at 600°C to a moisture content of about 5%. Particle size analysis was also carried out simultaneously.

A measured quantity of flakes was mixed with urea-formaldehyde (UF) resin, hardener and water in a Drais mixer. The particles were then laid in a wooden mould and pre-pressed at 3.5 kg/m*. The consolidated mat was finally hot-pressed for about 6 minutes at 160°C in a Taihei hot press. This process was carried out for making single-layered particle board of 1 2 mm thickness of three densities (561, 641 and 721 kg/m^3) and resin content (RC) of 6,8 and 10%.

The methods used for determining the physical and strength properties of the boards, namely, thickness swelling (TS), water absorption (WA), modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB) and screw withdrawal (SW), were based on the British Standard BS 5669 (Anonymous 1989).

Results and Discussion

Physical and strength properties

The physical and mechanical properties of the boards are given in Table 1. Almost all the boards tested passed the minimum requirements of mechanical properties prescribed in BS 5669 (1989). Boards made from 4-year-old bamboo, with 10% resin and a density of 721 kg/m^3 were found to have the highest values for MOR (30.2 MPa), IB (1.03 MPa) and SW (1029 N). Boards produced from l-year-old bamboo, with a resin content of 8% and below, were found to be inferior in TS value. In general, bamboo particie boards produced from bamboo aged 2 years or more, with a resin content

Table 1: Physical and mechanical properties of particle boards made from *B. vulgaris*

Age (year)	Resin (%)	Density (kg/m3)	MOR (MPa)	MOE (MPa)	IB (MPa)	SW (N)	TS (%)
1	6	561	15.23	2 275	0.42	391	16.26
		641	19.26	2 739	0.46	601	19.50
		721	22.47	3 135	0.53	785	22.01
	8	561	15.67	2 435	0.48	488	11.78
		641	21.22	3 023	0.50	664	15.21
		721	27.26	3 507	0.58	798	16.18
	10	561	17.97	2 848	0.46	542	5.66
		641	24.64	3 521	0.74	746	6.49
		721	27.99	3 686	0.80	797	10.10
2	6	561	14.82	2 488	0.34	508	12.71
		641	18.84	2 914	0.37	698	15.16
		721	23.29	3 275	0.36	950	19.64
	8	561	14.67	2 421	0.43	529	9.01
		641	21.33	3 149	0.53	777	7.90
		721	24.97	3 454	0.55	943	10.06
	10	561	16.32	2 580	0.53	474	6.70
		641	21.00	3 084	0.64	738	7.19
		721	28.78	3 939	0.75	1095	8.06
3	6	561	9.31	1692	0.40	393	10.94
		641	15.64	2 484	0.42	491	10.79
		721	19.55	2 799	0.40	648	14.68
	8	561	14.94	2 469	0.56	476	5.00
		641	18.95	2 054	0.64	642	7.05
		721	22.26	3 152	0.57	778	9.65
	10	561	15.83	2 474	0.64	494	4.83
		641	20.91	3 191	0.82	665	7.01
		721	26.94	3 553	0.86	897	9.21
4	6	561	13.64	2 298	0.45	551	12.46
		641	18.57	2 815	0.51	589	14.54
		721	19.88	2 985	0.55	842	17.13
	8	561	15.36	2 478	0.36	439	7.00
		641	23.68	3 348	0.62	782	7.60
		721	25.89	3 414	0.50	875	7.46
	10	561	15.73	2 455	0.59	512	5.68
		641	25.45	3 450	0.81	729	6.25
		721	30.19	4 123	1.03	1029	8.68
BS5669-1989			13.80		0.34	360	12.00

Note: The values given are average of 8 readings.

Table 2: Summaries of the analyses of variance (ANOVA) on the board properties

Source of variation	df	MOR	MOE	IB	SW	TS
Age (A)	3	15.82**	14.84**	16.79'*	24.45**	101.31**
Resin (R)	2	74.72**	86.56**	23.26**	24.92**	540.92**
Density (D)	2	286.42**	264.50**	63.90**	329.54**	105.63**
AxR	6	2.17*	3.07*	8.53**	1.71ns	23.78**
AxD	6	1.34ns	1.20ns	3.20**	4.27**	2.38*
AxRxD 1	6	2.10**	2.70**	5.66**	2.80**	3.31**

Note: ** = highly significant at $P<0.01$; • = signifkarit at $P<0.05$; ns = not significant at $P<0.05$.

Table 3: Duncan's Multiple Range Test on the effects of age, resin content and density on particle boards

Age	Properties				
	MOR (MPa)	MOE (MPa)	IB (MPa)	SW (N)	TS (%)
1	21.30[a]	3 019[a]	0.55[b]	646[b]	13.69[a]
2	20.45[a]	3 034[a]	0.50[c]	746[a]	10.72[b]
3	18.26[b]	2 752[b]	0.59[b]	609[b]	8.79[b]
4	20.93[a]	3 041[a]	0.60[a]	705[a]	9.64[c]
Resin	MOR	MOE	IB	SW	TS
6	17.54[c]	2 658[c]	0.44[c]	621[c]	15.48[a]
8	20.52[b]	2 984[b]	0.53[b]	683[b]	9.49[b]
10	22.65a	3 242a	0.72[a]	726[a]	7.15[c]
Density	MOR	MOE	IB	SW	TS
561	14.96[c]	2 409[c]	0.47[b]	483[c]	9.00[c]
641	20.79[b]	3 056[b]	0.59[a]	677[b]	10.39[b]
721	24.96[a]	3 418[a]	0.62[a]	870[a]	12.74[a]

Note: a, b, c = If the same letter repeats down the column, the difference is insignificant at $P<0.01$.

of more than 8%, surpassed the minimum requirements of BS. It is thus expected that with the incorporation of wax, the dimensional stability of the bamboo particle boards will be further enhanced.

The summary of analysis of variance and Duncan's Multiple Range T tests on the effects of age, resin content and density on the particle board properties are shown in Tables 2 and 3, respectively. The results indicated that all properties were influenced significantly by age, resin content, density and their interactions (except for MOR and MOE in age and density interaction). The older the bamboo culm used, the superior were the properties (especially, MOR, MOE, IB and TS) of the particle board produced. The explanation for this is that with older bamboos, less particles are needed for the board (because of the higher density of particles in older culms), and this allows for more bonding sites to be occupied.

The increment of resin contents, on the other hand, increased the strength properties and decreased the thickness swelling of the particle board simultaneously. It was further indicated (Table 3) that with the increment of 2% resin content (that is, from 6% to 8%), the MOR, MOE, IB and SW increased by 2.98 MPa, 326 MPa, 0.09 MPa and 62 N, respectively, but decreased the thickness swelling properties by about 6%. Similar observations on the linear relationship of strength properties and resin contents were reported also by other researchers who worked on materials like wood (Talbot and Maloney 1957; Burrows 1961; Moslemi 1974; Kelly 1977; Siti Norralakmam and Razali 1992), bamboo (Chen et al. 1991) and oil palm bunches (Shaikh et al. 1993). An increment of 4% resin content, in addition, decreased the thickness swelling value by more than 50%, thus resulting in a more stable board.

Density plays an important role on the physical and mechanical properties of the boards produced. This is particularly true since higher densities are usually associated with higher strength properties. As for the particle board tested, all the MOR, IB and SW increased with the linear increase of density levels. This could be related to the higher compaction ratio of higher density. Shaikh et al. (1993), Chen et al. (1991) and Chew et al. (1992) in their respective studies on oil palm fruit bunches, bamboo and solid wood also found similar trends of linear relationship. TS, on the other hand, was also found to increase significantly with density. As stated by Chen et al. (1991) and Chew et al. (1992), more spaces (owing to higher density) between the bamboo particles made available thus turn into more porous condition.

Conclusion

B. vulgaris particles are suitable as raw material for the production of Particle board. The study indicated that with a resin content of 8%, acceptable board properties can be made to easily meet the British Standards specifications. Culms of two-year-old and older bamboos were observed to yield suitable particles for particle board manufacture. Detailed studies on the addition of wax and its effect on the dimensional stability (especially the thickness swelling) are suggested for further research.

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Physical Properties of Node and Internode of culm and Branch of *Dendrocalamus hamiltonii*

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Abstract

The physical properties – such as moisture content, specific gravity and volumetric shrinkage – of the node and internode of culm and branch of *Dendmcalamus hamiltonii* have been investigated at three height positions. All these physical properties are affected significantly by the height and nodal position. The internode of the culm has higher moisture content and volumetric shrinkage with lower specific gravity. The branch shows inverse pattern of variation to that of the culm. The specific gravity of the branch is found to be lower than that of the culm.

Introduction

Bamboo is well known for its fast growth and versatile uses. The short maturity period, straightness and comparatively high strength make it popular with the users. Further, it needs very little processing before use.

Bamboo is a monocot with definite node and internode. The structure and properties of internode have been investigated by many researchers (Grosser and Liese 1971; Liese 1980, 1987; Widjaja and Risyad 1987; Wen Taihui and Chou Wenwei 1987). But very little work has been carried out on the structure and properties of the node. Liese (1987), and Liese and Ding (1994) have studied anatomical and some physical properties of the node. The node of bamboo may play an important role in drying, preservation, and in the physical and mechanical properties of the culm. The present paper deals with some physical properties of the node and internode of bamboo culm and branch.

Materials and Methods

Three culms of Dmdrocalamus *hamiltonii* were collected from the bambusetumof the Bangladesh Forest Research Institute, Chittagong. The culms were three years old, and each culm was divided into three equal sections – bottom, middle and top. The specimens for physical properties were prepared in the form of 2.5 cm wide rings from consecutive node and internode of each portion of the culm. The moisture content, specific gravity and volumetric shrinkage of these materials were determined. The properties of the branch were also determined from each culm in the same way.

Results and Discussion

The physical properties such as moisture content, specific gravity and volumetric shrinkage of the node and internode of the culm and branch of *D. hamiltonii* are presented in Table 1. The bottom of the culm was found to have higher moisture content, while the branch showed the reverse trend along the height with higher moisture content at the top. Moisture content varied significantly with the node and internode (Table 2). The node of both culm and branch exhibited lower moisture content, which may be related to the reduced quantity of parenchyma in which water is stored (Abd. Latifand Mohd. Zin 1992; Liese 1992).

Table 1: Physical properties of the internode and node of culm and branch of ***D. hamiltonii***

Part tested	Height Position	Moisture content (%)		Specific gravity based on oven-dry weight and oven-dry volume: Green volume		Specific gravity based on oven-dry weight and oven-dry volume: Oven-dry volume		Volumetric shrinkage (%) - green to oven-dry	
		Inter node	Node	Inter node	Node	Inter node	Node	Inter node	Node
Culm	Bottom	101	78	0.52	0.63	0.64	0.78	33.6	14.9
	Middle	82	68	0.57	0.68	0.75	0.83	26.9	11.4
	TOP	77	61	0.61	0.73	0.80	0.86	25.9	4.7
	Average	87	69	0.57	0.68	0.75	0.82	28.8	10.3
Branch	Bottom	84	66	0.54	0.47	0.64	0.75	19.6	23.0
	Middle	90	87	0.50	0.44	0.53	0.54	15.2	18.9
	Top	106	99	0.42	0.41	0.52	0.54	10.1	12.7
	Average	93	84	0.49	0.44	0.52	0.50	15.0	18.2

Table 2: Summary analysis of variance of physical properties of the culm and branch of *D. hamiltonii*

Part tested	Source of variation	df	Moisture content	Specific gravity Green	Specific gravity Oven-dried	Volumetric shrinkage
Culm	Height	2	47.80**	150.90**	12.99*	95.42**
	Nodal position	1	115.78**	731.65**	26.74**	1621.51**
	Replication	2	70.90**	192.90**	2.06ns	3.55ns
Branch	Height	2	192.63**	800.33**	63.50*	28.84**
	Nodal position	1	15.86**	588.00**	10.50**	8.92**
	Replication	2	108/83**	405.33"	59.36ns	2.04ns

* = significant at 5% level of probability; ** = significant at 1% level of probability; ns = not significant

The culm height affected specific gravity significantly both in green and air-dried conditions (Table 2). Specific gravity increased as the height of the culm increased. The higher specific gravity at the top portion of the culm is attributed to the decreasing wall thickness, which results in the gradual decrease in the actual number and size of the vascular bundles towards the top (Grossner and Liese 1971; Liese 1980; Janssen 1981). Specific gravity decreased with increase in branch height. It was found that the specific gravity varies significantly with node and internode (Tables 1 and 2). The culm node showed a higher specific gravity than the internode. Although the node had higher specific gravity, the presence of node reduced strength of the bamboo culm (Liese 1992). The reduction of strength by the node is due to the shorter, thicker and forked fibres and the randomly oriented vascular bundles in the nodal part (Liese and Ding 1994). In contrast to the culm, the internode of the branch showed a higher specific gravity. The reason for this is not clear yet.

The volumetric shrinkage varied significantly with the node, internode and height of the culm and branch (Tables 1 and 2). The internode of the culm was found to have a higher volumetric shrinkage than the node. The higher shrinkage value of the internode may be due to the higher initial moisture content. However, the branch showed a reverse trend with a lower volumetric shrinkage at the internode. Similar to other bamboo species, *D. hamiltonii* exhibited lower volumetric shrinkage for both culm and branch (Kabir et al. 1991; Sattar et al. 1994).

Conclusion

Moisture content, specific gravity and volumetric shrinkage vary significantly with the height and nodal position of the culm and branch of *D. hamiltonii.* The node of the culm has higher specific gravity, and lower moisture content and volumetric shrinkage. The branch shows the reverse trend in variation to that of the culm.

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Variation in Specific Gravity and Bending Properties of *Dendrocalamus asper* Culm Grown in Bogor

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Abstract

Information on the properties of bamboo-such as physical, mechanical and chemical properties-should be fully understood to optimize bamboo utilization. For instance, the specific gravity and bending strength of bamboo are very important when bamboo is to be used as a building material. In this experiment, specific gravity and bending properties of *Dendrocalamus* asperaged three years and grown in Bogor were investigated. Samples for specific gravity measurement were taken from each internode along the culm from the base to the top. Specific gravity increased from the bottom to the middle of the culm (from 0.37 to 0.58), became constant at the middle of the culm (around 0.60), and increased to the top. of the culm (up to 0.77). Samples for determining bending strength were also cut from each internode from the base towards the top of the culm, and selected variables, such as the presence of node and orientation of surface layer (up and down), were included in the test. The results showed that bending strength – modulus of elasticity (MOE) and modulus of rupture (MOR) -increased from the base to the top of culm. Bending strength of samples with node were lower when compared with those without node. The samples with outer surface oriented upwards showed a higher MOR, but did not show a definite trend of MOE, when compared with those in which it was oriented downwards. Average of MOE and MOR values of specimens without node were 120.9 tonf/cm^2 and 1524 kgf/cm^2 and those of specimens with node were 42.3 tonf/cm^2 and 707 kgf/cm^2, respectively.

Introduction

Indonesia has a wealth of bamboo resources, with more than 120 species (Widjaja 1994). Among them, 12 species have been chosen by INBAR as priority species (Williams and Rao 1994). Dendrocalamus asper Becker ex Heyne (Betung) is one of the priority species. The culm of *D.* asperhas thick wall, good strength and durability, and therefore is used as a material for houses and bridges (Dransfield and Widjaja 1995).

Data on structure and properties of bamboo (physical, mechanical and chemical) are considered very important to optimize the utilization of bamboo (Liese 1992; Lee et al. 1994). For example, the upper part of the culm with long fibres can be used as pulp, while the n-riddle and bottom parts of the culm with thick walls and homogenous diameter can be used as building materials, and furniture and handicrafts. Some studies have shown that the physical and mechanical properties of bamboo mostly depend on the species, growth condition (soil, climate), harvesting season, felling age, height of culm, and presence or absence of node (Lee et al. 1994).

The purpose of this experiment was to obtain data on the specific gravity and bending strength of the entire culm (from the base to the top) of *D. asper* with selected variables such as node presence and loading orientation of the outer culm surface.

Materials and Methods

Materials

Species of bamboo used in this experiment was *D.* asperaged about three years. Culms were cut from the bamboo plantation at the Bogor Botanical Garden, Bogor, West Java. The bamboo culms were more than 18 m in length, with base diameter averaging 15 cm, top diameter averaging 5 cm, and internode lengths ranging from 20 to 50 cm. Samples were taken from each internode from the base to the top. Samples were cut immediately after the culms were felled so as to prevent loss of moisture and decay. Bending strength was measured from three culms, while specific gravity was determined from one culm.

Methods

Determination of specific gravity

Specific gravity was determined from split specimens of 5 x 5 cm x culm thickness, cut from the internodal and nodal parts from the base to the top of the culm. Specific gravity was calculated based on oven-dry weight and oven-dry volume. Oven dry volume was determined by water immersion, or displacement method where samples were coated with wax.

Determination of bending strength

The size of specimen was 36 cm long, 2.5 cm wide and culm thickness. Bending strength samples were cut from each internode from the base to the top of the culm. Selected variables such as presence of node and orientation of outer bark (up and down) were included in the test. Samples were tested usingJJ Instrument's Universal Testing Machine (UTM) in air-dry condition, From the bending test, the modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated.

Results and Discussion

Specific gravity

The result of specific gravity measurements along the culm of *D. asper,* presented in Figure 1, showed that the specific gravity increased from the base of culm to the top. This conforms to the results found in earlier investigations on several other bamboo species (Espiloy 1987; Abd. Latif and Mohd. Zin 1992; Sattar et al. 1992; Lee et al. 1994).

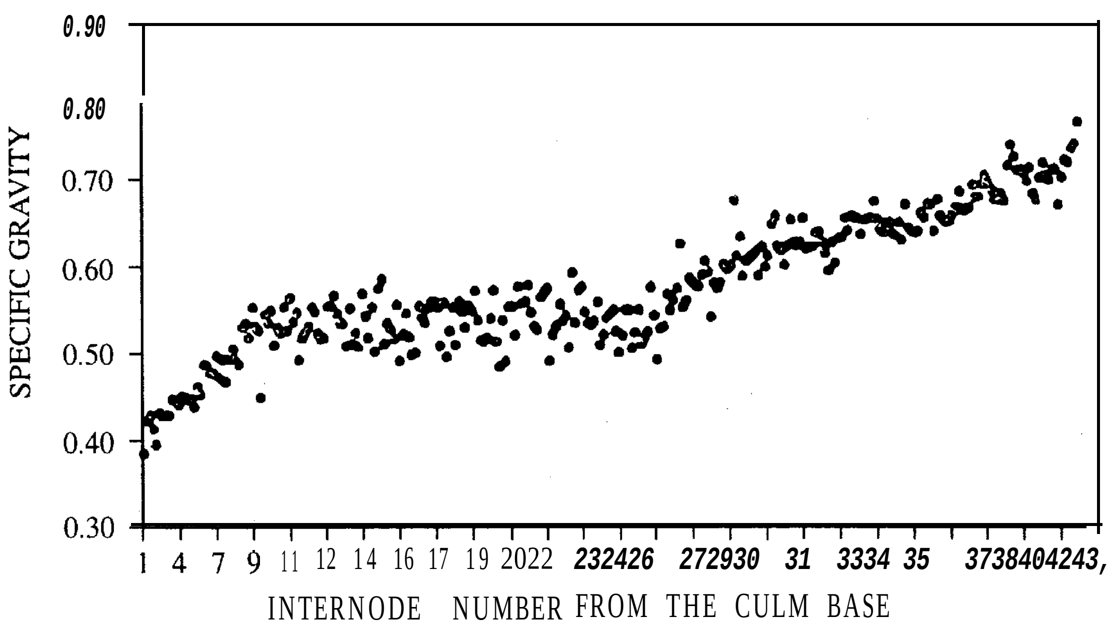

Fig. 1: Variation of specific gravity at different internodes of ***D.*** asper

The specific gravity along the culm increased from the base (0.37 at internode number 1) to the middle of the culm (1.58 at internode number 11). From internode number 11 to internode number 26, the specific gravity was almost constant with the value ranging between 0.58-0.60. Thereafter, it increased towards the top (0.77 at internode number 43). The increase of specific gravity from the base to the top of culm is partly owing to the increase in the proportion of vascular bundles and ground tissues, particularly the proportion of the thick-walled sclerenchyma cells (Higuchi 1989). Espiloy (1987) observed the same trend in *Bambusa blumeana* and *Gigantocbloa levis;* that is, the vascular bundles and specific gravity increased from the base to the top of culm. Dransfield and Widjaja (1995) mentioned that the average specific gravity of *Dendrocalamus asper is* about 0.7, which is comparable to the present result.

Bending properties

Results of bending properties measurement along the culm are presented in Figures 2 and 3. As can be seen from Figure 2, MOE and MOR values increased from the base of culm to the top for samples without node; but for samples with node, the MORvalues remained almost the same along the culm, The MOR values of samples without node were higher compared to those of the samples with node. In samples without node, it was obserued that the MOR values were higher when the surface layer was oriented upwards than when the orientation was downwards. However, in samples with node, no such trend was observed (Figure 2).

MOE values increased from the base of culm to the top in samples without node, but it remained constant or slightly decreased in these with node (Figure 3). Samples without node exhibited higher MOE values than those with node. Unlike in the case of MOR values, the effect of the orientation of surface layer was not clear on MOE values.

The specific gravity distribution along the culm indicated that the value increased from the base to internode number 11, levelled off up to internode number 26, and increased up to the top of culm (Figure 1). Based on these findings, an attempt was made to obtain average MOR and MOE values quantitatively for three positions: base, middle and top of the culm. Internode number 1 to 11 was grouped as base, internode number 12 to 26 grouped as middle and internode number 27 to 40 grouped as top. The average MOR and MOE values for each of the groups are presented in Tables **1** and 2.

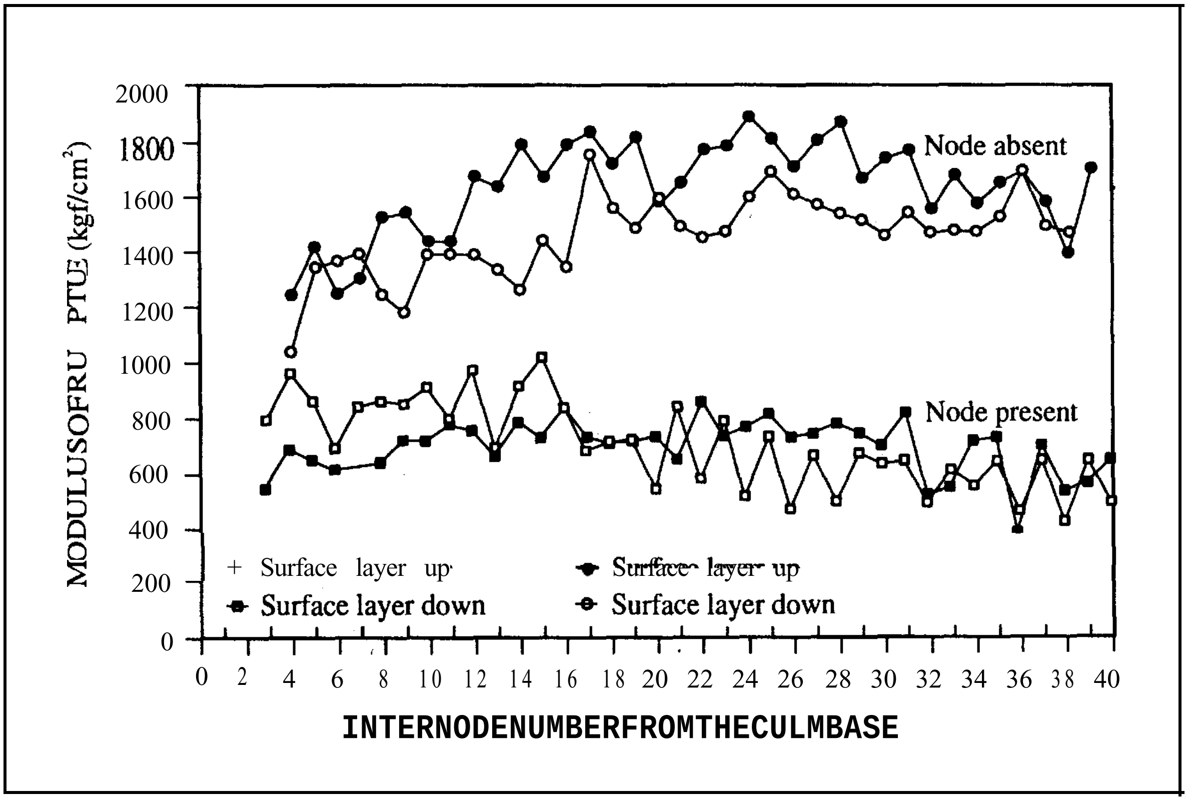

Fig. 2: Relation between MOR and internodes of D. asper

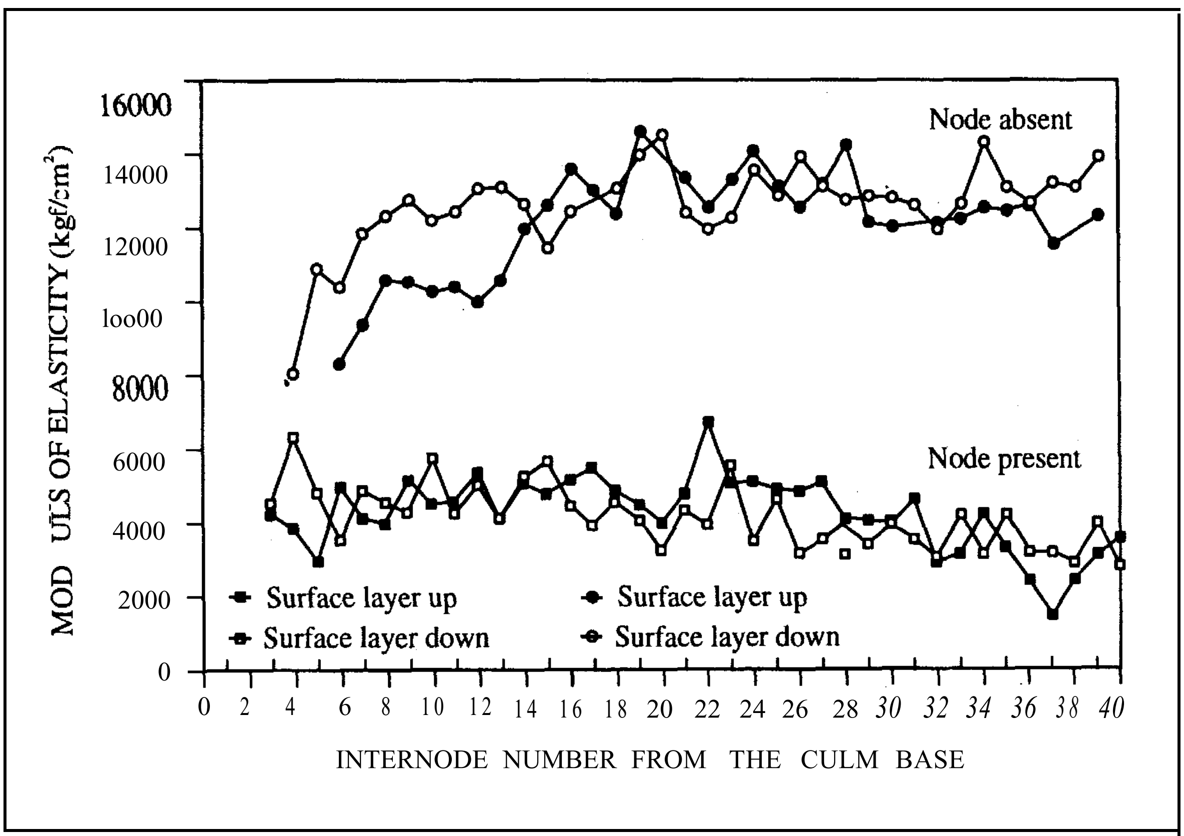

Fig. 3: Relation between MOE and internodes of *D. asper*

Table 1. Modulus of rupture (kgf/cm^2) of D. asper based on the position of the culm

Position	Node absent			Node present		
	Surface layer up	Surface layer down	Average	Surface layer up	Surface layer down	Average
Base	1387	1 284	1336	659	828	744
Middle	1742	1498	1620	747	737	742
Top	1702	1530	1616	670	597	634
	Average		1 524	Average		707

It can be seen from Table 1 that the MOR increased from the base to the middle and remained the same at the top of culm for samples without node, but registered a slight decrease for saniples with node. It can also be seen that the MOR values of samples without node (average 1 *524* kgf/ cm') were greater than with node (average 707 kgf/cm^2). Prawirohatmodjo (1990) recorded that the MOR values of D. asper grown in Yogyakarta were 1 091,962 and 1 109 kgf/cm^2 for bottom, middle and top, respectively, for samples without node, and 736,754 and 909 kgf/cm^2, respectively, for samples with node. The MOR values obtained in the present experiment are comparable to the result obtained by Widjaja and Risyad (1987) for *D. asper* grown in Bogor: 1638 kgf/cm^2 for MOR of specimen without node.

Table 2. Modulus of elasticity (tonf/cm2) of *D.* asper based on position of the culm

Position	Node absent			Node present		
	Surface layer up	Surface layer down	Average	Surface layer up	Surface layer down	Average
Base	99.1	113.6	106.4	42.5	47.6	45.1
Middle	127.1	129.6	128.4	49.9	43.7	46.8
Top	125.5	130.2	127.9	34.9	34.8	34.9
	Average		120.9	Average		42.3

Samples with surface layer oriented upwards exhibited higher MOR values than those oriented downwards (Table 1). This result is in line with the findings of *Lee* et al. *(1994)* who used *Phyllostachys bambusoides*.

For samples without node, the MOE value increased from the base to the middle of culm and remained the same up to the top of the culm. For samples with node, however, the MOE decreased at the top of the culm (Table 2). Similar to the MOR values, the MOE values of samples without node (average 120.9 tonf/cm^2) were higher when compared with those for samples with node (average 42.3 tonf/cm^2). Liese and Ding (1994) found that in the nodal part, the fibres are shorter, thicker and forked and so the mechanical elasticity is reduced. A slightly higher MOE value (132.3 tonf/cm^2 for samples without node) was observed by widjaja and Risyad (1987) for ***D.** asper* grown in Bogor. Unlike in the MOR, the orientation of outer bark showed no definite trend in the MOE values.

Conclusion

The study established that the specific gravity of three-year-old ***D.** asper* increases from the base to the top of the culm, with a plateau at the middle of the culm. Bending strength – modulus of elasticity (MOE) and modulus of rupture (MOR) -increases from the base to the top of culm. Presence of node lowers bending strength significantly. The orientation of the surface layer while testing has a bearing on the bending strength. Samples with the surface layer oriented upwards show higher MOR values than those with the surface layer oriented downwards, though no definite trend of the MOE is shown.

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Chemical Properties of Node and Internode along the Culm Height of *Dendrocalamusasper*

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Abstract

In the chemical or chemical-mechanical utilization of bamboo as raw material for pulping or production of bamboo composites, such as particle board or fibreboard, an understanding of the chemical properties of bamboo along the culm is essential.

In this study, the variations in chemical properties of node and internode along the culm height of *Dendrocalamus asper* were investigated. The chemical analyses of water content, pH value, total acidity, water extract, ethanol-cyclohexane extract, holocellulose, lignin and ash content were carried out.

Results showed that the variation in chemical properties is significantly influenced by node and internode, their position in the culm, and the portion of internode.

Introduction

Indonesia, with its warm climate and high rainfall, is an ideal place for the growth of bamboo and for the production of natural polymeric biomass. Because of the shorter harvesting cycle (3-5 years) as compared with wood, bamboo is an important alternative for the supply of lignocellulosic raw material. There are more than 120 bamboo species distributed over the Indonesian islands (Widjaja et al. 1994), and they play an important role in Indonesian economy, especially in the rural areas. As a raw material, bamboo is used for handicrafts, furniture, musical instrument, construction and several other purposes. Today, with the quantitative and qualitative decline of the wood supplies, the role of bamboo as a wood substitute has become more important.

The utilization of bamboo and other lignocellulosic materials for industrial purpose is related to their structure, and physical, mechanical and chemical properties. It is generally known that restrictions in the processing and utilization of a material are often related to its unsuitable properties (Liese 1992). Several studies have explored the chemical composition of lignocellulosic material, and its changes during storage or drying are attributed to several factors in the technological processing (Hemingway 1969; Roffael 1987; Prasetya et al. 1992).

Reviews on the importance of properties of bamboo that affect its utilization are given, for example, by Espiloy et al. (1992) and Liese (1992). Yet, while the chemical properties of wood are well documented in many publications, there is very little information on bamboo, particularly Indonesian bamboo. Sulthoni (1987) studied the starch content of the Indonesian bamboos *Dendrocalamus asper, Bambusa vulgar-is, Gigantochloa apus* and G. *atter.* The results indicated that the starch content depended on the felling time, and that the seasonal variation of starch content influenced the natural durability of bamboo.

An investigation on the carbohydrate content of Malaysian bamboos indicated that the starch and total sugar content of one to three-year-old bamboos *(B. blumeana* and *G. scortechinii)* were influenced by the age of the culm and the culm height. The sample used in this investigation was divided into three portions (bottom, middle and top) of 4 m each (Abd. Latif et al. 1991). The same tendency was shown by other chemical properties of *B. vulgaris,* studied by Jamaludin and Ashari (1994). The chemical properties such as cold water solubility, hot water solubility, 1% NaOH solubility, lignin, holocellulose, alpha-cellulose and ash content of bamboo depend on the position of the specimen in the culm (base, middle or top portion). The chemical properties of Indian bamboos and their pulping characteristics also depend on the age, position of culm, nodal or internodal portion and the species (Maheswari and Satpathy 1990).

An understanding of the natural chemical properties is necessary for promoting bamboo utilization. The main purpose of this study is to assess the variations of chemical properties between node, internode and internodal portions along the culm height of the Indonesian bamboo *Dendrocalamus asper* at 4-6 internode intervals.

Materials and Methods

Three bamboo culms of *D. asperwere* cut from the Botanical Garden at Bogor. Each bamboo culm was divided into nodal and internodal portions of 2-3 cm x culm diameter. The specimens selected were of 4-5 internode intervals (2nd, 6th, 12th, 17th, 22nd, 27th, 33rd, 37th and 41st nodes), starting from the base of each bamboo culm. Each internodal portion was further divided into bottom, middle and top portions. The specimens were converted into pulp using a ring flaker (Palmann) and dried at 50°C. After chipping and drying, samples were ground in a hammer mill (Palmann) and then screened. Material retained at 50 mesh sieve was used as samples for the following chemical analyses. All samples were subjected to the same procedure.

Water content

About 2-3 cm of fresh bamboo sample was weighed and dried in an oven at a temperature of 105% till it achieved constant weight. After drying, the sample was moved into a desiccator and weighed. The water content of the sample was determined as percentage of the weight loss after drying.

Cold water extract, pH value and total acidity (Roffael 1987)

Sample weighing 3 g (oven dry) was taken in a 250-ml Erlenmeyer flask together with 90 ml of aquadest and shaken at 50 rpm for 24 hours. After shaking, the sample was filtered and the extract was dried at 105°C to constant weight. Cold water extract percentage was determined from the amount of soluble substances before and after shaking. The filtrate was used for pH value measurement with an electronic pH meter. The residue was washed with aquadest and the filtrate was made up to 250 ml with aquadest. The filtrate (50 ml) was titrated with 0.01 N sodium hydroxide (NaOH) for measuring total acidity. The amount of NaOH needed for neutralization of the filtrate was the total acidity.

Ethanol-cyclohexane extract (Fengel and Przyklenk 1983)

Sample weighing 5 g extracted with 200 ml of ethanol-cyclohexane (v:v = 1;:l) by reflux for four hours. The extract was filtered with G3-filterglass, dried in a vacuum evaporator and placed in a vacuum desiccator. The dried material was then weighed and the percentage of weight loss measured.

Holocellulose content (Wiese 1946)

The sample (10 g) was extracted with ethanol-cyclohexane for 24 hours and then dried in a vacuum desiccator. The dried sample (5 g) was taken in an

Erlenmeyer flask and mixed with 150 ml of 1.5 g sodium chlorite and 1 ml of acetic acid. The solution was placed in a waterbath at 70°C and periodically shaken. After every hour, the same chemicals (1.5 g sodium chlorite and 1 ml acetic acid) were added. The reaction time was 7 hours, after which the solution was cooled at room temperature and filtered using G3-frlterglass. The residue was washed first with Aquadest and then with 50 ml acetone. It was then dried in a vacuum desiccator to constant weight and weighed. The holocellulose content was the percentage of the treated sample.

Lignin content (Klason lignin)

The sample (10 g) was extracted with ethanol-cyclohexane for 24 hours and then dried in vacuum desiccator. One gram of the extract was mixed with 50 ml of hydrochloric acid (HCl) in a 250-ml Erlenmeyer flask. Fifteen minutes later, 5 ml of sulphuric acid (H_2SO_4) was added. After one hour, the flask was shaken by hand for a few minutes. The reaction time was about 16 hours. After reaction, the, solution was placed in a 1-litre beaker with water and heated. The solution was then filtered, and the insoluble portion dried at 105°C to constant weight. The lignin content was obtained by subtracting the ash content from this weight.

Ash content

The sample weighing 3 g was placed in a ceramic crucible and heated in a furnace for about 3 hours at 700°C. It was then cooled in a desiccator and weighed. The ash content (%) calculated from the weight of the sample.

Results and Discussion

The water content of bamboo samples is shown in Figure 1. The water content showed wide-ranging variation (15-50%) as a function of nodal position. Generally, the water content decreases from the bottom to the top of the culm. The decrease of water content was 37.2 to 15% (node), 48 to 14% (top portion of internode), 38.2 to 13% (middle portion of internode) and 40.4 to 12.6% (bottom portion of internode), The water content between node and internode differed, with the node having a higher water content than the internode, except for the second node.

The water extract of bamboo contains soluble carbohydrates such as monosaccharide, disaccharide, starch and soluble hemicellulose (Browning 1978). Table 1 shows data pertaining to the cold water extract content

Table 1: Content of water extracts and ethanol-cyclohexane extracts of node and internode at different internodes numbered from culm base

	Water content (%)				Ethanol-cvclohexane content (%)			
	Node	Internode			Node	Internode		
		Bottom	Middle	Top		Bottom	Middle	Top
2nd	4.5	3.8	4.6	7.2	2.55	1.72	1.42	1.58
6th	6.6	5.7	5.0	7.0				
12th	8.8	6.4	6.2	4.5				
17th	8.4	6.5	4.4	6.0				
22nd	8.6	6.9	5.8	5.2	2:51	2.21	1.80	0.63
27th	7.6	6.7	5.0	5.6				
33rd	7.8	7.1	6.2	6.2				
37th	7.3	6.5	5.5	4.4				
41st	6.8	4.8	4.0	4.5	0.29	1.07	1.13	0.13

of bamboo. It was observed that the water extracts content varied between 3.8% and 8.8%. Generally, the nodal portion had a higher extract content than the internodal portion. The bottom portion of the culm, especially the nodal portion (2nd - 6th node), had lower values. The water extract content of the top portion of internode decreased continually with increase in culm height, while the bottom and middle portions of internodes from the middle part of the culm had higher values than those from the top and bottom parts of the culm.

Extracts of bamboo that are soluble in ethanol-cyclohexane are mainly fatty components (Fengel and Przyklenk 1983). As shown in Table 1, the ethanol-cyclohexane extract contents determined from the bottom (2nd), middle (22nd) and top (41st) of the culm were 0.13-2.55%. The extract content of the node and the top portion of internode decreased from the bottom part of the culm to the top part, while those of the middle and bottom portions of the internode portion of the culm (22nd) had higher values.

