IPT

Instituto de Pesquisas Tecnológicas

Final Technical Report DEC/AMCC nr. 32,500

LOAD BEARING WALLS APPLICATION BRAZIL II

Transference of "IPT/IDRC Wall Panel System" Technology

Volume I

Sponsor: International Development Research Centre -Canada (IDRC)
Centre File 90-0232

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VOLUME 1

SUMMARY

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1. INTRODUCTION

The main objective of this project was to transfer to the Brazilian market the "IPT/IDRC Wall Panel System". This technology is the principal result of the "Fibre-Agro Industrial By-Products Bearing Walls", a research project performed by IPT and sponsored by IDRC (Report DCC/AMPC nr. 27937/89).

The chapter two of this report presents an overview about the project development, including a presentation of the main and specific objectives, the major facts that affected the project and the new strategy that was adopted to handle these constraints in order to fulfill the objectives.

Chapters three to five show a detailed performance evaluation results, including a detailed economical feasibility study, done by Politechnical School from University of São Paulo. Chapter four, presents durability results and includes some improvements in blast furnace slag (BFS) cement mix in order to increase its chemical resistance against water.

Chapter 6 shows the main results of a grinding technology study. This study was not planned in the research proposal. Chapter 7 shows a summary of all dissemination activities performed by research team, including the dissemination seminars organized or under organization, TV's and newspaper reports and technical meetings where the new technology have been presented.

The last three chapters present the transference of the IPT/IDRC Wall Panel System technology results, the further activities that will be performed by the research team and the final remarks.

2. PROJECT DEVELOPMENT

2.1 Planned objectives and activities

The main objective of this project was to transfer "IPT/IDRC Wall Panel System" technology to the Brazilian market. This technology was developed with the IDRC support.

In order to help the technical transference activities, the original plan had the following activities:

- complete performance evaluation of the load bearing wall system;
- preparation of dissemination materials like a 15 minutes video tape, technical manual and leaflet;
- conduct a detailed cost comparison between the new and traditional technologies;
- to build 5 prototypes and conduct demonstration workshops.

However, during the project development this plan has been changed to overcome constraints (see item 2.2), mainly from national housing policy in order to fulfill the main objective.

2.2 Main constraints

2.2.1 National housing policy

By the time when research proposal was prepared (1990) the Federal Government was just getting started a plan to build, in the following 5 years, 4 million low cost houses, cutting down the national housing deficit in about 30%.

To fulfill this goal the building construction industry would have to build 3 times more houses per year than his highest production rate (during the seventies). For this reason we had expected a shortage of the traditional building materials. With this background, it would be quite easy to put into the market well developed and evaluated new building technologies.

Unfortunately the plan was not fulfilled. Between 1990 and 1991 about of 400 thousand houses were contracted, mainly in small cities, far from the steel industry. Due to the lack of financial resources the Federal Government had cut down the budget, mainly in the housing area, and about 250 thousand are still unfinished.

After a political crisis, the president was replaced by the vice-president. The new administration has adopted a policy based on financial austerity, and the budget for housing has been kept very low. During the last year (1993) the Federal Government expended only US $ 20 million in low cost housing, mainly for sanitation works in slums ("favelas").

For this reason it has not been easy to introduce new technologies in house building industry during the last 4 years due to lack of market.

2.2.2 Sponsoring of new building prototype construction

In the proposal was assumed that the Federal Government would give the financial and political support to build the prototypes. By that time this support was even unofficially accorded with Federal Government Housing Secretary Staff.

Due to a shortage of financial support to the housing program we had 5 different Federal Housing Secretaries in only 12 months, and the agreement has not been carried on.

As soon as the new government was inaugurated, IPT had presented an official funding request (Proposta DCC AMCC n°16320/92) to Programa Nacional de Tecnologia em Habitação - PRONATH (The National Building Technology Program). This program is under the National Housing Secretary and its mission is to finance research and development related activities in housing technology. The support technological transference on new building technologies was one of the goals of this Program. However it has not been possible to receive any financial support because the program actually have not funds. Thus it was impossible to build the prototypes as had been programmed.

2.2.3 Blast furnace slag supply

To establish a long term contract of blast furnace slag cement supply is one of the most important conditions to start the production of the panel system. In Brazil almost all basic blast furnace slag production was under contract of Portland cement producers at very low prices. They use only part of this slag as addition to the ordinary Portland Cement and the remainder part was wasted.

When the grant contract between IPT and IDRC was signed nearly all steel industries had already been sold by the Federal Government to private groups. It was expected that the new owners would try to get better prices for blast furnace slag making it available to other users.

However mostly of the contracts signed when these industries were under the Federal Government control are still valid and will continue for many years, being subject of expensive fines if broken. On the other hand, as the Brazilian economy was in bad situation the plan to build a new steel plant in the Northeast (State of Maranhão) was postponed. Fortunately, in the present two large steel company, COSIPA, located near of São Paulo, and AÇOMINAS, in Minas Gerais, are able to sell blast furnace slag in the market. Other steel companies have plans to do the same in the near future.

2.2.4 Grinding technology

As the cement industry grinds about 2,5 million of metric tones of blast furnace slag every year we had initially assumed that the grinding technology was easily available.

Unfortunately the Portland cement industry is almost the unique customer for the most important milling industries, and these companies have no interest to cause any harm to their main customer. Moreover as the Portland cement industry utilizes 100 metric tones/hour mills they even have no experience with smaller units as we need.

On the other hand smaller mills industries, who have interest in this new market, have no experience in building mills to grind blast furnace slag. For this reason, IPT has to perform some experiments to get some basic data to support these industries.

2.3 The new project guidelines

To handle these constraints and fulfill the main objective, the project team had made few changes in the original proposal.

Without financial support from Federal Government it was impossible to build prototypes. Therefore we started to organize Technical Seminars about "Recycling By-Products as Low-Cost Building Materials", when "IPT/IDRC Wall Panel System" could be presented as well as other similar technologies. The main hypothesis is that without prototype it was difficult attract people with the presentation of one single technology.

As the same time, the project team had done very important efforts to widespread the new technology by different ways. First at all we started sending press releases and make contacts with newspapers, magazines and TV networks. Also, we started presenting papers in almost all technical seminars and organizing stands in exhibitions related to technical conferences or even in commercial exhibitions.

The industrial plant to make the "IPT/IDRC Wall Panel System" require both equipment to make cement as well as usual precast concrete facilities. To build a plant to produce only alternative cement is cheaper than erect a panel industry and could be a starting point to produce panels. It was necessary point out that the price of cement in Brazilian market is very high.

Finally, as due to economical situation, the building entrepreneurs had no condition to make investments in new building technology, we to suggested to public housing companies, located near of COSIPA - a blast furnace slag supplier- to use our technology.

3. PERFORMANCE EVALUATION AND WALL SYSTEM IMPROVEMENTS

3.1 Introduction

The performance evaluation methodology means to evaluate a building technology to comply with the *user requirements*. Table 1 shows the user requirements as stated by International Organization for Standardization on *ISO 6241-1981- Performance standards in building* ...

Each user requirement is translated in terms of a set of *performance tests* that try to simulate in laboratory condition what could happen during the actual building use. The relative importance of each user requirements varies worldwide and even inside a same country. It depends on several factors, like human habits, culture aspects, environmental conditions and average national income. For these reasons, different countries and different regions in the same country could have different performance criteria for the same user requirements.