The acidity of lignocellulosic material plays an important role in properties such as adhesive bonding in the manufacture of composite materials (Roffael 1987). The pH value and total acidity are mainly used to describe the acidity of this material. The pH value of the cold water extract contents are given in Figure 2. The results indicated that the pH value fluctuated widely from 3.6 to 6.3. From the bottom to the top part of the culm (37th), the pH values of internodal portions decreased, while the pH values of nodal portions were relatively constant. The pH values of the bottom part

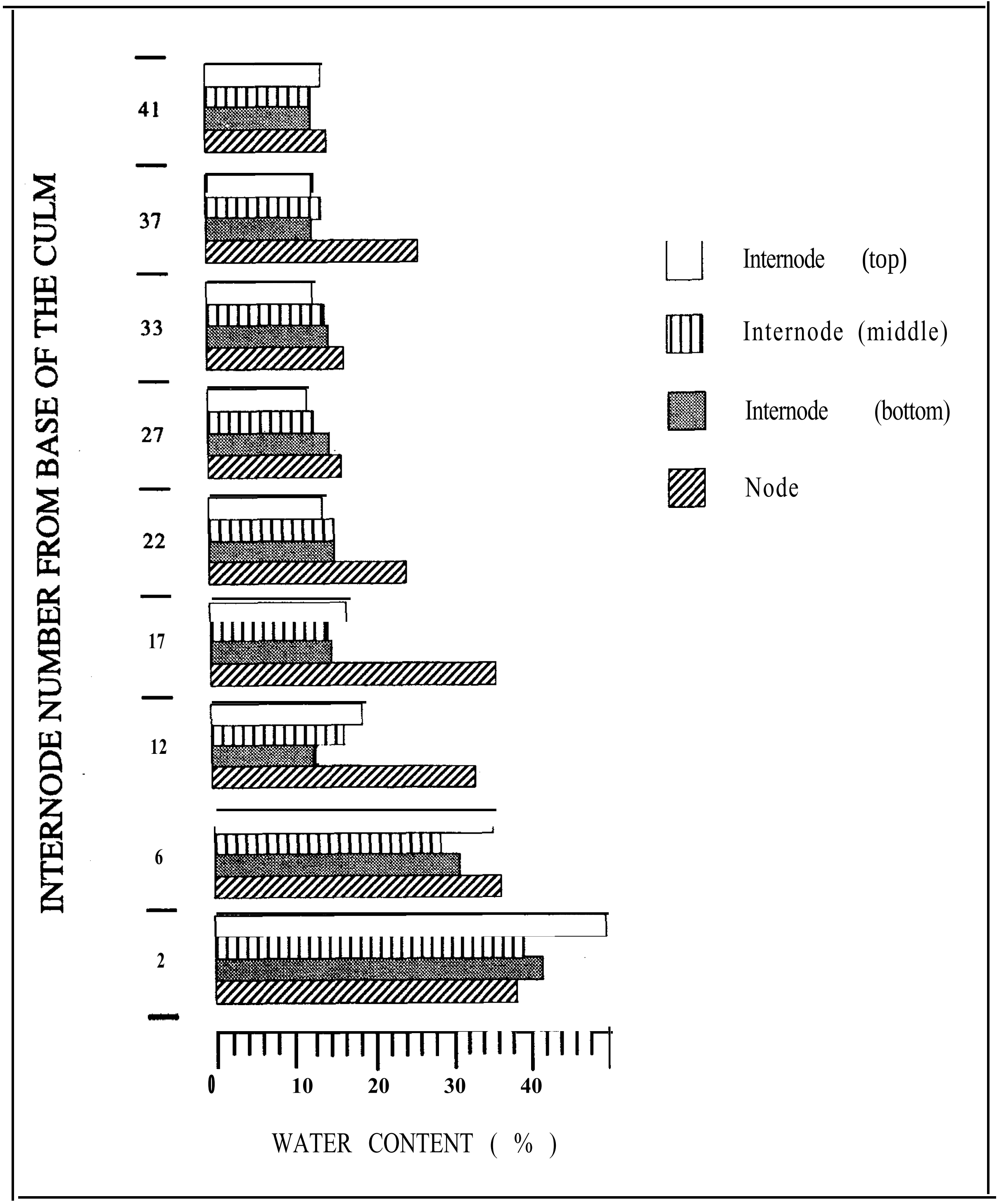

Fig. 1: Water content of node and internode at different internode positions numbered from the base of the culm

of the culm, especially the 2nd node of the culm, were much higher than those of other parts. Furthermore, the results showed that the nodal portions were more acidic (pH 3.5-4.2) than the internodal portions.

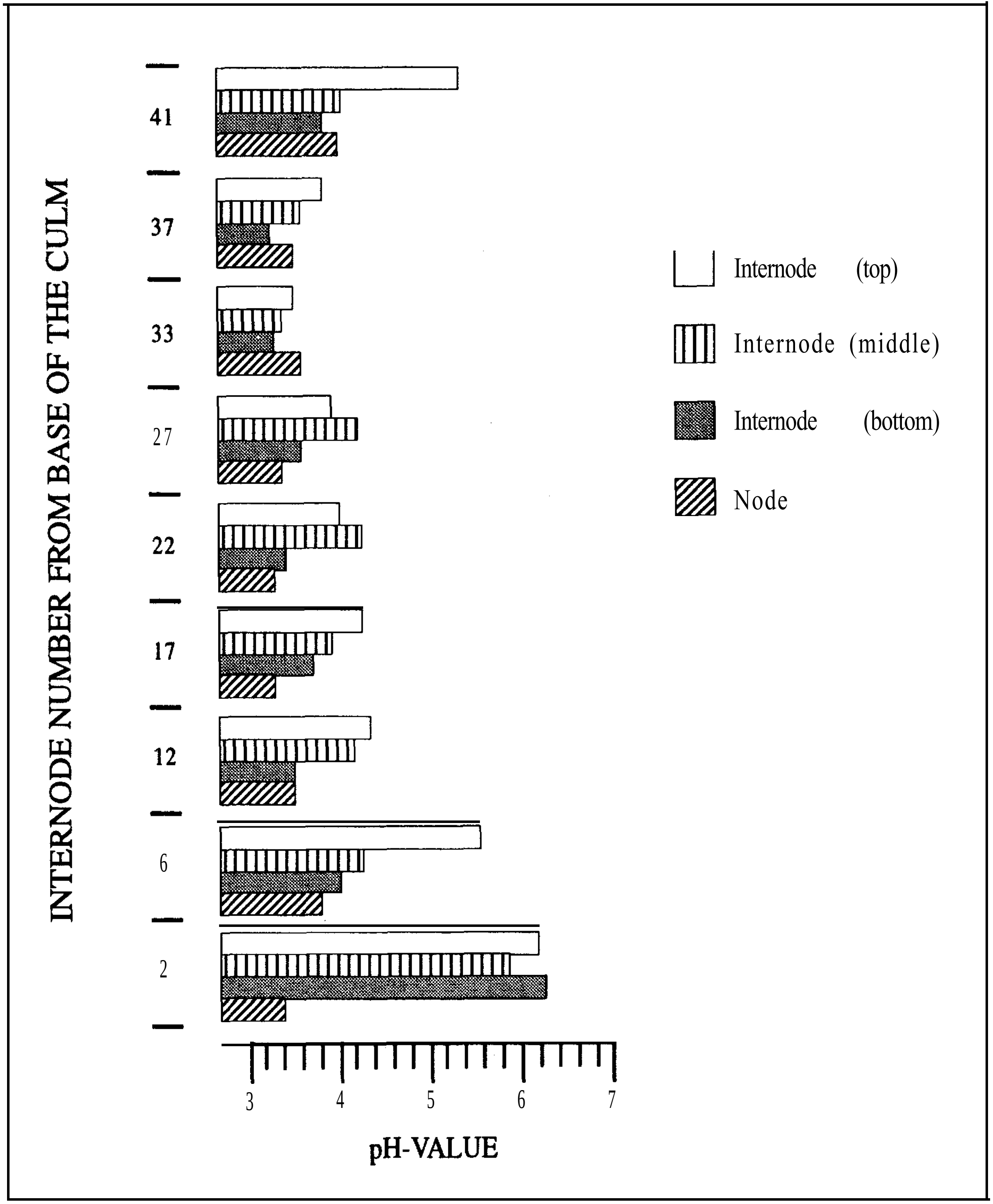

Fig. 2: pH value of water extracts of node and internode at different internodes numbered from the base of the culm

The total acidity of a solution gives more information on how much alkali is needed to neutralize it, and cannot be represented using pH-value. Data on total acidity are useful in pulping process, especially in

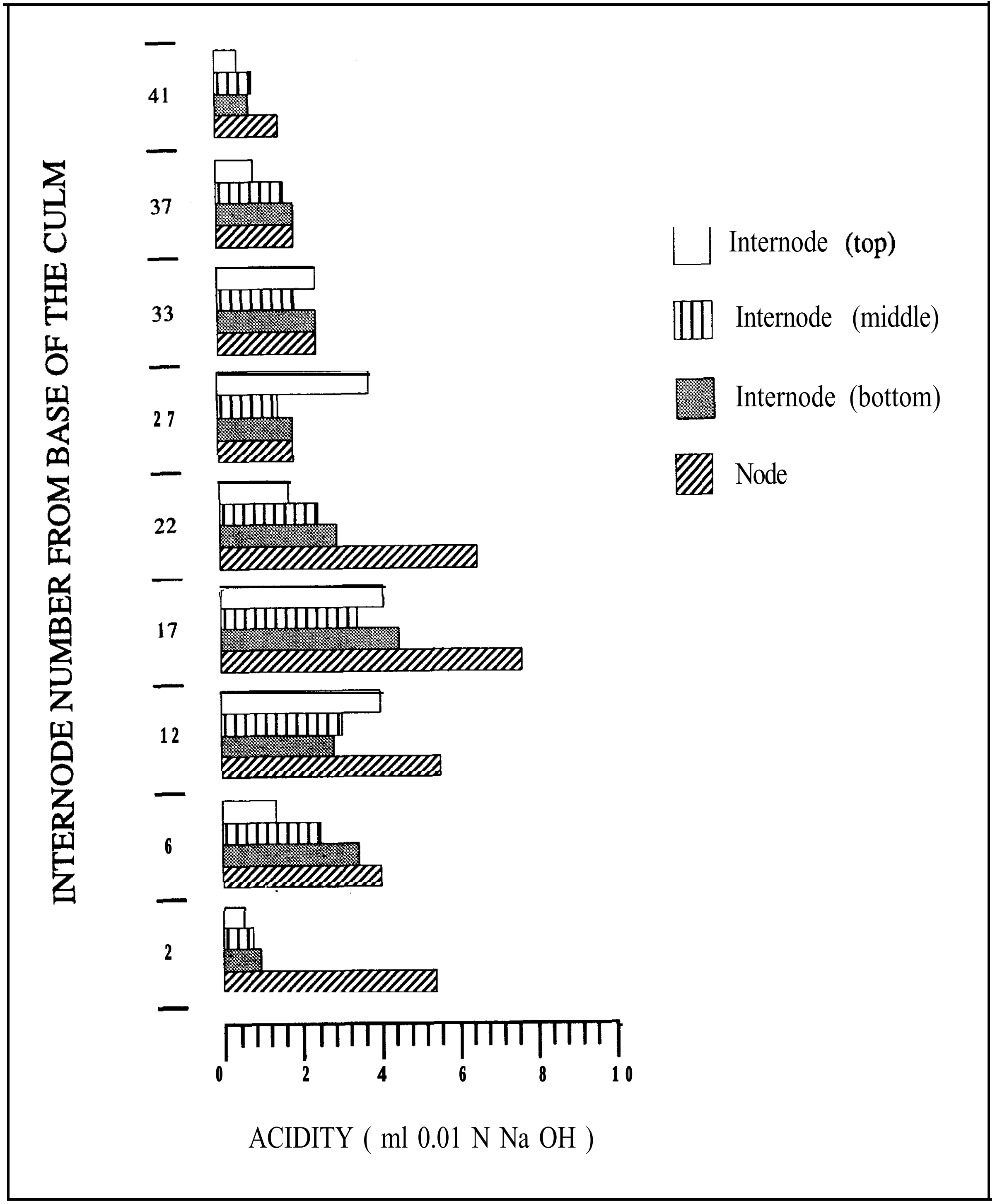

Fig. 3: Acidity of water extracts of node and internode at different internodes numbered from the base of the culm

alkaline process, because they indicate how much of the chemical used for deiignification was needed for neutralization (Prasetya 1992). The total acidity values of water extracts measured by titration with alkali solution

(0.01 N NaOH) were 0.6-7.6 ml (Figure 3). The nodal portion had a higher total acidity than the internodal portion, especially up to the 22nd node. In the internodal portions, the bottom part had a high value of total acidity. Generally, the upper part of the culm (27th - 42nd node) had a lower total acidity value.

Holocellulose and lignin can be used for the determination of the cell wall components of bamboo. The holocellulose content of bamboo is shown in Figure 4. The results indicated that holocellulose content varied from 61.9 to 75.2%. The lower part of the culm, up to the 6th node, showed a higher value than the higher part of the culm. There were differences between the nodal and internodal portions; the nodal portions always had much lower holocellulose content (61 .8-69.4%) than the internodal portions (68.8-75.2%).

The lignin content fluctuated from 18.5 to 29% (Figure 5). In contrast to the holocellulose content, the lignin content of the nodal portions showed higher value than that of the internodal portions. In the case of internodal portions, the lignin content of bamboo increased from the bottom part to the top part of the culm, while the lignin content in the nodal portions showed very little difference. Furthermore, the lignin content of the top and middle portions of internodes at the base of the culm (2nd) had very low values (18.8 and 18.5%). Maximum lignin content (29%) was found in the nodal portion of the middle part of the culm (17th).

Figure 6 shows the results of ash content analysis, indicating that the culm height influences the ash content, especially at nodes. The ash content in the nodes increased markedly from the bottom to the top of the culm (I .7 to 5.6%), while the variation in internodes was 1.4 to 2.4%. This difference may be related to the thickness of the surface layer of the culm which is greater at the top of the culm than at the bottom.

In general, the results of the chemical analyses indicated that the variations in chemical properties depend not only on the nodal or internodal portions, but also on culm height. Furthermore, the chemical properties of an internodal portion varied depending on its position within the internode (top, middle or bottom portion). Based on the results, it may be said that the variation in the chemical properties related to the culm height could be more wide-ranging than the variation related to the species of bamboo. For example, the variation of chemical properties in the species *D. latiflorus, Pbyllostachys* makino, *P. edulis, P. pubescence* and *Sasa kurilensis* were 70.54-74.34% for holocellulose, 19.4-26.08% for lignin and

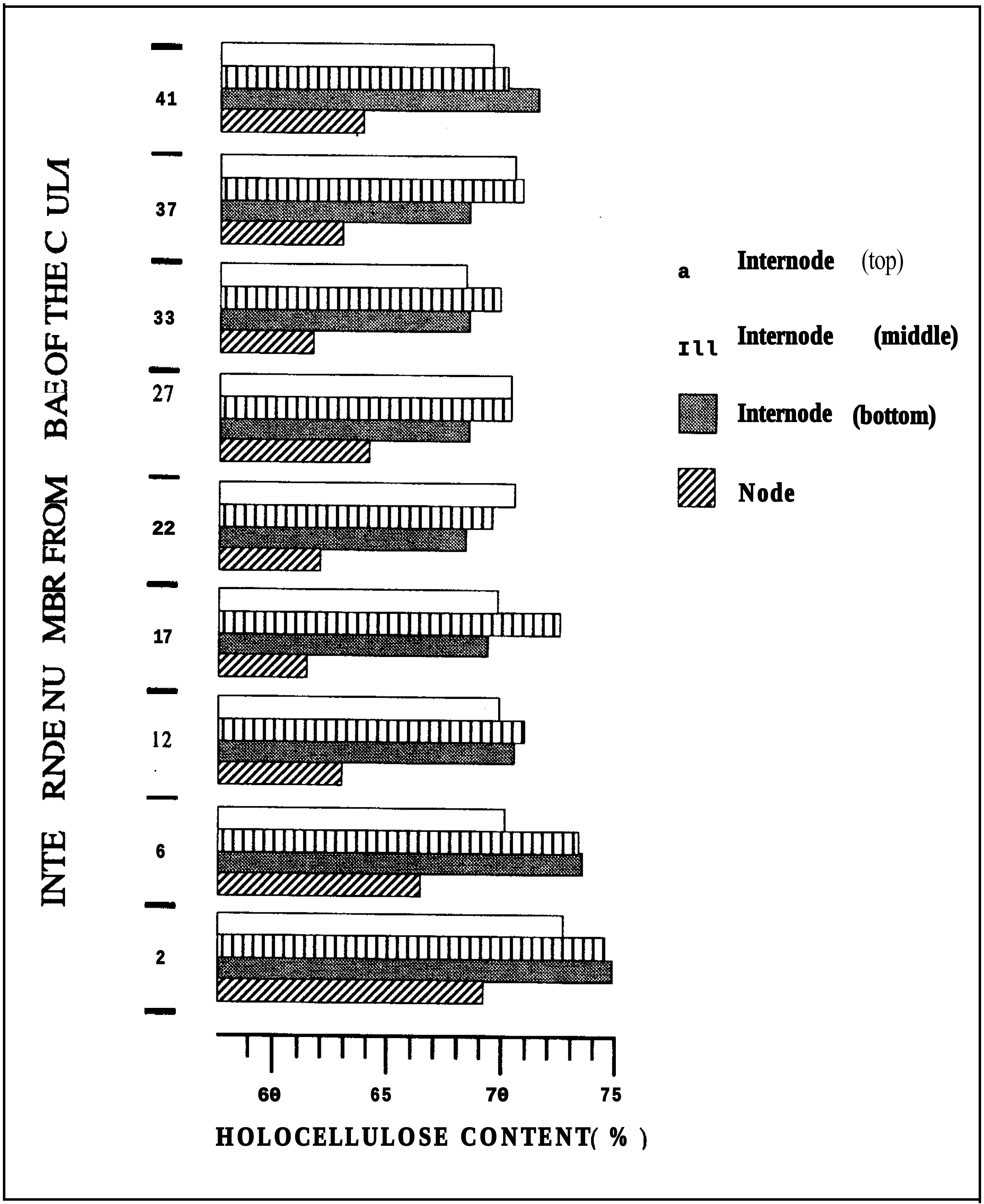

Fig. 4: Holocellulose contents of node and internode at different internodes numbered from the base of the culm

1.31-2.63% for ash content (Wang 1987, Higuchi et al. 1987). In this investigation, the variation of chemical properties were 61.9-75.2% for holocellulose, 18.5-29.0% for lignin and 1.836% for ash content.

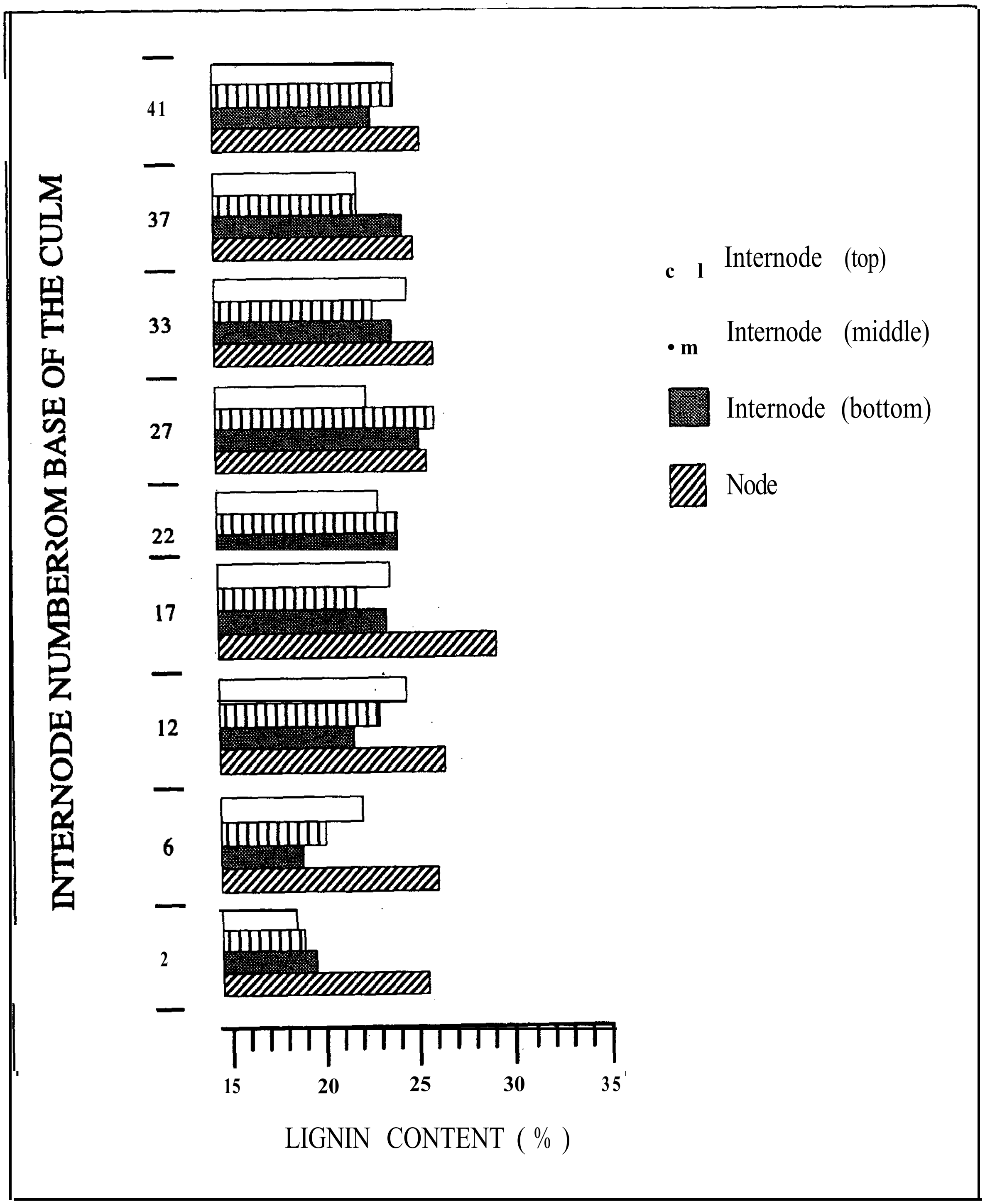

Fig. 5: Lignin content of the nodal and internodal portion with different internode number from the base of cuulm

Conclusion

The investigation results indicate that internodes had significant variation in the chemical properties, especially in water content, pH,

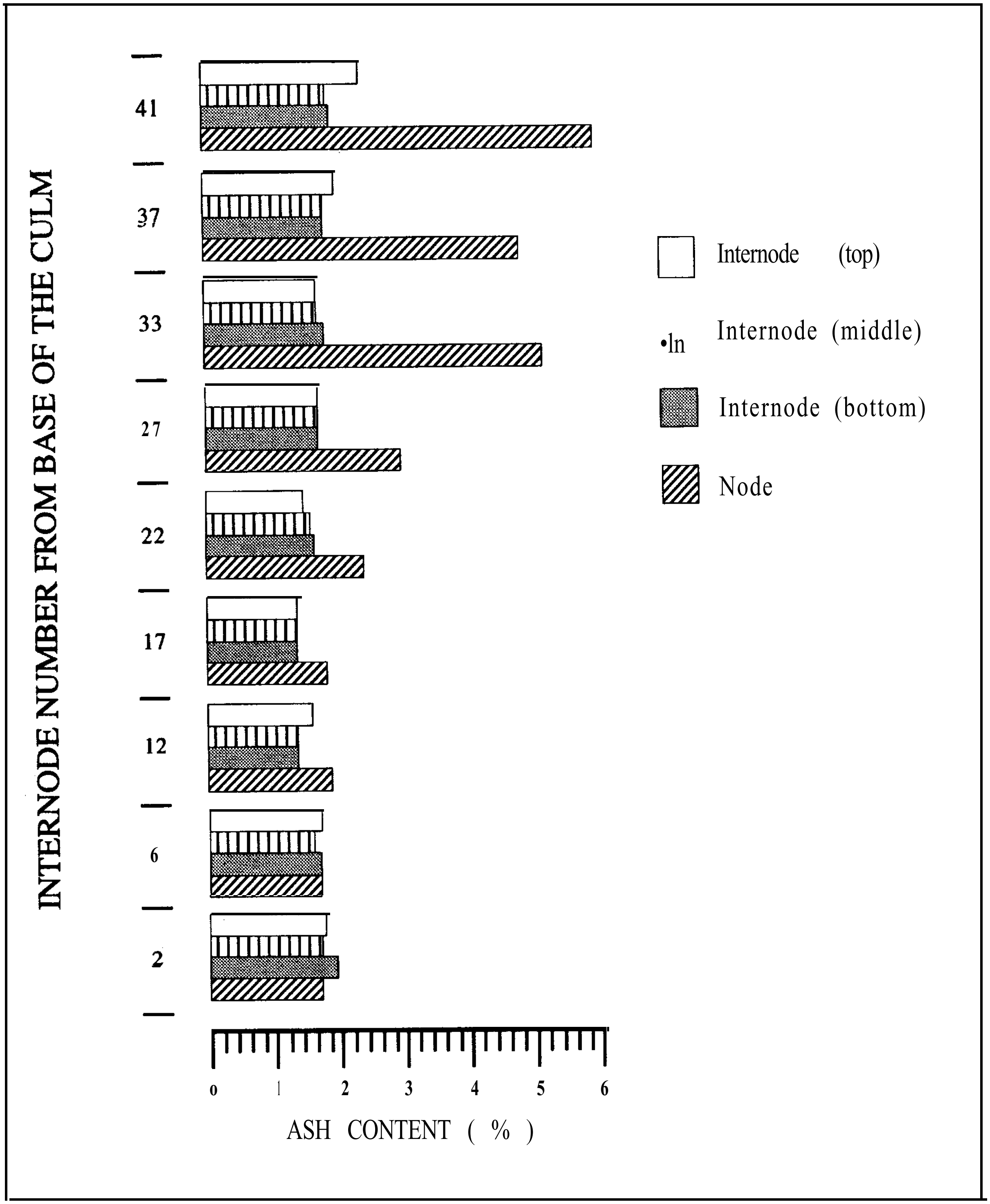

Fig. 6: Ash content of node and internode at different internodes numbered from the base of the culm

holocellulose content, lignin content and ash content. The variation in the chemical'properties depends on culm height. The influence of culm height on the chemical properties of the node is generally more significant than that of the internode.

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Lignin-Carbohydrate-Phenolic Acid Complex as an Indicator of Maturation of Bamboo

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Abstract

Lignin-carbohydrate-phenolic acid complexes (LCPACs) were isolated from five different l-m portions of a 5-m high, immature *PbyZZostacbyspu6escen.s* Mazel, and their chemical properties characterized in relation to maturation. The lignin and phenolic acid (mainly composed of pcoumaric acid and ferulic acid) contents decreased as the position of the samples became higher, whereas reverse was observed in the carbohydrate and protein contents. The core carbohydrate moiety was Oacetyl-arabinoxylan with increase of Xyl/Ara ratios from the top (2.7) to the bottom (16.9). The esterified pcoumaric acid content was closely related to the lignin content, whereas ferulic acid was rich in the upper immature portions. Bondings centred on carbohydrate were labile against alkali and 2, 3-dichloro-5, 6-dicyano-1, 4-benzoquinone treatments. The overall results indicated that LCPAC is a kind of non-cellulosic material present in the matrix portion of cell wall and usable as an indicator of maturation of bamboo.

Introduction

The association of lignin and carbohydrates in the lignified plant cell walls is of fundamental importance for characterization of the structure and function of cell walls, enhancement of the digestibility, improving the pulping and bleaching processes, and utilization of lignocelluloses as biomass.

In the tropical, sub-tropical, temperate and sub-frigid regions, bamboos are important resources for soil protection, prevention against natural disasters and production of numerous materials, including household goods, building materials, woven articles, handicrafts, musical instruments, paper, board and food.

The most outstanding characteristic of bamboo is its rapid height growth. It thus seems to be an ideal material to investigate the process of growth and maturation of plant. Previous research had established the height-dependent chemical composition change (Fuji et al. 1993a) and *W* and fluorescence microscopic variations within an immature culm of *Phyllostachys pubescens,* 6 m in height (Fuji et al. 1993b). In addition, lignin-carbohydrate complexes were isolated from mature *P.ptrbescens* and their chemical properties were characterized (Azuma et al. 1985). The presence of appreciable amount of phenolic acids was found to be an interesting feature for investigating cell wall components of monocotyledons such as bamboo (Shimada et al. 1970; Azuma 1989; Fry 1989).

In this study, the chemical changes of lignin-carbohydrate-phenolic acid complexes (LCPACs) during maturation of P.pubescens are investigated.

Materials and Methods

Isolation of LCPACs

An immature culm of P.pubescens, 5.18 m in height, was harvested on 22 May 1993 from the Botanical Garden of Kyoto University and cut into 5 pieces of 1 m lengths after removal of sheaths. The sample No. 5 was 1.18 m in length. The other pieces were designated as No. 1 - No. 4 from the bottom to the top of the culm as shown in Figure 1: They were cut into small pieces, lyophilized and milled to pass 24-mesh screen. For isolation of LCPAC, each sample was treated as previously described by Azuma et al. (1985) and Azuma (1989). After extraction with alcohol-benzene (1:2, v/v) for 48 hours, depectination with aqueous 0.25% potassium acetate at 60°C for 24 hours and vibromilling for 48 hours under nitrogen atmosphere with external cooling by running water, bamboo powder was extracted twice with 10 volumes of 80% aqueous 1,4-dioxane for 48 hours at room temperature. Crude water-soluble LCPAC was recovered by centrifugation of the dialysate of the extract against water, and purified by solubilization in 50% aqueous 1,4-dioxane and extraction with chloroform, followed by solubilization in a mixed solvent of pyridine-acetic acid-water (9:1:4, v/v) and extraction with chloroform. In each extraction, the aqueous layer was taken, dialysed against water and lyophilized to give purified water-soluble LCPAC.

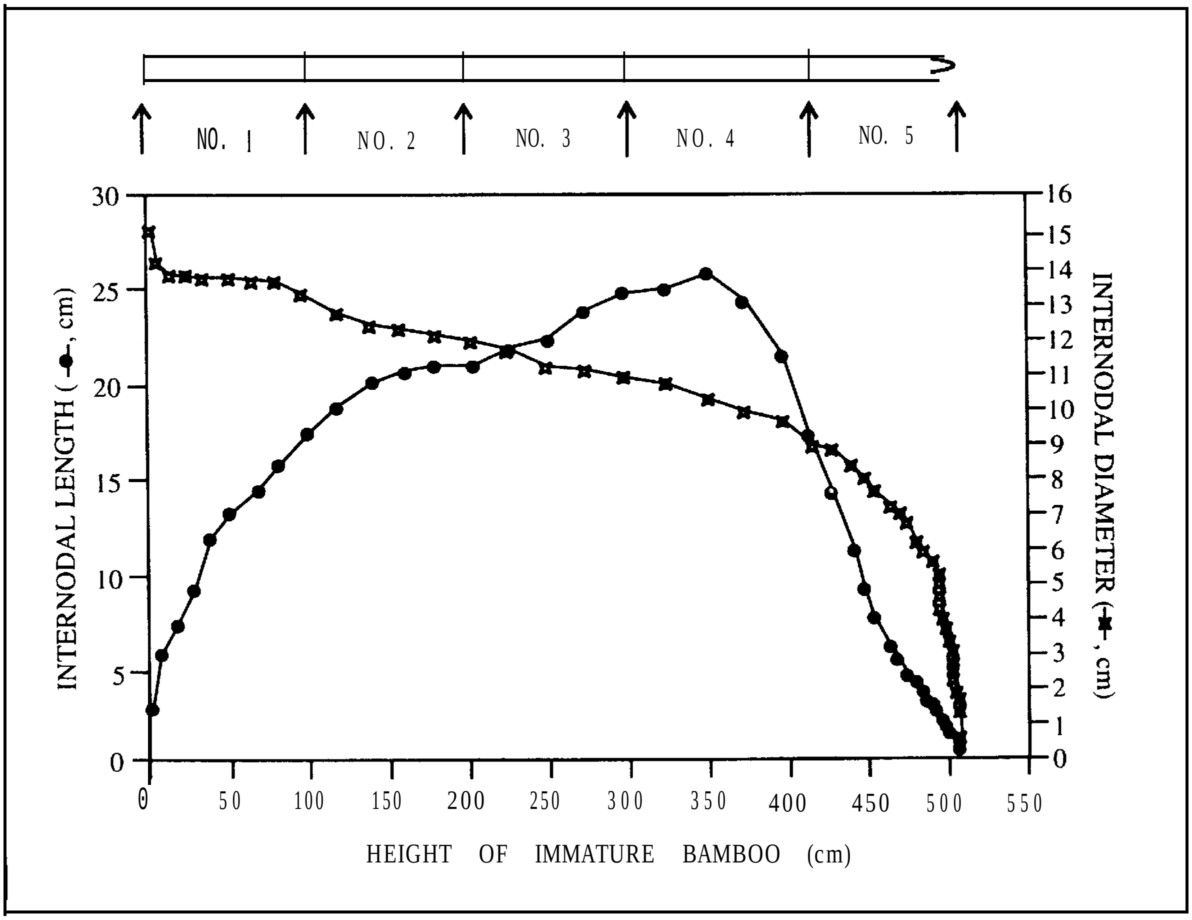

Fig. 1: Relation of internode length and diameter with height in immature bamboo (portions no. 1-5 of a 5.18-m high culm taken as samples)

Chemical composition analyses

Chemical composition of the originally separated bamboo powders and the isolated LCPACs were analysed according to the methods described by Fuji et al. (1993a), unless otherwise specified. For sugar composition analysis, Saeman hydrolysis (Saeman et al. 1954) with 72% sulphuric acid followed by dilution to 4% sulphuric acid was adopted for the original samples, while hydrolysis with 0.5 M sulphuric acid for 6 hours at 100°C was carried out for LCPAC. Crystallinity of cellulose in the powder samples was determined by the X-ray diffraction method of Segal et al. (1959) (Rigaku RINT 1200 diffractometer, Ni filtered CuKa, 40kV and 30mA, reflection mode). ^{13}C-NMR spectra of LCPACs were recorded in a 17:3 (v/v> mixed solvent of DMSO-d, and deuterium oxide at 70°C with chemical shift (ppm) being adjusted to methyl carbon of DMSO, 39.5 ppm from tetramethylsilane (Brucker ARX-500 NMR spectrometer, 125 MHz for carbon).

Molecular weight distribution analysis

Analytical gel filtration was carried out on a column (58.0 x 1 .0 cm) of Sepharose 4B equilibrated with 0.05 M sodium phosphate buffer, pH 6.8, and calibrated against pullulans having known molecular weight (Shodex Standard P-82, Showa Denko, K.K.). Elution was monitored by measuring absorbency at 280 nm for lignin and absorbency at 480 nm for carbohydrate after development of colour by the phenol-sulphuric acid method (Dubois et al. 1956).

Alkaline and 2,3-dichloro-5,6-dicyano-l4-benzoquinone treatments

LCPAC from the bottom portion (No. 1) was treated with 1 .O M sodium hydroxide and 1 .O M sodium borohydride at 25°C for 48 hours. The reaction solution was neutralized with acetic acid and applied on a column (32.0 x 1 .0 cm) of Sepharose 4B as described above. LCPAC from No. 1 was solubilized in 50% aqueous 1,4-dioxane and treated with 2,3-dichloro-5,6-dicyano-l,4-benzoquinone (DDQ) at 40°C for 24 hours (Koshijima et al. 1984). After unreacted DDQ was removed by passage through Toyopearl HW4OS using distilled water as an eluant, the reacted materials were recovered by lyophilazation and subjected to hydrophobic interaction chromatography on a column (7.0 x 1.8 cm) of Octyl-Sepharose CL-4B as previously described (Takahashi et al. 1982), and the amounts of adsorbed lignin and carbohydrate were estimated.

Results and Discussion

Height-dependent changes in internodal length and diameter

Figure 1 shows relationships of internodal length and diameter at each central position against the height of the bamboo. The profile of internodal length showed a maximum (26 cm) at the 20th internode located at the centre of the sample No. 4 (about 3.5 cm in height). Loss of sheath was observed in the internodes from the bottom to the 13th internode (below 181 cm), indicating the completion of elongation in this region. The elongation rate in the region from the 13th to 20th internodes was diminishing with decrease in height, whereas that in the region higher than the 20th was in progress. The profile of internodal diameter indicates that the diameter expanded rapidly at the top l-m portion, No. 5, and attained 60% of the full size at the lowest 23rd internode in the No. 5 portion. In the other portions (No. 1 - No. 4), the diameter expanded almost linearly with decrease in height. The whole profile thus indicated the suitability of the samples for studying the chemical changes of LCPAC in relation to height growth.

Overall chemical composition within theulm

Before isolating LCPAC, the overall chemical compositions of the five separated portions were analysed. The results, listed in Table 1, indicated that the quantity of materials extracted with alcohol-benzene **(1:2. v/v),** water and weak alkali increased with increase in height, whereas the relationship was reverse in the case of major cell wall constituents - cellulose,

Table 1: Chemical composition of immature bamboo (% dry weight)

Component content	Position of specimen in the culm (from bottom)				
	No. 1	No. 2	No. 3	No. 4	No. 5
Alcohol-benzene extract	5.5	6.3	7.7	8.6	9.1
Ash	2.4	3.0	5.2	8.0	10.8
Cold water extract	15.8	20.5	29.2	39.0	44.0
Hot water extract	16.9	23.1	35.5	48.7	53.4
1% NaOH extract	44.0	50.8	61.6	76.6	88.0
Protein	8.4	10.3	16.6	23.9	35.8
Acid insoluble lignin	9.1	6.5	2.9	0.8	0.3
Phenolic acid	0.415	0.410	0.311	0.155	0.039
Phenolic aldehyde	0.014	0.010	0.011	0.004	0.002
Holocellulose	66.8	60.1	49.5	35.8	24.6
Alpha-cellulose	37.0	31.7	24.9	15.1	7.8
Pentosan	28.7	25.0	23.4	14.8	7.6
Uranic acid anhydride	4.1	3.7	3.6	3.3	3.1
Acetyl	3.0	2.8	2.4	1.3	0.5
Crystallinity index of cellulose	44.4	42.1	36.8	35.2	18.6

hemicellulose and lignin. Crystallinity of cellulose increased with maturation. Neutral sugar composition data, shown in Table 2, also supported the observation that maturation of cell wall gradually progress within a culm in the top-to-bottom direction. Protein and ash were rich in the rapidly growing portions, No. 4 and No. 5. The contents of uranic acid and acetyl attached to hemicellulose or pectic substances were rich in the lower portion in accordance with accumulation of matrix polysaccharides. Since bamboo is a monocotyledon, phenolic acid and aldehydes were present both in the free (Shimada et al. 1970) and bound states (Azuma et al. 1985; Ishii and Hiroi 1990a, b; Ishii et al. 1990). The total phenolic acid and phenolic aldehyde contents and their compositions are listed in Tables 1 and 3, respectively. The increase in the phenolic acid contents was clearly

Table 2: Neutral sugar compositions of immature bamboo and LCPACs (% relative weight)

Component	Position of specimen in the culm (from bottom)				
	No. 1	No. 2	No. 3	No. 4	No. 5
IMMATURE BAMBOO					
L-rhamanose	0.4	0.4	0.5	0.6	0.8
L-arabinose	1.8	2.1	2.8	3.9	6.4
D-xylose	34.0	32.4	30.2	19.6	12.7
D-mannose	0.3	0.4	0.6	0.9	1.4
D-galactose	0.8	1.2	1.5	3.0	5.7
D-glucose	62.7	63.5	64.4	72.0	73.1
Xylose/arabinose	18.9	15.4	10.8	5.0	2.0
LCPAC					
L-arabinose	5.5	5.8	6.9	14.1	22.5
D-xylose	93.2	92.7	91.6	82.7	61.8
D-mannose	0.2	0.2	0.2	0.3	0.6
D-galactose	0.5	0.6	0.6	0.8	1.3
D-glucose	0.5	0.6	0.7	2.2	13.9
Xylose/arabinose	16.9	13.4	6.5	5.9	2.7

correlated to maturation. Phenolic aldehyde contents also showed similar profile, but not so evident as in the case of phenolic acid distribution. The variation ofpcoumaric acid contents was closely related to the progress of lignification, while ferulic acid was the major phenolic acid in the immature portion. A previous report had detailed the chemical composition change from top to bottom of an immature, 6-m high *P.pubescens* (Fuji et al. 1993a). In a culm of this height, the deviation given from the bottom

2-m portions were, however, not so evident as observed in the present 5-m sample. Based on the present results, it was concluded that a 5-m culm of P. *pubesdens* is adequate to analyse growth-dependent chemical composition change.

Chemical properties of LCPACs

LCPACs were then isolated from the five different portions of the culm and their chemical composition was analysed. Yields of the crude LCPACs were 7.2% (No. 1) 7.0% (No. 2). 6.6% (No. 3), 3.8% (No. 4) and 3.5% (No. 5), and the values for the purified LCPACs were 2.9% (No. 1), 2.9% (No. 2), 2.3% (No. 3), 1.9% (No. 4) and 1.2% (No. 5), on the basis of extractive-free bamboo powder obtained from each sample. The results are listed in Tables 2-4. The contents of all of the phenolic constituents – lignin, phenolic acid and phenolic aldehydes – increased with decrease in the height of the culm, while both protein and carbohydrates were rich in the immature top portion as observed in the native immature culm of bamboo (Table 1).

Table 3 shows relative phenolic acid and aldehyde composition of LCPACs. Each LCPAC was saponified with alkali, and free phenolic acids and aldehydes released were extracted with dichloromethane after acidification and analyzed by GC and GC-MS. At least 6 phenolic acids and 3 phenolic aldehydes could be detected with pcoumaric acid and ferulic acid as predominating compounds. It is interesting to note thatpcoumaric acid and ferulic acid showed quite different reversal behaviour: the former was closely related to the lignin content, whereas the latter was rich in immature portions. By treatment of the LCPAC from No. 1 with Driselase, both arabinofuranosyl xylobiose and triose feruloylated at C-5 hydroxyl groups of arabinofuranose residues could be isolated in pure forms (data not shown) [for details on structures, see Kato et a1.,(1983), Kato et al. (1987) and Azuma et al. 1990)].

Because phenolic acids were mainly present in esterified states, LCPACs had a characteristic UV absorption of lignin and esterified phenolic acids with two peaks at 280 nm and 31.5-317 nm. The ratios of a3 15/a260 closely related to the content of esterified phenolic acids. Since all LCPACs showed rather high protein content in contrast to matured bamboo, the amino acid compositions of LCPACs were further analyzed. The results, listed in Table 5, showed very similar amino acid profiles for all LCPACs (rather high proportions of Asx, Glu, Gly, Ala and Leu, and low in basic amino acids).

Table 3: Phenolic acid and aldehyde composition of immature bamboo and LCPAC (% relative weight)

Component	Plsition of specimen in the culm (from bottom)				
	No. **1**	No. 2	No. 3	No.4	No.5
IMMATURE BAMBOO					
Benzoic acid	0.38	0.2.0	0.92	0.35	1.17
phydroxy benzoic acid	0.28	0.43	0.82	1.15	4.48
Vanillic acid	0.27	0.36	0.40	0.65	1.12
Syringic acid	0.25	0.32	0.63	1.80	2.02
pcoumaric acid	59.08	49.04	43.41	27.23	17.14
Ferulic acid	36.52	47.23	50.55	66.47	68.10
phydroxybenzaldehyde	1.80	1.22	1.53	0.90	4.00
Vanillin	1.03	0.80	1.20	0.75	1.03
Syringalde hyde	0.38	0.40	0.54	0.70	1.04
Ferulic acid/p-coumaric acid	0.60	**1 .00**	1.20	2.40	3.80
LCPAC					
Benzoic acid	0.04	0.08	0.52	0.58	1.12
phydroxy benzoic acid	0.02	0.12	0.09	0.03	0.13
Vanillic acid	0.54	1.50	1.52	0.81	1.17
Syringic acid	0.32	1.17	0.35	0.31	0.31
pcoumaric acid	**71.33**	67.25	64.68	47.87	18.96
Ferulic acid	24.69	27.43	30.98	48.76	76.47
phydroxybenzaldehyde	0.97	0.63	0.75	0.46	0.76
Vanillin	1.07	1.05	0.83	0.78	0.91
Syringaldehyde	0.56	0.76	0.34	0.33	0.16
Ferulic acidlpcoumaric acid	0.30	0.40	0.50	1.00	4.10

The amino acid profiles of LCPACs were very different from those of arabinogalactan-proteins, extensins and glysine-rich proteins previously found in the plant cell walls (Showalter 1993). Neutral sugar composition analysis of LCPACs, listed in Table 2, indicated that the carbohydrate portion of LCPACs was mainly composed of arabinoxylan. The ratios of Xyl/

Ara increased about 6-fold from the top to the bottom of the culm. This indicated that the number of branching points decreased as the growth of the culm proceeded. High proportion of arabinose residues in the immature plant cell walls was also reported in wheat (Lam et al. 1995) and sorghum (Goto et al. 1991). The glucose residues present in the top portion (No. 5) could be due to starch because of diminishment of this sugar by treatment with glucoamylase.

Table 4: Chemical composition and properties of LCPAC

	Position of specimen in the culm (from bottom)				
Component content	No. 1	No. 2	No. 3	No. 4	No. 5
Carbohydrate	(% dry weight)				
Neutral sugar	71.5	73.8	78.4	80.1	82.6
Uronic acid	**1.1**	0.9	0.9	0.9	0.9
Lignin					
Acetyl bromide	18.5	16.7	14.4	12.8	10.7
Acetyl content	6.9	7.7	8.6	7.5	4.1
Phenolic acid	4.480	4.000	2.844	1.969	0.687
Phenolic aldehyde	0.120	**0.100**	0.056	0.031	0.013
Protein	2.2	2.7	3.0	6.0	16.2
$[a]^{25}$ (c ,20 ,9 5 50% dioxane)	-49.7”	-53.7”	-62.1”	-59.4	-51.8”
λ max (50% dioxane, nm)	315	315	315	316	317
λ min (50% dioxane’, nm)	259	259	261	263	264
a31 5/a260	2.3	2.3	2.0	1.4	1.4

Carbohydrate chain analysis

Glycosyl linkage analysis of LCPACs were carried out by methylation, and NMR and IR spectroscopic analyses. Table 6. lists the methylation analysis of LCPACs. The 1,4-linked xylopyranose residues at the higher portions were concluded to exist at a highly branched state. Arabinose residues were mostly present as single arabinofuranosyl pendants. However, the presence of 2,3-di-O-methyl arabinitol residues indicated that a small amount of arabinofuranose residues were further substituted at O-5. The l-4-linked glucopyranose residues present in the No. 4 and No. 5 potions were eliminated after treatment with glucoamylase, indicating the presence of starch in the upper portions.

Table 5: Amino acid compositions of LCPACs (% mol)

	Position of specimen in the culm (from bottom)				
Amino acid	No. 1	No. 2	No. 3	No.4	No.5
Hydroxyproline	3.9	0.8	1.3	1.2	1.0
Aspartic acid	9.7	9.8	10.3	10.3	10.4
Threonin	6.0	5.4	5.8	5.4	6.1
Serine	6.4	5.9	6.2	6.2	6.5
Glutamic acid	10.3	10.7	10.8	10.3	10.2
Proline	7.0	7.2	7.2	7.0	7.6
Glysine	10.8	10.5	9.8	9.3	9.8
Alanine	10.4	10.7	11.1	10.5	11.3
Cysteine	0.4	0.4	0.3	0.3	0.3
Valine	7.3	7.7	7.8	7.6	7.6
Methionine	1.6	1.6	1.6	1.8	2.0
Isoleucine	4.7	5.3	5.1	5.3	4.9
Leucine	9.3	10.9	10.2	10.3	9.3
Tyrosine	2.5	2.6	2.3	2.7	2.8
Phenylalanine	4.0	4.7	4.3	4.4	3.8
Lysine	2.2	2.1	2.3	2.7	2.5
Histidine	1.2	1.2	1.2	1.2	1.2
Arginine	2.2	2.5	2.6	3.0	2.7

The ^{13}C-NMR spectra of LCPACs in the anomeric carbon region are shown in Figure 2. Eight signals revealed between 110 and 85 ppm with assignments indicated the presence of partially acetylated arabinoxylan. Presence of 2-0 and 3-0-acteyl groups indicated the position of acetylation in the xylose residues. The strength of each signal was related to the abundance of the corresponding sugars. Beta glycosidic linkage of xylopyranose residues was assigned by the values of chemical shifts and the presence of IR absorption band at 895 cm^{-1}, as shown in Figure 3. The IR spectra of the LCPACs were quite similar to that of partially acetylated arabinoxylan (Azuma et al. 1985) and showed the presence of strong absorption at 1 740 cm^{-1} owing to esterified carbonyl groups.

Table 6: Methylation analysis of LCPAC (% mol)

Component	Linkage	Position of specimen in the culm (from bottom)				
		No. 1	No. 2	No3	No. 4	No. 5
2,3,5-Ara*	Araf →	3.7	3.5	5.4	12.2	17.6
2,3-Ara	→ 5)Araf →	1.5	3.0	1.3	**1.1**	2.0
2,3,4-Xyl	Xylp →	1.4	1.7	1.8	1.5	1.5
2,3-Xyl	→ 4)Xylp →	88.3	86.3	83.9	67.8	48.0
2- or 3-Xyl	→ 2or3)Xylp →	5.2	5.5	7.6	15.7	18.5
2,3,4,6-Glc	Glcp →				0.3	1.5
2,3,6-Glc	→ 4)Glcp →				1.5	10.8

* 2,3,5-Ara = 2,3,5-tri-Omethyl-L-arabinitol, etc.

Molecular weight distribution of LCPACs

Figure 4 shows the molecular weight (MW) distribution profiles of LCPACs. The elution profile of esterified phenolic acid monitored at 315 nm (not shown in the figure) was very similar to that of lignin monitored at 280 nm, because all LCPACs showed two UV peaks of similar intensities at 280 nm and 315-317 nm. The overlapping of the distribution profile of lignin with those of carbohydrate and phenolic acids supported the bondings between these three components to form lignin-carbohydrate-phenolic acid complex. The top fraction had only a component which appeared at a position having apparent MW near 1 .0 x 10^4. The MW gradually increased with decreasing height, and a new fraction having Mw of 2.0-3.0 x 10^5 clearly appeared and was more evident at the lower portions. At the bottom portion, No. 1, gel filtration profile of the LCPACs was similar to that of the mature bamboo and separated into three distinct peaks, W-l, W-2 and

W-3 (Azuma et al. 1985). Gradual appearance of a new higher MW component with progress of maturation indicated the occurrence of crosslinking of LCPACs during the growth of bamboo.

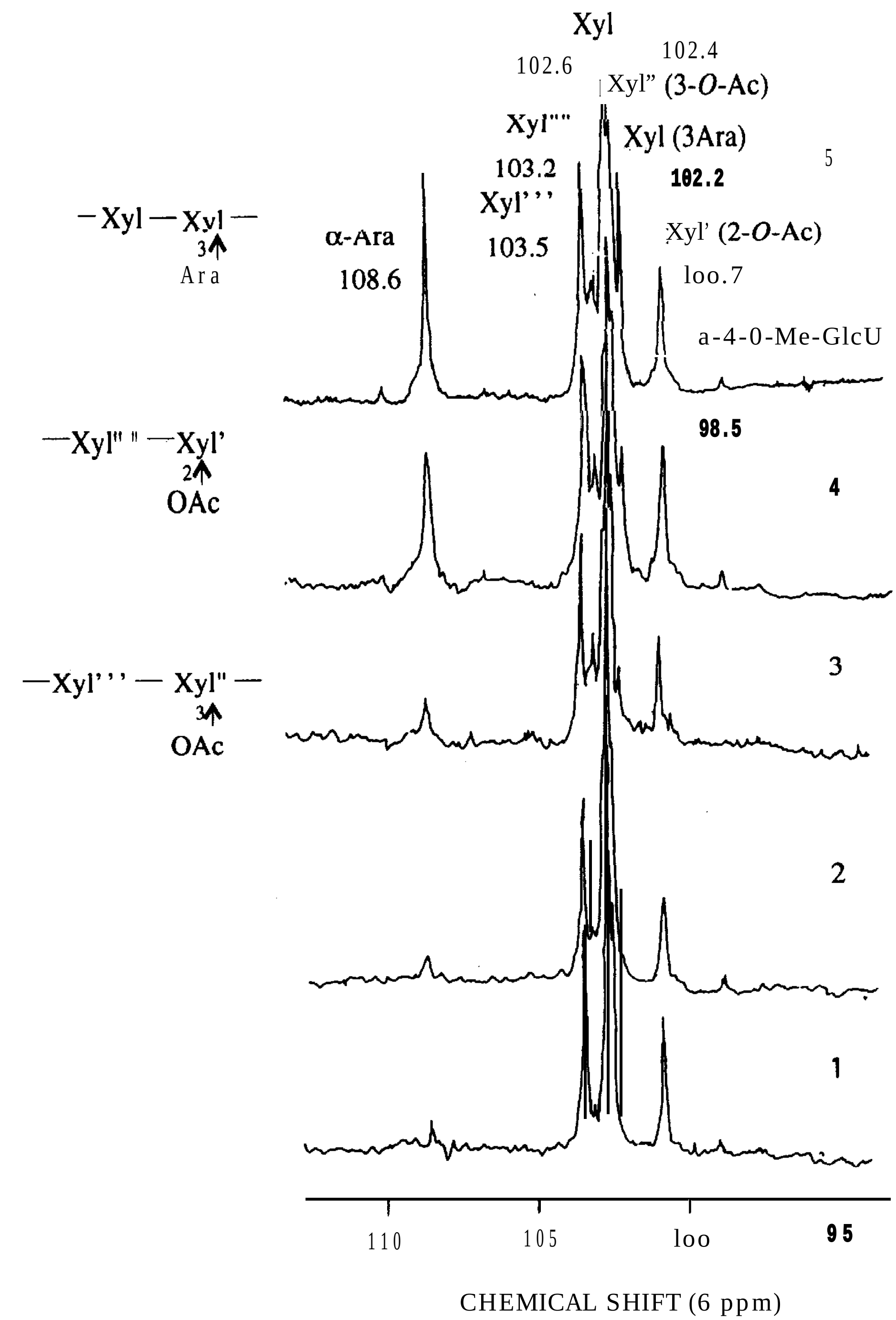

Fig. 2: ^{13}C-NMR spectra of LCPACs in the anomeric carbon region (chemical shifts and assignments of signals)

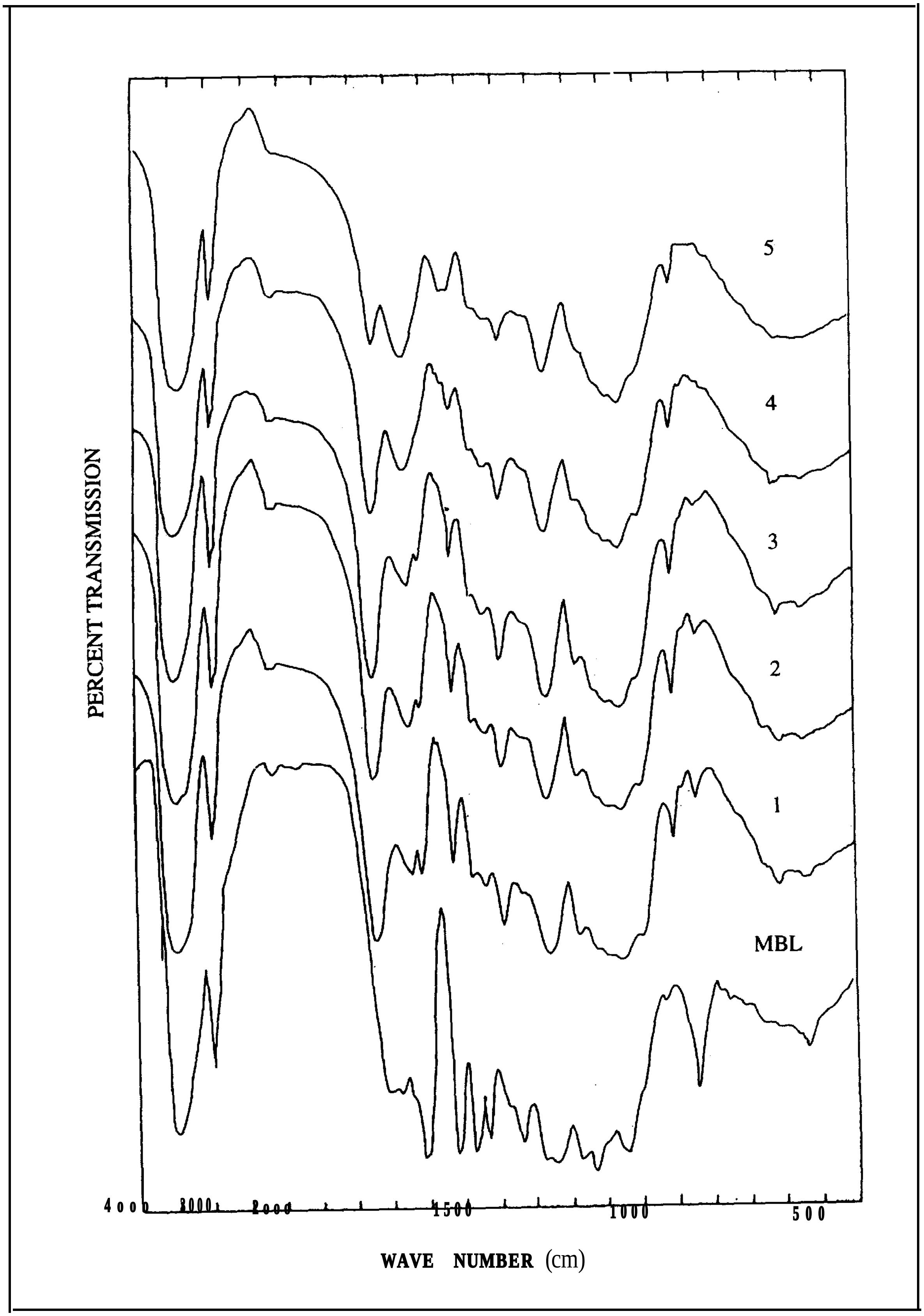

Fig. 3: IR spectra of LCPACs and milled bamboo lignin (MBL)

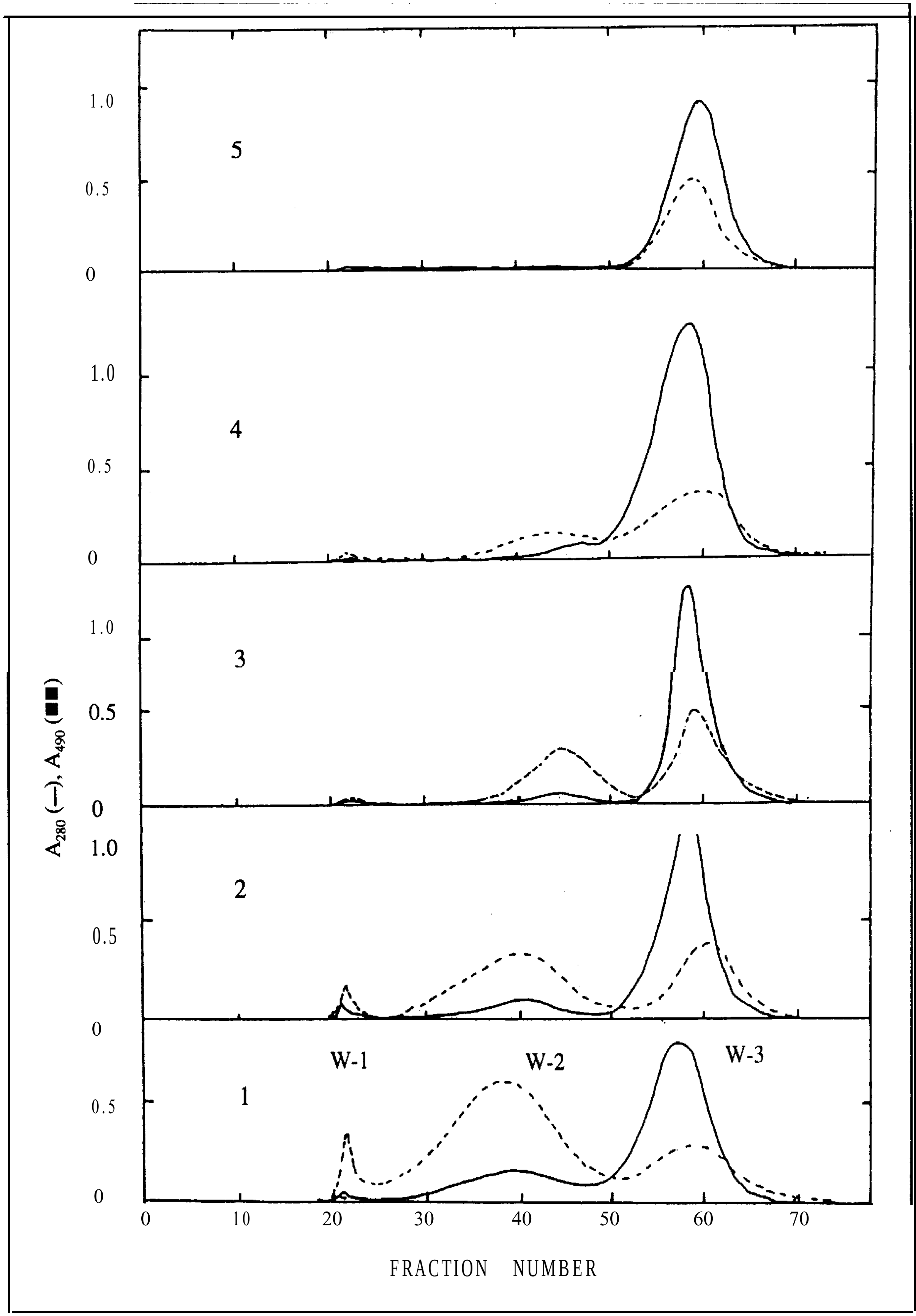

Fig. 4: Gel filtration of LCPACs using Sepharose 4B

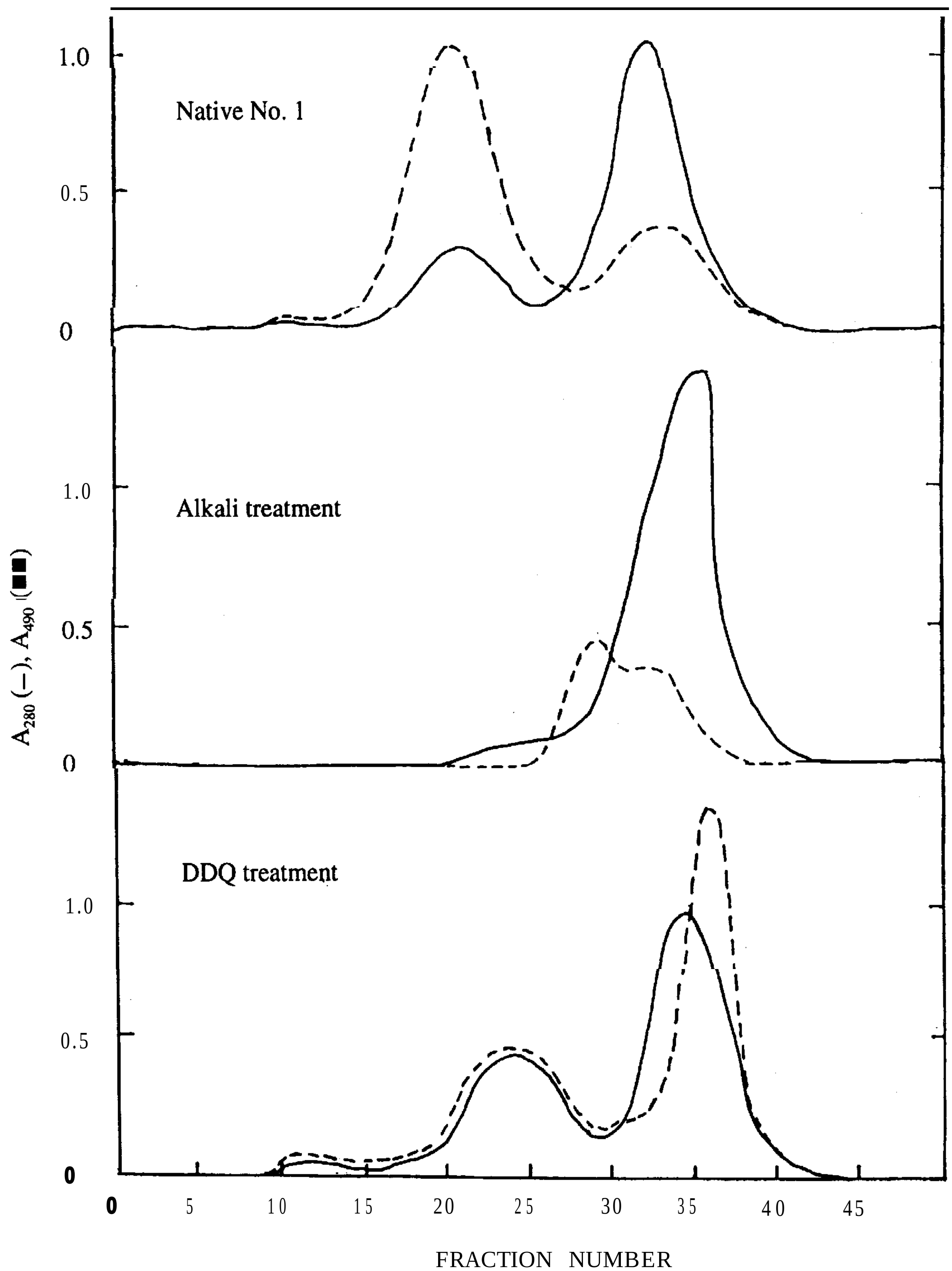

Fig. 5: Gel filtration of LCPAC from No. 1 sample using Sepharose 4B

Linkages between lignin and other components

For analysis of linkages between lignin and the other components in LCPACs, effects of strong alkali treatment in the presence of sodium borohydride and DDQ treatment in the presence of 50% aqueous 1,4-dioxane in LCPAC were analysed. Figure 5 shows the change of elution of LCPAC from No. 1 portion after these treatments. Complete diminishment of the W-l and W-2 fractions, and splitting of absorbencies by lignin and carbohydrates in the W-3 and the newly appeared fractions by alkaline treatment supported the well-known esterified nature of the bondings between carbohydrate-phenolic acid (Fry 1989) and phenolic acid-lignin (Shimada et al. 1971). However, the W-2 fraction disappeared during DDQ treatment and a new broad peak having MW 1.0×10^5 appeared with retention of overlapping absorbencies by lignin and carbohydrates. In the W-3 fraction, both absorbencies shifted to the lower MW region with splitting. In addition, hydrophobic interaction chromatography of the LCPAC from No. 1 after DDQ treatment revealed that about 50% of the linkages between lignin and carbohydrate and/or phenolic acid was estimated to survive the treatment. Previously DDQ treatment was reported to split almost completely the phydroxy-benzyl-ether linkage, 68% of phydroxy-benzyl glycoside linkage and 38% of p-methoxybenzyl glycoside linkage (Koshijima et al. 1984). Although no information was available on the effect of DDQ on benzyl ester linkages in aqueous condition, the results indicated the presence of benzyl ether linkages with substitution at p-hydroxyl positions in LCPACs.

Previously, Lam et al. (1994) had pointed out the importance of ether linkages between carbohydrates and'lignin which are stable to alkali treatment under moderate temperature, and the interactions between carbohydrates and lignin through phenolic acid ester-ether bridges (1992). Since morphological analyses indicated that lignification occurred after the accumulation of hemicellulose has sufficiently progressed (Takabe et al. 1989), the formation of lignin-carbohydrate and lignin-phenolic acid complexes may be a key step for de novo synthesis of complex lignin-carbohydrate-phenolic acid networks in the bamboo cell walls. On speculation, formation of bondings between these three components are necessary to make the cell walls more rigid and physically stable. Further chemical analyses are currently in progress to clarify the precise nature of lignin-carbohydrate-phenolic acid networks.

In conclusion, LCPAC was found to be non-cellulosic, and to form a complex lignin-carbohydrate-phenolic acid network associated with the progress of growth in bamboo.

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Chemical Constituents and Physical Properties of *Bambusa heterostachya*

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Abstract

The chemical constituents and physical properties of culms of *Bambusa heterostachya* were assessed at different ages. With the exception of density, the moisture content and shrinkage were negatively correlated to age. The chemical compositions, on the other hand, differed significantly with maturity and position in culm (except for cold water solubles, holocellulose and ash content). Despite age and height, the high cellulose content of this species indicates its good potential as a raw material for pulp and paper.

Introduction

Bambusa beterostachya (Bulah galah) is known in cultivation rather than in the wild. This medium-diameter bamboo is commonly used for plucking coconut fruits and oil palm fruit bunches, and for making ropes and basketry, especially in the southern part of peninsular Malaysia, where it is abundant.

Detailed infonnation on this species is lacking. The only available docu mentation was initiated by Abd. Latif et al. (1993), with special emphasis on its culm characteristics and physical properties. Since this species shows potential in the development of bamboo industries in peninsular Malaysia, more information was needed in order to assess its suitability for other end-uses. In this study, the patterns of variation in chemical constituents and physical properties at different ages and culm height were determined as a guide for future application.

Materials and Methods

Nine culms each from &month-old, and 1, 2, 3 and 4-year-old *B.* heterclstachya clumps, obtained from the plot established since 1987 at Parit Haji Salleh, Broleh, Batu Pahat, Johor, were used in this study. The sampling was conducted in July 1993 when the rainfall, temperature and relative humidity was about 169.5 mm, 31.7°C and 82.5%, respectively. The culm length, diameter, wall thickness, number of internode and weight were recorded. Each bamboo sample was then equally divided into three portions – basal (B), middle (M) and top (T).

The methods used for the determination of moisture content, density and shrinkage of bamboo were based on IS 6874 (Anonymous 1973). Proximate chemical analysis, on the other hand, was conducted on air-dry milled bamboo samples according to the followingstandard methods:

Cold water solubles	: TAPPI T-207 (Anonymous 1978)
Hot water solubles	: TAPPI T-207 (Anonymous 1978)
1% NaOH solubles	: TAPPI T-212 (Anonymous 1978)
Alcohol-benzene solubles	: TAPPI T-204 (Anonymous 1978)
Lignin	: TAPPI T-222 (Anonymous 1978)
Holocellulose	: Wise et al. 1946
Ash	: TAPPI T-15 (Anonymous 1978).

Results and Discussion

Culm characteristics

The physical characteristics of *B. hetemstachyu* such as diameter, internodal length and culm wall thickness are presented in Table 1. The species has a hollow culm with no branches at lower nodes. The culms are straight, with average lengths of l0-14 m and diameter of about 2.8-5.4 cm. It is of sympodial type and easily recognized by the irregular pale green horizontal stripes on the culms. The total number of internodes were observed to be 3140 per culm with an average internodal length and culm wall thickness of 22-66 cm and 2-10 mm, respectively. The culm sheath is about 12 cm long, covered with black hair on the back, and with lacerated edge shape of the ligule.

The effects of age on culm height and other characteristics are given in Table 2. The culm, like other bamboos, tapers from the base towards the top with a decrease in diameter (r = 0.70), internode length (r = 0.26) and culm wall thickness (r = 0.76). As the bamboo ages, the thickness and internodal length increase (r = 0.25 and r = 0.02, respectively). The bamboo attains its maximum height within six to nine months (Table 1). With age increment, mature tissues start to develop and continue to change in density, strength properties, growth of branches and established root system (Abd. Latif et al. 1992b).

Table 1: Characteristics of *B. betemstacbya* culms

Property	Age (years)				
	0.5	1	2	3	4
Weight (kg)					
- Culm	12.82	11.06	9.51	9.84	8.43
- Branch	0.59	1.04	1.26	2.13	1.01
- Leaves	0.15	0.60	0.72	0.95	0.52
- Total	13.56	12.70	11.49	12.92	9.96
Culm length (m)	14.79	13.45	12.78	11.83	10.39
No. of internodes/culm	37	36	33	33	32
Internode length (cm)					
- Basal	44.88	35.25	35.60	33.35	43.10
- Middle	64.92	65.70	63.40	48.40	54.48
- Top	26.43	27.30	24.41	27.70	29.66
Internode diameter (cm)					
- Basal	5.38	4.70	4.71	5.22	5.41
- Middle	4.50	4.79	4.72	4.64	5.20
- Top	2.76	4.04	4.01	3.41	4.12
Culm wall thickness (mm)					
- Basal	9.10	9.45	7.58	8.89	10.59
- Middle	5.43	5.15	6.00	6.19	7.61
- Top	4.08	4.31	4.56	2.41	5.58

Notes: (1) Values shown are averages of nine culms.
(2) Shorter culm lengths up the age level are because of broken tips or drooping culms.

Variations in physical properties

The average physical properties of *B. heterostachya* are given in Table 3 and the respective summary of analysis of variance are presented in Table 4. Table 5 and Table 6 give the summary of Duncan's Multiple Range test and correlation coefficients of different physical properties with age, height and culm characteristics. For convenience, each property is discussed, separately below. The physical properties discussed are the variation in initial moisture content, oven-dry density and shrinkage.

Table 2: Correlation of coefficients of culm characteristics with age and height of bamboo

Characteristics	Age	Height
Diameter	0.33**	-0.70**
Internode length	0.02ns	-0.26**
Wall thickness	0.25**	-0.76**

Note: • * = highly significant at P<0.01 ns = not significant at P<0.05.

Moisture Content

The initial moisture content varies significantly with age, height and the interaction of age and culm height. In general, it tends to decrease with increases of age (r = 0.57) but insignificantly increases with height (r = 0.11). The initial moisture content, regardless of age and height, varies between 92.1 to 167.7%. The lowest and highest mean initial moisture contents were observed in the respective top portion of the three-year-old (92.1%) and the half-year-old culms (167.7%), respectively. While the lowest moisture content at the top of the three-year-old bamboo could be associated with the decrease in percentage of parenchyma cells (the site of water storage) within the top portion of the culm (Liese 1987; Abd. Latif and Mohd. Zin 1992a), the latter is probably because of the thin-walled fibres and lesser concentration of vascular bundles distributed in the immature tissues of the younger bamboos (Abd. Latif and Mohd. Tamizi 1992).

The initial moisture content tends to remain stable or slightly decreases after six months to three years of age, but seems to increase again at the age of four years. While the decrease in moisture content after six months (juvenile stages) may be related to its growth establishment (such as the

Table 3: Physical properties of *B. heterostachya*

Portion	Age (years)				
	0.5	1	2	3	4
Moisture content (%)					
Basal	122.5	116.3	109.1	127.1	120.2
Middle	157.8	132.1	128.0	126.6	136.5
Top	167.7	122.1	115.6	92.1	130.5
Oven-dry density (g/cm3)					
Basal	0.49	0.52	0.52	0.48	0.49
Middle	0.40	0.48	0.44	0.48	0.47
Top	0.39	0.51	0.51	0.58	0.48
Longitudinal shrinkage (%)					
Basal	0.22	0.19	0.52	0.41	1.11
Middle	0.52	0.70	1.01	0.55	0.5 0
Top	0.57	0.34	0.25	0.26	0.54
Radial shrinkage (%)					
Basal	18.11	17.16	19.09	19.18	15.10
Middle	31.13	21.92	23.10	23.49	27.25
Top	28.63	19.85	19.04	18.87	22.33
Tangential shrinkage (%)					
Basal	10.57	8.20	9.17	9.06	9.63
Middle	12.53	10.88	9.22	6.83	8.06
TOP	11.80	7.73	5.66	5.12	6.53
Diametrical shrinkage (94)					
Basal	10.35	9.50	7.89	7.61	7.83
Middle	10.13	7.61	8.39	9.61	8.86
Top	8.27	6.99	7.16	4.88	8.89
Volumetric shrinkage (%)					
Basal	35.75	32.28	33.36	34.08	28.33
Middle	44.46	35.49	35.30	33.56	30.22
Top	35.72	30.22	29.53	20.98	27.20

Table 4: Summary analysis of variance on physical properties of *Bhetemstacbya*

Source of variation	df	Mean squares and statistical significance						
		Moisture content	Density	Shrinkage				
				Longitude	Radius	Tangent	Diameter	Volume
AiF	4	1.2E5**	0.2**	10.3**	1.4E3**	1.7E3**	5.2E2**	3.5E3**
Height	2	6.2E3*	O.lns	1.7ns	3.9E2**	3.2E1ns	1.5E2*	1.3E2**
Age x height	8	6.0E3**	0.1ns	1.2ns	1.0E2*	1.0E1ns	1.4E2*	1.5E2**

Note: * = highly significant at P<0.01; * = significant at P<0.05; ns = not significant at P<0.05.

Table 5: Duncan's Multiple Range Test on physical properties of *B. heterostacbya*

Source. of variation	Age (years)					Portion		
	0.5	1	2	3	4	Basal	Middle	Top
Moisture content (%)	149.3a	123.5a	117.6a	115.3a	129.1a	143.8a	158.9a	167.8a
Oven-dry density (g/cm3)	0.43a	0.50bc	0.49bc	0.52c	0.48bc	0.43a	0.46a	0.47a
Shrinkage (%)								
- Longitudinal	0.44a	0.41a	0.45a	0.41a	0.72a	0.69a	0.94a	1.09a
- Radial	25.96a	19.64a	20.41a	20.51a	21.56a	21.13a	26.94a	25.75a
- Tangential	11.63b	8.94b	8.01ab	7.07a	8.07ab	10.32a	13.25a	9.73a
- Diametrical	16.25b	8.03a	7.81a	7.36a	8.53a	13.04a	12.95a	11.48a
- Volumetric	38.64b	32.66a	32.72a	29.54a	28.58a	36.98a	39.40a	35.99a

Note: a, b, c, ab = Averages denoted by same letters down the coulmn differ insignificantly at P<0.05.

Table 6: Summary of correlation coefficients of physical properties with age,

Source of variation	Physical properties						
	Moisture content	Density	Shrinkage				
			Longitude	Radius	Tangent	Diameter	Volume
Age	-0.57**	0.50'''	-0.19*	-0.49**	-0.63”	-0.47*	-0.57**
Height	O.llns	-0.04ns	0.07ns	0.16ns	-0.06ns	-0.03ns	-0.03ns
Internode length	-0.12ns	-0.04ns	0.08ns	-0.02ns	-0.07ns	0.10ns	-0.03ns
Diameter	-0.33**	0.24**	-0.07ns	-0.34**	-0.25**	-0.21’	-0.22*
Wall thickness	-0.24**	-0.21*	-0.13ns	-0.25**	-0.15ns	-0.16ns	-0.19*

Note: ** = highly significant at $P<0.01$; * = significant at $P<0.05$; ns = not significant at $P<0.05$.

development of branches and leaves), the increase after three years of age (mature stages) might be due to its lower transpiration rate which is closely associated with the reduction of the total above-ground biomass (Table 1) (Liao 1990; Noggle and Fritz 1979).

With regard to culm height from bottom to top, it appears that the density of bamboo does not vary much with height, but slightly tends to have a lower value near the top of the culm (r = 0.04), especially at the age of less than one year. This could be due to the higher percentage of moisture content in immature tissues. The higher oven-dry density of the top portion of the bamboo culm could be attributed to the gradual decrease in the actual number and size of the vascular bundles, i.e. they get close together with thinner culm walls (r = 0.21) towards the top and thus reduce the initial moisture content but increase the density (Grosser and Liese 1971; Abd. Latif & Mohd. Tamizi 1992; Abd. Latif & Mohd. Zin 1992b).

Shrinkage

All the shrinkage values vary significantly with age, height (except for longitudinal and tangential shrinkages) and the interaction of age and culm height (except for longitudinal and tangential shrinkages) (Table 4). Regardless of age and height, the shrinkage values ranged from 0.19 to 1.11% (longitudinal), 15.10 to 31.13 % (radial), 5.12 to 12.53% (tangential), 4.88 to 10.35% (radial) and 20.98 to 44.46% (volumetric). The results (Table 5 and 6) further show that the magnitudes of shrinkage are almost similar in that they generally decrease with age and culm height, thus indicating that the dimensional stability of the top portion and older bamboo were much greater than that of the basal and young ones. These phenomena are probably correlated with high density but low initial moisture content within the older bamboo, and the higher amount of vascular bundles per square unit within the top portion (smaller diameter and thinner wall) of the culm (Abd. Latif and Mohd. Tamizi 1992).

The norm that the shrinkage in tangential direction is highest than the radial as specified in wood (Panshin and De Zeeuw 1970) and some Malaysian bamboos (Abd. Latif and Mohd. Zin 1992a, 1992b) seems to be in contradiction with the results obtained in this study. The ratio of tangential to radial shrinkage was found to be within the range of 0.34:1 (three-year-old culm) to 0.46:1 (half-year old culm). Espiloy (1987), in her study on *B. blumeana* and *Gigantochloa Zevis,* also found similar patterns of variation. As mentioned by Sulthoni (1989), this order of magnitude of

Table 7: Chemical composition of *B. beterostachya*

Age (years)	Portion	Cold wates solubles (%)	Hot water solubles (%)	Alcohol-benzene solubles (%)	1% NaOH solubles (%)	Lignin (%)	Holo-cellulose (%)	Ash (%)
0.5	Basal	4.5	6.1	3.1	23.4	20.9	73.5	2.8
	Middle	5.6	8.4	2.2	23.5	20.4	74.3	2.8
	Top	3.8	6.6	2.0	21.7	20.7	73.7	2.9
1	Basal	1.1	2.5	3.9	18.1	21.9	77.6	3.9
	Middle	2.2	4.7	1.9	21.4	21.7	76.0	4.5
	Top	2.8	3.6	2.5	19.3	21.5	79.5	4.2
2	Basal	4.9	6.3	1.6	19.0	23.1	68.8	2.7
	Middle	5.8	5.8	1.9	21.6	22.4	69.1	3.3
	Top	5.3	5.3	1.4	20.9	22.3	70.0	3.9
3	Basal	6.0	6.3	1.6	19.0	23.1	68.8	3.8
	Middle	6.4	6.9	3.3	26.8	19.7	69.4	3.3
	Top	5.9	6.1	2.7	24.6	21.3	70.2	2.7
4	Basal	7.3	9.1	3.0	28.0	20.0	70.0	4.4
	Middle	3.2	7.2	2.9	26.4	20.7	69.7	4.3
	Top	4.7	6.1	2.7	27.7	22.5	70.1	5.3

Table 8: Analysis of variance on the chemical properties of *B. heterostacbya*

Source of variation	df	Cold water solubles	Hot water solubles	Alcohol-benzene solubles	1% NaOH solubles	Lignin	Holo-cellulose	Ash
Age	4	66.19**	26.15”	11.74**	134.80**	10.36**	364.50**	68.60**
Portion	2	0.82ns	5.38*	5.60*	11.14**	4.51;	1.12ns	3.61ns
Age x portion	8	13.60**	3.82*	4.71”	5.82**	2.30ns	6.25"	9.16**

Note: ** = highly significant at P<0.01; • = significant at P<0.05; ns = not significant at P<0.05.

shrinkage is still questionable and requires to be studied further. From the utilization point of view, bamboo may shrink less than timber. As argued by Liese (1987), this reflects the properties of the parenchymatous tissues of bamboo which shrink less, while the vascular fibres shrink as much as those in wood of the same density. Compared to wood, *B. heterostacbya* seemed to have better dimensional stability with maturity.

Proximate chemical analysis

The approximate chemical composition of *B. heterostacbya* is tabulated in Table 7. The analysis of variance and Duncan's Multiple Range Tests on the effects of age and culm height on the chemical properties are shown in Tables 8 and 9, respectively.

The results indicate that the contents of all the chemical components of B. *heterostuchyu* varied significantly with age and height (except for cold water solubles, holocellulose and ash contents). The contents, however, generally increased with age (except for cold water solubles and holocellulose content) but decreased along the culm height (except for lignin, holocellulose and ash contents).