For the Brazilian conditions, IPT has selected the following requirements: (1) Stability, evaluated by soft-body impact test, hanging load test, hard ball impact test and compressive strength test; (2) fire safety requirements by the fire resistance test; (3) safety in use requirement, evaluated by soft-body impact test and hanging load test; (4) watertightness requirement, evaluated by watertightness test; (5) acoustical requirements, evaluated by airborne sound insulation test; (6) hygrothermal requirements; (6) durability requirements, evaluated by Quick Condensation Test and accelerated carbonation (in previous phase) and by in-use evaluation (see item 4); (7) economical requirements, performed by a specific study made by the University of São Paulo (see item 5).

3.2 Soft-body impact test

In foregoing stage (Report DCC/AMPC nr. 27937/89) the load bearing wall had failed under this test with an impact of only 240 J. For this reason, the panel was considered not suitable for external load bearing wall use.

During this phase, two standards soft-body impact test were performed, with samples of 250 cm high and 320 cm wide, including one door. In these samples, a series of successive impact loads from 120 J to 960 J were applied. All impacts are done by a 400 N sand bag falling in free pendulum movement. The performance criteria includes both instantaneous and plastic deformation as well as limitations on sample damage (like cracks) and do not accept failure.

Table 1 - User requirements (ISO 6241-1981)

1. Stability requirements	8. Visual requirements
2. Fire safety requirements	9. Tactile requirements
3. Safety in use requirements	10.Dynamic requirements
4. Tightness requirements	11.Hygiene requirements
5. Hygrothermal requirements	12.Suitability of spaces for specific uses
6. Air purity requirements	13.Durability requirements
7. Acoustical requirements	14.Economic requirements

During the first test the sample has resisted all standard impacts, but had show cracks in the panels joints.

After a sample analysis was evident that the cement grout that was designed to stick together two adjacent panels had no adhesion to these panels. The problem was that the panel had no enough roughness to stick the grout.

In order to improve the roughness of joint surface , a new production step was introduced. Just after a side part of the mold is removed, a steel brush is applied by hand over the joint surface. After this change the performance test was repeated successfully showing that the problem was solved (Relatório de Ensaio 819.62).

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3.3 Watertightness test

In this test one side of a sample (120 x 120 cm, painted with two layers of PVA based water emulsion paint) is exposed to a simulation of an non stop 8 h rain associated with 60 km/h wind. At the end of the test no more than 10 % of the sample surface exposed to the indoor area can show moist (*IPT Standard*).

During the first test the sample failed, showing a seepage in vertical joint between panels. The sample analysis had showed that, again, the poor grout adhesion to panel joints was the source of the leakage. The test was repeated using panels produced as described in item 3.2, and no leakage was observed (Relatório de Ensaio 819.624).

3.4 Thermal stress resistance test

In this test (*IPT Standard*), the 120 cm wide and 240 cm high sample is exposed to a light radiation until its surface temperature grows up to 80 °C.. After 1 h in this temperature, the sample was abruptly cooled with water spray until the temperature of sample surface falls to indoor air temperature level. The entire cycle is repeated once time a day, during 10 days.

After the first test we could observe cracks in the vertical panels joints. A new wall sample was prepared and submitted to the test. Again cracks could be observed (Relatórios de Ensaio 819622 and 819.623).

Considering that no cracks were observed during the soft-body impact test after the panel production improvement, and only small cracks were observed in the prototype after almost 5 years of use (see chapter 4), a flexible joint located each 4 m in external walls was adopted in order to control the cracks.

3.5 Airborne Sound insulation

This test was performed as stated in *ISO 140/III - Laboratory Measurements of Airborne Sound Insulation of Building Elements* standard. A wall sample, with a surface area of 9.6m^2, assembled in a rack, is fixed between two standard rooms. During the test, a standard noise is generated in one room and the transmitted sound is measured in the other.

The calculated *RW - Weighted Sound Insulation Index* (ISO 717/1) and the *CTSA - Sound Transmission Class* (ASTM E 413) are 41 dB (Relatório de Ensaio 814.548). IPT standard require RW ≥ 40 dB, and the load bearing wall fulfill this requirement.

3.6 Fire resistance test

In this test, performed following the Brazilian standard *MB 1192/77 - Determinação da Resistência ao Fogo de Componentes Construtivos Estruturais* (Fire resistance test for load bearing structure components). In this test one side of a wall sample (240 cm high *x* 240 cm wide) stressed with a vertical load of 740 kgf/m, is exposed during 30 minutes to a furnace which reaches 800 °C.

At the end of the test the temperature in the not exposed surface, an average, was 71 °C. No damage could be observed, except some cracks in joints. The load bearing wall accomplished the standard requirements (Certificado n° 805,496).

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3.7 Hygrothermal comfort

As the hygrothermal comfort depends not only of the materials but also of the building design. Usually IPT evaluate it by a computer simulation of the house design. Because in our case we have only a load bearing wall panel with no house building project, it was impossible to do the computer simulation.

For this reason, only the thermal conductivity of the panel was estimated. The thermal conductivity of the composite (dry basis) measured following *ASTM C 177/85 - Steady State Thermal Transference Properties by Guarded Hot Plate* recommendations is 0.64 $W.m^{-1}.K^{-1}$, and the estimated thermal conductivity in the equilibrium moisture content of about 12 % (*DIN 52612 - Part 2)* is 1.6 $W.m^{-1}.K^{-1}$. With this data it is possible calculate the thermal resistance of the panel. Using *ASHRAE Handbook of Fundamentals 1985,* the computed thermal resistance of the wall was 0.4 m^2KW^1. This thermal resistance was very similar of the normal concrete blocks or ceramic brick wall, a traditional building technology in Brazil. Considering that the weight of IPT/IDRC Wall Panel System is similar to the concrete and ceramic walls it could be concluded that the thermal comfort of IPT/IDRC Wall Panel System is similar to the traditional ones.

3.8 Other performance tests

In the wall *compressive strength test* (sample 1.2 m wide x 2.5 m high) performed during the first stage of the project, the wall showed a compressive strength of 6.48 MPa, a stiffness of 9.65 GPa and Poisson's ratio of 0.067. The strength is high enough to allow these panels to be used in two story houses (Report DEC/AMPC nr. 27937/89).

During a *Hanging Load Test* performed also in the first phase the panel supported more than 1500 N, about tree times more than the requirement. This force is enough to broke a normal fastener (see Report DEC/AMPC nr. 27937/89).

In the *hard ball impact test* (IPT Standard Method) a steel ball of 0,5 kg falls from 200 cm high in pendulum like movement against the panel. The impact energy is of 20 J. The standard requirement is that the ball does not perforate the wall. The panel sample suffered only a 2 mm depth concavity, with some microcracks (Relatório de Ensaio 819.619).

The *door impact test* (ABNT ME 45/81) shows the performance of the connection between the door frame and the wall panel against stresses produced during the use. The IPT/IDRC Wall Panel System has fulfilled the standard requirements (Relatório de Ensaio 819.620).

4. DURABILITY EVALUATION

The durability evaluation was carried on observing the building prototype.

Two main building inspections were done in this period. The first one was in December 1991, when the prototype had 2.5 years old. The second was performed in June 1993. Data was recorded and samples was collected in both observations.

4.1 Inspection of December 1991

During this inspection the following observations were recorded:

- as a rule, no visual damage of the building panels could be observed (Figure 1, Appendix I);

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- in the shower room, where a permanent pipe leakage was observed for almost 2 years, a localized area, where the cement was leached out, could be observed (Figure 2, Appendix I)
- the wall in front of the kitchen sink, frequently exposed to water, have an extensive area with mould growth, but no dissolution (Figure 3, Appendix I);
- some panel joint cracks (Figure 4, Appendix I) could be observed, although no watertightness fault occurred;
- some cracks was noticed in the joints between doors and panel (Figure 5, Appendix I);

A sample of the leached panel was removed for further analysis (item 4.3).

4.2 Inspection of June 1993

In this inspection no further degradation could be observed. Two different samples of the composite were removed for further durability studies. It is necessary to point out that the prototype was repainted by IPT six months before this inspection.

The first sample was removed from the external face of the wall (Figure 6). This surface was painted with of PVA water emulsion paint, and was exposed to rain and sun cycles. The other sample was removed from a small panel, placed right over the soil during the prototype assembling (Figure 7). This panel With no paint or any other protection, had been exposed to sun and rain. Because it was in contact with the soil, a moisture content higher than observed in the wall was maintained. This high moisture content allied with the direct contact with soil make an excellent condition for mould growth. Mould is the most important degradation factor for woods and, of course, for vegetable fibers.

No further lixiviation could be observed. Even the panel in contact with the soil and exposed to direct rainfall during 4 years had no remarkable lixiviation as the fibers were still inside of the matrix (Figure 8, Appendix I).

4.3 Cement composition and durability

4.3.1 Original binder

During the first phase, we had selected a binder composition of 0.88 : 0.06 : 0.02 (BFS:gypsum:hydrated lime).

As was pointed out in the technical report DCC/AMPC 027937/89, the reaction between some hydrated cement components and the CO_2 of the air, named as carbonation, reduces the strength of cement. The probable reaction is:

$$C_3A.3CaSO_4.32H_2O + 3CO_2 \rightarrow 3CaCO_3 + 2Al(OH)_3 + 3CaSO_4.2H_2O + 23H_2O \quad (1)$$

Thus, the ettringite produced by the hydration reaction among water, gypsum and the aluminates from the blast furnace slag (BFS) is converted again in gypsum by carbonation. Gypsum is a water soluble material.

4.3.2 Analysis of the cement

A X-ray diffraction of the panel sample collected in the first inspection was done in order to evaluate the mineralogical compounds in the hydrated and carbonated cement (Figure 9). It was possible to conclude that, after carbonation, the binder have calcium carbonate ($CaCO_3$), and gypsum ($CaSO_4.2H_2O$), possible C-S-H and quartz and other minerals characteristics of sand as well as a amorphous phase.

The existence of gypsum and calcium carbonate confirms that during the carbonation part of ettringite, is decomposed, as stated by the equation (1).

Gypsum is a water soluble mineral, and probably, is the responsible for the binder lixiviation. Then, a reduction in the gypsum content of the binder will reduce the water solubility.

, Since the panel placed for more than 4 years over the soil and exposed directly to rainfall of about 1462,4 mm/year is still in suitable conditions, the degree of solubility of the cement was not very high.

4.3.3 Binder composition improvements

In order to evaluate the possibility of gypsum content reduction a short study was performed.

The BFS (Table 2), produced by COSIPA, was grinded in a lab ball mill until a Blaine surface area of 412 m^2/kg was reached. A commercial hydrated lime and gypsum were used.

Mortar samples, with 5 cm diameter and 10 cm high, were produced as following the Brazilian standards. The mix proportions are 1:3:0.48 (binder:sand:water, by weight).

Figure 10 (Appendix I) shows the effect of the variation of gypsum between 0 and 10% with 2% of hydrated lime. It is clear that a reduction of gypsum amount from 10% to 6% did not affect the compressive strength at 1 day. Even an increase of the strength in older ages was observed. With 6% of gypsum a binder solubility will be reduced about 40% and, as gypsum is the most expensive binder component, this reduction will result in a cheaper binder.

Table 2 - Chemical composition of blast furnace slag

Component	(%)	Component	(%)	Component	(%)
SiO_2	34.88	Fe_2O_3	0.85	Mn_2O_3	1.04
Al_2O_3	11.49	S^{-2}	0.50	TiO_2	0.84
CaO	42.72	K_2O	0.42	Fe^o	0.57
MgO	6.79	Na_2O	0.28	Insoluble	0.22

But even with only 6 % of gypsum, ettringite carbonation processes of the still produce soluble material. Thus a further reduction of gypsum would be useful if the strength reduction is counterbalanced by an increasing in the lime amount. Of course, in order to prevent the vegetable fiber degradation by alkaline attack, the maximum lime amount must be about 6 %.

Figure 11 shows the influence of the increasing of the lime content up to 6 % with 2 % gypsum. The variation of lime content could not improve the 1 day strength at a suitable value to precast production. Thus the reduction of the gypsum content to 2 % is not feasible.

4.3.4 Conclusion

The in use durability evaluation had showed that the cement have some solubility. X-ray diffraction analysis confirmed that the soluble component of the binder is gypsum, produced by carbonation of the hydrated cement paste. For this reason, it was necessary to reduce the gypsum amount in the cement.

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Experimental results shows that it is possible to decrease the gypsum amount to 6% without remarkable effect on mechanical performance of the binder.

Then, a new binder composition is:

- blast furnace slag 0.92
- gypsum 0.06
- hydrated lime 0.02

As gypsum carbonation could produce some soluble material it is recommended a mortar rendering or other kind of waterproof coating over the walls in shower room and other surfaces exposed frequently to water, like near kitchen sink. No surface protection is necessary in other outside or inside walls, even a PVA paint.

4.4 Fibers durability studies

Figure 12 (Appendix I) shows a composite sample removed from the external wall during the second inspection (see Figure 6). Several cracks were observed but the fibers were still working, keeping all the parts together. Even during the cutting activity the ductility of the composite was evident, as the chisel used to cut the wall had been strongly attached to the wall (Figure 13, Appendix I).

These characteristic ductile behavior could not be noticed if the fibers were strongly attacked by binder alkalinity, mould degradation as well for a combination of these degradation factors.

The sample removed from the panel placed over the soil had shown almost the same performance. Figure 14 (**a** and **b**) shows that, despite of the intensive cracking, fibers are still working, keeping all parts together.

4.4.1 Biological analysis

In order to observe any biological attack, biological analysis was performed in fibers removed from the panel in contact with the ground.. Fresh fibers were analyzed also for reference.

The analysis were performed under optical microscope, with colored samples. In the fibres removed from the panel it was possible detect pigmented fungi hyphae (Relatório de Ensaio 818.056). This kind of fungi normally did not cause decay to wood, and probably, to the vegetable fibers.

4.4.2 Alkaline attack

From the optical microscopy it was impossible to observe any other kind of attack to these fibers.

As was figured out in the first phase study, direct observation of the fibers removed from the matrix in the scanning electronic microscope (SEM) was not possible because a coating of calcium and silicium hides the fiber surface. In the present IPT are working to develop technology suitable to remove this coating without damaging the fiber.

4.4.3 Remarks on fiber durability

After 4 years inside of the matrix, even in the most aggressive media, the fibers are still working as reinforcement.

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The results from optical microscopy analysis did not show any damage. The detected fungi very probably is innocuous to the mechanical performance of the fibers.