The holocellulose content, regardless of age and height, varied from about 68 to 80%. The results also indicated that the increase in holocellulose content within and between age and culm height was usually accompanied by a decreasing amount of water soluble contents. Abd. Latif et al. (1994) in their study on one-to-three-year-old culms of *G. scortechinii* also found a similar pattern. The highest and lowest mean holocellulose contents were observed in the top portion of the one-year-old culm (79.5%) and the basal portion of the two-year-old culm (68.8%). Duncan's Multiple Range Test (Table 9) further revealed that even though the holocellulose content differed insignificantly with culm height, its value was lowest in the middle than the basal and top portions (71.66, 71.82 and 71.94%, respectively), and was higher in the younger than the older culms (76.47 and 69.90% of the respective one-to-four-year-old culm). While the higher holocellulose content of the younger culms could be due to its active development stage, the lower values observed in the older ones may be due to the regeneration processes. A comparison of the holocellulose content of *B. heterostacbya* (68-80%) with those of Malaysian timbers (5985%) (Khoo and Peh 1982) indicates its potential as an excellent material for use in pulping.

The highest and lowest mean lignin contents were observed in the basal (23.1%) and middle (19.7%) portions of the two and three-year-old culm respectively. Table 9 of the Duncan's test indicated that the amount of lignin increased from 20.6% in the half year old culm to 22.57% in the two-year-old culm, decreased to 20.82% in the three-year-old but increased again (even though differs insignificantly) to 21.3% in the four-year-old culm. This could be due to the fact that the full lignification of the bamboo culm is completed within one growing season with no further significant ageing

Table 9: Duncan's Multiple Range Test on the effect of age and culm height on the chemical composition of *B. heterostachya*

Parameter	Cold Water solubles (%)	Hot water so1ublcs (%)	Alcohol- bcnzcnc solllidcs (0/0)	1% NaOH so1ubles (%)	Lignin (0/0)	Holo- cellulose (0/0)	Ash (%)
Age (year)							
0.5	4.60b	7.05ab	2.44a	22.85c	20.63b	73.78b	2.83d
1	2.05c	.3.63c	2.80a	19.60d	21.65ab	76.47a	4.21b
2	5.34ab	5.80b	1.66b	20.45d	22.57a	69.02d	3.31c
3	6.13a	6.46ab	2.83a	25.23b	20.82b	69.87c	3.28c
4	5.06b	7.48a	2.88a	27.33a	21.30b	69.90c	4.66a
Portion							
Basal	4.77a	6.09ab	2.82a	22.55b	21.61a	71.82a	3.54a
Middle	4.64a	6.61a	2.47ab	23.91a	20.94a	71.66a	3.63a
TOP	4.50a	5.55b	2.28b	22.82b	21.63a	71.94a	3.80a

Note: Averages denoted by the same letter down the column differ insignificantly at P<0.05.

effects (Abd. Latif et al. 1994). The amount of lignin tended to decrease from basal (21.61%) towards the middle (20.94%) but increased again to the top (21.63%). This finding contradicted data reported in bamboos from China (Chen et al. 1987). As mentioned by Liese (1987), this reflects the individual characteristics of the bamboo itself. The lower mean lignin content of B. heterostacbya (about 20-23%) than those of G. *scortecbinii* (24-28%) (Abd. Latif et al. 1994), nevertheless, is within the range of those of four Indian bamboos that are widely used for papermaking (Subash and Sathpathy 1990).

The ash content which ranged from 2.73 to 5.27% exceeds those of Malaysian hardwoods (0.1 to 2.5%) (Khoo and Peh 1982) and G. *scortechinii* (1.09 to 1.18%), the most commonest bamboo species used in Peninsular Malaysia, but falls within the ranges of bamboos from India, Japan, Burma, Indonesia and Philippine (0.8 to 9.7%) (Semana et al. 1967). Since the ash content is commonly associated with the amount of silica in material like bamboo, thus affecting its working properties (Wang 1976), the selection of this material with its relatively high silica content for specific products such as furniture, structural components and skewers is significant.

The hot and cold solubles are important in the evaluation of water solubles extractives such as tannin, starch, sugar, pectin and phenolic compounds within the woody materials (Janes 1969). Higher concentrations of these water solubles extractives (1.13-7.26% and 2.54-9.14% for cold and hot solubles, respectively) may influence the durability of the bamboo materials (Plank 1951; Purusotham etal. 1953). Generally, the portion of the culm in each age group with lower lignin content contained higher cold and hot water solubles, but those portions with higher holocellulose contents had lower cold and hot water solubles. A similar trend was also observed in G. scortechinii(Abd. Latif et al. 1994).

The alcohol-benzene solubles of *B.* keterostachya ranged from 2.39% in the top portion of the two-year-old culm to 3.96% in the basal portion of the one-year-old culm, i.e. within the range for various bamboo species (Semana et al. 1967; Chen et al. 1987) and Malaysian timbers (Khoo and Peh 1982). The highest and lowest mean percentages of alkali solubles, on the other hand, were observed in the basal portions of the respective one (l8.1%) and four-year-old culm (28%). High alkali solubles could be associated with high degradation of cellulose and high polyphenol content (Clayton 1969; Tadena and Villaneuva 1971). Compared to Malaysian hardwoods (Khoo and Peh 1982), this bamboo appears to have high alkali solubility. The relatively lower yield from chemical pulping of the material due to this property could, however, be compensated for by its high holocellulose content.

Conclusion

The physical properties of *B. heterostachya* were observed to be governed significantly by age, diameter and culm wall thickness. The initial moisture content generally decreased with age but correlated insignificantly with the position in culm. The density, on the other hand, increased with maturity and tended to have higher values towards the top portion of the culms. Older bamboos were found to shrink less than the younger ones.

There is wide variation in the chemical constituents within the culms of the same age group and between culms of different age groups of the half- to four-year-old samples studied. The considerably high holocellulose content is the attractive feature of this species for pulping. The relatively high alkali solubility may, however, affect the yield in chemical pulping.

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Bamboo Shoot Drying Technology

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Abstract

Bamboo shoot is one of the perishable vegetables. Among the several technologies employed to preserve the quality of bamboo shoots, drying is perhaps the simplest yet most effective. This research was aimed at studying the pre-treatments for *Dendmcalamus aspershoots* – pre-cooking and the use of anti-browning agents (ascorbic acid, sodium chloride and sodium metabisulphite)- during drying.

Results showed that pre-cooking significantly influenced the quality of dried bamboo shoot – fastest rehydration (maximum absorption reached within 30 minutes), highest rehydration ratio (19 times the dried shoot) and an excellent texture of the rehydrated shoot (softer than the pre-cooked). Among the anti-browning agents, sodium metabisulphite (2 000 ppm) was the most effective in preventing browning. Brine (2%) and plain water, although not as effective as sodium metabisulphite, gave a lighter colour to dried shoot when compared with ascorbic acid. Submersion of bamboo shoot in ascorbic acid (0.05%) prior to drying did not prevent browning.

Materials and Methods

Raw material

Dendrocalamus asper(Betung) shoot

Chemicals

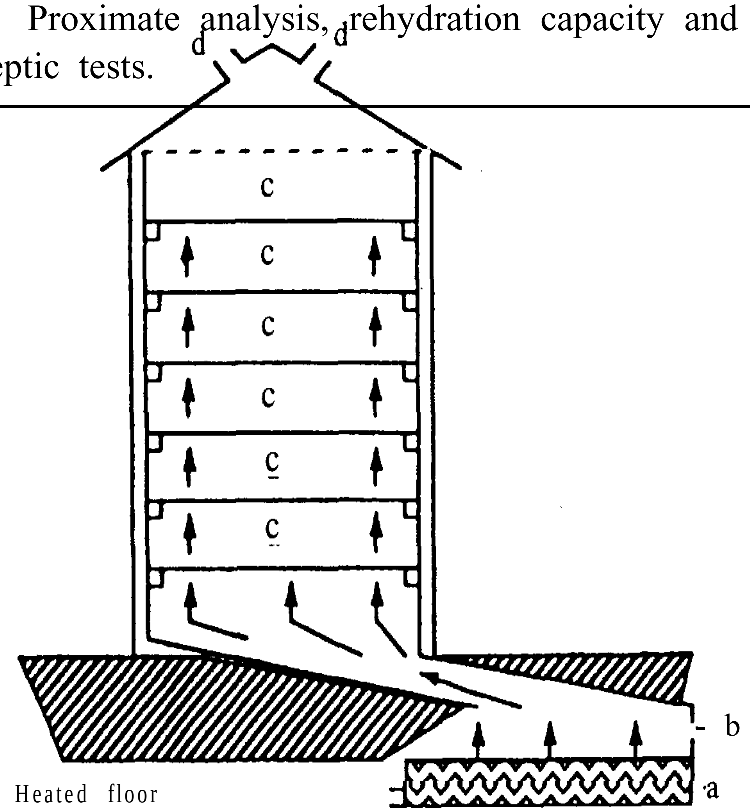
Sodium chloride (NaCl), sodium metabisulphite ($Na_2S_2O_3$), ascorbic acid, etc.

Equipment

Cabinet drier (Figure l), autoclave, glassware, etc.

Test methods

Proximate analysis, rehydration capacity and texture tests, and organoleptic tests.



a = Furnace, b = Air inlet, c = Tray, d = Air outlet

Fig. 1: Scheme of cabinet drier

Results and Discussion

Proximate analysis

The procedure adopted is illustrated in Figure 2. The test results obtained are given in Table 1.

Table 1: Proximate analysis of the bamboo shoot

Compound (% db)	Fresh Shoot	Dried Shoot
Water	92.64	4.56
Protein	27.79	21.63
Starch	28.32	9.20
Fibre	5.20	4.96
Ascorbic acid	2.07	0.23

Significant decreases in starch and ascorbic acid were observed. Starch in leucoplast was gelatinized during the drying process, while ascorbic acid

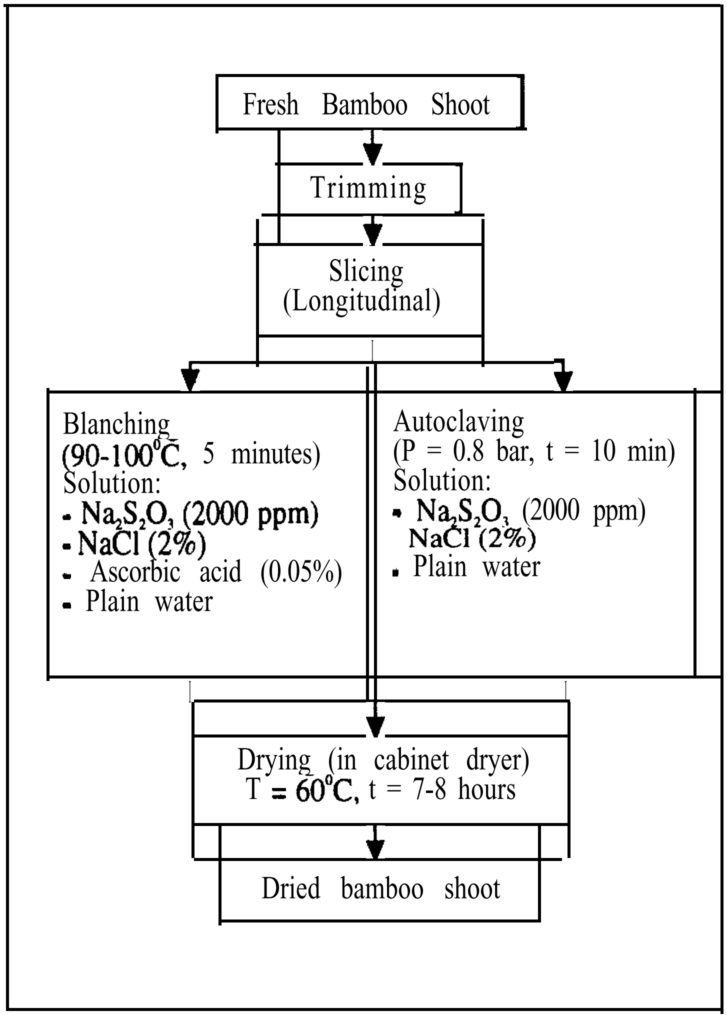


Fig. 2: Scheme of bamboo shoot drying process

dissolved in water and was unstable at high temperatures. Although the ascorbic acid content prevented browning reaction, the role of $Na_2S_2O_3$ treatment was more to prevent discolouration.

Rehydration capacity and texture

Rehydration capability depends on the cell wall elasticity and starch gelatinization. Pre-cooking stimulated starch gelatinization and increased the water absorption of rehydrated bamboo shoot. Bamboo shoot which is not pre-cooked needed a longer time to reach the maximum rehydration capacity (90 minutes) than the pre-cooked dried bamboo shoot (30 minutes) (Figure 3). The rehydration ratio for the pre-cooked shoot was higher (10 to 19 times) than the one which was not pre-cooked (9-13 times).

The pre-cooking treatment had a significant effect on the texture of the rehydrated shoot (Figure 4).

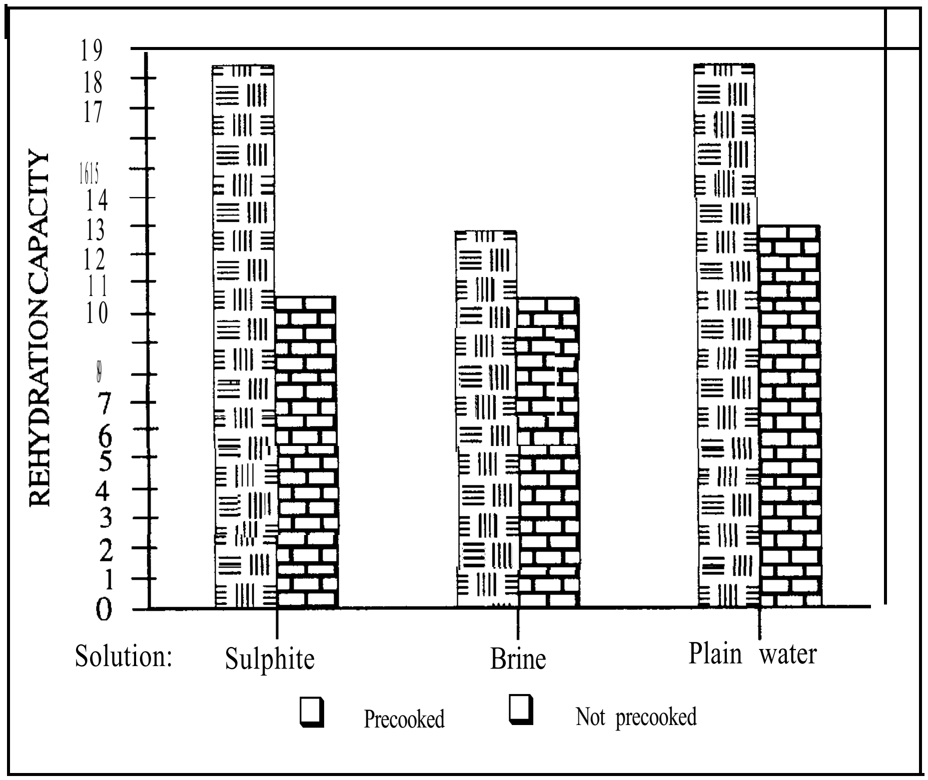


Fig. 3: Effect of pre-cooking on the rehydration ratio

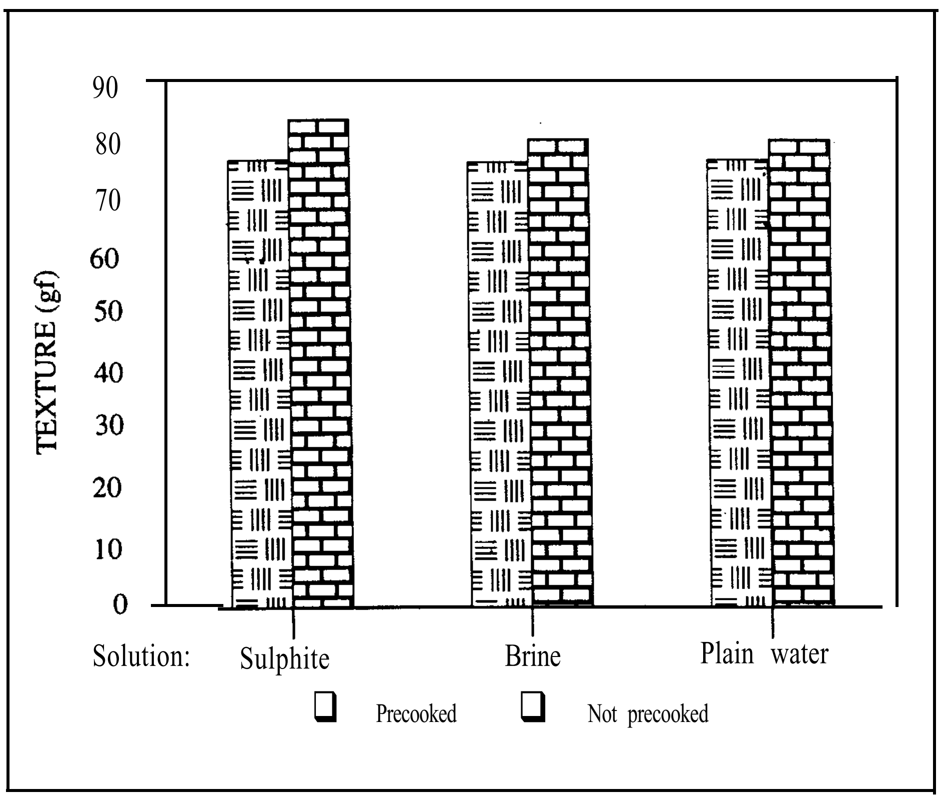


Fig. 4: Effects of pre-cooking and anti-browning agent on the texture of rehydrated bamboo shoot

Organoleptic test

Organoleptic tests were carried out to determine the difference in colour and aroma (hedonic scale: 1 to 5). In general, the panelists scored both dried and rehydrated bamboo shoot as acceptable in terms of aroma (3-5 on a scale of l-5). The pre-cooking treatment gave a pale colour because anthocyanin, which gives the shoot its yellow colour, dissolves in water during the process. Hence, the pre-cooked bamboo shoot scored less in terms of colour than the untreated shoot (Figures 5-S).

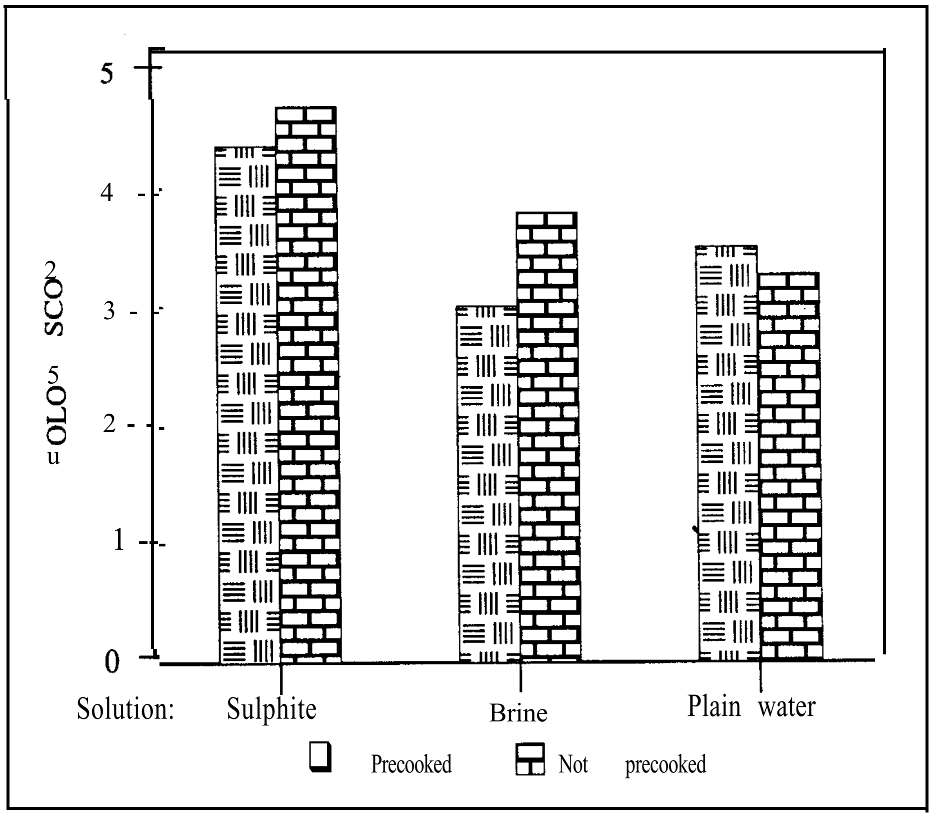


Fig. 5: The score of dried bamboo shoot colour

$Na_2S_2O_3$ as an anti-browning agent gave the highest score for colour and aroma. NaCl solution (brine) and water had no significant effect on the shoot, but gave acceptable results.

Conclusion

The benefits of pre-cooking, as indicated by test results, are as follows:

- Minimized the time to reach maximum rehydration capacity;
- Increased rehydration ratio; and
- Decreased hardness value after rehydration process.

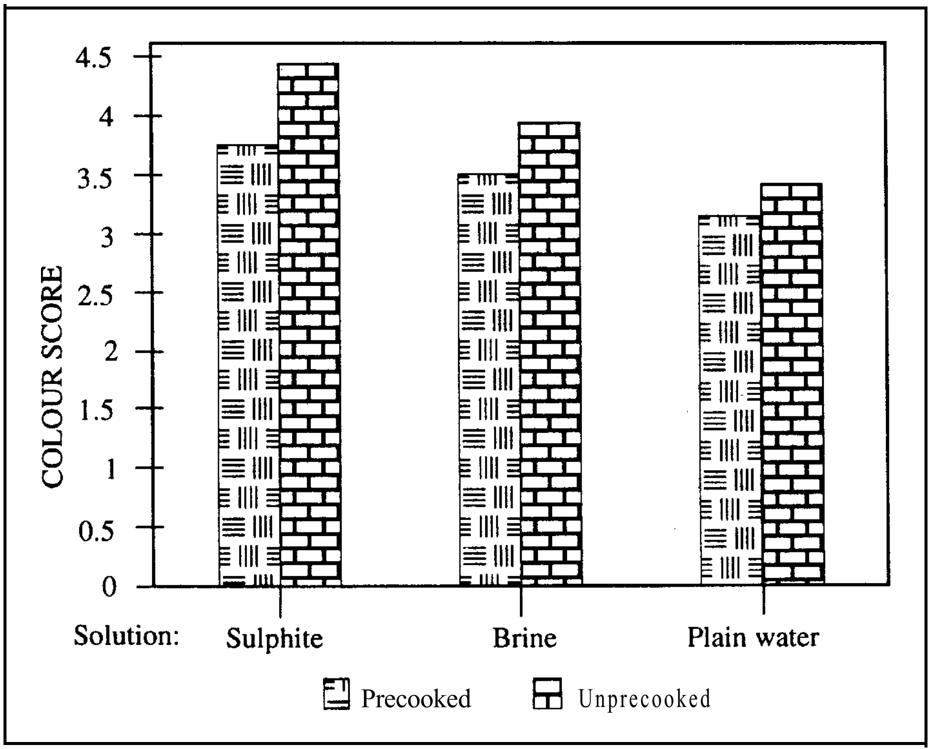


Fig. 6: The score of rehydrated bamboo shoot colour

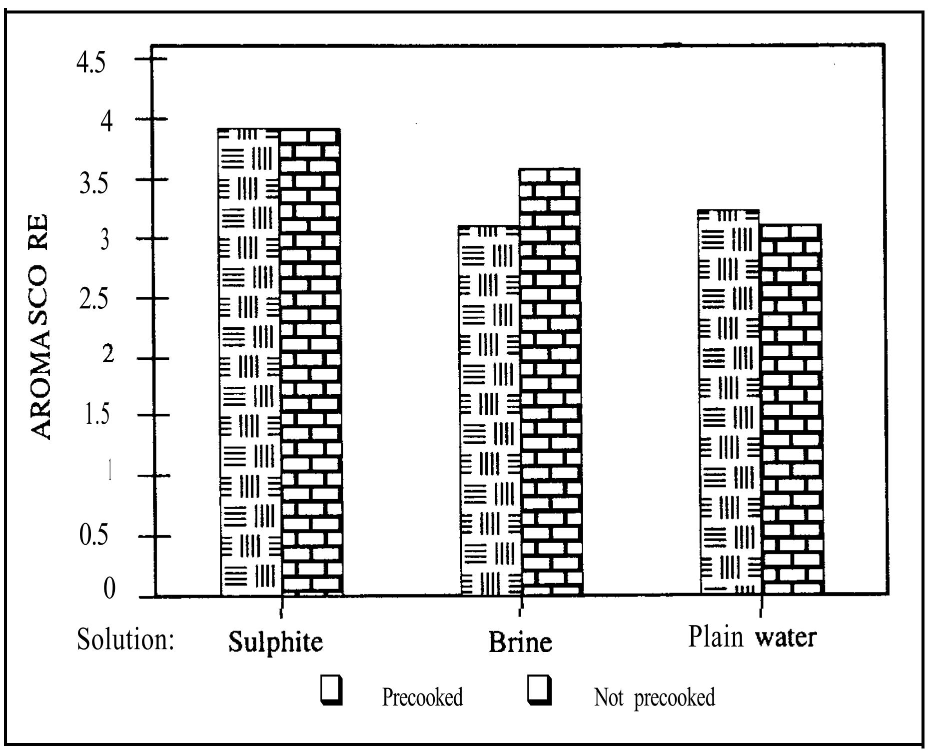


Fig. 7: The score of dried bamboo shoot aroma

Ascorbic acid solution was found unsuitable for use in bamboo shoot drying, because it oxidizes and produces brown colour.

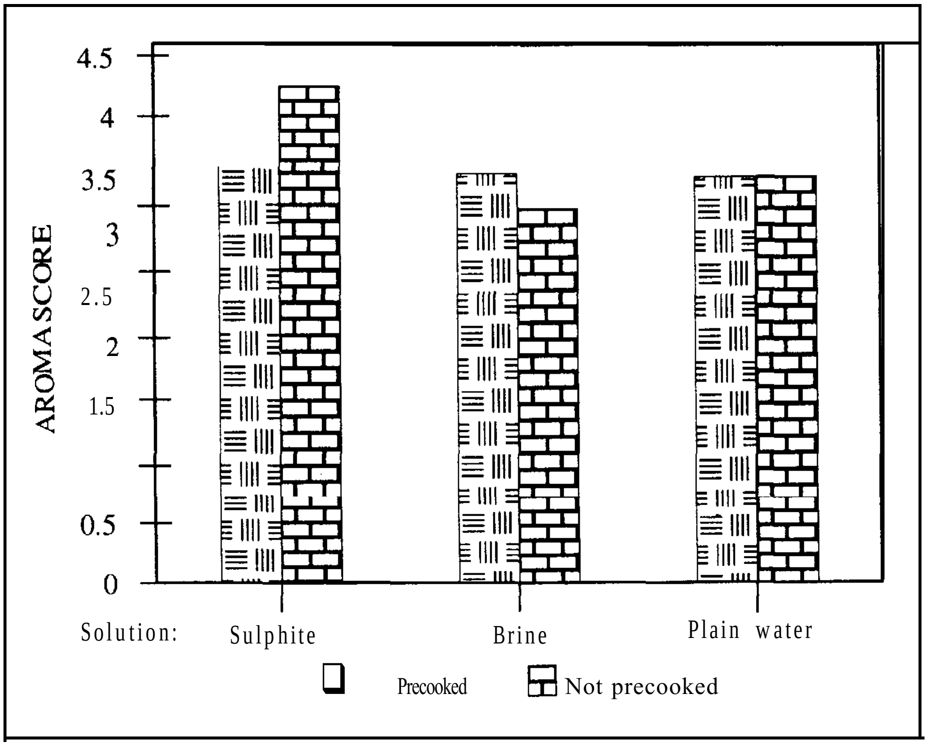


Fig. 8: The score of rehydrated bamboo shoot aroma

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Can Bamboo Substitute pinus merkusii in Paper Making? An Overall Comparative Study

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Abstract

Bamboo has a woody structure and relatively long fibres, and the culms can be harvested when 2-3 years old. *Pinus merkusii,* on the other hand, is a softwood with long fibres and its rotation is 15 years. It is of interest to know whether some bamboo species could be used as a substitute for *P.* merkusii in paper making and thereby save timber resources and promote industrial bamboo plantations.

This paper reports the results of a comparative study of *Gigantochloa* apusand *P.* merkusii with regard to producing pulp for making strong paper. The results showed that G. apus pulp can be used as a substitute for *P. merkusii* pulp in paper making by choosing appropriate pulping conditions and pulp mixture composition.

Introduction

Indonesia started its pulp and paper industry in 1923 with the utilization of rice straw, in the form of merang at the Padalarang Paper Mill in West Java. This mill produced 10 tons/day of writing and printing paper. Two more mills were established more than 15 years later based on the same raw material.

In 1967-68, bamboo was introduced by two new mills in Banyuwangi, East Java, and the Gowa Paper Mill in south Sulawesi. The bamboo raw material came from the natural forests nearby. Soon both mills were producing writing and printing paper from 100% bamboo pulp. In the course of time, however, the production of bamboo from the forests decreased tremendously, probably because of population pressure and rapid mechanized exploitation. In the 1970s, the conversion of bamboo natural forests into *Pinus merkusii* plantation started in East Java. The paper mills were then forced into using wood.

Bamboo has a woody structure and relatively long fibres, longer than most hardwood species. Culms can be harvested when 2-3 years old. P. *merkusii,* on the other hand, is a softwood with long fibres and its rotation is 15 years. *P. merkusiiin* natural stands and plantations in Aceh and North Sumatra are at the moment used as raw material for Kraft paper pulp to make strong packaging paper. Countries like India and China which are not endowed with adequate softwood resource have used bamboo, by itself or in mixtures, as a base for strong paper. It is, therefore, of interest to know whether some bamboo species in Indonesia could be used to substitute P. mmkusii in paper making. If feasible, it would save timber resources and help establish industrial bamboo plantations. It would also give the opportunity to people in the villages to earn additional income by participating in the supply of bamboo for the paper industry. Although Indonesia ranks as number 20th in world pulp production (1992), it mostly produces short-fibre hardwood pulp. The demand for long-fibre pulp is covered by imports, which seems to increase every year.

This paper is a report of a comparative study of *Gigantochloa* apus (Bambu tali) and *P. merkusii* with regard to pulp production for paper making. An attempt is made to understand their pulping and paper making characteristics in order to determine the potential for effective utilization.

Materials and Methods

Gigantochloa apus and *Pinus merkusii*

The bamboo species used in this study was *Gigantochloa apus* from the Bandung area in West Java. The age of the culms were one and three years. Pinus *merkusii* came from a plantation in Aceh, Sumatra, and had a diameter of 30 cm. 'They were all chipped in a pilot plant chipper and screened to standard size. The fibre dimensions were measured under a microscope, and chemical analysis carried out on *G. apus* and *P. merkusii* to determine the suitability of these materials for making paper pulp.

The pulping process used in this study was the Kraft process. The experiments were performed in three-litre laboratory digesters rotating in hot air. Conditions were created to obtain pulps of kappa number 30, 45, 60 for G. *apusas* well as *P. merkusii.* The pulping temperature was set at 165°C for bamboo and 1 70°C for *P.* merkusii which were reached after two hours heating. The liquor to material ratio was 1:4. The chips of the one-year and three-year-old bamboo culms were mixed.

The pulps obtained were beaten in a laboratory beater, made into sheets and tested for their physical properties. Tests were performed on individual sheets of bamboo and softwood pulps, as well as their mixtures. TAPPI standard methods were applied.

Results and Discussion

Fibre morphology and chemical composition

Knowledge of the morphological characteristics of fibres help in determining the suitability of a raw material for paper making. Fibre length and fibre strength affect sheet properties, especially the tearing strength. Many studies have shown that longer and stronger fibre would give a paper of higher tearing strength. The tensile strength, however, is dominated by the deformity that the fibre undergoes because of the relatively thin cell walls. This is indicated by a Runkell number of less than one.

The length of G. *apus* fibres was found to be 3.3. mm and that of P. *merkusii 5.4* mm, the latter being more than one-and-a-half times longer than the former. The bamboo fibres, however, showed a fibre diameter of 16.5 microns, while that of the pine was 35.7 microns. The slenderness ratio -the ratio of length to diameter – was 20 1 for G. *apus* and 15 1 for P. *merkusii.* Furthermore, the Runkell number of the pine was 0.93, indicating relatively thin cell walls, while that of G. *apus* was 5.32, indicating relatively thick cell walls.

Table 1 shows the chemical composition of the bamboo and the pine. The lignin contents of the one-year and three-year-old G. *apus,* and that of *P. merkusiiwere* very similar. The holocellulose and =-cellulose contents, which have significant effect on pulp yield, of G. *apuswere* found to be greater. The higher pentosans content of bamboo is characteristic of the grass family, while the low pentosans content of the pine conforms to that of softwood. The higher 1% NaOH solubilities of bamboo indicate better accessibility to liquor penetration, which could also mean a more open structure.

Pulping

Thanks to previous orientation studies on G. *atter,* target kappa numbers of 30, 45, 60 could be more systematically obtained. Pulping temperatures were set at 165°C for G. *apus* and 170°C for *P. merkusii*. Manipulations were made on time and chemical charge. Although *P. merkusii* and G. *apus* have similar lignin contents, it turned out that the bamboo was easier to delignify. For a similar kappa number, bamboo needed less chemicals (13-15% active alkali at 20% sulfidity) and less energy (30-60 minutes at maximum temperature). *P. merkusii,* on the other hand, needed 17% active alkali at 25% sulfidity and 30-90 minutes time at maximum temperature. This could be due to the more open physical structure of the bamboo, as well as its lignin structure which is more susceptible to degradation. According to Li Zhiquing, bamboo lignin consists of large amounts of syringyl and phydroxyphenyl units. Besides requiring less chemicals and energy to obtain the same kappa number, G. *apus* also gave a higher total yield (47.2%, 49.5% and 50.7%o for kappa numbers 30,45 and 60, respectively) while the yield of *P. merkusii* was lower (39%, 46.2% and 48.3% for kappa numbers 30,45 and 60, respectively). The difference was largest at kappa number 30.

Table 1: Proximate chemical analysis (% OD)

Parameter	*Gigantochloa apus*		*P. merkusii*
	1 year old	3 years old	
Lignin	26.58	26.85	26.77
Holocellulose	71.23	71.34	67.31
Alpha cellulose	47.09	45.73	42.04
Pentosans	19.02	19.96	7.52
Solubilities in:			
- Alcohol-benzene	4.78	4.54	4.33
- Hot water	6.26	6.67	2.63
- 1% NaOH	22.58	24.65	12.68
Ash	2.13	2.48	0.18
Silicon dioxide	1.21	1.49	

Beating and Freeness

The pulp evaluation was performed by beating in a laboratory beater to four levels of beating time. The change in freeness values is shown in Figure 1. In the unbeaten state, the freeness values of both bamboo and pine pulps at all kappa numbers were very similar. As the beating cycle

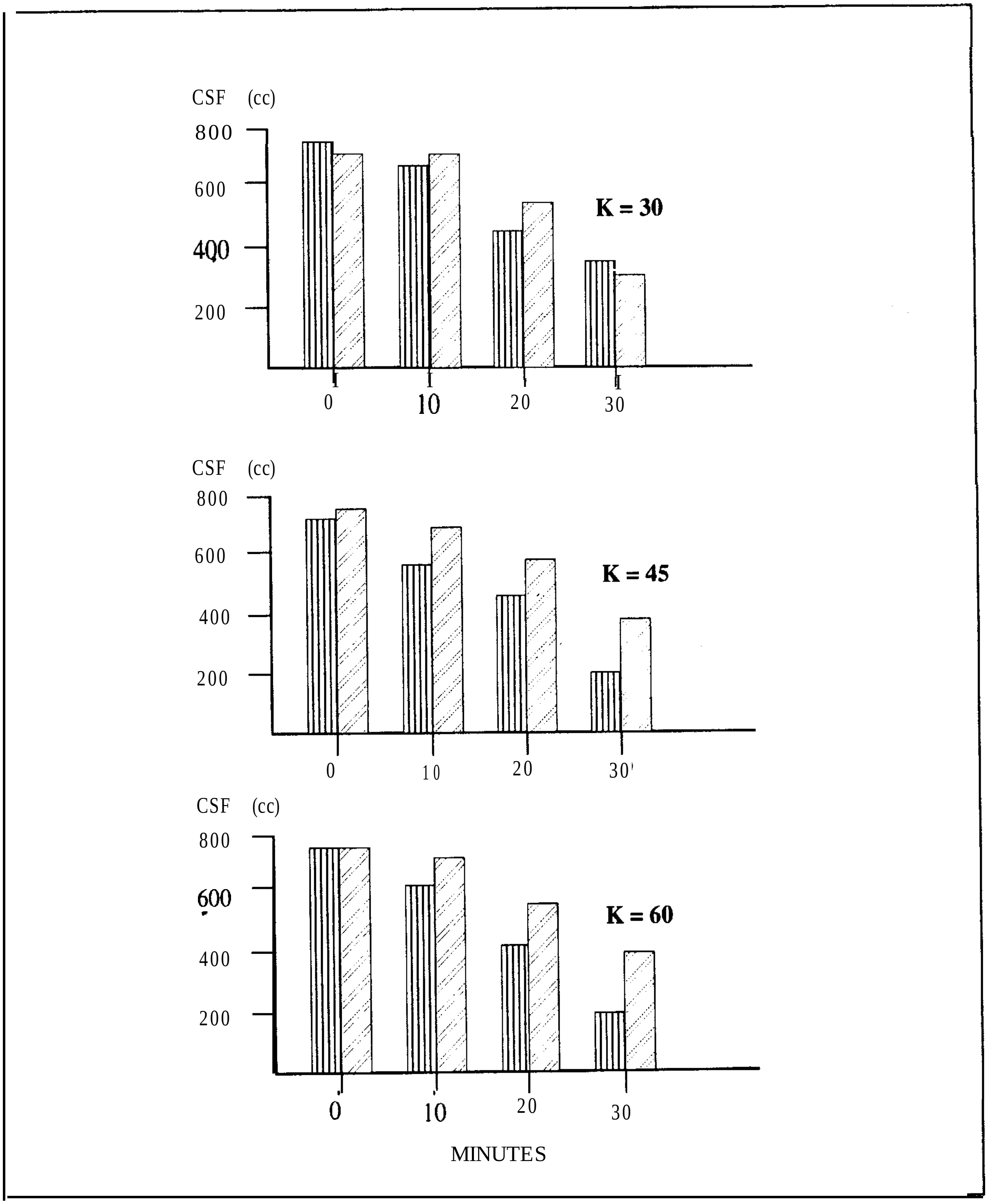

Fig. 1: Freeness change in pulps

broad and narrow lamellae. According to Wai et al. (nd.), the outer secondary layer of bamboo fibre has a microfibril angle of about 20° with respect to the fibre axis, which is much smaller than that of the secondary layer of a wood fibre. As a result, this layer appears to offer little resistance to prevent external swelling of the broad layers, causing more rapid decrease in freeness during beating.

Sheet Strength Properties

Individual pulps

After the pulps were beaten, made into sheets and tested, a comparison of the sheet strengths was made. Figures 2-4 show the strength potential of G. apus compared to that of *P. merkusii* at several degrees of delignification or kappa number.

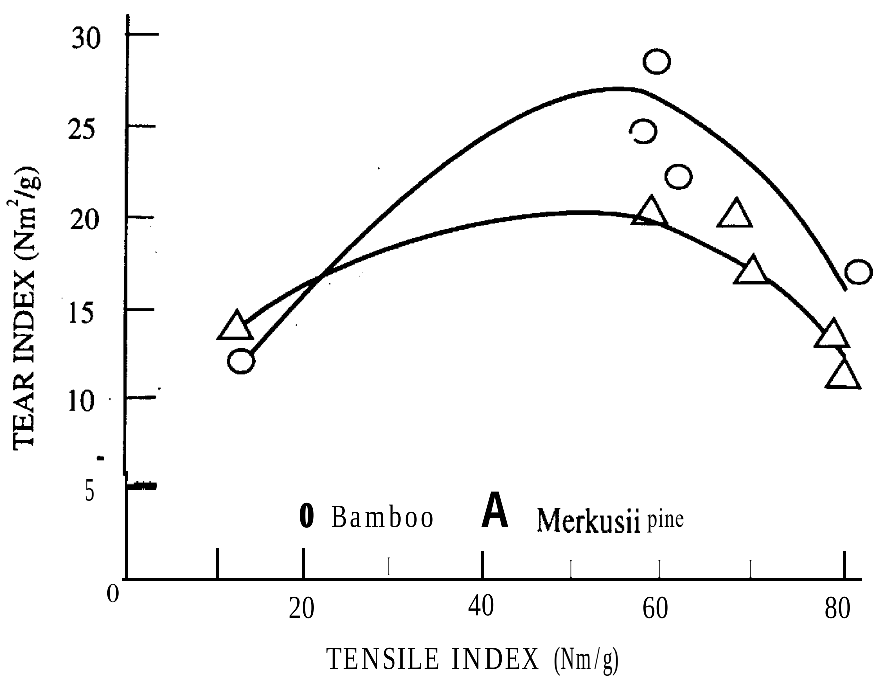

Fig. 2: Strength properties of bamboo and pine pulps (kappa 30)

At kappa number 30, the strength of G. apuspulp was found to be superior to that of P. merkusii pulp, especially in tearing strength. It seems that at this degree of delignification, bamboo fibres still preserve their strength, and because of polylamellate structure and rapid internal fibrillation, good fibre bonding is also obtained. The relatively thick walls and the slenderness are responsible for the good tearing strength of bamboo

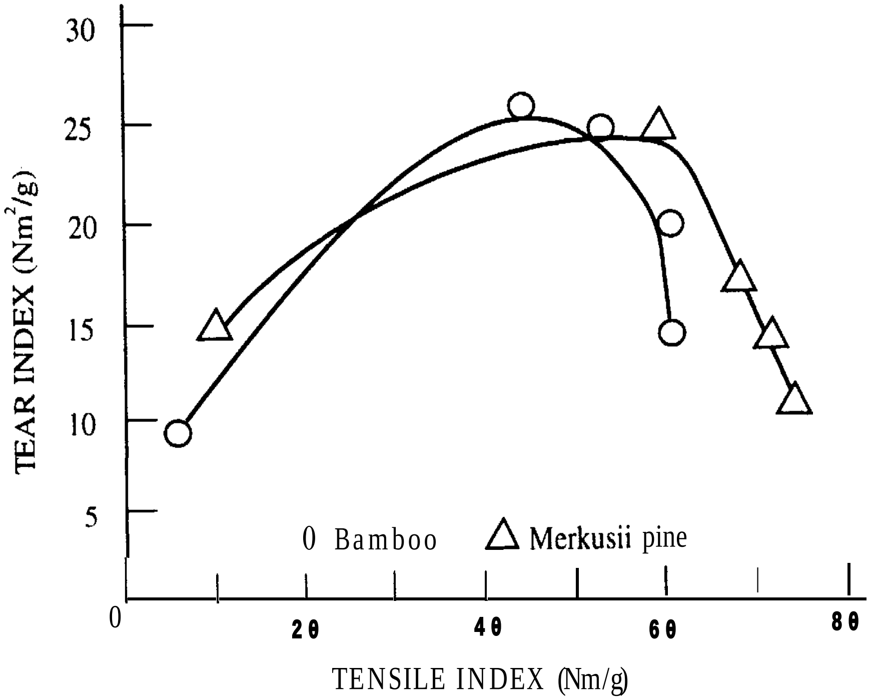

Fig. 3: Strength properties of bamboo and pine pulps (kappa 45)

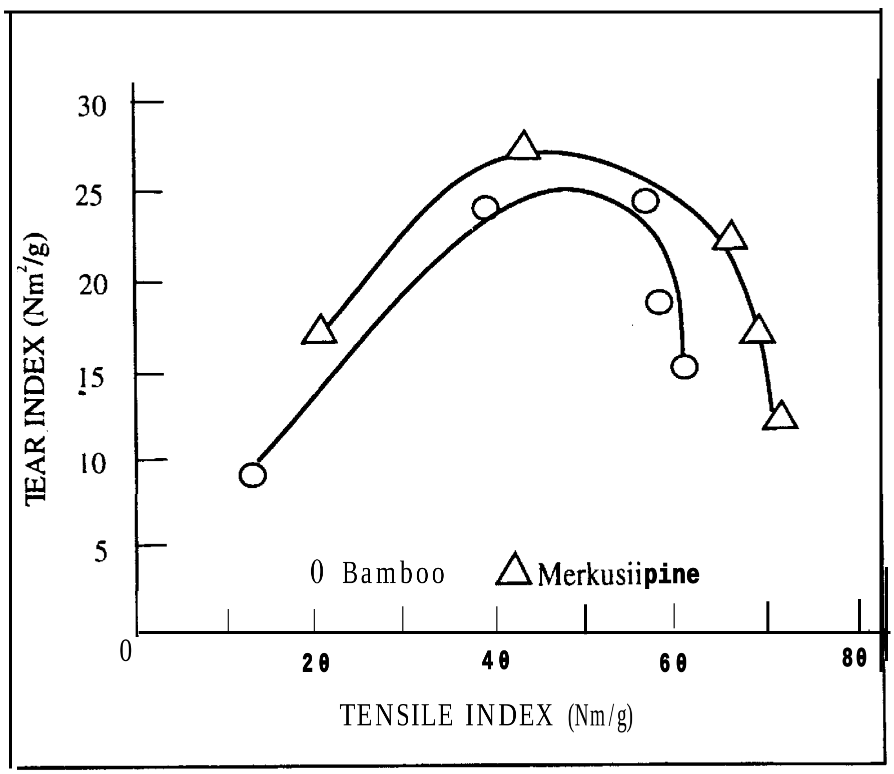

Fig. 4: Strength properties of bamboo and pine pulps (kappa 60)

fibres, although the fibre length is only two-third that of a *P. merkusii* fibre. In the case of softwood fibres, however, kappa 30 is mostly used as the lowest limit in the degree of delignification, since the cellulose molecules are more easily degraded. This is also shown by *P. merkusii* fibres. At kappa 30, the tearing strength of its pulp was considerably lower than that of the bamboo pulp, probably because of cellulose degradation. At kappa 60,.it was somewhat higher as it could preserve fibre strength owing to milder pulping conditions.

That G. *apus* pulp gives sheets of higher tearing strength, while P. *merkusii* pulp gives sheets of higher tensile strength conforms to their respective fibre morphology. So there is an option to develop the potential of G. *apus* as well as *P. merkusii* for papennaking by choosing the right pulping conditions and beating treatment. This would also give an option to substitute bamboo for pine.

Pulp mixtures

Sheets were made of mixtures of G. apus and P. merkusii pulps of the same kappa number after beating in. the laboratory beater. The composition of the mixtures were of 25%, 50% and 75% of bamboo pulp content in order to see the effect of bamboo substitution. Figures 5-7 show their strength compared with that of the pure *P. merkusii* pulp.

For kappa numbers 60 and 45 course strength development of the pulp mixture were close to that of *P. merkusii.* Improvement of tearing strength

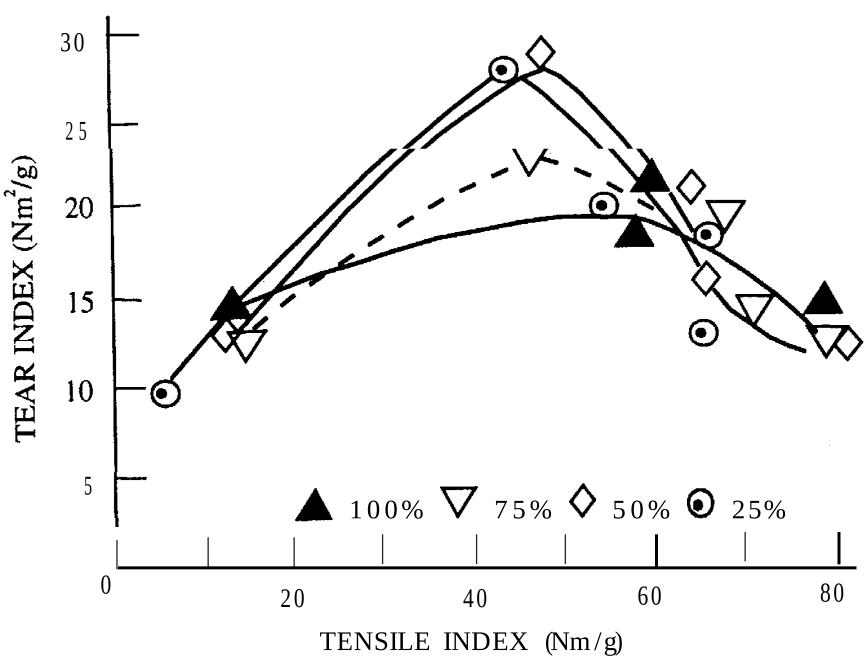

Fig. 5: Strength properties of different pulp mixtures (kappa 30)

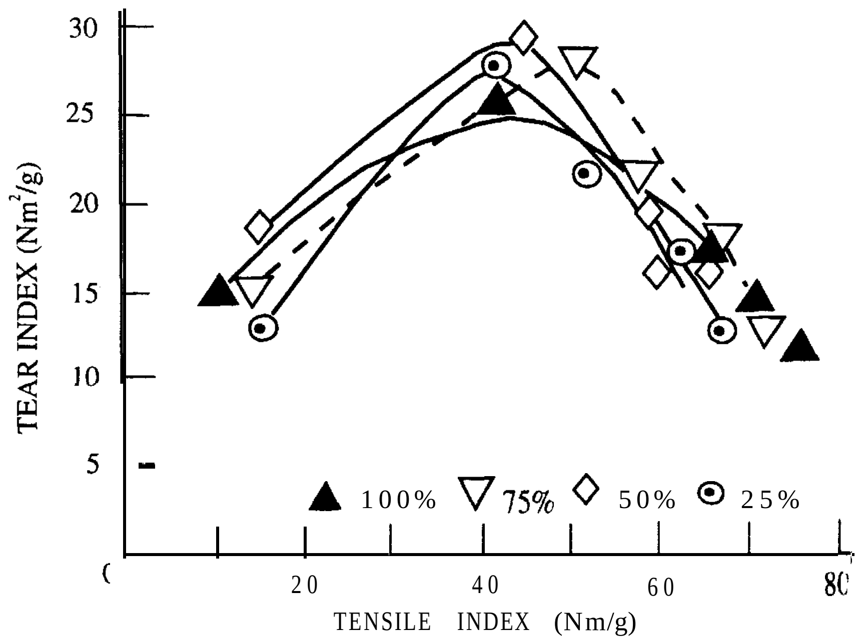

Fig. 6: **Strength properties** of different pulp mixtures (kappa 45)

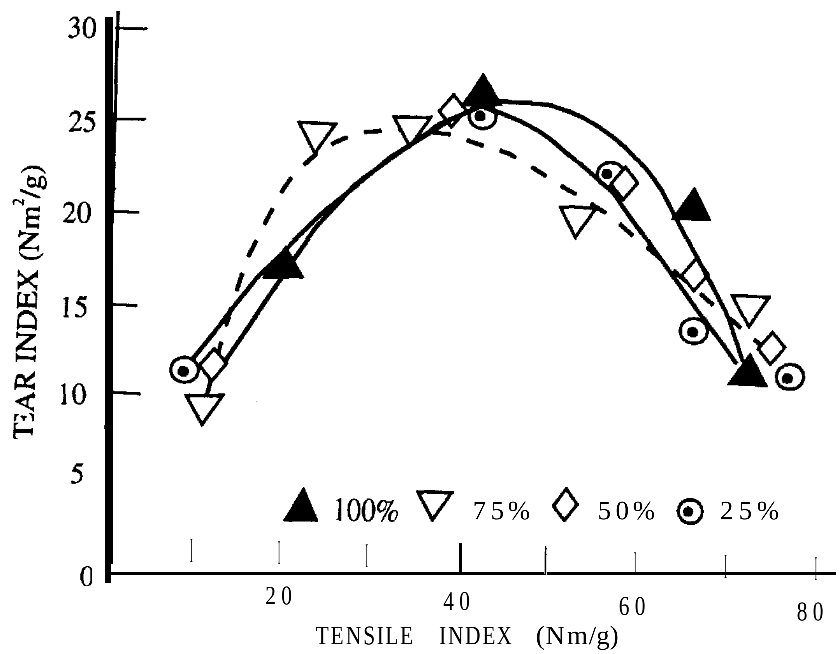

Fig. 7: Strength properties of different pulp mixtures (kappa 60)

at an early stage of beating was clearly shown for mixtures at kappa 30 and 45 (Figures 8-10). When compared at a freeness of 400-500 CSF, the pulps at kappa 60 gave sheets of almost similar tear index, irrespective of their composition. All these show that *Gigantochloa* aptlscan be used as a substitute for *P. merkusii* in paper making. There is an option to obtain paper with the required properties by choosing the proper pulping conditions and the composition of the mixtures.

Conclusion

1. The strength properties of the pulp of G. apus are comparable to that of P. merkusii at similar degrees of delignification (kappa 30,45 and 60).

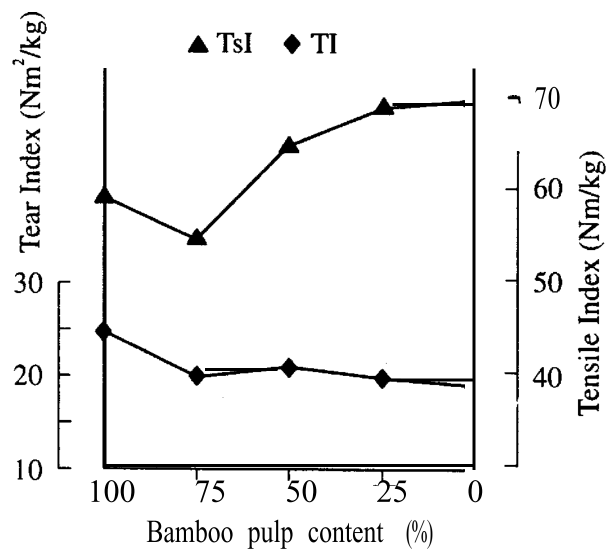

Fig. 8: Strength properties of pulp mixtures at 400-500 CSF (kappa 30)

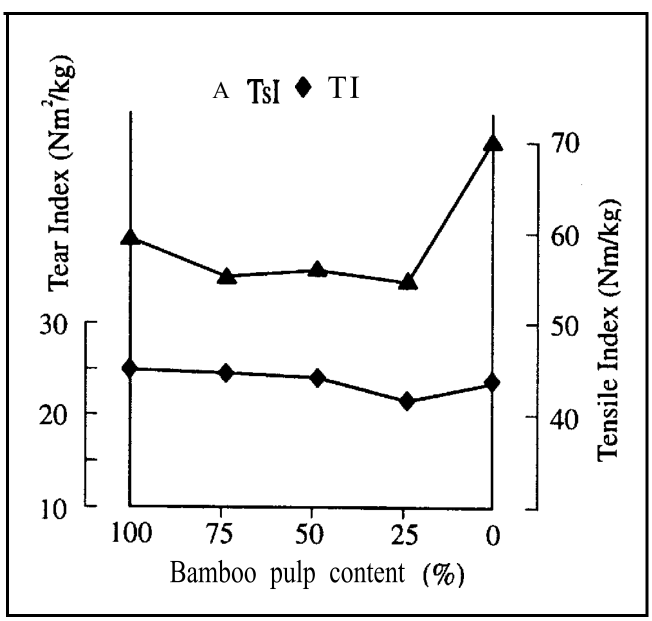

Fig. 9: Strength properties of pulp mixtures at 400-500 CSF (kappa 45)

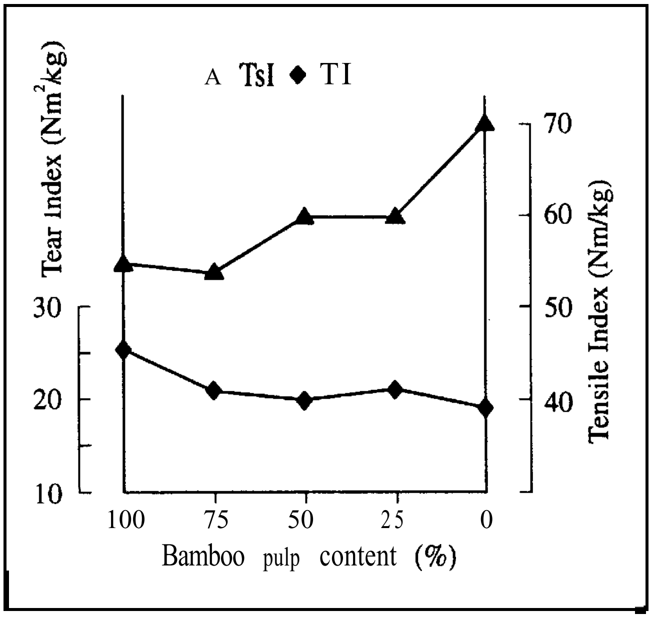

Fig. 10: Strength properties of pulp mixtures at 400-500 CSF (kappa 60)

2. Bamboo pulp sheets are of higher tearing strength and the pine pulps sheets of higher tensile strength. At a low degree of delignification (kappa 60), however, *P. merkusii* can give a pulp comparable in tearing strength to that of the bamboo pulp.
3. The mixing of the bamboo and pine pulps gives an option to obtain sheets of desired strength properties. If a sheet of high tensile strength is needed, pulp delignified to kappa 30 are required and the pine pulp could be substituted by bamboo up to 50%. For high tearing strength, a 100% bamboo pulp can be used at all kappa numbers.
4. The differences in behaviour of G. *apus* and *P. merkusii* during pulping and beating, as well as in their strength properties, could be caused by their different physical structure, lignin structure and ultrastructure.
5. It is possible to save chemicals and energy when using bamboo pulps at similar kappa numbers as that of *merkusii* pine.

It is hoped that this study would encourage further exploration into the potential of bamboo pulp in substituting *merkusii* pine pulp in paper making, thereby making a positive contribution to saving natural forests.

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Bamboo Furniture Industry in the Philippines

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Abstract

This paper deals with the development and status of the bamboo furniture industry in the Philippines. Bamboo furniture manufacture in the country dates back to the Spanish conquest period, although as an organized industry it is only a few decades old.

The species considered suitable for furniture are: *Bambusa bhmeana, B. vulgaris, Dendrocalamus asper D. merrillianus, Gigavztochloa levis, G. atter, Schizostachyum lumampao, S. lima* and *Sphaero-bambos philippinensis.*

During 1985-94, bamboo furniture became an important foreign exchange earner for the country as it slowly found its way into the export market. In 1991, it went up to US$1.93 million, and accounted for a 1% share of the furniture market in 1992. In subsequent years, however, there has been a decline. It is expected that the performance of bamboo furniture will increase considerably in 1995 since the national government has initiated a series of measures to develop the bamboo industry, and bamboo furniture industry in particular.

Introduction

Bamboo is one of the oldest materials used by people in almost every aspect of their daily life. Its importance is better known in areas where they abound, or where wood is either not readily available or is very expensive. The shortage in wood supplies and the long period required to produce them have prompted major industries to look for wood substitutes.

The many uses of bamboo and the associated technologies which benefit various local bamboo industries include housing and construction, handicrafts, furniture, fishing structures, banana props, and pulp and paper.

In the Philippines there are 47 species of bamboo reported, but only a few are considered commercially important. Thirty five species are erect and the rest are climbing (Anonymous 1991). Presently, only the following nine species are considered suitable for furniture: *Bambusa blumeana* (kauayan tinik), *B. vulgaris* (kauayan kiling), Dendrocalamus asper(giant bamboo), *D.* merrillianus (bayog), *Gigantochloa* levis (botong or bolo), *G. atter* (kayali), *Schizostachyum lumampao* (buho), *S. lima* (anos) and *Sphaerobambos philippinensis* (laak). The distribution description and important uses of these are presented in Table 1.

Bamboo Furniture Industry Profile

Bamboo furniture manufacture in the Philippines is several centuries old, dating back to the period of the Spanish conquest. At that time, simple chairs, beds, cupboards and tables were made usually by the householders themselves. However, bamboo furniture as an organized industry is only a few decades old. At present, furniture of traditional and old-fashioned designs are being marketed into the United States, Australia and several European countries. In rural areas, it is still a common sight to see bamboo benches and stools in front of local stores. As such items were crudely made and roughly finished, the potential of bamboo furniture remained un-appreciated and unexploited until recently.

Furniture makers have commercialized the use of bamboo because of the need to increase and sustain incomes during times of economic crisis. Displays of bamboo furniture are a familiar sight along provincial and national highways. At present, big department stores also carry bamboo furniture as one of the many product lines they sell (Table 2).

There is a great demand for bamboo items because of its numerous uses. However, very little is known about the actual demand for bamboo, much less the demand of each industry.

Duringthe 10 year period 1985-94, bamboofurniturehasbecome an important foreign exchange earner for the country (Table 3) as it slowly found its way into the export market. In 1985, bamboo furniture exports amounted to only US$625 525, but by 1991 it went up to US$l.93 million. Because of the economic problems in the country, the export decreased to US$1.83 million in 1992, US$l.4 million in 1993 and US$1.22 million in 1994. The share of bamboo furniture in total furniture exports was mostly less than l%, which declined to 0.51% in 1994. Aware of the good local and export market potentials of bamboo furniture, people are being encouraged to go into bamboo furniture

Table 1: Description, distribution and uses of bamboos suitable for furniture

Species	Description	Distribution	Use
Bambusab lumeana (Kauayan tinik)	It has an erect, thick-walled culm with 10-25 m height and 10-15 cm diameter. Has superior strength and durability.	Almost everywhere in the country, except in high elevations.	Most useful and valuable among all local species.
Bambusa vulgaris (Kauayan kiling)	Compared to B. blumeana,culm is smaller in size, has thinner walls, and lower strength and durability.	Backyards along the periphery of cultivated lands,creeks and foot hills.	Furniture, toys and cages.
Dendrocalamus asper (Giant bamboo)	It is called 'giant bamboo' in view of its height (25-32 m) and diameter (14-20 cm>.	Mt. Makiling, Bukidnon, South Catabato, Samar and Leyte.	Furniture and their components.
Dendrocalamus merrillianus (Bayog)	Slender, thick-wailed culms with prominent nodes. Forms a large, open-tufted clump. Height is 10-15 m and diameter is 6-10 cm).	Native of the Philippines, specifically Pampanga, Tarlac, La Union, Ilocos Provinces.	Housing construction and furniture.
Gigantochloa atter (Kayali)	Height is 22 m and the diameter 6-10 cm.	Davao, Bukidnon, Surigao, Samar, Leyte.	Furniture components.
Gigantochloa levis (Bolo)	Resembles *B. blumeana,* but the culm is straight and smooth with less prominent nodes. Height is about 20 m, and diameter 8-13 cm.	Mt. Makiling, Laguna, Batangas, Mindoro, Palawan, Basilan,Panay and Leyte.	Furniture, construction materials and bamboo mats.
Schizostachyum lumampao (Buho)	Culm is erect, spineless, with a height of 10-12 m and a diameter of 4-6 cm. Outer culm surface is covered with yellowish hairs.	Batangas, Laguna, Mindoro, Panay, Palawan, Basilan and Leyte.	Bamboo mats, used for walling in rural areas.
Scbizostacbyum lima (Anos)	Thin-walled, spineless, erect and forms a dense clump. Culm height is 6-8 m and diameter 2-4 cm. Culm internodes are 12-60 cm long.	Native to the Philippines, Agusan, Mindoro, Rizal in Central and Northern Luzon.	Bamboo mats
Spbaerobambos pbilippinensis (Laak)	Culm is usually 4-6 m in height and about 5 cm in diameter	, Abundant in Davao del Norte.	Banana props

Table 2: Product lines of furniture manufacturers

Traditional Product	New Product
Benches or *bangko*	Living room and dining sets,
Light beds or *papag*	Beds, display racks, cabinets, dividers, window shades, bookshelves and lounging chairs.

Table 3: Bamboo furniture exports (1985-94, FOB value in US$)

Year	Bamboo furniture	Total furniture	Percentage of total
1985	625 535	79743235	0.78
1986	858 923	89 352 587	0.97
1987	880 998	130 380 353	0.68
1988	1 335 521	183 704 011	0.73
1989	1815 866	203 710 396	0.89
1990	I 655 411	189 459 734	0.87
1991	1932 578	177 227 566	1.09
1992	1836 159	181 175 337	1.01
1993	1401830	203 213 324	0.69
1994	1224 229	238 585 118	0.51

Source: Foreign Statistics 1985-88, 1989-93, 1994,

making. Many furniture firms have also expanded from rattan and/or wood into bamboo furniture. Other factors - such as the availability of raw materials, low capital investment and low level of skills required - have contributed to the development of the industry.

This industry cannot be taken for granted, and measures are urgently required to improve and nurture its growth. For this, more must be known about bamboo furniture manufacture, especially about the processing aspects and the training needs of the industry. This is essential to improve production as well as product quality. It needs to be appreciated that the external appearance of a furniture piece is a key factor in the preferences of prospective customers.

Under the Philippine Furniture Industry Classification, furniture manufacturers can be classified based mainly on the invested capital, number of workers employed, area and location of the shops (Table 4). Cottage type is usually a backyard operation with number of workers at any one time depending on the orders received; small-scale type is usually at barrio (a small assemblage of houses or a subdivision of a town), with l-8 workers including family members; medium-scale type has 9-20 workers including family members; large-scale type has more than 20 workers plus clerical jobs. The area of shops ranges from 10 to 600 sq.m.

Table 4: Classification of the Philippine furniture industry

Type of manufacturing unit	Capital investment	Size of shop	Location of shop	No. of workers
Cottage	Up to P250 000	10 sq. m. or less	Backyard type	No. of workers at any one time depends on the order to be completed within a given period.
Small-scale	P250 000 to P2.5 million	10 to 20 sq. m.	In barrio houses or an assembling division of a town	1 to 8, including family members
Medium-scale	P2.5 million to P10 million	150-270 sq. m.	In subdivision of provinces with area and income generated smaller than in a city	9 to 20, since this involves the mass production of two or more product lines at a given time
Large-scale	P10 million an above	400-600 sq. m.	Important and progressive town, or the official capital of the province	More than 20

Review of Significant R& D and Related Aspects

Anatomical properties

Identification and characterization of bamboo will help to develop improved technologies. Grosser and Zamuco (1971), Zamuco and Tongacan (1973) and Zamuco (1972) reported that the length and percentage composition of fibre varied in the horizontal and vertical directions within the internode as well as from the base, middle and top portion of the culm. Using these findings, culrns could be apportioned to obtain maximum utilization. Espiloy (1983) showed that fibre length in B. *blumeana* increased from internode 2 of the butt portion to internode 18, after which it decreased.

Shape, size, arrangement and number of vascular bundles influence the bamboo's specific gravity, moisture content, shrinkage and strength properties which could be used as criteria in the choice of species and portion of the culm to be utilized for a particular component.

Physical and mechanical properties

The physical and mechanical properties of bamboo (Espiloy 1983) is a valuable index of strength to determine its utilization for furniture. Specific gravity and moisture content are useful indices of its approximate strength, shrinkage and swelling. This property influences the method of processing for various purposes; and it is also a factor considered to devise suitable kiln drying schedules. Table 5 shows some physico-mechanical properties of six species, namely, *Bambusa blumeana, B. vulgaris, Dendrocalamus merrillianus, D. asper, Gigantochloa levis* and *Schizostachyum lumampao.*

Generally, increase in strength properties was observed towards the top portion of the culm. This trend could be attributed to the corresponding increase in specific gravity and fibrovascular bundle frequency (Espiloy 1983). Research has shown that three-year-old culms have the highest specific gravity and the lowest moisture content and shrinkage. They have also the highest modulus of elasticity in bending and rnaximum crushing strength parallel to grain.

Durability, seasoning and preservation

Although endowed with excellent properties, bamboo is susceptible to attacks by decay fungi – such as the soft rot, brown rot and white rot (Liese 1970) – and powder post beetles, particularly *Dinoderus minutus* Fabr. (Casin and Mosreiro 1970). Dipping the handicraft products made from bamboo for 3-5 minutes in 0.10% of 2-thiocyanomethyl-benzothiozole + methylene bisthiocyanate arrests fungal growth (Giron 1992).

For treating whole culms, a multi-cap, high-pressure sap displacement (HPSD) apparatus was developed. It follows the principle of the boucherie process, wherein the sap from the freshly felled culm is forced out by pressure and replaced by a water-borne preservative, i.e. the preservative is introduced into the culm by pressure through a cylinder cap fitted over one end of the pole.

Processing of bamboo for any use needs drying. The moisture content should be consistent with the average atmospheric conditions prevailing

Table 5: Physical and mechanical properties of important bamboo species

Species	Specific gravity	Moisture content[a]	Shinkage (%)[b]		Static bending		
			Thickness	Width	Stress (MPa)[c]	MOR (MPa)	MOE (100 MPa)
Dendrocalamus merrillianus (Bayog)	0.58	108.39	10.39	8.08	32.43	55.17	6.00
Dendrocalamus asper (Giant bamboo)	0.55	17.59	10.66	4.75	12.60	30.40	3.53
Bambusa *blumeana* (Kauayan tinik)	0.50	135.80	13.30	7.70	22.60	32.10	9.00
Bambusa *vulgaris* (Kauayan kiling)	0.63	104.30	9.66	6.03	19.20	39.30	7.08
Gigantochloa levis (Bolo)	0.54	117.30	11.00	6.60	17.00	23.70	10.10
Schizostachyum lumampao (Buho)	0.46	183.11		-	20.43	35.80	6.11

a = Based on volume at test; b = moisture content at green to 12% ; c= At proportional limit.

in the intended place of use. Most of our furniture industries, especially the small and medium-scale and cottage type, lack facilities to dry their raw materials which reduces their competitiveness in the export market. The Forest Products Research and Development Institute (FPRDI) has developed a furnace type kiln which is cheap yet efficient. It can be constructed out of locally available materials such as concrete blocks, wood and asbestos cement sheets. In conjunction with the dryer, suitable drying schedules for some Philippine bamboos were also developed (Laxamana 1984).

Another technology developed in FPRDI is for steaming and bending of round bamboo. A simple hydraulic bending equipment was fabricated with a 60 cm radius of curvature. This technology is yet to be improved. Finishing is another important technology developed in FPRDI to help the furniture industry. Although the entire finishing operation basically involves the same set of activities as for wood (surface preparation, staining, sealing, sanding and top coat application), poor application can be a source of numerous finishing troubles. Bamboo surfaces are prepared through scraping, filing and sanding. Shaving or scraping of bamboo culm is done manually using a bolo, a scythe or fabricated scraper. Sanding is done, using No. 100 abrasive grits or sandpaper, along the direction of the grain.

Once the surface is prepared, staining, if desired or required, is carried out. After staining, the application of a sealer follows. Sealers are meant to protect the stain. If no stain is applied, sealers are used to facilitate sanding. Once the sealer dries up, the bamboo surface is again sanded to prepare it for the actual coat application.

A special effect finish has been developed for bamboo to give it marble type, crackled or spider web finish (Figures **1-2).**

Issues pertaining to design, production and technology transfer

- Inadequate knowledge of product design. This is not confined to the rural-based furniture producers only, but is experienced even by manufacturers and exporters in the city. Often, furniture designs are old-fashioned and do not conform to present day styles and standards. The adoption of internationally accepted standards is dictated by customers' preferences and prevailing lifestyle (Rojo et al. 1994). Product development is adversely affected because of the lack of innovation on the part of furniture makers.
- Inadequate knowledge on production. Majority of the furniture shops are inadequately equipped. Many cannot afford to acquire appropriate or modern equipment. Even when enough capital is available, operation

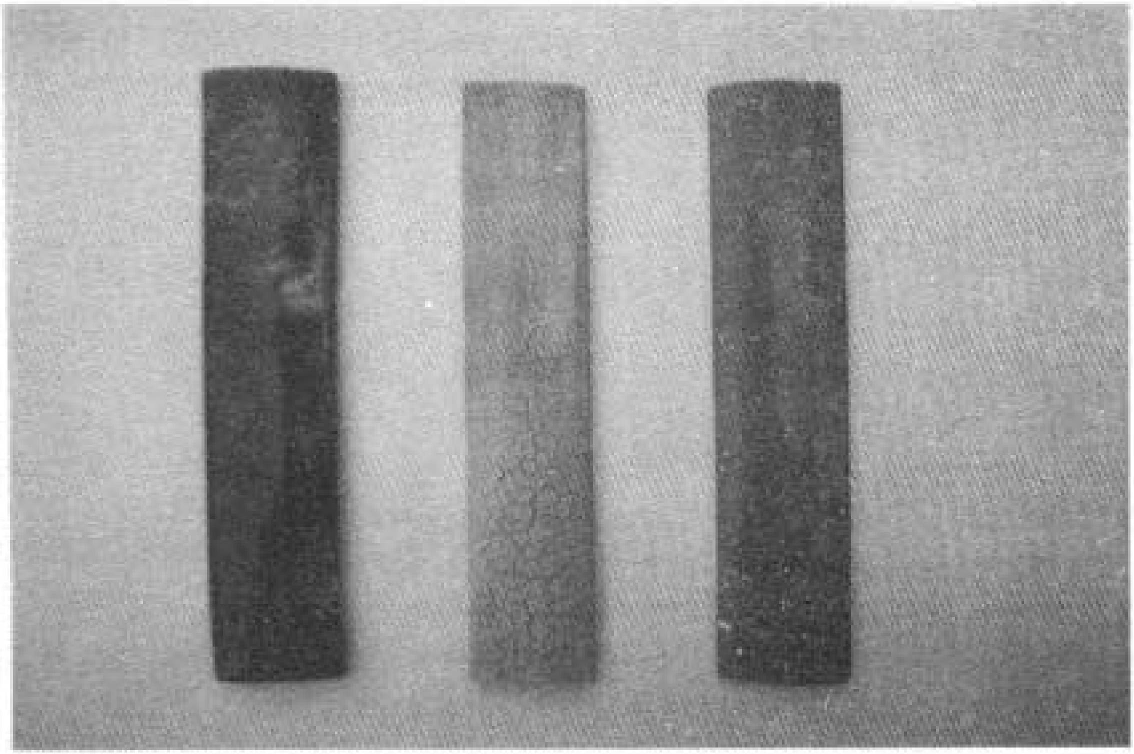

Fig. 1: Special efiect finishes applied on bamboo slats (from left) marble, crackled and spider web finish

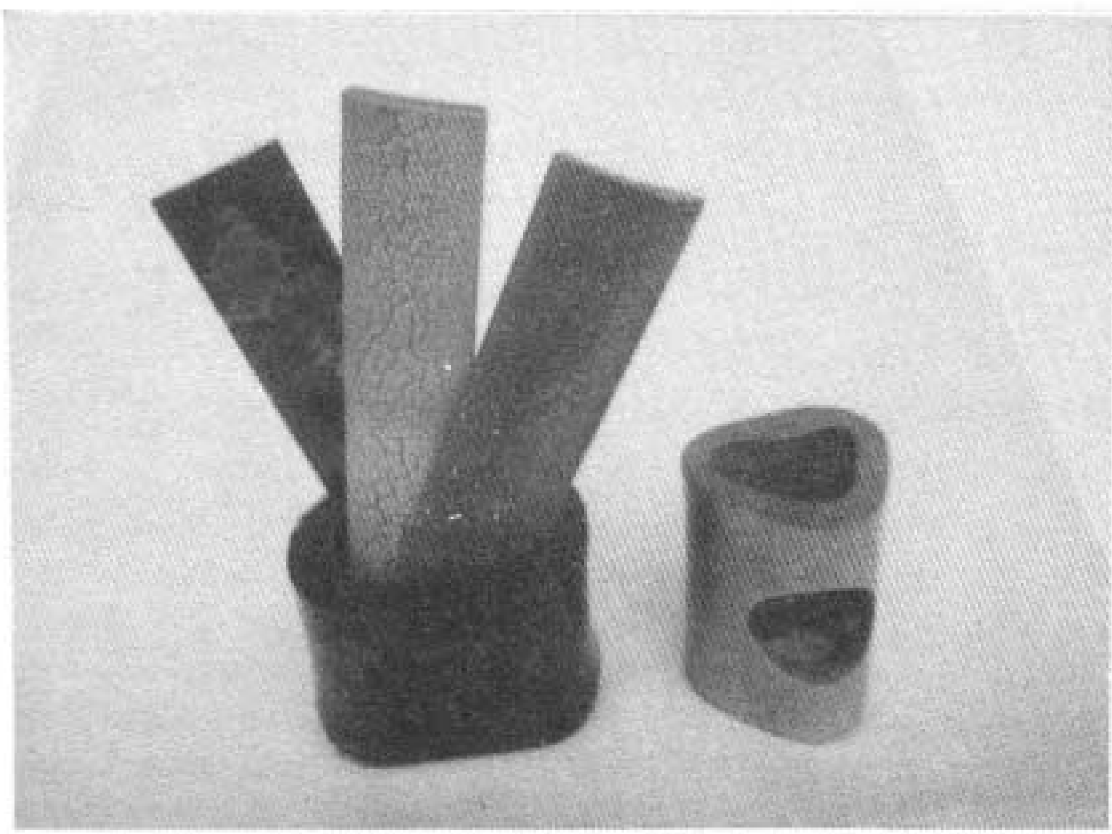

Fig. 2: Special effect finish applied on modified bamboo culm – marble finish (left) and sealed stain with pearl essence top coat (right)

knowledge of the equipment is lacking. Basic knowledge of bamboo as raw material is also absent (Rojo et al 1994).

Inadequate knowledge of drying bamboo is another problem. The condition of the raw materials before processing is a good indicator of the resulting product's quality. Although a number of proprietors and entrepreneurs know this, the correct drying of bamboo is not given adequate attention. Air drying is still the most common practice among small furniture producers.

Equally evident is the lack of quality control. Many furniture producers/exporters do not control the quality of their products. The only system employed is the checking of dimensions and shapes of the products. Non-inspection of in-process materials and failure to prescribe standards result in inferior quality furniture, saleable only in the domestic market.

. One of the most important factors that hampers the progress of the majority of furniture makers is the fact that technical information and technology transfer services often reach only the more accessible and progressive entrepreneurs. Such information and services are seldom disseminated to the smaller furniture firms. While a few, bigger and progressive firms continue to advance, the majority are left behind with their traditional, if not antiquated, techniques and processes. The gap is so wide that 90% of the 4 000 to 5 000 furniture producers belong to the backyard type chancterized by inadequate capital, limited facilities and poor managerial and technical skills. It is towards narrowing this gap that identification of training needs in furniture industry is necessary.

The furniture manufacturers will be receptive to innovations only if they are convinced that the technological changes will meet their specific needs and solve problems relevant to their specific situations.

Specific gaps in research and how these can be addressed

With the numerous uses of bamboo, it appears that there is no need to do research on the efficiency of utilizing bamboo as raw material. Some research areas which require greater attention, despite the large amount of information already generated, are:

- Improved processing techniques;
- Generation of data on physical andmechanical properties of lesser used species; and
- Evaluation of technologies/knowledge gathered from the research already undeltaken.

More research is required on determining the properties of the culm, especially for the selection of new species of high quality for introduction, Studies on the correlation between species and their properties for traditional utilization has to be conducted. The significance of anatomical, physical and chemical properties, and the arrangement of the tissues in the culm and their effect on preservative treatment, splitting, etc. have to be addressed. Guidelines on the methods of economically and effectively treating bamboo have to be established. A continuing research on product development for the local furniture industry and improved processing for industrial uses are needed to obtain high-quality products.

On the part of the government, incentives are given to farmers who wish to establish plantation of bamboo (Anonymous 1991). These incentives are incorporated in the Omnibus Investment Code of 1989 which include, among others: (1) income tax holiday, (2) tax and duty exemption on imported capital equipment, (3) tax credit on domestic capital equipment, (4) tax and duty free importation of genetic materials, and (5) tax credit on domestic genetic materials. Despite these incentives, the idea of growing bamboos in plantation has not picked up. This may indicate that the existing supplies can adequately meet the demand.

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High-Quality Bamboo Furniture: Lessons Learned from Indonesian-German Cooperation

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Abstract

Traditionally bamboo is the most widely used material for furniture making in Indonesia. But an export oriented industry has started to grow only recently.

From the 1970s German advisers, designers and importers have been an integral part of the evolution of modern Indonesian bamboo furniture. By the 1980s the island of Bali had become known for its unique bamboo furniture. The paper explains the successful development of modern furniture, which was due to a pure market approach adopted under special circumstances.

The appeal of bamboo furniture owes much to the designs developed under Indonesian-German cooperation. A common characteristic of these designs is the "high-quality approach" in combining bamboo with other materials like wood, recycled paper/carton, plastic and metal.

The paper lists some of the most urgent problems facing the bamboo furniture industry, and specifies challenging goals for the future of bamboo-based furniture production in Indonesia.

Introduction

In Indonesia, the development of bamboo furniture has always been treated as an extension of promotion of the rattan furniture industry. The major workshop of the Asia-Pacific Forest Industries Development Group held in 1989 in Jakarta illustrates this point. Although named "A Workshop on Design and Manufacture of Bamboo and Rattan Furniture" most bamboo-specific information discussed were about plant characteristics and

Fig. 1: Bali furniture shop owner

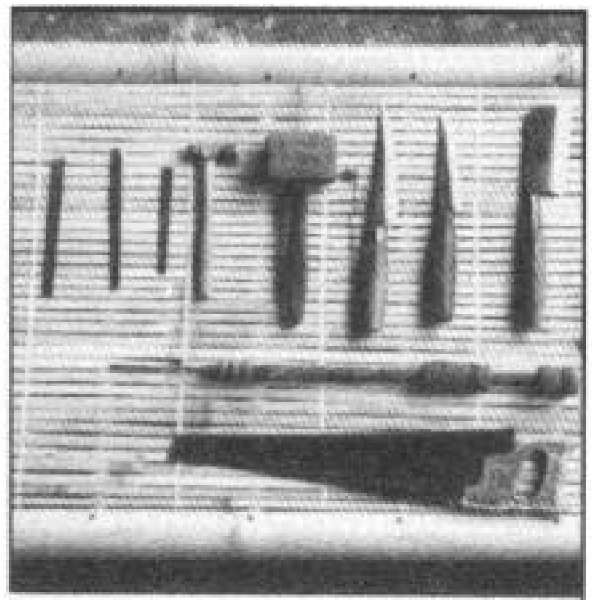


Fig. 2: lndonessian bamboo working tools

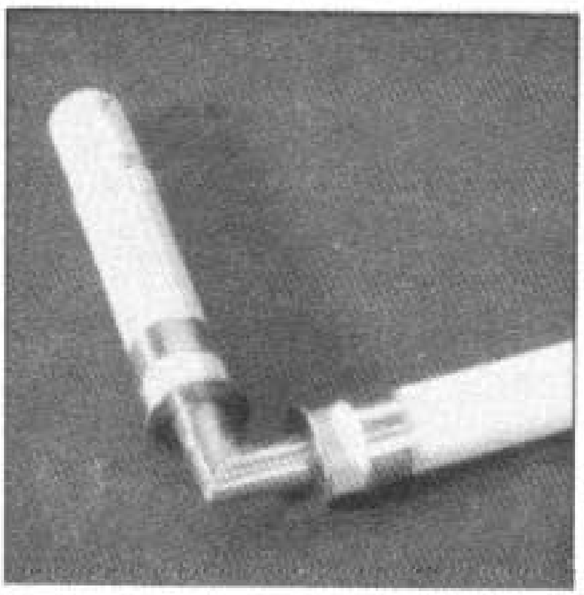


Fig. 4: Bamboo metal joint by Lnge Schrade

Fig. 3: A German bamboo hut owner in the cold

properties; there was no mention about bamboo furniture design or production (Bassili and Davis 1990).