Observation of fibers picked out from the matrix through optical microscopy did not show alkaline attack.

4.5 Conclusion

After 4 years of exposition to a very aggressive media, the composite had presented excellent performance.

The observed solubility problem was limited to a very specific environment.. This problem was fixed with the reduction of the amount of gypsum from 10 to 6 % and also by the specification of a ordinary mortar rendering in mostly wet surfaces, like kitchen sink and shower room.

It was proved that outdoor environment does not impair the performance of the composite, an for external walls no further protection is necessary.

5. ECONOMICAL FEASIBILITY

The economical feasibility of the load bearing wall panel system was evaluated by Escola Politécnica of USP , under supervision of Prof. Dr. Vahan Agopyan, the basic data being supplied by IPT.

5.1 Methodology

In the economic point of view, the adoption of the new technology will be interesting only if the rate of return can be greater than those possible with the other alternatives.

In order to evaluate the competitiveness of the "IPT/IDRC Wall Building System" in the market, the likely rates of returns obtained building houses with this new technology were compared with those obtained with the houses using traditional bricklaying (concrete and ceramic blocks). Brick walls are the most common technology in low-cost housing.

For each technology, the cash flow is evaluated considering all activities in a hypothetical company, estimating the amount of resources that is necessary to produce as well as all incomes during a fixed time period.

The competence in transforming investments in return, in a established time period, determine the rate of return.

The rate of return depends on costs, prices and time of operation. Selling houses at the same price with lower total costs or faster production give rise to the rate of return. Also it allows sell houses at small prices with the same rate of return, giving a better competitivity in the market.

In this study, to simulate the cash flow, the following assumptions were done:

- the same house building project was simulated for all technologies;
- all prices and costs adopted, except from IPT/IDRC Wall Building System, are market prices in São Paulo;
- the price of panels of IPT/IDRC Wall Building System were simulated after a deeply study of the main variables of the panel production process.

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The minimum price for one panel was calculated using the payback concept. This methodology of economic evaluation determines the time required for the cumulative benefits from an investment to recover the investment cost and other occurred costs, with a given discount rate.

5.2 Panel prices estimation

In order to estimate the panel prices a production scale of 6,000 panel/month was adopted.

The production processes was simulated in 5 main steps as follows:

- raw-material preparation, that includes reception, storage and cut the coir fibres;
- grinding the BFS;
- composite mixing and panel casting;
- first wet curing and demolding of panels: transportation to the 1st curing site, removing mold pipes; and demolding;
- final curing of panels: panels transportation to the curing site, storage, panel minor repairs and delivering.

The Technical Manual (Appendix II) shows a flow chart and the adopted lay out of the panel production plant. This plant have a 12,700 m^2 of floor area, but only 2,100 m^2 covered place.

For each step the amount of labor, equipment, raw materials, and floor area was carefully estimated. Then, the amount of investment in equipment and the monthly operation cost were calculated and the results are in Table 3.

Table 3 - Total investment cost and monthly operation costs

	Source	**US$ x 10,000**	**Totals (US$ x 1,000)**
Investment F	Equipment	332	**632**
	Building	300	
Monthly cost C	Manpower	20,4	**41,4**
	Raw materials	9,2	
	Administration costs	10,0	
	Rent of land area	0,8	
	Reservation fund	1,0	

5.2.1 Minimum price for one panel

The minimum price, for different payback time and discount rates, were calculated using the equation

$$pu_{min}=f_p(F+C)(1-Imp)/VP$$

where:

pu_{min} is the minimum price;
f_p is the Price factor for different payback periods and discount rates;
F is the amount of investment;
C is the monthly cost of operation;

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Imp is the impost of 18%;
and *VP* is the monthly panel production.

Figure 15 shows the results. It is evident that for payback periods lower than 7 years the minimum price of the panel increase sharply.

A simulation done with a reduction in the degree of mechanization that had reduced in 9% the investment cost (F) had showed one increase in the monthly operation cost in 9%, due to a increasing in labor. In this hypothesis, the minimum price of the panel was greater than the former.

Than it was possible to conclude that a increasing in the mechanization degree was economically interesting.

5.3 Economical feasibility of "IPT/IDRC Wall Panel System"

A production of a house building project was simulated with all technologies (concrete blocks, ceramic bricks and IPT/IDRC Wall Panel System). The hypothetical project had 80 houses with the same layout of 65 m^2 of floor area. In the production strategy adopted all project was divided in 8 groups of 10 houses.

5.3.1 Cost of each house

All prices was market prices collected in specialized periodicals. The price of IPT/IDRC Wall Panel System was fixed in US $ 11.12/panel. This prices corresponds to discount rate of 10 % per year and a payback period of 5 years. Also, it was assumed that the distance between the panel production plant and the building site was 35 km.

The adopted labor productivity was the normal observed in each kind of activity.

Table 4 shows the calculated costs for one house unit made with the different technologies.

Table 4 - Cost of each house (US $)

Ceramic bricks	Concrete blocks	IPT/IDRC
16,000	14,900	14,200

The cost of a house built with IPT/IDRC Wall Panel System is 11 % cheaper than the same house made with ceramic brick walls.

5.3.2 Rates of return

With these data it was possible to estimate the amount of resources required for all activities during the different phases of construction and the cash flow of the building project for each technology.

In order to calculate the rate of return of each system it was accepted that all houses have the same price of US $ 19,5 thousand, equal the cost of the ceramic bricks house unit plus 6 %. Table 5 shows the estimated rates of return. The adoption of IPT/IDRC Wall Panel System technology give better economical results.

5.4 Conclusion

The results shows that IPT/IDRC Wall Panel System is economically feasible. It have the lower cost of house unit and also give better rates of return in a small house building project.

Table 5 - Rate of return (%) of building project made with different technologies

Ceramic bricks	Concrete blocks	IPT/IDRC
100	366	604

6. GRINDING TECHNOLOGY

As pointed out in item 2.2.4 p.4, because BFS is a very hard material to grind, therefore it was necessary to perform some experiments in order to supply small mill companies with information about BFS grinding process.

6.1 Grinding work index

Grinding work index according to Bond[1], is a standard measure of the grindability of any material.

The summarized results from Bond's working index (WI) tests of the same sample presented in Table 2 are presented in Table 6. Due to restriction on the standardized equipment the test could not succeed to smaller meshes.

Table 6 - Bond's working index for BFS and its bulk density

Mesh (μm)	WI (kWh/short tone)
210	14.54
150	17.66
Bulk Density (kg/m^3)	1227.2

6.2 Performance of IPT pilot plant grinding

During the first phase of the project, a pilot mill ball, with continuous feeding and closed circuit, had been used only to do the first grind of BFS. After this, a last grinding was performed in a small laboratory mill ball, with 20 kg/batch capacity. It was necessary to achieve the specified fineness.

In order to collect reliable data to guide the suppliers of small BFS ball mill, this pilot mill was improved to grind until the specified fineness of about 400 m^2/kg.

A 1200 kg of grind balls made with new special steel, harder than the usual, and also with new size distribution was casted in IPT Metallurgy laboratory.

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[1] DUDA, W.H. **Cement data-book**. London, Macdonald & Evans, 1976 2nd edition.

WH

Also the air separator, which collects the smaller particles and return the coarse ones to the mill, was modified in order to collect particles with the suitable sizes to produce a ground BFS with Blaine's surface area up to 600 m^2/kg.