Bamboo seemed to be of little importance for the booming Indonesian export economy. Even to calculate the value of bamboo exports has been difficult, as different bamboo products are often not mentioned in the statistics. Only recently has a group of researchers from the Forestry

Products and Forestry Research and Development Centre started to collect bamboo related data*.

Available statistics relating to bamboo have to be treated with caution and can often only be used as an indicator of trends. The data presented here, although verified by the author independently, are therefore used in this way.

Bamboo furniture manufactured by cottage industries is widely available in this country of 14 000 islands. It is nearly totally produced in the informalsector of the economy and therefore often of poor quality. Not a single major bamboo furniture factory plant exists, although there have been some attempts which failed because of lack of capital or management skills, or both. Successful development of high-quality furniture, all of them in small-scale ventures, was possible only in production sites, which benefit from a very close relation to its customers from abroad.

Besides the examples discussed here, the experiences from production sites near Yogyakarta and from a Swiss-assisted company in Kediri, East-Java (Schmidmeier 1991) also can provide valuable insights into the current Indonesian high-quality bamboo furniture industry.

The Bali Bamboo Furniture Industry

Thesuccess

In Bali, according to the Directorate General for Industries, more than 15 000 workers are involved in bamboo craftwork. Bamboo furniture for local use is being produced in the village since the 1940s like in many other places in Indonesia and in the tropical bamboo belt. Furniture for export comes mainly from the small village of Belega, District Gianyar, from the shops of people like Mr I Wayan Mastra, who quit his job as a teacher at the local elementary school in order to concentrate full time on the development of a new approach to the bamboo furniture industry.

After the first successful designs based on the giant bamboo (Dendrocalamusa sper) were developed together with German designers, Ms Linda Garland (of Environmental Bamboo Foundation) and others, a small but high-priced market emerged: the private houses of wealthy Indonesians and Western expatriates. In a couple of years, the first pieces were

1 See various papers of B.D. Nasendi prepared for the socio-economic working group of International Network for Bamboo and Rattan (INBAR), and also his presentation in the Socio-Economics volume of this Proceedings.

exported. By the middle of the 1980s bamboo furniture from Bali began to appear in more and more interior design magazines around the world.

Table 1: Bamboo exports from Bali (1993)

Country	Volume (pieces)	Average price per unit (US$)	Total export value (US$)
Germany	32 724	3.69	120 655
France	18 228	2.40	43 738
Spain	4 810	8.31	39 975
Italy	176 464	0.19	33 938
UK	79 536	0.42	33 509
Other EU countries	61292	0.84	51393
Japan	447 065	0.34	151335
USA	70 000	1.95	136 210
Australia	64 273	0.86	55 097
Singapore	3 141	5.68	17 849
Other countries	151 199	1.19	179 389
TOTAL	1 108 732	0.78	863 088

Source: Bamboo Export Profile (unpublished), the Indonesian Ministry of Trade, Bali Chapter, Denpasar, Bali, 1995.

In 1991, the most successful year in Belega village's business history, exports went to more than 20 countries with Tahiti, Hawaii (USA), Germany, France, Spain and Australia as the major importers. Mangku Bamboo Furniture, as Mr Mastra called his business, alone handled up to 20 containers a month, with an additional 5 to 7 containers handled by other producers from the village of Belega.

By that time, bamboo furniture had already achieved a fair share of the Balinese handicraft export market of 3.5% and was steadily increasing (Table 1). At the beginning of the boom in the mid-1980s itself some efforts were made to invite western customers, consultants, designers, bamboo lovers to find a way to work together. But project proposals to Australian and German development aid organizations were turned down, as the business prospects looked too bright to need developmental assistance.

In more and more places in Indonesia, copies of the designs developed in Belega appeared. Several successful training courses for bamboo businesses and craftsmen from.all over Indonesia were organized. Today one can travel from Jakarta to Surabaya, from Sumatra to Timor, from Sulawesi to Kalimantan and find bamboo furniture of similar designs, made using production techniques similar to those used in Belega. Even in remote places in the South of India or the East of China, the author has seen copies of furniture designs originated in Bali'.

Mr Mastra's sales were the base for the success of the village, where nearly fifty small-scale businesses together with more than 400 workers depended on his great managing skills. They were producing a great variety of designs, with a standard range of more then two hundred items. New designs are developed by the dozen each month. The product range covers nearly everything imaginable from standard sofa sets to tables with unique chairs, and from cupboards to office furniture. There is also a wide range of decorative items being produced, from cupboards to office furniture, from lamps to chests, and from hammock stands to flower pots. Worth mentioning are also ready-to-assemble (RTA) small pavilions, which are exported to tropical paradises like Hawaii and Tahiti, and also to rather cold places like Germany. Especially impressive is that the tiny village of Belega accounted for nearly 80% of the bamboo export by value, using only a small portion of the workers involved in the bamboo craft industry in Bali. The progress of the Bali bamboo export industry till 1991 (and the decline thereafter) is displayed in Figure 5.

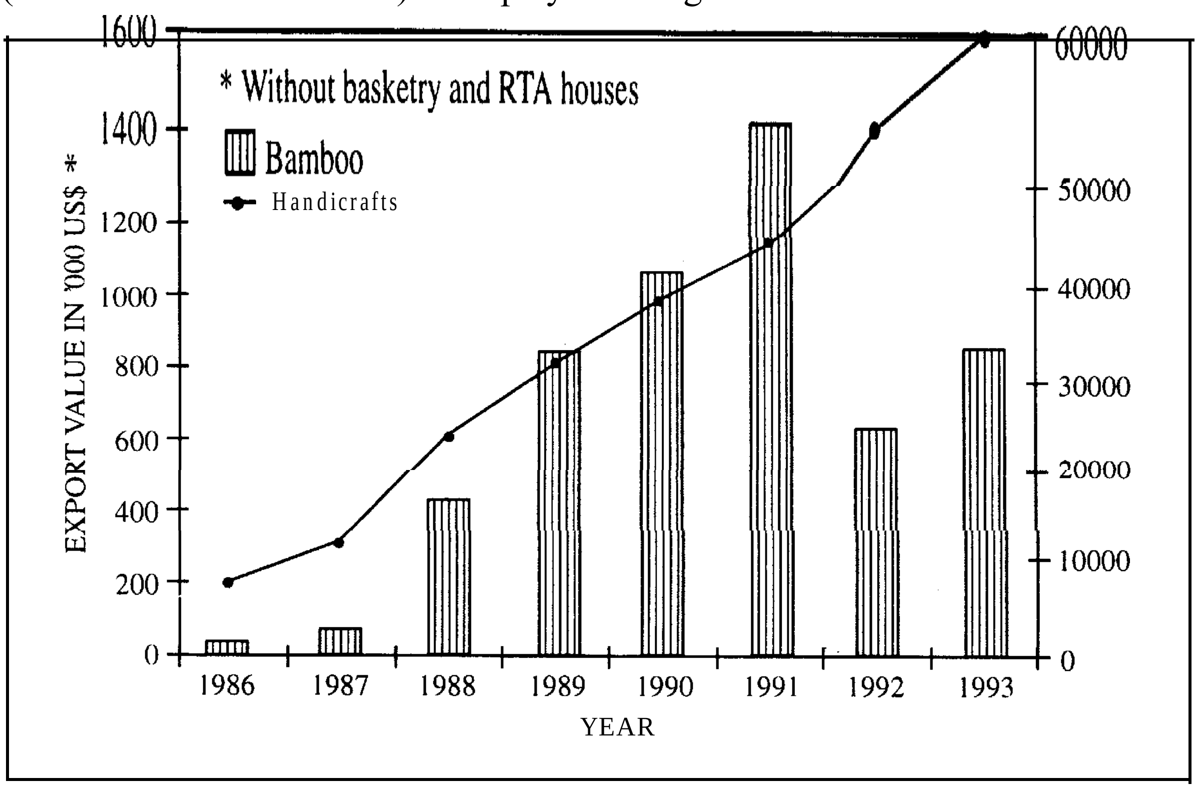


Fig. 5: Total bamboo and handicraft exports from Bali 1986-93

The crisis

The crisis that started in 1992 calls for a careful analysis of the bamboo furniture business. Although a similar trend can be seen in the case of the Philippines[2] and other countries, it is worth mentioning that the beginning of the crisis in Indonesian bamboo furniture industry coincided with the death of Mr Wayan Mastra.

Bali's bamboo furniture business is now in a difficult situation, as Figure 5 clearly shows. It also bears a mention that by 1993, the price (in real terms) of bamboo was twice the 1988 price, but the average sales price of a furniture piece had fallen by 40%. The average income per business unit in 1993 was nearly the same as in 1988, registering a 40% decrease from the peak in 1991. These figures are clear indicators of the decline in quality of exported goods (Wardana 1994).

There is little to add to the concern articulated in a 1989 report about the situation in Belega: "Bali products will eventually attract an unfavorable reputation for quality and finish throughout she markets of the world" (Wilson and Danu 1989). This has become a reality. Recent trends of change should be carefully watched[3], in order to prevent repetition of old mistakes and to improve performance.

A lesson learned from the crisis is that the close relationship between design and quality requirements of foreign buyers and local produeeers can override shortcomings of production facilities, if combined with extraordinary management skills of a local producer. But in such a case, progress will be limited and will depend mainly on the individual. If no further improvement is made in factors affecting design, quality and production, then a crisis is unavoidable in the longer term.

A Social Bamboo Project in Bandung[4]

In April 1991, Harkat *(Harapan anuk-anak yang terhntar* or hope for lost/abandoned children) was founded as a social organization in Indonesia

2 For details, please see the paper by Josephina Palisoc and Emmanuel Bello elsewhere in this volume.

3 A more detailed treatment of the matter is beyond the scope of this paper. However, INBAR intends to publish such an analysis in one of their forthcoming publications, focusing on the importance of small-scale businesses in an emerging industrial sector.

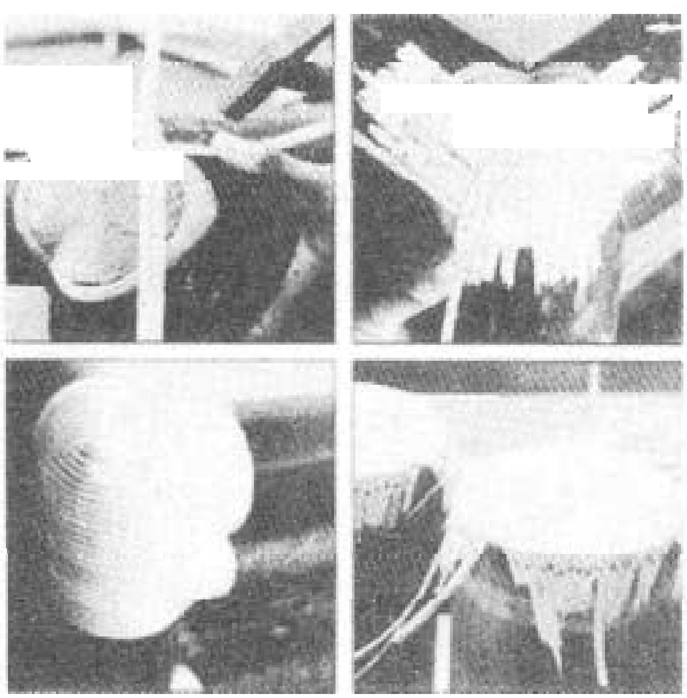
4 The author would like to thank Dr Dietrich Lerche for his support in gathering information on the Harkat Project. Much of what is presented here can be credited to him, although the conclusions are solely those of the author.

to provide a home for orphaned and semi-orphaned children and to prepare them for later life as adults. It was based on the SOS children's village concept that children should grow up and live together with parental figures in a family setting, rather than in an institution.

Background

The aim of Harkat was to provide children and youngsters with practical and useful training in various vocations. A basic skill development or vocational training program, parallel to and after school life, became a vital component of the project. Training was aimed at building up a skill base as well as self-esteem among the trainees, and to teach them not to waste materials and resources.

As a model for an integrated approach-combining social aims with training, production and marketingwhich would also contribute to the self-financing of the children's village - a project proposal was submitted to the European Commission (Development Fund) through the German social organization Susila Dharma. In 1992, the proposal was approved with a substantial grant covering capital investment (children's houses, community hall,workshops, etc.) as well as part of the operating costs for the initial years. A donation, valued about US$250 000, from a German expatriate provided necessary funds for the project start-up, including the acquisition of the project site (15 000 m2 with some workshops and housing) in the village of Ciwidey, 30 km outside Bandung, in a serene and cool setting.



In 1992,there were 20 children. The overall plan was for a village of 100 children in 10-12 families. The first trainees also included local unemployed youngsters. The vocational training-cum-production started out with bamboo furniture and forged iron which were to be followed later by ceramics, weaving, wood working and other crafts.

Fig. 6: From the vocational training material: rattan binding for joints

This provided a starting point for a project with facilities, funds and a sound concept. But it reflected also a rather ambitious approach as complex activities had to be organized, integrated and implemented simultaneously, not to mention the time pressure that accompany a foreign technical assistance project. This complexity could not be handled by the management and finally led to the downfall of the project.

Production and marketing

Bamboo has a long-established tradition in the Bandung region. Several bamboo varieties grow in the coastal as well in the mountain areas. Thus basic skill and raw materials were readily available. Designs included classical styles found in Bali, as well as some more fancy or artistic products by the artist Reinhard Wolke. In order to accommodate the demand for smaller sized European housing, a line of bamboo furniture for apartments was developed.

Since it was assumed that there would be no local'market for the newly designed Harkat bamboo furniture which, although of higher quality, were in the high-price bracket, it was first exhibited and marketed through the Interior Craft Art Design Gallery in Jakarta, together with other crafts from Indonesian designers.

Export for world market

Soon after the marketing efforts began, the first container with Harkat bamboo furniture was exported to Germany. However, as products were not yet fully developed and did not have consistent quality standards, export marketing faced problems. Much had to be learnt by a trial and error process. Training was provided by skilled supervisors, but there was no master around who could cope with all the design, construction, production and finishing problems.

Absence of proper management was the main problem both in the production front in Bandung and in export marketing. Without proper training and production facilities, the business ventures became very risky. Rather than acting as a wholesale agent, who could exercise strict quality control, the German sponsor opened his own sales outlet in Munich.

Lack of marketing expertise coincided with a major recession in Germany in 1992-93. Given the high operation cost this led to considerable losses and the closing of the retail shop. The gallery in Jakarta also had to be closed. As problems got out of control, the German sponsor gave up and returned the unused funds.

The Harkat project taught another lesson: that too ambitious goals can lead to a downfall of the best project. Careful management adjusted to local conditions, sufficient capital and inside knowledge of the business are necessary to secure sustained success. Foreign assistance programs must be carefully implemented on a team basis, and based on a long-term approach. Private business and social programs should be separated as clearly as possible.

Cooperation in Design

Designs, especially modern and contempqrary designs, can hardly be developed in surroundings that do not value bamboo highly. Waiting for inputs from foreign buyers alone is not enough, aithough even export promotion agencies sometimes recommend that for international markets “product designs are determined very much by the buyers, so that exporters should just follow their needs.“[5] These potential buyers and their designers often do not have the necessary knowledge and experience about the material, as it is not grown and/or used in there home countries as furniture material. What they do know are the actual trends and how to be creative in combining bamboo with other materials. Therefore the most popular designs for bamboo furniture for use in developed countries are created by a joint venture of local expertise in craftsmanship and western design inputs. For instance, all products pictured in this paper have been created by Germans who have studied the technical aspects of bamboo furniture making in Bali and/or other parts of Indonesia.

Combination with Other Materials

The Interior Design Faculty of FH Coburg, situated at the centre of the centuries-old German weaving/processing industry around Coburg, concentrates on designs for fast-growing renewable materials and efficient resource management. Traditionally, the focus was on home-grown grasses like osier; later on, rattan work was added. With strong support from Prof. Stubbe, the renowned designer and head of the department, and with the support of the biggest European rattan furniture producer Schutz, a centre for German wicker work has recently been established?

5 From Bamboo Export Profile (unpublished) by the Indonesian Ministry of Trade, Bali Chapter, Denpasar, Bali, 1995.

6 Innovations-Zentrum des Deutschen Flechthandwerks, Kleinaustr. 32, 96215 Lichtenfels, Germany. Tel: **+49** (9571) 4625, Fax: +49 (9571) 71902.

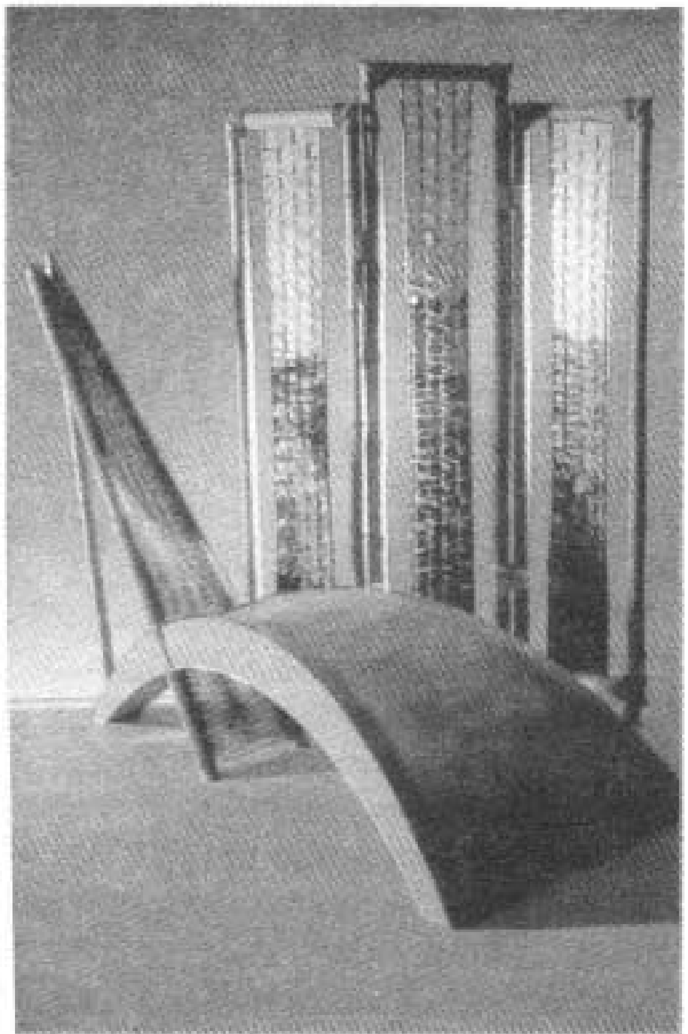


Fig. 7: Lazy Chair AK 1 and Screen Merapi (by Peter Adami and Heike Walk).

Prof. Stubbe's inputs have helped to develop some of the most interesting contemporary designs for bamboo furniture and gift items, some of which are given in Figures 7 to 11.

Every piece is finished using a complicated shellac process. Although the process requires special care and a lot of time, there is no comparison for the protection and brilliance it gives. (This is a very organic way of coating materials, since shellac is produced from a special species of the Indian green fly and the thinner used is natural alcohol. Furthermore, products with shellac finishingrequires little maintenance – just cleaning with a damp cloth will maintain bamboo's beauty and luster).

Steps to improve the Business

A serious study of the Indonesian bamboo furniture business, covering the resource base, recent trends, and constraints and prospects, is necessary. The export sector is related to hotel industry, and together can be the prime driving force for business improvement. Collaboration between potential importers from target countries, and hotel designers and furniture production units in the supplier countries is of high importance. At least two separate areas need to be addressed: the foreign markets and the local situation. The first step will be to identify local and foreign firms which have the technology, resources and inclination for investing in bamboo-related business, possibly through joint ventures

Fig. 8: Prof. Srubbe, with one of his creations, chair seats made of joined bamboo and fibreglass.

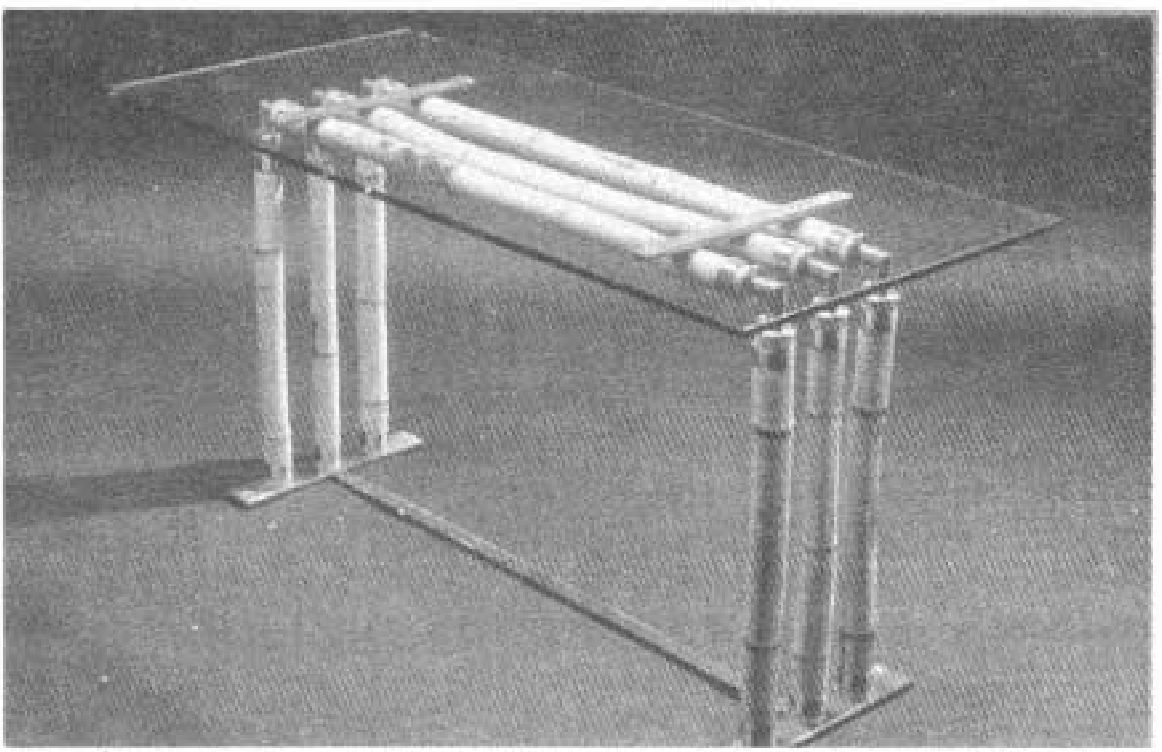


Fig. 9: Bamboo table with refined steel elements (by Inge Schrade)

An easy starting point would be the analysis of the businesses with particular reference to the markets already existing in Indonesia. The exercise should cover:

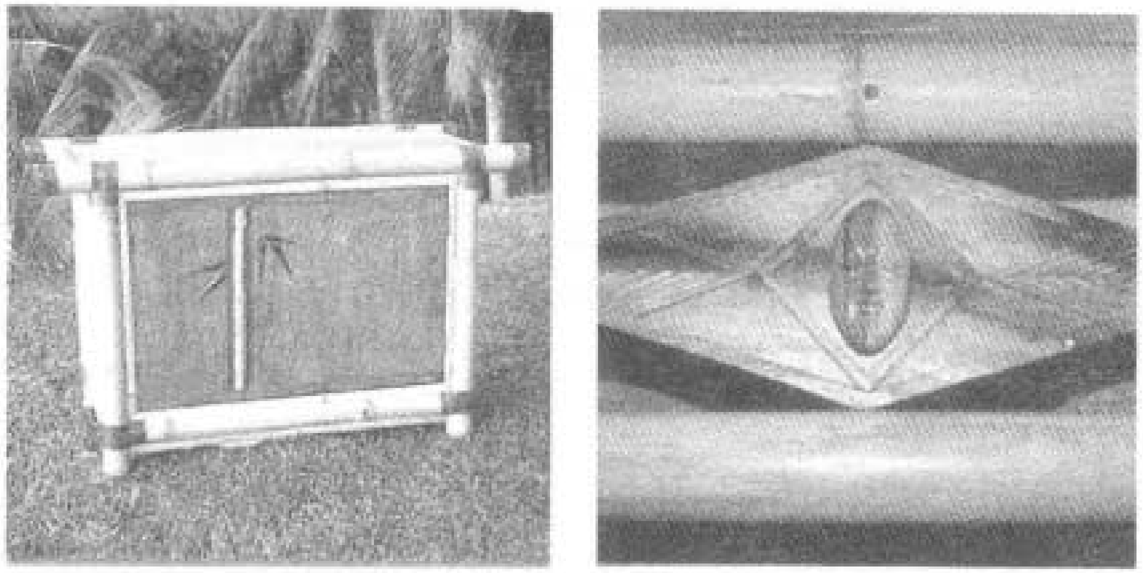


Fig. 10: Kayu cupboard and its detail (by Marlene Kussmaul)

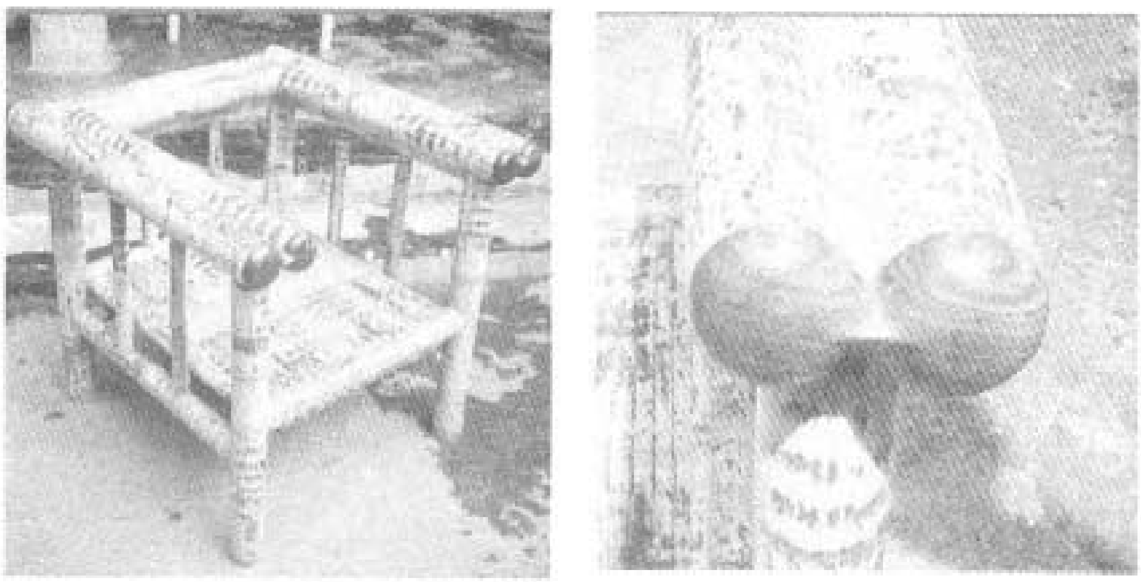


Fig. 11: Tiger chair (made from Phyllostachys nigra) and its detail (by Willy Muller)

- Activity of the companies, location and date of establishment;
- Infrastructure, equipment and production system;
- Existing product designs;
- Number and type of staff, and their qualifications;
- Supply of raw material and tools;
- Commercial aspects, costs and profits;
- Management and organization involved; and
- Problems identified by the producers themselves.

For such a study, the method of participatory evaluation would be suitable since it supports the objects of the analysis to become the subjects of further development (Anonymous 1992, Anonymous 1993).

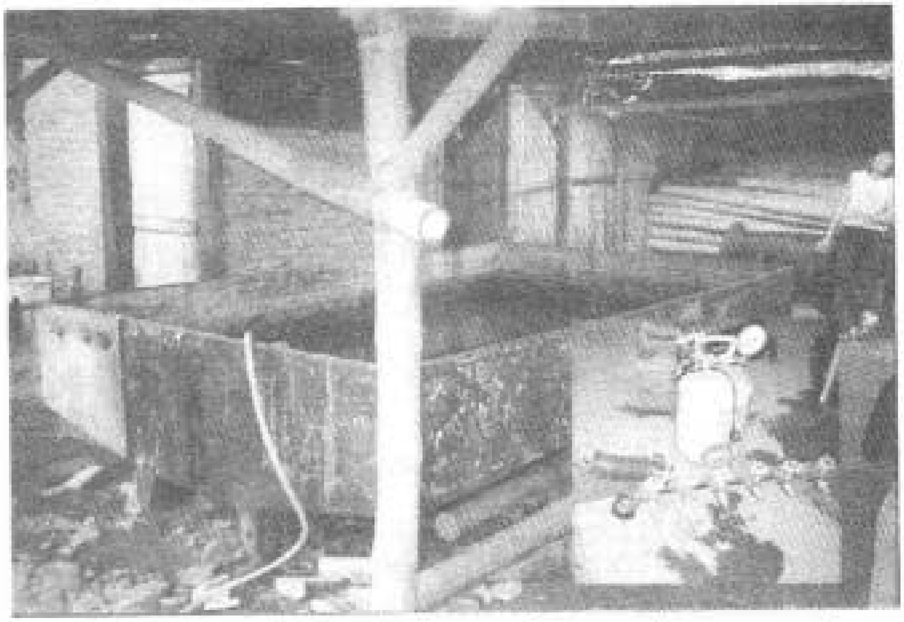


Fig. 12: Banned chemicals are often used in processing under unsafe conditions

The secoqd step should be the formation of an association of Indonesian bamboo furniture producers. Such a trade association will be essential for persuading the government to back manufacturers with legislation, export promotion and import regulations. Additionally, it can provide a forum for the exchange of information and ideas, as well as organize business promotion activities, starting with the formulation of a strategy on raw materials and marketing.

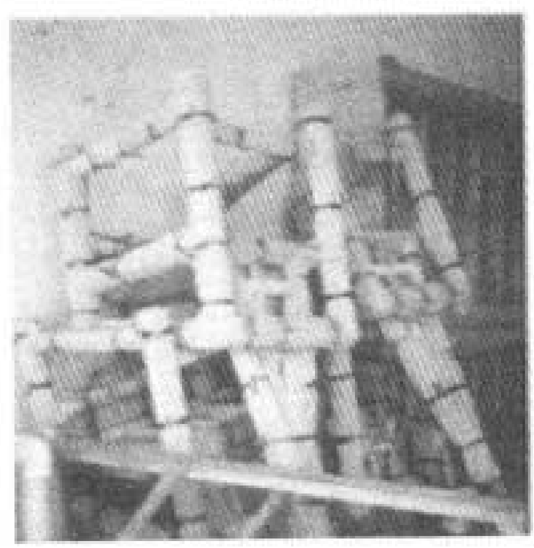


Fig. 13: Canon paper hand-wrapped with synthetic strings is the standard packaging used

A systematic approach to business development would be the third step. Elements of such an approach include:

- Market research on targeted markets;
- Identifying suitable bamboo species and sustainable management practices;
- Identifying/developing environmentally safe post-harvest treatments, such as seasoning and preservation of bamboo culms.
- A regular environmental audit to ensure safe supplies and production methods;
- Ensuring adequate supply of good quality raw material, and guaranteeing minimum buying prices for semi-finished products made by home-based enterprises;
- Effective product costing that would enable the producers to regulate their business;
- Design development tailored to different target markets (use of computer-aided design and manufacture would enable the production of several unique variations to a basic design);
- Adoption of effective copyright protection measures;
- Laying down technical specifications of products;.
- Careful and thorough study of contractual terms and business instruments;
- Development of suitable production technologies for standard parts;
- Training of supervisors and workers, focusing on raw material selection, production planning and control, quality and process control, surface finishing, and tool maintenance;
- Establishingquality standards and implementing effective quali~ty control;
- Efficient packaging (preferably using recyclable materials, and including graphical explanations in the case of knock-down furniture) and transport.
- Effective marketing; and
- Careful selection of distribution channels.

Such a detailed approach would ensure bamboo furniture a significant position among the ranks of non-oil product exports from Indonesia

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Design Inputs into Craft Areas: Implications for Rural Development and Employment Generation

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Abstract

Craft should be understood in terms of its deep significance as an expression of creativity and as an employment generator. In Japan, bamboo craft has reached high standards and has been given the stiltus of art A fresh approach to craft in developing countries is necessary to recognize craft as an an form, an industrial activity and a means to develop creativity in general education. Design has evolved from craft. Design inputs can make bamboo craft a sustained source of viable employment generation in rural areas. Action programs like 'Inter Designs' and 'Exhibition on Wheels', in addition to conventional research, are required to rejuvenate bamboo craft in the rural areas of developing countries.

Introduction

Crafts have a deep significance to our lives. Traditional craft stands as an example of human creativity expressed over generations. Industrial design has evolved from craft as a consequence of the mechanization of production processes. Crafts lost their crucial place in the lives of people, with the all-pervading industrial culture dominating the scene. Craft creations became objects to be seen in museums. However, folk crafts continued to survive in the developing countries, despite poverty and exploitation. Crafts will have to be economically viable, if they are to continue to play a meaningful role in our lives. Taking bamboo craft as an example, let us see how design can play its part in rejuvenating crafts.

Use of bamboo and bamboo craft are practised in countries like China, India and Korea from ancient times. Early evidence of bamboo weaving in

China can be seen in a museum exhibit of early times. But today, we look at Japan for excellence in bamboo craft. The high quality of a Japanese bamboo basket, for example, has many things to say. But what is its relationship to the poor and unemployed in the developing countries,who have abandoned their craft in their search for making a living? For many people, appropriate employment means better nutrition, better health and hopes for the future. Only such hopes can make school education and family planning meaningful to them. Lack of employment in rural areas and the consequent exodus to metropolitan centres are serious problems that the developing countries with large populations face. Capital-intensive industrialization has accentuated this problem. Unlimited exploitation of natural resources in industries has led to ecological imbalance and environmental degradation. In this complex scenario, bamboo as rapid growing resource and bamboo craft as a rural-based occupation offer a ray of hope. In the craft sector, one tonne of bamboo can provide 100.300 workdays for craft workers. Taking an average of 150 workdays per tonne, the raw material required to provide work for one bamboo craftsperson for one year will be two tonnes. This means, two million tonnes of bamboo can create one million jobs.

Taking India as an example, the current potential for bamboo production is 4.5 million tonnes per year, which can be increased to 11 million tonnes (Adkoli 1994). Allotment of 20% of bamboo harvested for one million jobs seems to be an attractive proposition if economically viable job opportunities can be provided to craftspersons in rural areas.

Let us look at the current scene. Bamboo craft has been practised as a folk tradition to make objects of daily use in many developing countries. Althoughlarge number of families, includingwomenandchildren, depend on bamboo craft, the earnings have been low. In Sri Lanka, a bambooworker gets an income of Rs 5 000 (US$l 18) per year. In India, it would be around Rs 20 to 30 (little less than US$l) per day for a semi-skilled craft worker. In Thailand, it is 20 to 60 Baht (US$l-2) per day. Employment in bamboo craft in rural areas tends to be seasonal, confined to non-agricultural seasons. Another reason for low payments for crafts has been the castes they belong to. In Sri Lanka and most parts of India, bamboo craftspersons belong to castes of low social status. But in places like north-eastern India where high skills exist, a bamboo craft worker who has moved to urban centres can command a salary of Rs 5 000(US$118)permonth(i.e.US$3.5perday). Continuous employment with a salary of Rs 1 500 to 2 000 (i.e. US$50-70) per month in bamboo craft would make it an attractive vocation for a villager. Such possibilities need to be explored.

Understanding Craft as a Profession

Historically, craft has been skilled work to create objects of utility. Over the years, high ornamentation has become the hallmark of cnft work patronized by the elite and the rich. In contrast, folk crafts which catered to the needs of the rural population have remained simple. The creativity of folk crafts excelled in harmonious social settings. The result was an expression of simplicity and elegance. The creativity of the craftsperson reflected in the high level of product aesthetics. Every part of the product was functional, wastage was minimal and the appearance elegant. An earthen pot and a bamboo basket are good examples. With the advent of industrialization three things happened.

1. Industrial design emerged as a substitute to craft, to take care of aesthetics suitable for mass production and mass marketing;
2. Crafts appreciated by the rich and the elite acquired a status similar to 'art'; and
3. In certain parts of the world, less influenced by industrialization, crafts continued in their traditional forms.

In most of the bamboo-growing developing countries, bamboo craft continued as a folk craft. But in Japan, it took many strides that are worth taking a detailed look.

Bamboo craft in Japan

In Japan, bamboo has been widely used for making utility articles such as baskets, tableware, utensils for tea ceremony and other ceremonies, weapons, armour, and for fencing (Keneko 1985). Chinese-style baskets, which came along with Buddhist monks, became popular. Fine weaves of Chinese baskets slowly replaced rough weaves. Japanese craft workers soon started innovating new designs after adopting the Chinese styles. Bamboo baskets called *hanabako* and *kara,* used for carrying and cleansing flowers, excelled in number of designs during the Tempyo period. A total of 565 variety of baskets that originated at this time exist even today. But bamboo craft took a new shape with craftspersons like Rokansai Iizuka and others. They give it the status of art. A 1969 flower basket with fishnet weaving, the *sankai* by Azuma Chikuensai, is a good example. There are 70 different weaves with names like pine needles, turtle shell or ajiro, a fish net, etc. Various basket forms and weaves of Japan reveal the creative potentials in bamboo craft. Japanese crafted baskets are like art-pieces and, of course, very expensive today. Today, Japan imports bamboo craft products like baskets as the cost of local products, which are of high quality, is three times to that made in countries like China and Taiwan.

An Approach to Bamboo Craft in Developing Countries

We need to take a fresh approach to bamboo craft in developing countries to ensure it a status, in addition to generating employment in rural areas. It is essential to recognize bamboo craft as an art, an industrial activity, and an input in general education at appropriate levels. Integrating craft education as a stream in design at various levels is vital in this endeavour.

Bamboo Craft as Art

Though it may look like a luxury for developing countries, bamboo craft needs to be recognized as an art to sustain the creativity needed to keep the craft alive. In Japan, bamboo craft as art, for example, has set the standards of aesthetics for flower baskets. New experiments in forms, finishes and details are undertaken to create new types and varieties. They percolate to local craftspersons who adopt them. In effect, art like research will be a source of new ideas for bamboo craft.

Bamboo Craft as Industrial Activity

To achieve a higher level of commerce arid the consequent employment generation in production and trade, bamboo craft should be recognized as an industrial activity. Bamboo industries should have no inhibition to employ machinery, whenever it is advantageous. Crafted parts can be judiciously mixed with machined parts in bamboo and other materials. Long-term economic viability, and competitiveness vis-a-vis *mass* produced products made in materials like plastics, can only be achieved by seeing bamboo craft as an industrial activity.

Bamboo Craft in Education

Potentials of craft learning in education are yet to be recognized. Specialists in the development of creativity are concerned about the neglect of right-side brain learning. It is now known that the right side of the brain deals with emotional, aesthetic and intuitive thinking, whereas the left side deals with language, and logical and analytical thinking. Craft can become an important mode ofdeveloping right-side brain abilities. Tatsumo (1990) attributes much of japanese success in creating miniature modern electronic gadgetry to the training given to every Japanese child in Origami paper craft. Art, craft and design need to be revitalized in school education as they form the base for creativity in science and technology later. Bamboo craft offers an excellent scope for such an introduction in rural and urban schools in developing countries. This would give a spurt to employment opportunities for craft teachers as well.

Education and Training in Bamboo Craft

Bamboo craft was learnt traditionally in families. Now it is also taught through goyernment schemes. In India, for example, there are 35 centres which train persons in villages for six months. Trainees are given a stipend of Rs 280 (US$9) per month. However, the craft trainers themselves do not have scope to update their training. Craft training is not offered parallel to technical training. It is important to integrate craft training at various levels. Bamboo craft should be seen as a part of design for training purposes. Course contents at various levels need to be worked out. This would also provide craftspersons to acquire the necessary qualifications to become craft teachers and trainers in schools and colleges. There is need to develop educational materials in the form of books, videos, kits and exhibits to facilitate education of bamboo craft at all levels.

Design Problems Facing Bamboo Craft

Many practical problems affect bamboo craft, and these are discussed below and some possible solutions suggested.

Current mind-set

The prevailing mind-set of bamboo craft is that of a "thing belonging to the past". General knowledge of an educated person about bamboo craft is negligible. Most people do not know even the difference between bamboo and rattan (cane). Many see it as a poor man's occupation, irrelevant to modern life. Even designers and architects are unaware of potentials of bamboo craft. Bamboo craftspersons in villages also do not see a future in the craft for his children to pursue the profession. There is an urgent need to change this mind-set.