6.2.1 Mill characteristics

The closed circuit ball mill have one compartment with internal diameter of 800 mm and 1100 mm of length. 600 kg of balls with diameter of 1" plus 600 kg with 3/4" diameter was used. The internal surface of the mill have single wave mill liners. The mill have a speed of 36 rpm.

6.2.2 One pass grinding experiment

A 30 h experiment was performed in order to evaluate the mill production for different grinding slag fineness output, measured by Blaine surface area. The same slag of item 4.3.3 p.9 was used in this experiment, with 97 % of particles smaller than 2,4 mm.

The mill was fed with 30, 45, 60, 90 and 120 kg/h of BFS. Each rate of feeding was maintained until the mill operation was stabilized, in a time that had varied between 8 h for 45 kg/h and 3 h for 120 kg/h. In each step, the surface area of the ground product was measured three times. Only the last two measurements were taken into account in this analysis.

As Figure 16 shows, the mill productivity increase 4 times when the fineness of the ground BFS is reduced from 600 m^2/kg to about 420 m^2/kg. This increase rate is almost two times greater than the observed by JACOB *apud* DUDA (1976, p. 200)[2] for BFS-Portland cement. The difference can be explained by: (1) the smaller dimension of our mill; (2) the grinding ball size distribution and other mill project details are most efficient in coarser fineness; and (3) by the fact that BFS is harder to grind that the mixture BFS-Portland cement clinker.

6.2.3 Two pass grinding experiment

As the commercial grinding installation uses ball mills with two or more compartments, and the mill efficiency is proportional to the input BFS size, a short experiment was done with BFS reduced to final fineness by two step grinding.

The pilot mill was fed with 120 kg/h of BFS with surface area of 220 m^2/kg, produced in previous experiment. The observed throughput BFS fineness had a surface area of 590 m^2/kg.

6.3 Roller mill and microsizer pilot plant experiment

As the efficiency of ball mill sharply decreases with its size (DUDA, 1976), experiments using both a Raymond Roller Mill and a Microsizer mill of CBC Indústrias Pesadas were done. These mills have, theoretically, lower energy consumption than the ball mill and require small floor area. This experiment was performed in Varginha -MG.

The results achieved with these equipment were bellow of expectations. With a feeding rate of 204 kg/h the Raymond Roller Mill had produced BFS with a fineness of only 206 m^2/kg.

[2] [2] DUDA, W.H. **Cement data-book**. London, Macdonald & Evans. 1976 2nd edition

Grinding this pre-ground BFS in a microsizer with a feed rate of 38 kg/h, the fineness of the output was 606 m^2/kg.

As the cost of this equipment is higher than ordinary ball mills with the same capacity, it was concluded that this technology was not suitable for our purposes.

6.4 Basic project of BFS grinding plant

In order to support the technology transference allowing small industries of ball mills to adapt its technology to grind BFS, a basic project of BFS grinding plant was developed. All design details was based in the experimental results obtained in the IPT pilot ball mill grinding plant.

The plant monthly production of ground BFS established by the first purchaser of the technology (COHAB-Santista), was 150 metric tones/month. This project could be easily adapted to different monthly production.

It is important to notice that a drying equipment is necessary only when the raw slag arrives at the mill plant with high moisture content. This happens mainly when the mill plant is located very near of the steel plant.

This basic project is part of the technical documentation supplied in technological transference contract (see Relatório n°32.238/94 Appendix II).

7. TECHNOLOGY DISSEMINATION ACTIVITIES

7.1 Commercialization materials

In order to support the transference of the technology the following materials were prepared:

- leaflet;
- 15 minutes video tape;
- technical manual, including a basic project from a grinding plant;
- technical papers and color overhead transparencies that were presented in the seminars.

Appendix III contains sample of leaflet and a copy of technical materials prepared to the dissemination seminars. Appendix II shows a sample of technical manual. Appendix V contains a copy of video tape.

7.2 Dissemination seminars organized by research team

In order to widespread the technology two technical dissemination seminars were organized.

The first one was done in Vitoria, Espírito Santo State in March 21-22, 1994, and was organized by IPT and University of Espirito Santo and sponsored by IDRC, CST - Companhia Siderúrgica Tubarão a local steel company, Aracruz Celulose a big cellulose producer and by FCCA - Fundação

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Ceciliano de Almeida, a foundation belonged to University of Espírito Santo (see Seminar Announcement in Appendix II). About 90 people attended to the Seminar, included civil engineers and architects from both public and private companies, building entrepreneurs and students. The local TV broadcasting station (Rede Manchete) and a newspaper had reported the event. The seminar was announced also by 5 street placard displays (Figure 17). At the end of the Seminar a demonstration panel production was performed in the building materials laboratory of University.

The second Seminar was in Belo Horizonte, Minas Gerais State in July 11-12, 1994. It was organized by IPT, CREA-MG - the regional council of civil engineers and architects, PMB - Municipality of Belo Horizonte, and EP USP, Politechnical School from University of São Paulo and sponsored by IDRC, CEF a public bank that supports housing projects, AÇOMINAS and Mendes Júnior Siderurgia, two important steel industries from Minas Gerais. About 100 people attended to the seminar. The opening session was chaired by vice-major of Belo Horizonte. TV Manchete and two local newspapers had reported the event.

During the seminars the video was presented and the leaflet distributed. In the proceedings 3 different papers present the technology (Appendix II).

In the present IPT and COHAB-Santista, the first purchaser of IPT/IDRC technology, are organizing other Seminar. The seminar is scheduled to happen in October 21, 1994 in Santos-SP. Also CSN (Companhia Siderúrgica Nacional), one of the most important Brazilian steel producer, is interested now to organize a Seminar in Rio de Janeiro or Volta Redonda, Rio de Janeiro State.

Due to the fact that a construction of a large steel plant in the Northeast of Brazil (Maranhão State) was postponed, there is no interest by now to conduct a Seminar in this region.,.

7.3 "IPT/IDRC Wall Panel System" in newspaper and TV network

After several contacts and press releases distribution to the main newspapers and Brazilian news agencies, more than 20 reports of the technology had appeared.

This list include all of national important newspapers: Folha de São Paulo (São Paulo, January 31, 1993); O Globo (Rio de Janeiro, July 22, 93), Jornal do Brasil (Rio de Janeiro, July 06, 1994); and Gazeta Mercantil (São Paulo, July 24-26, 1993) the most important business and financial newspaper.

Also other local newspaper had reported the technology. We had detect the following: Diário do Pará (Belém, January 23, 1994); A Gazeta (Vitória, March 23, 1994); O Diário de Mogi (Mogi das Cruzes, August 19, 1993), Notícias (August 22, 1993), Correio do Estado (Campo Grande, July 30, 1993), Jornal do Comércio (Recife, July 29, 1993), Jornal da USP (São Paulo, March 22-28, 1993), O Poti (Natal, July 25, 1993), Correio da Bahia (Salvador, July 23, 1993), Vale Paraibano (São José dos Campos, July 15, 1993), Correio Brasiliense (Brasília, July 25, 1993), Indústria Imobiliária (São Paulo, dec. 1993), Imprensa Livre (São Sebastião, August 20, 1993) and Mercosul (São Paulo, April 1994), a new business magazine focused on the common market of Brazil, Argentina, Uruguay and Paraguay.

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Rede Globo, the most important Brazilian TV network presented the technology in its weekly science and technology program on October 17, 1992. After that this report was retransmited more than three times in the same network.

Other presentation was recorded in August 19, 1994 and will be showed in October 1994 by the same network. This report will be showed during the Brasil Ecologia, a weekly program dedicated to ecological related subjects. Each presentation in Rede Globo have an estimated audience of more than 5 million people in the country-wide.

SBT, the second most important TV network in Brazil, TV Cultura, the most important public TV channel in the State of São Paulo, and TV Manchete (November 25, 1993) had also presented the technology. Local channels in Vitória and Belo Horizonte reported the technology and the Seminars.

The technology was also presented in Sem Censura, a talk-show of TV Cultura, the national public network, in December 1, 1993.

Through the TIPS (Technological Information Promotion System), a United Nations Developing Program trade information system, the technology was disseminated in other 16 countries around the world, including India, China, Egypt, Mexico, Argentina and Cuba. Organizations and/or companies from Argentina, India e Zimbabwe had contacted IPT looking for more detailed information.

7.4 Technical meetings

The research teem had made oral presentation and/or published papers in the following technical events:

- CIB 92 World Building Congress, Montréal, May 18-22, 1992 (400 participants worldwide); all costs of the participation were supported by IDRC (CIB 92 - World Building congress - Centre File 91-4901-28);
- Simpósio Internacional sobre Materiais Reforçados com Fibras para a Construção Civil (Int. Symp. on Building Fibre Reinforced Materials), São Paulo, July 05, 1993 (200 participants);
- III Enc. Estadual de Arquitetos do Rio Grande do Sul (3rd Sem. of Architects of Rio Grande do Sul), Porto Alegre, July 21, 1993 (50 participants);
- V Congresso Brasileiro de Engenheiros Civis (V National Congress of Civil Engineers), São Paulo, August 11, 1993 (100 participants);
- III Simpósio Ibero-Americano sobre Técnicas Construtivas Industrializadas para Habitação de Interesse Social (III Ibero-American Symp. about Industrialized Building Technology for Low Cost Housing), organized by CYTED (Spain), São Paulo, October 18-22, 1994 (300 participants from Latin America, and Spain).

Appendix IV contains the papers presented.

The IPT/IDRC Wall Panel System technology was also presented in three specialization courses in "Building Planning and Technology". These courses are organized by IPT with the support of Japanese International Cooperation Agency (JICA). Every year about 30 civil engineers and architects from Latin America and Africa attend to the course.

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7.5 Technical exhibitions

The IPT/IDRC Wall Panel System was showed in the following technical exhibitions:

- Technical exhibition during the "Simpósio Internacional sobre Materiais Reforçados com Fibras para a Construção Civil (Int. Symp. on Building Fibre Reinforced Materials)" São Paulo, July 05, 1993. This exhibition was visited by more than 200 people.
- I EXPOCIENCIA, during the National Meeting of Brazilian Society for Science Development (SBPC), in Recife, State of Pernambuco, July 13-17, 1993. This exhibition was visited for about 30 thousand people, including the General Secretary of the Ministry of Science and Technology.
- Technical Exhibition during the 38° Congresso Estadual de Municípios (38th Congress of Municipalities) March 16-20, Serra Negra SP with participation of local authorities of Municipalities of State of São Paulo.
- Technical Exhibition during "III Simpósio Ibero-Americano sobre Técnicas Construtivas Industrializadas para Habitação de Interesse Social (III Ibero-American Symp. about Industrialized Building Technology for Low Cost Housing)", São Paulo, October 18-22, 1994. Organized by CYTED (Spain) and IPT, was visited for 300 atending people from Latin America and Spain.
- Technical Exhibition during the "ENTAC 93 - Encontro Nacional de Tecnologia do Ambiente Construído (National Meeting in Built Environment Technology). Organized by National Association of Built Environment Technology (ANTAC), São Paulo, November 17-19, 1994, was visited by more than 300 people.
- FEHAB-94 - 12ª Feira Internacional da Indústria da Construção (Int. Fair of Building Industry) São Paulo, August 22-27, 1994. This fair is the most important technical exhibition of housing industry in Brazil, visited bymore than 100 thousand people.

The technology will be exhibited at a TECHNOLOGICA 94, 1st. Int. Fair on Technical Service and Products, a fair of technologies for small and medium companies. São Paulo, August 30 - September 02, 1994.

In all exhibition information materials like the leaflet and other technical publications were available for people interested and the video have been showed.

8. TRANSFERENCE OF IPT/IDRC WALL PANEL SYSTEM TECHNOLOGY

The IPT/IDRC Wall Panel System technology was transferred to COHAB - Santista, a public company for low-cost housing. The cement production plant is under construction. Due to economical constraints, in a first phase, the alternative cement will be used to produce ordinary concrete block, in replacement of ordinary Portland cement. During a second phase, a panel production plant will be constructed and the IPT/IDRC Wall Panel System produced.

On the other hand, the research team have great expectations in fulfill further transferences of the technology as soon as the Brazilian economy achieve better situation. By this time, both economical and technical results of the production plant of COHAB - Santista will be available yelding strong marketing argument. Even steel companies will be more confident to sell your BFS for small consumers.

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After all dissemination activities, the IPT/IDRC Wall Panel System is now relatively well-known and we have a mailing list of interested entrepreneurs.

9. FURTHER ACTIVITIES

IPT will continue its activities in the project. The development of suitable durability evaluation techniques using scanning electronic microscope are under investigation. As soon as available, a final durability evaluation will be done.

During the next twelve months the research team will give technical support to COHAB Santista, first in the construction of the BFS grinding plant and after in plant operation.

Also, the research team will maintain dissemination activities, doing presentations in technical seminars, in order to show the results obtained in COHAB plant and the new durability studies results.

Finally, we expect do further transference of the IPT/IDRC Wall Panel System technology to other companies.

10. FINAL REMARKS

The main goal of the project, i.e., transference of IPT/IDRC Wall Panel System, technology was fulfilled..

The five specific objectives stated in the Memorandum of Grant Conditions were also fulfilled with minimum exceptions.

Now the IPT/IDRC Wall Panel System was well-known among entrepreneurs and for people from public organizations. It is possible to suppose that further transferences of the technology will be done in the near future.

11. RESEARCH TEAM

The main research team was:

IPT

Angelo Derolle - Consulting Technician (DEC-AMCC)
Benedito Cotogni - Technician (DIMET - ATM)
Carlos Eduardo de S. Tango - Civil Engineer (DEC-AMCC)
Fúlvio Berçot Miranda - Civil Engineer (DEC-ACSC)
Gilson Lameira de Lima - Architect (DEC-ACSC)
Hiran Rodrigues de Souza - Mining Engineer (DIMET - ATM)
Iraci Teixeira da Silva - Technician (DIMET - ATM)
Jaime A. da Silva - Technician (DIMET - ATM)
Juan Luiz R. Gonzales - Architect (DEC-ACSC)
Oscar De Nucci - Metallurgic Engineer (DIMET - ATM)
Pedro Bielewski - Technician (DEC-AMCC)
Raimundo Lustosa Pereira - Technician (DEC-ACSC)
Robinson Salata - Designer (DEC-ACSC)
Sidney Derole - Technician (DEC-AMCC)
Vanderley M. John - Civil Engineer - project leader (DEC-AMCC)

Polithecnical School - USP

Eliane Monetti - Civil Engineer
Giglio Celso Pecoraro - Architect and post-graduate student
João da Rocha Lima - Civil Engineer
Vahan Agopyan - Civil Engineer - project leader