One such effort was Jagruti(awakening)-a bamboo craft design workshop held at the Industrial Design Ccntre (IDC) of the Indian Institute of

Technology (IIT), Bombay, for a week, in May 1993. Altogether, 15 professional designers, 15 craftspersons and 40 design students participated. Several experts presented papers related to bamboo craft and on products which can be made with bamboo. Half of the time was devoted to 'inter-design', where craftspersons and designers came together and brought out several product concepts in bamboo. Results-which were in the form of sketches, models and prototypes - have been documented in a publication entitled Bamboo Craft Design. Jagruti succeeded in generating tremendous enthusiasm in craftspersons and designers which led to implementation of a few new designs.

Research and development related to bambooraft

Published research specific to bamboo craft is meager. A study and documentation on bamboo craft of north-eastern India (Ranjan et al. 1986) by National Institute of Design, Ahmedabad, India, is significant. The International Network for Bamboo and Rattan (INBAR) has sponsored a study on indigenous tools and processes for bamboo and rattan. Engineers of Forest Research Institute Malaysia (FRIM) have designed a tool to make thin strips (0.2 mm) of bamboo. Some more problems which need research attention are: evaluations of raw material suitability, finishes, tooling, technologies and product designs. Dissemination of available information across the countries has been poor. Research in these areas may include documentation and evaluation in addition to new proposals.

Raw material suitability

Easy identification of bamboo which is suitable for craft work is a problem. Bringing out a manual on the types of bamboo suitable for craft work, with information on local names and test procedure to evaluate the suitability, would be of high value.

Finishes

Comprehensive documentation of finishes available and how to apply them, along with evaluation procedures for aspects like cost and durability, is required. Variety of colours and finishes available need to be made known, akin to colour charts of paint manufacturers.

Tools

Documentation of tools, along with evaluations and information on availability, will be useful. New tools to obtain finished edges, rims, legs and handles are needed. Tools which can achieve higher productivity and better quality have attraction for the craftspersons.

Technologies

Small-scale technologies available across the countries for bamboo finishes, jointing and processing need documentation. New technologies need to be developed for bamboo bending, laminating and polishing.

Product design

Research is needed to develop new product designs. In a project completed at IDC, IIT Bombay, several product concepts were generated under seven product categories:

- Gifts and souvenirs;
- Stationery items;
- Kitchen and household items;
- Lamps;
- Furniture;
- Carry items/containers; and
- Packages.

Strategic research is required to evaluate the areas in which bamboo crafted products can become competitive. Evaluation procedures and methods to link design strategies need to be evolved. An integrated approach – including market needs, product design and technology to apply the new design-would be important in terms of transfer and absorption by craftspersons. Industrial Arts Institute at Beppu, Japan, has evolved a methodology by which craftspersons, designers and scientists work together to evolve new products.

Marketing and professional design inputs

In rural areas, where folk crafts are practised, bamboo products fetch low prices. With the advent of plastic, many bamboo products have lost rural markets. However, increased awareness and fascination for the unusual have developed markets for bamboo crafted products in urban centres. There is also a growing demand in developed countries for quality bamboo products. Biodegradability of goods has acquired great importance in developed countries and bamboo has an edge in this regard over plastic products. To enter into competitive markets, professional industrial design inputs into bamboo craft are required. At present, bamboo craft and industrial design stand segregated. It is important to create facilities where professional designers work together with bamboo craftspersons. Two case studies are discussed below.

Adi Crafts

Adi Crafts is a small-scale industrial unit started by an architect and an industrial designer trained at IDC. Adi Crafts employs 30 workers many of them skilled craftspersons. The unit, based in the suburbs of Nagpur, manufactures bamboo lamps which are sold all over India. The designs were evolved by industrial designers and craftspersons. Many industrial concepts like segregating components for manufacture, using jigs and fixtures have helped to achieve high standards. The craftspersons are paid Rs 2 000 per month. Many local women are employed. Wages are linked to the number of pieces they produce. Since the designer is also the owner, the design service is in-built.

Sign Design

Sign Design is a design office at Pune (India) started by two young industrial designers trained at IDC. They came in touch with craftspersons from their home town of Sangli during "Jagruti". They developed a bamboo tray and a few other products working with the craftspersons. Sign Design markets trays in Pune and Bombay. They give contract work to the craftspersons. This tray is currently included in the training at IDC where craftspersons are trained.

Market-based design strategies

Crafts have inherent attributes, like personal touch, which are exclusive. In course of time, it may acquire the qualities of mass-produced products. It is important to evolve design strategies to make use of the strengths of crafts process. Some strategies are articulated here.

Multiple design

Craft process, by its very nature, can offer wide variety, thus giving exclusiveness. There is a market demand for such exclusive products, especially in gift items and personal ware. A wide variety of designs with similar base structure could satisfy such market demand. India has such a tradition in textiles (saris). An attempt made at IDC led to a wide range of designs of paper knives in bamboo. Initial generation of such multiple designs can provoke the imagination of bamboo craftspersons to come out with innovations of their own.

Add-on design

In this strategy, bamboo crafted items can be added to existing mass-produced items to produce culture-friendly designs, such as casings for thermos flasks, thermal wares, ice-buckets, etc. Bamboo spoons can be added to Teflon-coated frying pans. Woven bamboo cover for a mosquito repellent can make it aesthetically more attractive.

Technology-based new products

Bamboo woven mats can be moulded into different shapes. Resin impregnation can give a smooth finish. Patterns in the weaves can be changed to give a variety of designs.

Moulded bamboo mats specifically woven to suit a shape can have a market advantage, unlike bamboo boards which get compared with plywood. Products like chair seats and backs, trief cases, helmets, magazine racks, etc. will be most suitable to exploit this strategy.

Recommendations

Although conventional research is needed in bamboo craft, communication and dissemination of available information at various levels require greater attention. In view of this, the following action plans are suggested.

Inter-design in bamboo

In inter-design, a concept supported by International Council of Societies of Industrial Design (ICSID), designers from different countries get together and solve design problems in specific areas by suggesting new designs, renderings and models. Results are published and circulated widely.An inter-design involving industrial designers, craftsmen and other experts over two-week periods can be held. Usually host countries take care of stay and hospitality of participants, while designers bear travel expenses themselves. INBAR could initiate such inter-design with possible cooperation of UNIDO.

Mobile exhibition or exhibition on wheels

The bamboo craftspersons at village level remain unexposed to the developments elsewhere in spite of many workshops and seminars. A bamboo craft product exhibition can go to rural places where the craftspersons work and workshops can be held involving local designers.

Similar exhibition on wheels are successfully used for science education by the Nehru Science Centre at Bombay.

Creation of a marketing agency for bamboo crafts

Marketing is most important to the financially hard pressed bamboo craftspersons. An international marketing agency, hired on a commercial basis, can become a powerful conduit to usher design quality in bamboo craft. Though there are government run marketing agencies in countries like India, they are largely ineffective. Only marketing agencies in private or joint sectors can ensure novelty and quality in craft work. Some companies like 'Body-shop' have a policy to promote craft items from developing countries.

Design exposure programs for craft trainers

Craft trainers are crucial in promoting change. Exclusive design exposure programs for them for two to six months can trigger their enthusiasm.

Schemes for designer-craft worker interaction

Schemes to support professional designers working for a craft group need to be evolved. In some countries, 50% of the industrial designer's fee is borne by government to ensure good design. Similar schemes for bamboo crafted product can enthuse new designers.

Educational material

Educational material-in the form of videos, booksandkits-on bamboo craft need to be developed at various levels. These can cover various design issues for the use of craftspersons. Educational kits for school children to learn bamboo craft need to be designed. Such kit can also be used for others to pursue bamboo craft as a hobby. Large number of housewives in urban areas, for example, pursue hobbies. Training in craft, and kits to learn craft, can increase employment opportunities for craft workers.

Studies of craft

Research on the pedagogy of craft needs special attention. Comparative studies of craft training in different countries could provide valuable information to evolve new methods of training.

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Bamboo and Modern Design: Application and Design Innovation in a Traditional Asian Material

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Abstract

The potential of bamboo as an engineering material has not been fully exploited, although bamboo is an eminently renewable resource and its properties are far superior-in important aspects – to man-made engineering materials.

In this paper, the author examines the reason for the non-exploitation of the potential of bamboo and findsit to be mainly the reluctance to transform bamboo from its natural state to forms which render themselves to mechanized mass production. To remedy this, the author advocates formulation of new designs, involving industrial designers. Unless such designs are developed, bamboo will not be able to compete other materials, despite its many desirable attributes, including environment friendliness.

Introduction

Many materials currently employed in consumer products are facing challenges on account of their ecological disadvantages (Fox 1989; Burall 1991). In parts of the world where materials such as plastics, alloy metals or wood are scarce, the substitution by indigenous materials is increasingly justified, although this may run counter to consumer preference.

Bamboo is renewable and grows abundantly in tropical and sub-tropical countries (Ranjan et al. 1986). In the last two decades, research on the cultivation of the plant and the data generated on its engineering properties have verified two important criteria: (1) bamboo plants grow quickly, even in extreme agroclimatic conditions (Zhou 1993), and (2) the properties of the material are generally advantageous, especially in tensile and bending strength in which they outperform many man-made engineering materials (Dunkelberg 1985; Schaur 1985; Janssen 1991). Such findings have important implications for both the supply of source material and its potential application in contemporary product design.

A large part of China lies in regions where bamboo is plentiful (I Isiung and Ren 1983, Hsiung 1991). The application of bamboo as part of new designs for modern living could potentially ease the pressure of limited timber supply within the country (Hsiung and Ren 1983; Schaur 1985). A more generally effective and efficient use of bamboo could also make a significant contribution to the economic development of China and the rest of the world, and more importantly, to the earth's ecological balance.

Bamboo artifacts, however, are rarely employed in modern life for both known and unknown reasons. One possible reason is that normally bamboo does not have a long life and is therefore assumed to be only appropriate as a craft material for low-cost items. In recent years, there have been ways to preserve the material, but consumer acceptance of bamboo in place of, plastics for example, is unknown. It is therefore an appropriate period in -which to examine whether methods of developing well-designed and efficiently manufactured bamboo products might reduce both design and consumer neglect of the material. The primary focus of this study, therefore, is design process innovation through evaluation of the comparative characteristics, performance and manufacturing context of bamboo.

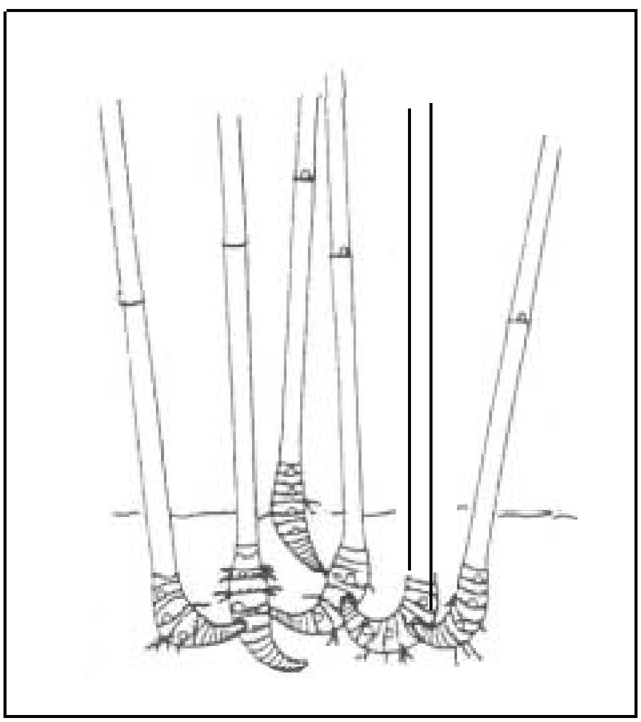

Fig. 1: Bamboo plant: the culms and rhizomes

The Transformation of Bamboo

The term "transformation" refers to the physical change in appearance of bamboo material in end-use applications.

A bamboo plant (Figure 1) contains two main parts: the cylindrical stem or "culm" that stands tall above ground, bearing thin branches and leaves; the underground stem called rhizome on

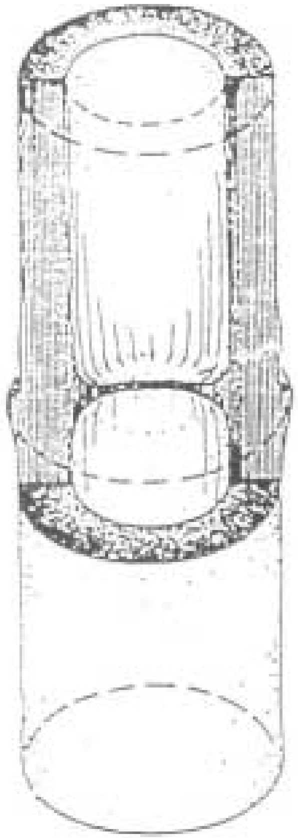

Fig. 2: Bamboo fibres in a sectioned Culm

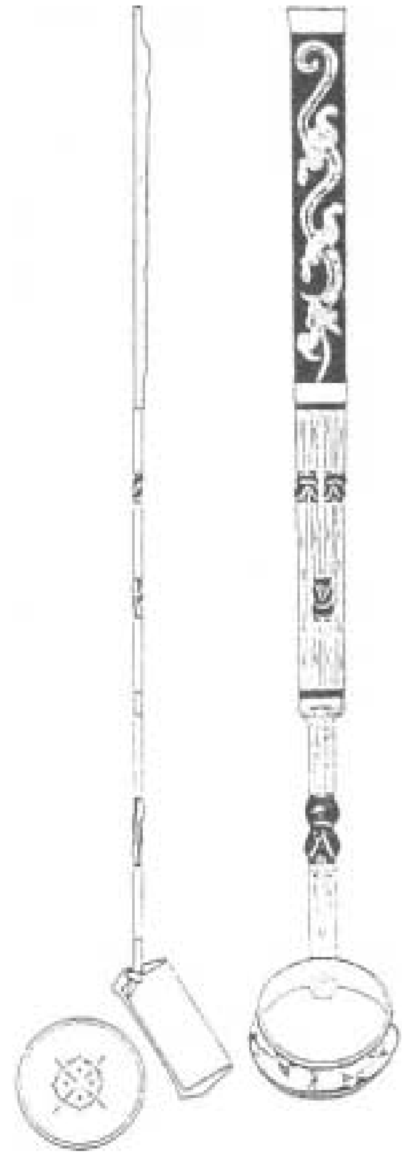

Fig. 3: Water ladle from a Han tom1 (174-145 BC

which culms grow. It is evident from numerous applications that the most useful part of the plant is the culm, along which fibres (Figure 2) run longitudinally. These fibres are held together by soft tissues formed of thin-walled cells (in which starch is stored) resulting in weak transverse bonding (Ranjan et al. 1986). It is this weak bond that allows bamboo culm to be split from tip to bottom with simple tools. Splitting is one form of physical change that transforms the bamboo culm into a different appearance, whether or not its relation to the original material can still be recognized by the naked eye.

In the change of appearance bamboo requires "technology" to work on it. In Neolithic period, the technology was simple as hammering or cutting with stone tools. Softening of the material by heating it in water or on top of fire and smoke leads to the possibility of bending or flattening the culms. Although this is an ancient technology, it is still employed, except that the heat source may be different (for example, heating by microwave which differs only in the method of thermal generation).

The application of one or more secondary materials in combination with bamboo to carry out a new purpose is viewed as a kind of technology aiding transformation of the physical form. For instance, a water ladle (Figure 3) unearthed in a Han tomb (Anonymous 1973) was decorated as well as protected by a thin layer of lacquer to make the utensil look substantial and at the same time more durable. The finish hides the natural colour and texture of bamboos. The layman would perhaps find it difficult to identify the original material. But the long thin and yet strong handle of the ladle clearly displayed the characteristics of bamboo.

The two circles in Figure 4 which remain intact illustrate how bamboo remains recognizable when it is not touched by technology.

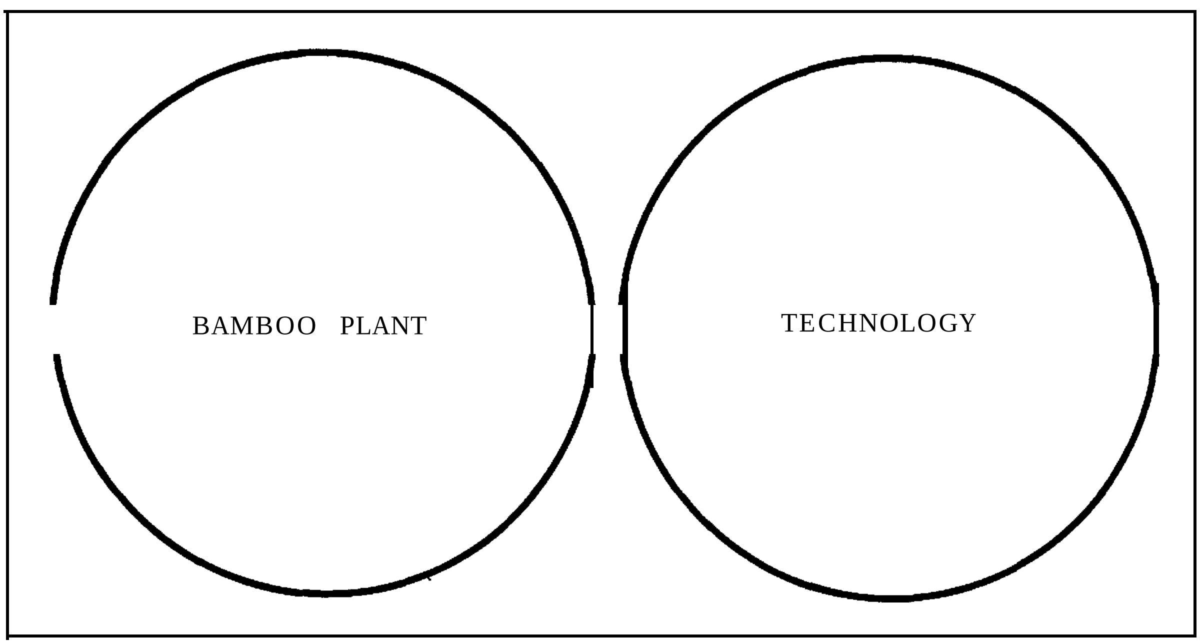

Fig. 4: The two circles remain intact and separate

When the circles move and overlap (Figures 5 and 6), transformation takes place. In transformation, the change of bamboo appearance involves one or more processes, or to be exact, technologies. Therefore, the degree of change often depends on the nature and number of processes employed (Figure 6).

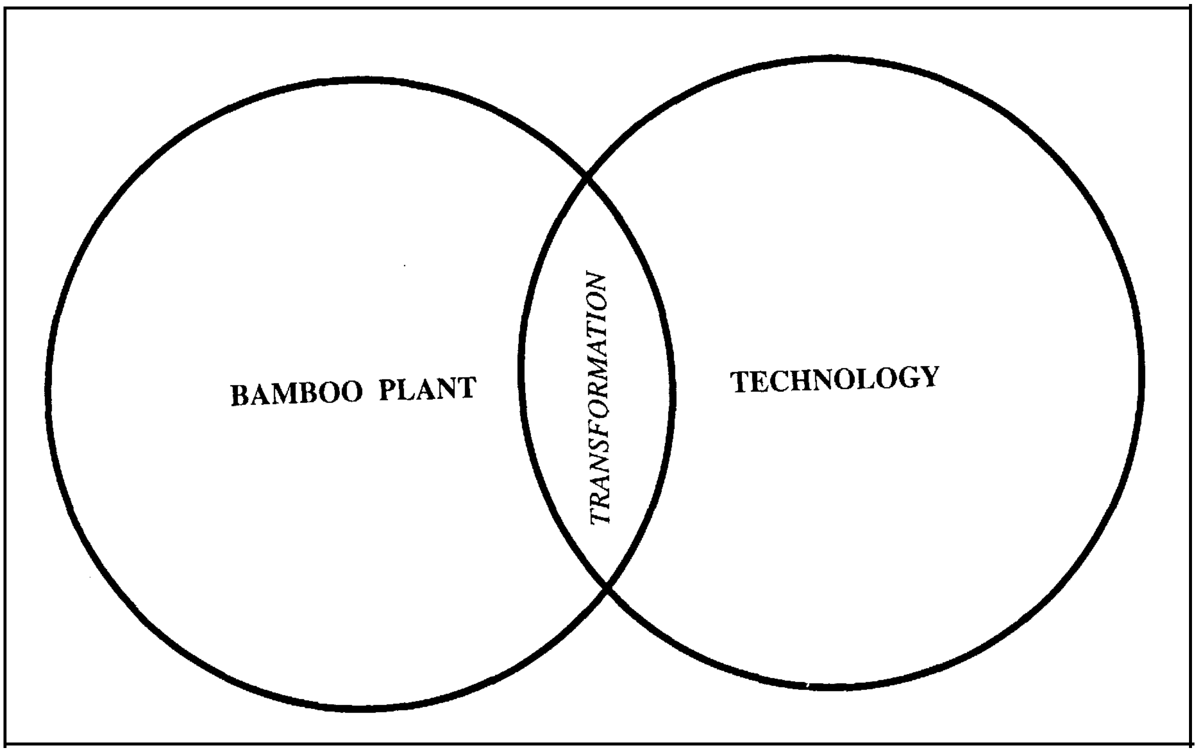

Fig. 5: The circles overlap and transformation takes place

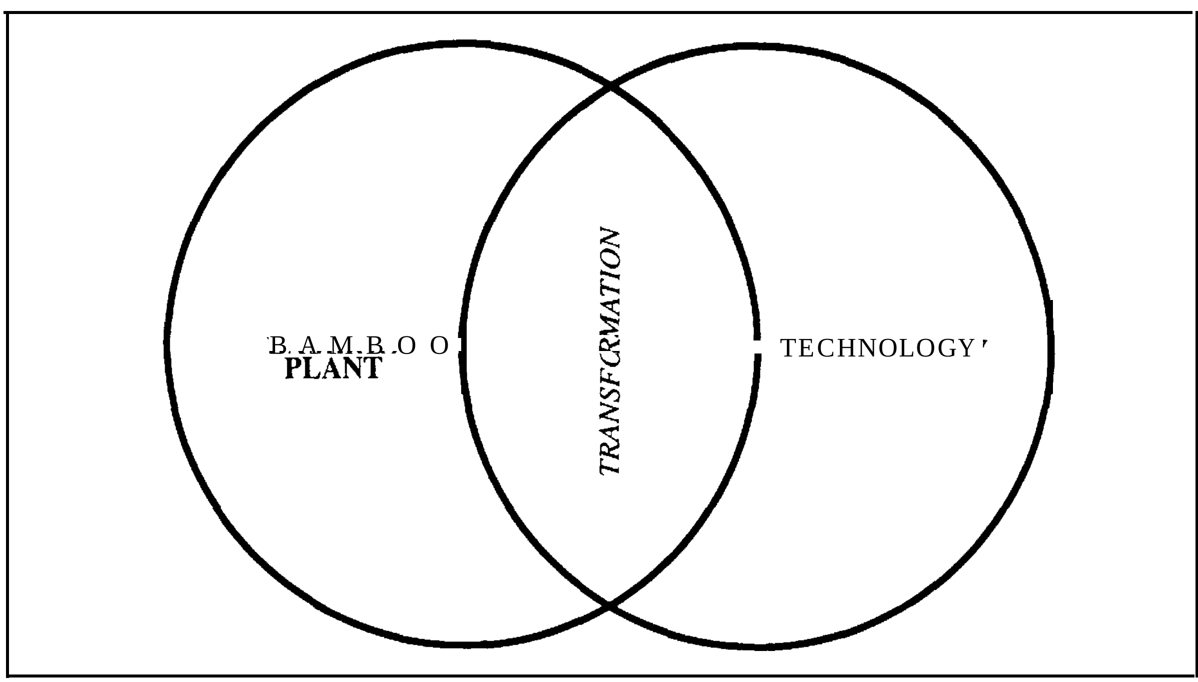

Fig. 6: Greater transformation creates greater change in appearance

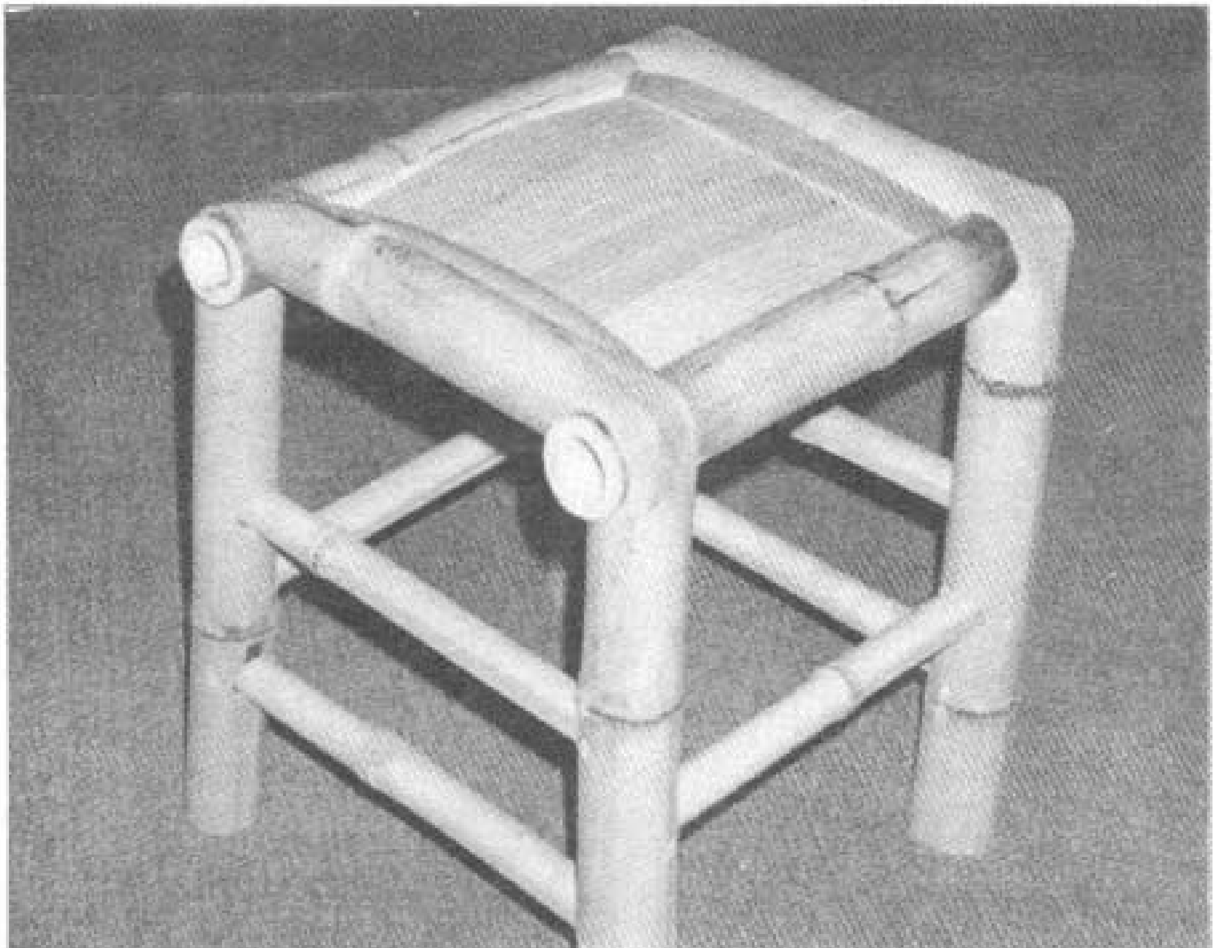

Fig. 7: Bamboo stool

To illustrate this point, consider a bamboo stool (Figure 7) commonly found in South China. The four legs of the stool are made from two pieces of bamboo culm. The first process has been the cutting or sawing in order to separate the culms from the rest of the plant. Two notches (Figure 8) were then cut by chiselling on each culm. The notches are bent around another two pieces of bamboo culms thus encircling the latter. To create a permanent

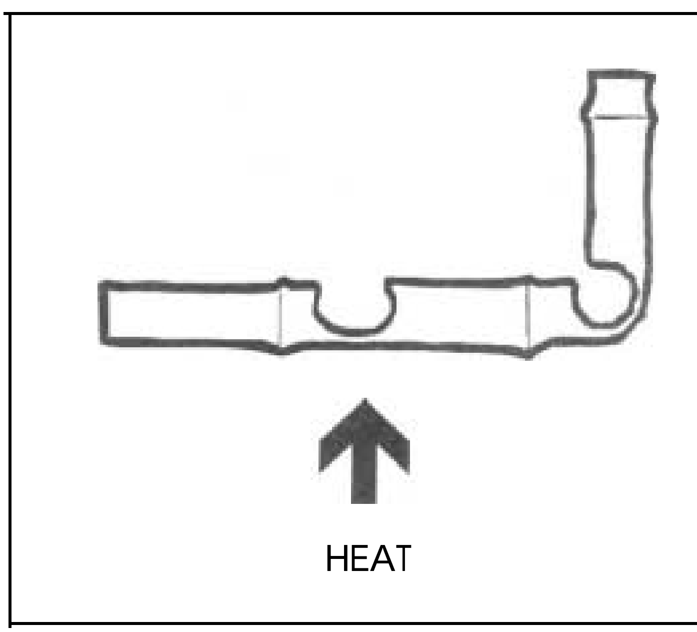

Fig. 8: Softening of bamboo fibres using fire

bend, the culm is usually put on top of a fire or smoke to heat and soften the bamboo fibres at the notch (Figure 8). This will make bending easier when hot, and stable when cooled. The change in appearance in the bamboo culm resulting from these processes is not substantial, as the material is still recognizable. The more dramatic transformation is perhaps on the main part of the seat in which bamboo has been split into a number of splints to form a plain surface (Figure 9) to support whoever sits on it.

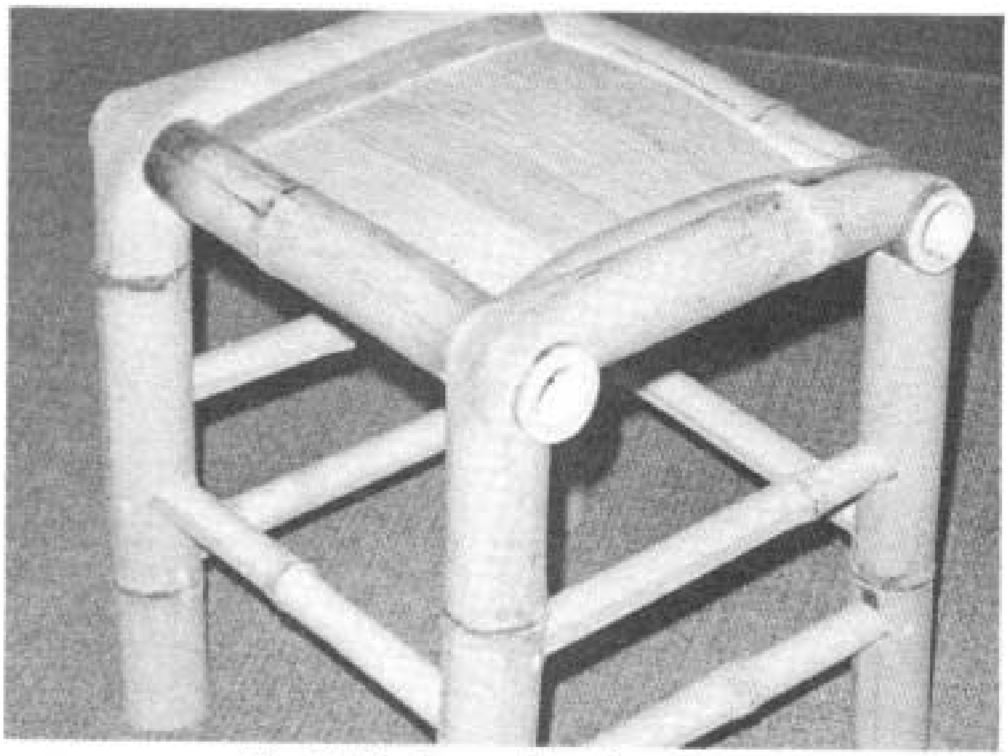

Fig. 9: Bamboo splints form the seat

Bamboo fibres were once woven into textile for clothing. This was done by cutting and splitting the culms which were then boiled in caustic soda for days. Repeated boiling and washings exposed and softened the fibres which were carded, combed and baled for weaving or mixing with other materials like cotton, wool or even silk. Such "cloth" was expensive as the method of obtaining fine fibres was complicated and tedious. This method of using bamboo therefore died out. Today, one can find similar application in a hand-fan (Figure 10) from Sichuan Province of China made of very fine bamboo weaving. The appearance of the "fabric" material is very different from its original form, and may therefore run counter to consumer preference, an issue that will be explored in greater depth later in the paper.

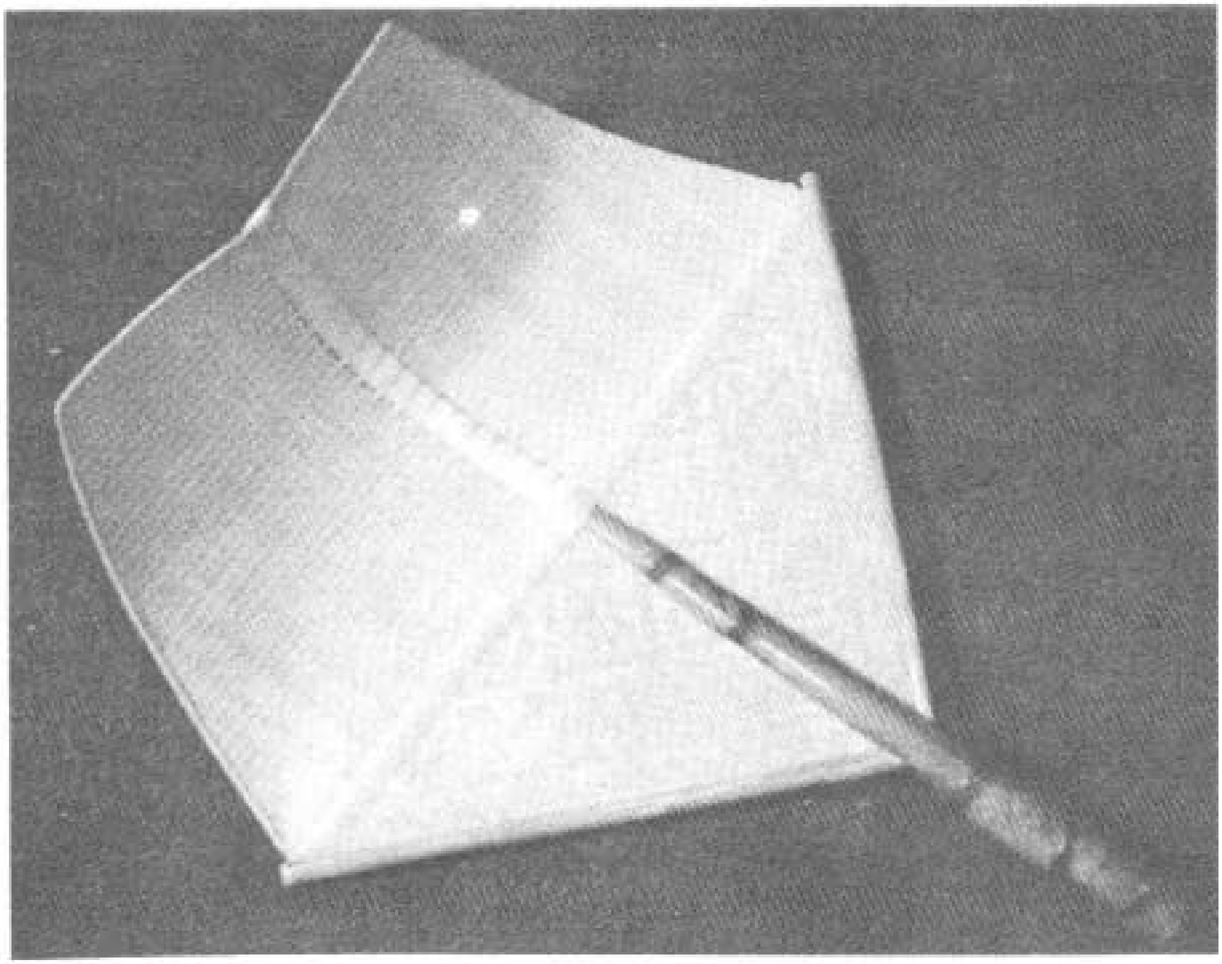

Fig. 10: A fine woven bamboo fan from Sichuan, China

Ihere are examples of material transformations which are of much greater significance when compared to the stool or the hand-fan. The variation is due to differences in the nature and complexity of the processes involved.

Despite such transformations which bamboo undergoes in the making of different products, however, the material has fared badly in the market place and lost out in many fields to other materials. For instance, as a material for furniture, bamboo was not able to compete with timber and metal, or more recently with plastics. 1n South China, bamboo is still a poor man's timber and has not easily moved up-market. Demand for fabric fibre materials like cotton, silk and hemp have long since dominated the market, not tomention the more recent synthetic fibres. Bamboo fibre, therefore, stands little chance in the field of textiles.

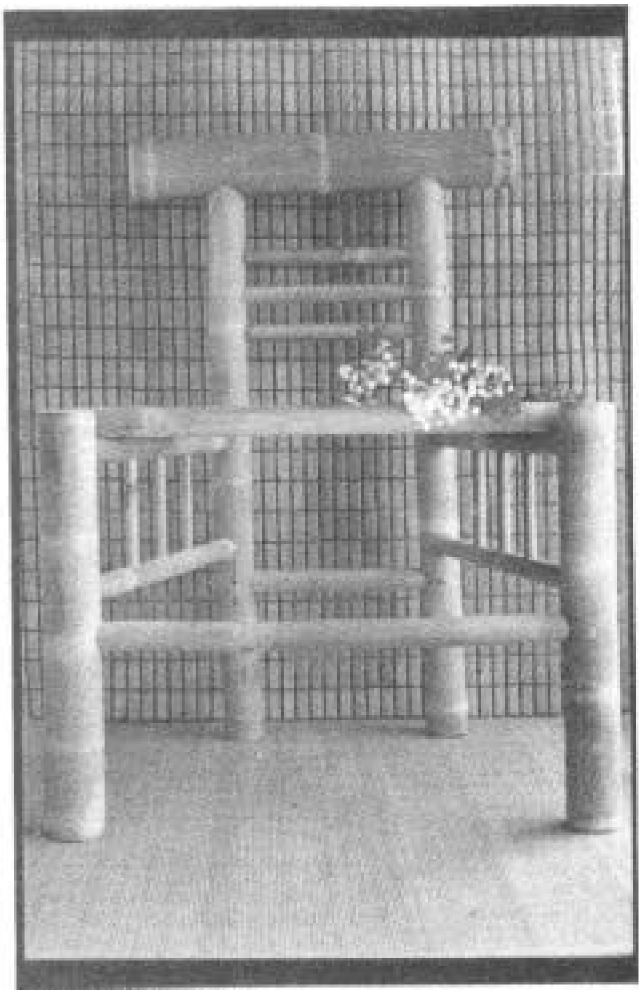

Fig. 11: A modern full-culm bamboo chair (designer Li Yen-en, China)

There are perhaps reasons for this. Unlike timber, cotton or silk, and being a poor man's timber, bamboo has never been a status symbol. Hence, there was little demand for volume production and consequently, manufacturing technology on bamboo rarely progressed. In addition, artefact makers tend to think that users prefer the natural appearance of bamboo to any of its changed forms, in which the recognizable aesthetics of the material are lost. This opinion can be extended by the common belief that, in general, the Chinese love bamboo as it is, and Westerners are fond of it for its exotic origin. For a long time, such a view prohibited much exploration of turning bamboo into different forms of material. The result is that bamboo has largely remained just a craft material. Such bias to the natural form allows variations in culm diameter and wall thickness, but does not permit processing for mass production.

In the example of the bamboo stool, although transformation has taken place, it was at a low level and did not advance for many hundreds of years. When many materials were developed to meet new demands, and to be worked on by new methods or technologies, bamboo was left behind. Therefore, in the case of furniture, one can say that the transformation of bamboo has only been half-achieved. The situation requires careful strategic consideration.

To meet new challenges, needs and demand, bamboo must be further transformed. There is substantial evidence to support the proposition that when bamboo takes a different physical form, it stands a better chance of competingwith other materials. As one of the most environmentally friendly materials and a readily available substance, bamboo must be transformed in order to remain useful to people and to find new areas of application.

At present, in the Shenzhen region of China, an industrial designer Li Yewen has created a bamboo chair (Figure 11), using sections of full-culm bamboo. The construction is traditional, and yet the form is new. Although the appearance of the chair is modern, one can hardly say that there has been much transformation. Same problems of the old version remain. The chair is formed of culms of various diameters and straightness, and put together mostly by human hands in low-volume production. Li agreed that quality has been difficult to maintain. As they dry, the culms shrink and crack. The chair then shakes and loses stability.