São Paulo August 29, 1994

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Appendix I
FIGURES

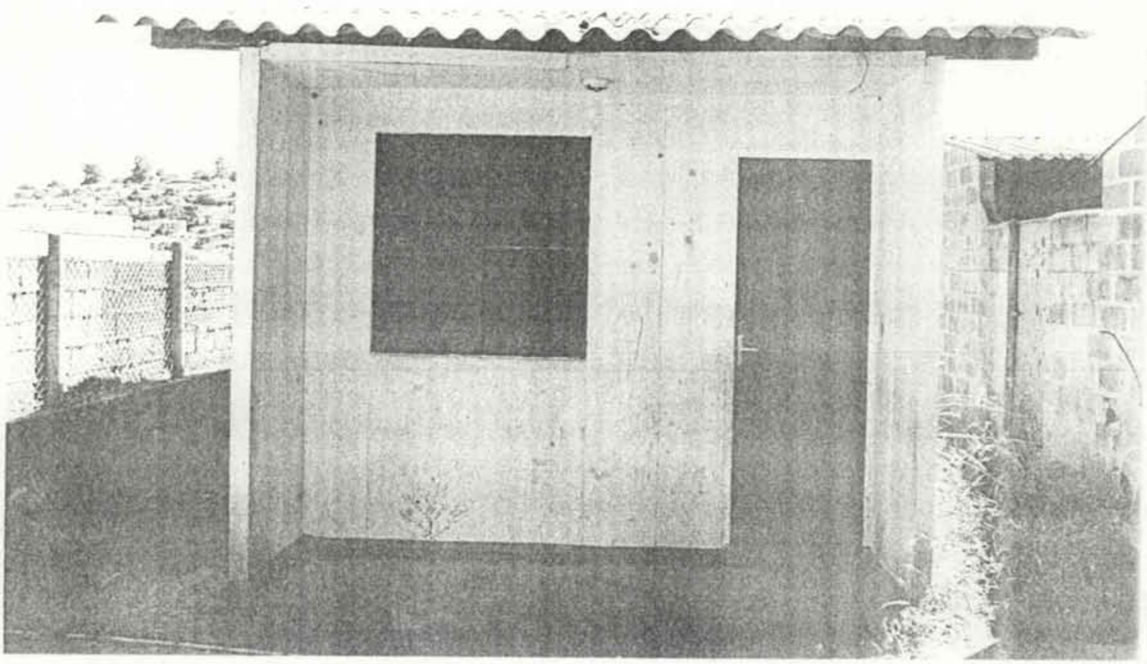

Figure 1 - View of prototype in december 1991

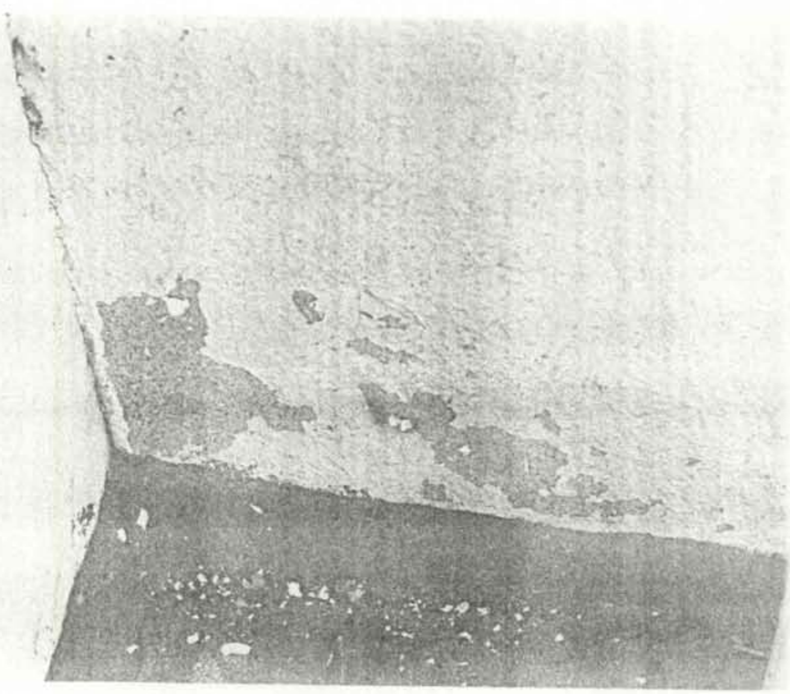

Figure 2 - Local degradation due to water solubility of the cement

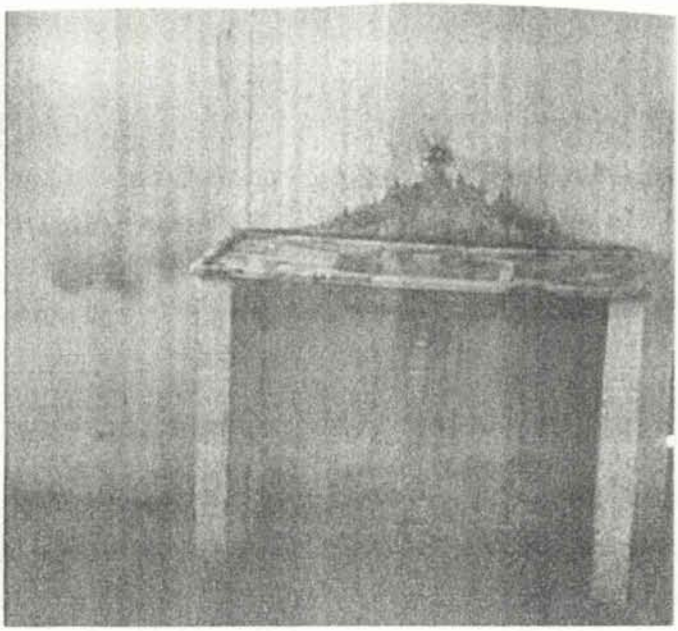

Figure 3 - Mould growth with no panel lixiviation in front of kitchen sink

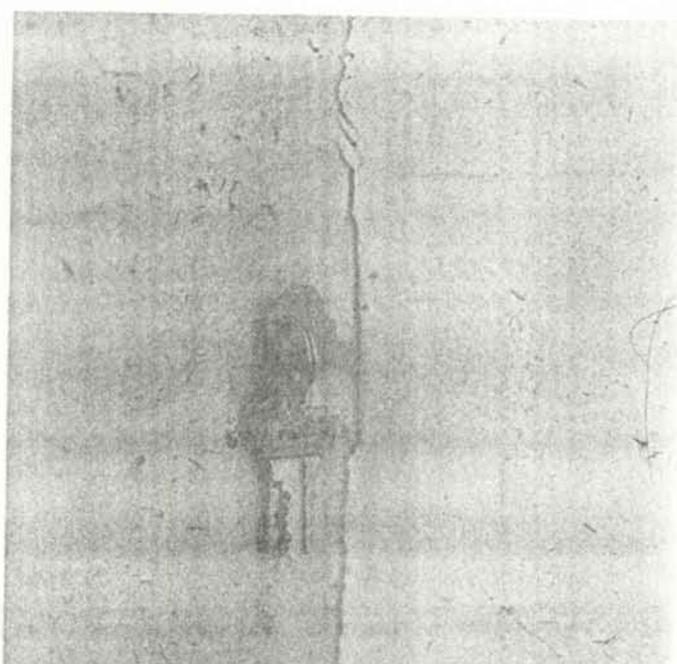

Figure 4 - Crack in joint between panels

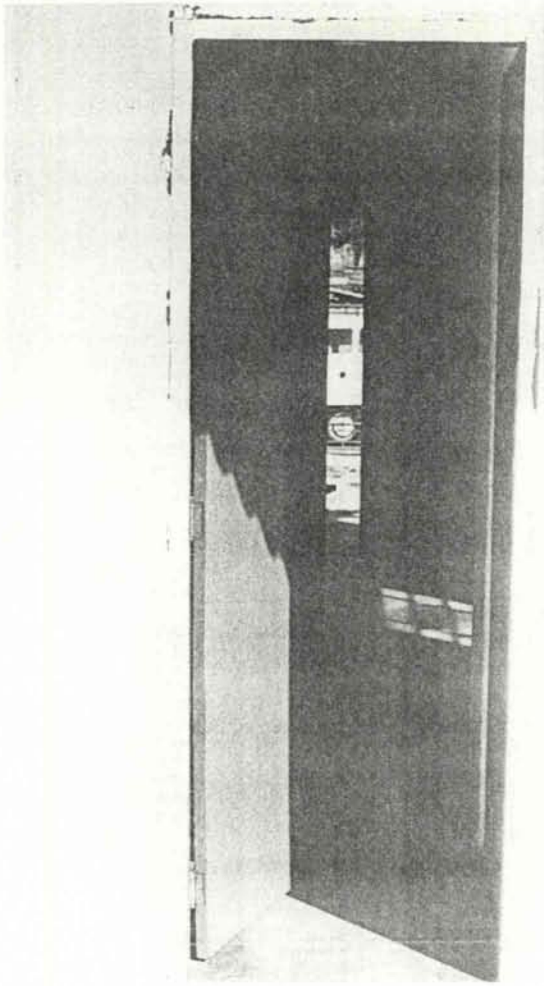