Fig. 12: A Japanese bamboo-laminated cantilevered chair (by Oriental Manufacturing Company Limited, Japan)

In Japan, a cantilevered bamboo-laminated chair (Figure 12) was introduced (by the Oriental Bamboo Manufacturing Company) and marketed locally in 1993. Although the artefact resemble the chair design in laminated wood (Figure 13) by the famous Finnish architect Alvar Alto in 1931, the bamboo version may be a more superior because of material advantages. Recent research has provided the evidence that the mechanical properties of bamboo materials are better in many aspects than timber. Klaus Dunkelberg of Germany evaluated bamboo as a building material in 1978

Fig. 13: The wood-laminated cantilevered chair (by Alvar Alto, Finalnd)

and compared it to spruce, a common timber for house constructions in Europe. He concluded in the summary that "bamboo is far superior to our building timber" (Table 1).

Bamboo in the cantilevered chair has been transformed much, into a new form of material that provide manufacturers the possibility of mechanization to achieve uniformity, precision and durability. The notorious image of "bamboo-does-not-last" is thus reversed. Here, bamboo is no longer just a craft medium, but a material for modem technology. It requires someone who is more than just a traditional craftsperson to work with. Someone who has a wider exposure to many new things and issues, based on which he or she will be able to formulate reasonable designs in the new material to meet current consumer needs. This "someone"" we may call "industrial designer". An industrial designer is "one who is qualified by training, technical knowledge, experience and visual sensibility to determine the materials, construction, mechanisms, shape, colour, surface finishes and decoration of objects which are reproduced in quantity by industrial

Table 1: Spruce and bamboo in comparison (values in kg/cm^2)

Species	Module of elasticity	Compression strength	Tensile strength	Bending strength	Shear strength
Spruce	110 000	430	900	660	67
Bamboo	200 000	621-930	1484-3 843	763-2 760	198

(Source: K. Dunkelberg 1978, Technical University of Munich, Germany)

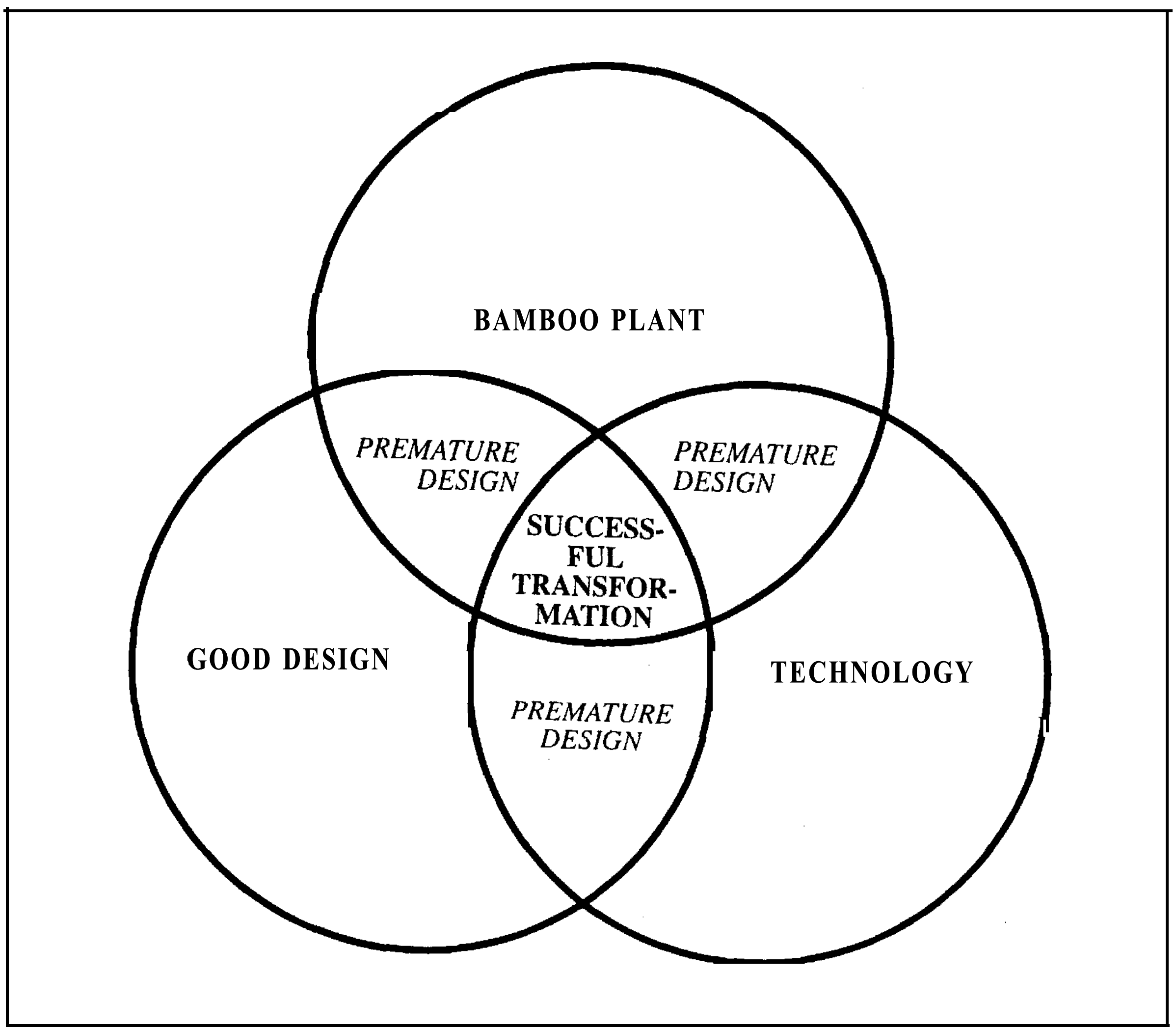

Fig. 14: The successful tranformation of bamboo

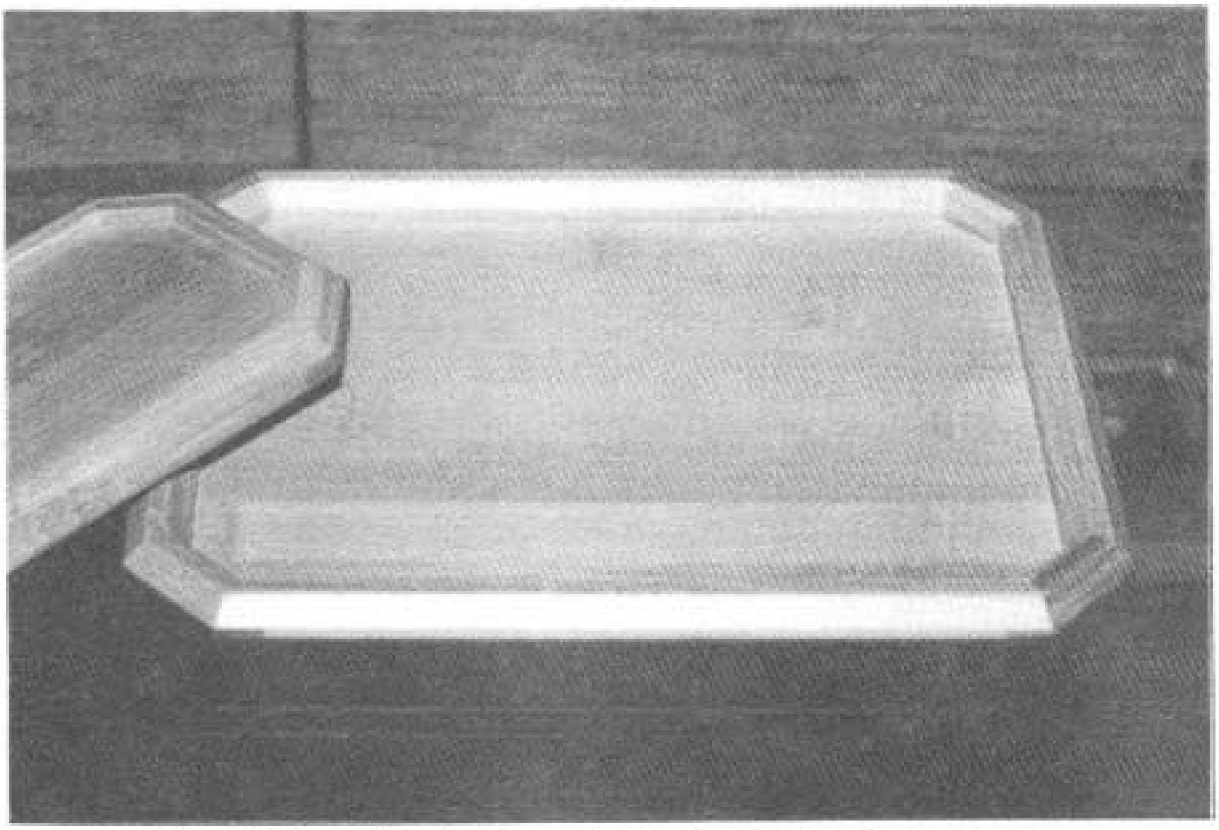

Fig. 15: A modern bamboo-laminated tea-tray from Taiwan

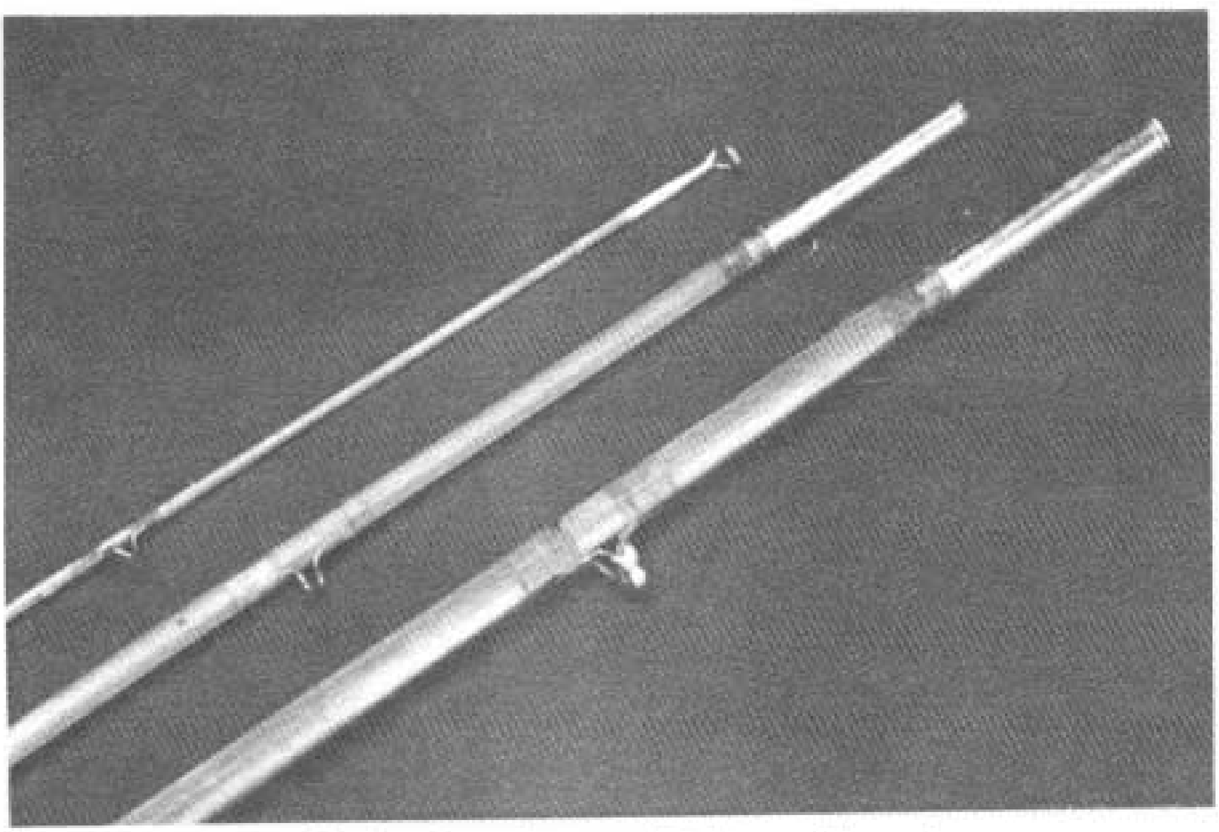

Fig. 16: A bamboo-laminated fishing rod from Japan

processes (International Congress of Societies of Industrial Design). To illustrate the point, this profession of "industrial design" is best to be viewed as a process, or to be exact, amethodology. Good design is always a result of sound methodology, and "good design is a taproot to stimulate all operations which generate, market, service and finance products offered for consumer needs and wants" (Pollock 1974; Archer 1974).

In the early part of this chapter it was argued that bamboo needs to be transformed in order to remain useful, and that bamboo is transformed only by the direct influence of technology. In successful transformation, good design plays an important role. Figure 14 helps to illustrate the essentials for the successful transformation of bamboo.

Conclusioti

Preliminary research suggests that bamboo may be a suitable substitute for a range of materials in contemporary product design from plastic to metal, especially in developing countries where these are expensive and/or rarely available. Bamboo may also offer new product development potential based on advances in materials technologies or manufacturing processes.

To bring bamboo into the modern stream, the industry needs to include the service of industrial design profession also for the reason discussed earlier. Also, it is advisable that the industry and designers should get together to develop a methodological connection between the theory and resources available, and contemporary industrial design practice, and subsequently develop a detailed set of design specifications to directly support the design process.

It is anticipated that these aims can be realized by detailed analysis of product design practice, industries that employ or could employ bamboo technology, and the systematic development of methodologies, tools and resources, so that access and applications by design practitioners, theorists and educationists can be optimized.

Two more bamboo artefacts need mention before this paper concludes. One is a bamboo-laminated tray for tea-cups from Taiwan (Figure 15). The bamboo has been transformed and yet has not lost its character. The second is a fishing rod made of laminated bamboo (Figure 16), given to the author as a present during childhood. The author is now in mid-forties. Who says bamboo does not last?

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Green Design and Bamboo Handicrafts: a Scenario for Research and Action in the Asian Region

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Abstract

Asia has the world's largest resource of bamboo and an enormous pool of skills in working with bamboo for a variety of purposes. Rapid changes in the region's economy are swiftly changing the way people of this region live, thereby leading to a loss of knowledge that is inherent in the bamboo culture that has evolved over several thousands of years. Research initiative is urgently required to study and document this vast body of knowledge before it disappears. Sustainable, eco-friendly development is the premise on which the new bamboo culture can serve the future development of the people of this region. New methodologies are needed to coordinate the research involving a number of scientific disciplines, and systems design and green design are suggested as a framework for this coordinated initiative. The research strategy and specific research and development initiatives have been outlined along with a preliminary identification of various disciplines that need to be mobilized. Sophisticated information technology tools need to be used to ensure effective networking and assimilation of knowledge that are critical for the success of this initiative. Also needed are experience and knowledge in managing such an effort. This would involve a very large number of local collaborators in a cooperative format for solving local problems while drawing on the global database of the new bamboo culture.

The Challenge

Asia is the world's store-house of bamboo resources, with an incredibly intricate and massive traditional knowledge base on bamboo utilization. This knowledge resides in the minds and hands of the local populations of the Asian region. I call this knowledge base "the bamboo culture" wherein a vast repertoire of techniques and know-how is retained by the communities living in the villages and forests of Asia. This bamboo culture zone of Asia extends from India in the west to Japan in the far-east, and from China and Vietnam in the north to Indonesia and the Philippines in the south. Incidentally, this is also the region that is expected to face rapid economic development in the next decade with the emerging 'Asian Tigers' fuelling phenomenal growth rates in their respective economies. Unfortunately, such a rapid growth is also a major threat to the very survival of the bamboo culture that has been nurtured, consolidated and refined over thousands of years. We stand to lose all these if urgent, coordinated, integrated action is not taken. The action needed is international and of great magnitude.

Bamboo has a major role to play in the future of humankind's journey into the next millennium. Of the over 1 200 species identified around the world, more than 60% are found in Asia. The East and the South Asia account for the maximum diversity of the world's bamboo resources. Similarly, bamboo is understood in all its subtle variations by the populations of this region, quite unlike other regions which tend to use a very few local species. Bamboo as a plant has been studied by botanists and foresters for the scientific classification and resource administration, Bamboo as an ethnographic material has been studied by anthropologists and ethnographers as part of their larger studies conducted for the purpose of understanding culture. However, a fresh look at our bamboo resources from an integrated standpoint is needed, so that we can use this knowledge for development initiatives that can be sustained in the future. Bamboo as a modern material for the production of houses, agricultural implements, household articles and a wide range of yet-to-be-discovered uses poses an enormous challenge, particularly for the designers, architects, artists and engineers who wish to work with this material.

As a renewable resource, bamboo must be used in a sensitive and sustainable way to continue to serve human needs in the years to come. Some of these ideas had earlier been presented by this author in a paper entitled *Ecology and Design: Lessons from the Bamboo Culture.* Before specific directions for action and research are proposed, some of the key concepts associated with the terms "Green Design" and "Bamboo Handicrafts" need to be defined. (Both these terms were explored in some depth at the National Institute of Design during client-sponsored projects undertaken there.) First, let us define handicraft in the context of a developing economy, and the role that this definition can have in changing the lives of large populations which are barely able to keep themselves above the poverty line. Second, the emerging concepts of green design can be explored, and then these two key concepts linked to the role that bamboo can play in the fulfillment of their needs. These two concepts bring about a close link between the local populations, their use of bamboo resources and the potential for beneficial effect on the environment (Figure 1).

Redefining the Term "Handicrafts"

While the craft sector in Asia has several problems, it also represents a major area of opportunity for development planning; especially, when the financial resources available in the local economy are too scanty for a widespread development initiative. The handicrafts sector has massive resources of fine skills and technical know-how which, in some cases, have evolved through centuries and are still active. Furthermore, it cannot be ignored that the handicrafts sector is an enormous source of employment, particularly self-employment, for a vast number of people who are otherwise dependent on agricultural activities. In many areas, handicrafts form the sole source of income and sustenance for the communities.

Traditionally, such handicrafts producers have dealt solely with local markets with which they have had direct links through personal contact. However, with the vast economic changes that are taking place, most of these crafts are being marginalized by a variety of industrial products. Marketing and development organizations, in their efforts to bring stability and prosperity to the local economies, have, however, explored the possibilities of new markets for these traditional craft products ,

It should be understood here that the terms "handicrafts" and "crafts" are used in a very specific sense to mean those activities that deal with the conversion of materials into products, using primarily hand skills with simple tools and employing the local traditional wisdom of craft processes (in this case, limited to bamboo). Such activities usually form a core economic activity of a community of people called "craftspersons". The emphasis here is definitely not on "art", although a very high level of aesthetic sensibility forms an inherent part of our definition of craft, along with a host of other factors that constitute the matrix. This being an economic activity that is exposed and influenced by all the competitive pressures of a dynamically shifting market place, our new generation of craftspersons would have to depend increasingly on high-quality market intelligence and strategies

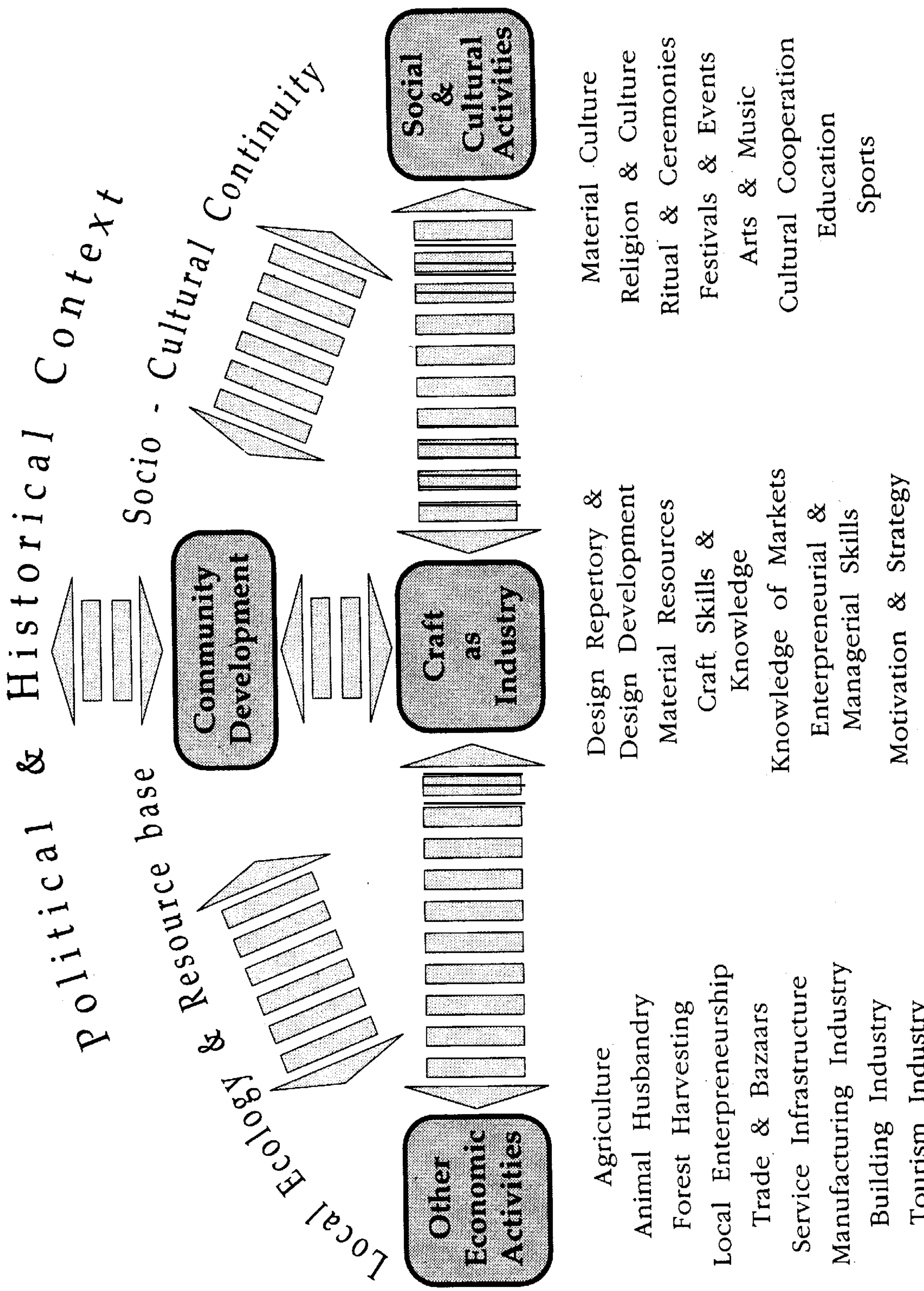


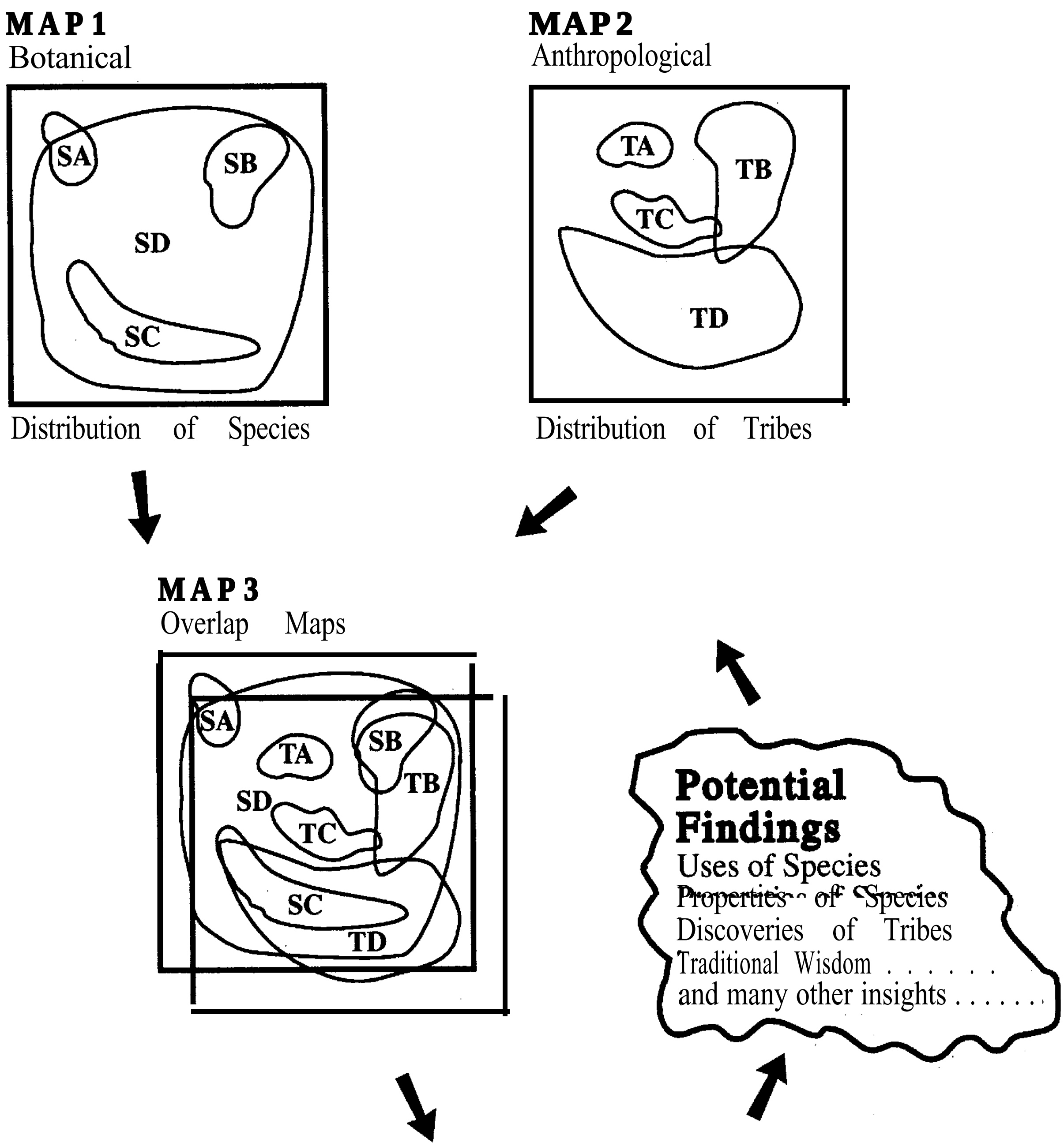
Fig.1: Bamboo craft and village ecomony

designed to be pro-active, particularly while dealing with remote and export markets. Their ability and responsiveness to such changing needs are adversely affected by the generally low level of education that is available today to the average craft worker. The scarcity of capital and the lack of a free flow of knowledge about the competitive shifts that are constantly taking place in this information-centric world further restricts them. While the "know-how" (how-to-make-things-knowledge and skills) exists abundantly in the crafts sector, there is a severe shortfall in the "know-what" (what-to-make-strategies and designs) that curtails the ability of crafts communities to survive intense competition or, better still, develop value-added solutions in the complex economic and social matrix in which they exist.

In a recent feasibility report prepared by the author for the State Government of Rajasthan (India), a new institutional framework was proposed in order to address these issues and to find sustainable solutions for them. The institute's research will also contribute to new developments in the "know-how" and "know-what" areas of technology, design and management that can advance the state-of-the-art in the crafts sector on a professional basis. Such institutes need to be given support to enable them to address a larger agenda that include the needs of Asian handicrafts, with particular reference to the living bamboo culture of the region. Other organizations need to be identified to network the ongoing research and market development efforts that are critical for the development of an interactive and alert community of researchers and beneficiaries, so that the development objectives outlined here will be realized.

What is Green Design?

With increasing environmental consciousness, the practice and teaching of design is undergoing remarkable changes. Systems design methodologies have for some time been explored from various perspectives by designers and others, and in recent years, there has been a resurgence of public interest in environmental issues. Consumer protection lobbies have further reinforced the awareness of corporate bodies to the need for an eco-friendly approach to doing business which strikes at the very roots of the organizations' corporate visions and business purposes. Where this change is not spontaneously forthcoming from the leaders of industry, suitable legislation has been hammered out to reign in the blatant misuse of the environment for short-term goals.



Species & Tribes Matrix

Co-relation Tables	Significant Applications
SA used by TA	Bridges, Ropes, Traps . . . . . .
SB used by TB	Houses, Baskets . . . .
SC used bv TD	Water Tubes, Baskets . . . . .
SD used by TA, TB, TC & TD	‘Fences, Houses, Baskets, Furniture . . . . . .

Fig. 2: Interdisciplinary approach

The emerging eco-conscious designer is charged with the responsibility of not only solving the immediate problems at hand, but to also to take cognizance of and to resolve the long-term impact of contemporary design decisions. This means that the designer must use a systematic design methodology and involve a host of specialist consultants and collaborators so that the complex web of factors that influence each problem are adequately addressed before solutions are offered for each. There is a particular emphasis on the close interaction with communities of users in the design process, along with the subjugation of the designer's ego to the needs and responses of the user groups in selecting design solutions from amongst a host of design alternatives generated in the process of discovering and implementing appropriate solutions. These solutions would necessarily undergo a rigorous process of user evaluation and approval. Today, designers are increasingly incorporating user evaluations as an integral part of the design processes, and this forms the hallmark of the green design movement. New criteria for evaluation include the impact of design decisions on the environment that influence at a very deep level the choice of materials and technology, the kind of application that is benign to the environment, the energy consumed in the process, and the entire life-cycle of the product or system.

This methodology presumes that the design teams adopting such processes require a sound of knowledge about materials, processes of manufacture, and uses, the domain of the user and the long-term environmental impact of such use. Traditional societies of Asia have already discovered many of these intricately linked parameters, and have innovated durable responses to these factors in the form of their traditional products and systems used in day-to-day activities. It is this knowledge resource that can form the backbone of the proposed development initiative.

Bamboo: the Research Agenda

A research initiative to study and document the bamboo culture of Asia is urgently required. Keeping a pattern discovering methodology as the focus of the study and the discovery of key operational principles as the main objective, other areas of knowledge need to be correlated and systematically interwoven to map the boundaries of the knowledge base which may be termed the "New Bamboo Culture". Some of these are listed below, and would naturally be elaborated with the intervention of others from a variety of special disciplines (Figure 2). All these research tasks will be interdependent in many ways and must be closely coordinated. New communication technologies permit a great degree of interaction between remotely located research groups, and the benefits of such an ongoing interaction must be integrated at the very conception of this research initiative. Unless the directions and methodologies of the various participating groups are carefully inter-meshed, the real benefits of such an effort will not be realized. Hence, we need to develop a common overarching objective that will guide and motivate all the participants in each of their specific investigations. Moreover, the lead time between field work and analysis needs to be considerably reduced so that the valuable data generated is put to immediate use.

1) Botanical information related to the distribution and availability of particular bamboo species needs to be updated. A map of the available gene pool of bamboo resources needs to be generated and preserved for the future. Bamboo constitutes a diverse group of plants, greatly differentiated in physical stature and structural properties that are influenced by local climatic and environmental conditions. Knowledge relating to the variety and the suitability of each species to particular environmental conditions will be a major factor influencing the future use of bamboo. Furthermore, comparative structural properties need to be codified and organized for easy use in the design decision making processes.

2) Information relating to the propagation, maintenance, harvesting and post-harvest processing of bamboos suitable for structural applications need to be developed and disseminated. These would include areas of biotechnological explorations. The anomalous and often mystical flowering of bamboo species over very long cycles of gestation has been a major bottleneck in past researches. However, recent research in genetic engineering and tissue culture seems to suggest potential solutions to the problems relating to sustained regeneration.

3) Mechanical engineering data relating to particular species of bamboo need to be harmonized. The variables would include properties influenced by the age at harvest, part of culm used, properties influenced by environmental conditions in which the species grows, and property changes caused by post-harvest practices. Mechanical properties of each species in respect to a minimum set of variables need to be experimentally verified to generate a database that can be interpreted by the heuristic processes used by designers and craftspersons. The tacit knowledge of local craft workers need to be discovered and recorded in the form of a suitable database that can

be used effectively. Some of these insights will be region-specific while others will have universal application.

4) Information related to structural, mechanical and physical properties of bamboo of various species, generated in laboratories and field situations, needs to be linked to the above database to provide a direction for future research, as well as to confirm and reinforce the findings of the field studies. Building codes, as well as mechanical engineering data sheets, would need to be generated and disseminated to establish the status of bamboo as an important material.

5) Information relating to the diverse structural applications of bamboos in different cultures and geographic regions – particularly with reference to the variety of interpretation of structural form as a result of cultural differences – needs to be studied. This is, perhaps, the most urgently needed research as the sources sustaining this knowledge base are getting rapidly eroded by contemporary education and social and economic upheavals of the information age. Various cultures have interpreted the same species of bamboo with subtle differences that reflect and preserve their unique identity. Such variations offer an enormous opportunity to discover the interrelationship between cultural forces and technological factors which is critical for the development of new products that will find acceptance in those cultures.

6) Experimental data relating to contemporary explorations into the utilization of bamboo in structural and product design applications need to be generated by conducting numerous design and development projects, each of which would create new interpretations for the application of the enormous bamboo resources that are available. These would include the creative re-interpretation of potential applications in the light of new technological insights developed in diverse fields such as structures and manufacturing. Bamboo is nature's marvellous composite material, and needs to be reappraised in the light of developments in carbon fibre composites. Numerous such projects are required to develop a large bank of applications that would cover the diverse needs of both local and export markets.

7) Information related to techniques, processes and tools/equipment used for the processing and conversion of bamboos for structural applications needs to be compiled. New and improved tools would result from a systematic study in this area. Tests of existing tools for efficiency and precision would enable the development of suitable guidelines for good practices

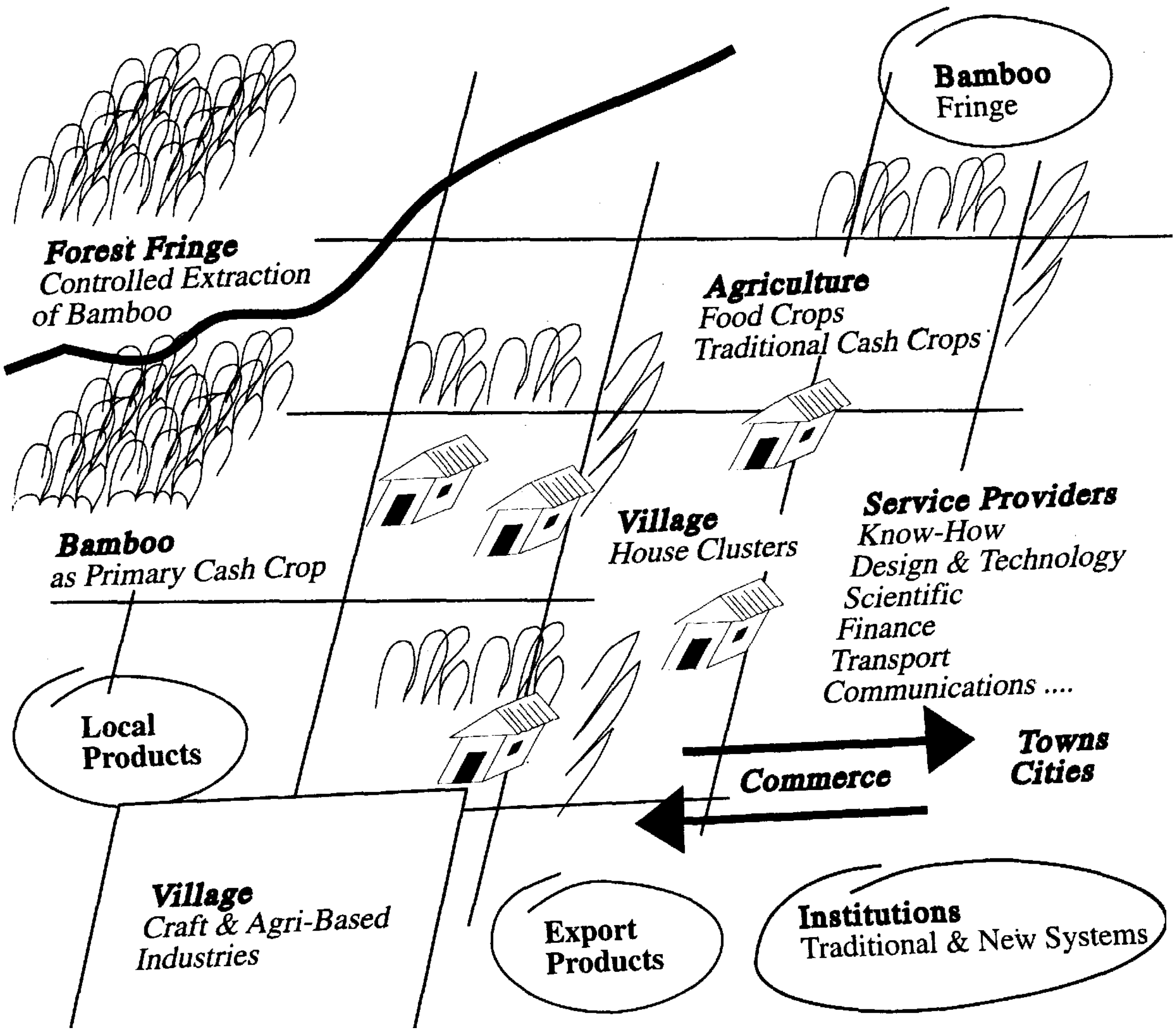


Fig. 3: Schematic representaion of bamboo-driven village economy

in the felling and conversion of bamboo. Materials can be transformed with the brute force of modern technology, but they can also be handled with a deep understanding and a fine sense of aesthetic and artistic interpretation which would elevate them from the prosaic to the sublime. Hence, it is not only a gross type data that is needed here, but something that reflects a fine appreciation of the material and its contextual manipulation possibilities. Most ethnic cultures have very fine examples of such highly refined interpretations of material and form.

8) Principles of structure and morphological characteristics of structural form that show potential for application in bamboo need to be developed. These would include principles of lightweight architecture and micro-mechanical structures that cover product-scale applications. These structural principles can help understand the new potentials of bamboo as a structural material in a cost-effective manner. New advances in structural engineering have made possible the production of extremely lightweight structures for a variety of applications ranging from housing to hang-gliding. Experiments with bamboo would open up a vast range of potential applications that have hitherto escaped attention.

9) Materials akin to bamboo – such as rattan and a vast range of grasses – could be put to effective and sensible use. This will be a beneficial spinoff from the proposed initiative with bamboo, and the network of research efforts will open up new and interesting questions to be explored in the future.

10) Human experiences in the setting up and running of decentralized cooperative societies which have been practised in several cultures need to be re-evaluated in the context of a global information society in order to explore new and sustainable forms of ecologically responsible behaviour. This, combined with the messages embedded in the bamboo culture, promises to be of vital significance for the environmentally friendly use of the available resources. Cooperative agricultural practices in India and China have shown the benefits of this development format. Much of this know-how needs to be transferred to the cultivation and utilization of local bamboo resources by communities who willingly collaborate to achieve sustainable results. The linking of this development to the market economy is also essential for the program to be meaningful (Figure 3). The success of co-operative production and use of milk products and agricultural crops can be replicated for the extensive use of bamboo to meet the needs of local populations and for the development of export-oriented local economies,

11) Design and development projects with specific objectives need to be undertaken under the framework of the green design initiative so that a body of experience can be built up, which will provide benchmarks to evaluate the.progress of the entire development initiative from time to time. It is in the implementation of such projects that all the knowledge available can be put to use. These projects will also provide the push needed in other areas of research. Most of these projects will deal largely with pressing problems of a local nature, while others could focus on the development of commercial applications for the export economy.

Each of these core areas need to be elaborated and articulated as action plans with the participation of those who are both able and willing to embark on this major initiative. For this initiative to bear fruit, it is imperative that close coordination be maintained between all the distributed research groups. Advanced communication technology can be used to keep researchers in constant contact since the need is to reduce cycle time between primary field research and the distributed and simultaneous secondary and tertiary analysis and research. This way, several cross-disciplinary collaborations can be initiated and sustained across the region of Asia. Computer-based networks make such a conception both feasible and desirable. The time is ripe for action and this paper is a call for a co-ordinated thrust that can be realized in the near future.

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IVth International Bamboo Congress
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RECOMMENDATIONS

1. There should be integrated development at the national level of bamboo resources and products to meet both domestic and external markets.

2. Improved technologies, such as computer designing or microwave heating, have to be adopted for quality improvement of products by providing extension services to workers and users. In this respect, simplified technology guidelines need to be produced.

3. Multi-disciplinary research and networking of results in bamboo craft should continue to be promoted by INBAR to aid sustainable development. Training is particularly needed on basic furniture design.

4. Directories of crafts people, manufacturers and commercial outlets, as well as documentation on tools, techniques and products should be prepared country-wise, and knowledge exchanged between countries through information networking.

5. In developing such information, special attention needs to be paid to traditional knowledge and skills so that they may be incorporated in processing systems which benefit rural people.

6. Studies on species properties form a basis for deciding what material should be grown in plantations to support specific microindustries.

7. INBAR is requested to organize a task force to discuss and finalize a building code for bamboo.

8. There is a need to promote much wider demonstration of appropriate bamboo housing and associated microenterprises in a number of tropical areas. Socio-economic aspects of wider implementation of bamboo housing, as well as its potential for the conservation of the tropical rainforest, should be studied. INBAR is asked to promote such demonstrations which

will be a vehicle for more rapid South-South transfer of technology. There will also be a need for INBAR to promote advanced training to spearhead continuing technological development.

9. There is a need to develop a technical manual on construction technologies for bamboo housing, incorporating ranges of options and appropriate recommendations. There is a further need for simplified illustrative guides applicable to NGOs and other non-technical users.

10. INBAR is asked to promote indigenous capabilities to use bamboo in disaster housing. The technology already exists, but should be assessed by an expert panel and collated in formats appropriate to whatever type of organizations would be involved in disaster response.