Figure 5 - Cracks in junction panel-door

Figure 6 - Cuting sample from the external wall surface

Figure 7 - Cuting sample from the external wall surface

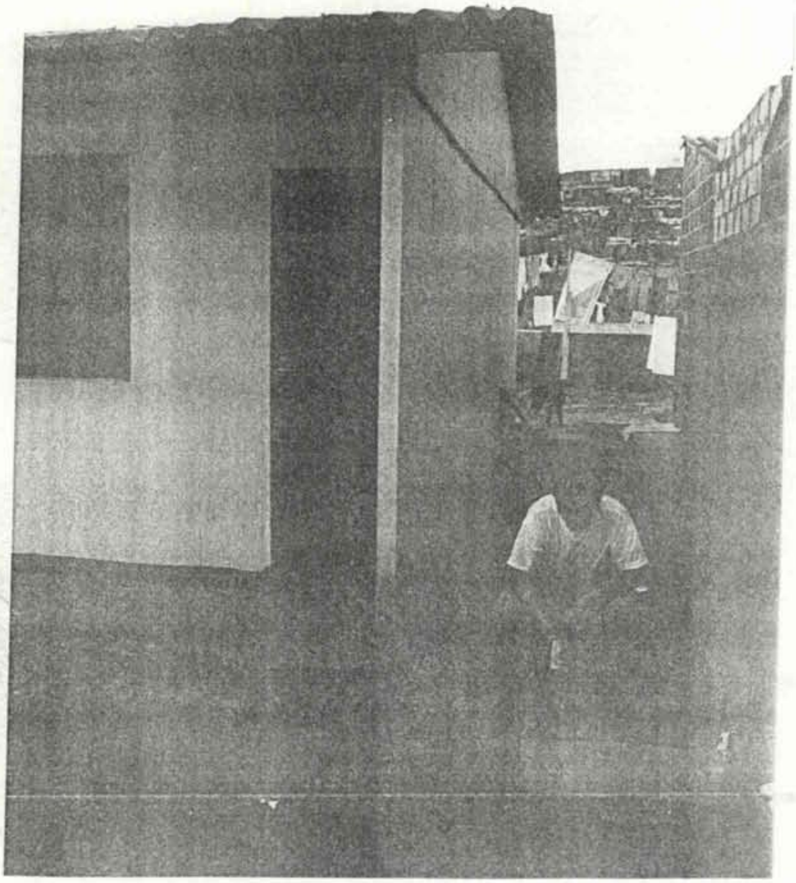

Figure 8 - View of the outside surface of the panel

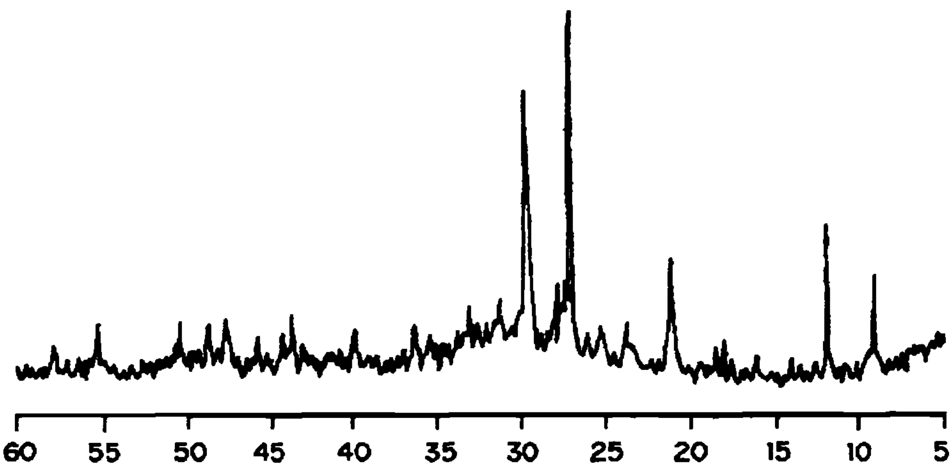

Figure 9 - X-ray difraction patter of cement composite

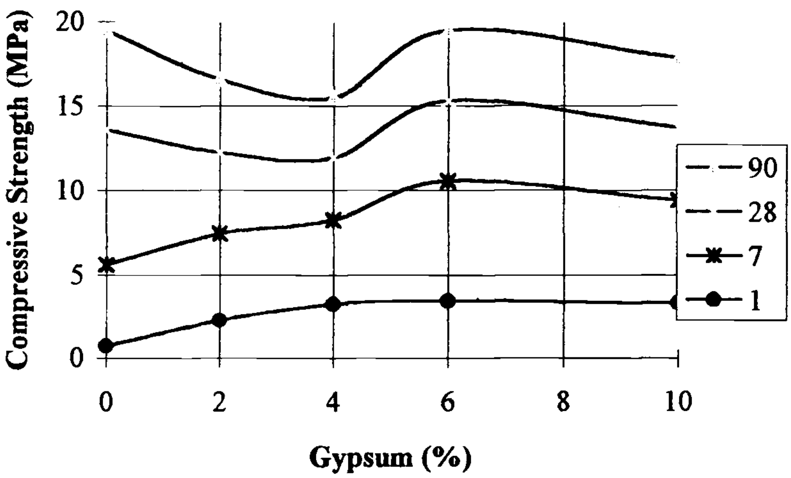

Figure 10 - Compressive strengh against gypsum content in different ages (2% of hidrated lime; average of 6 samples)

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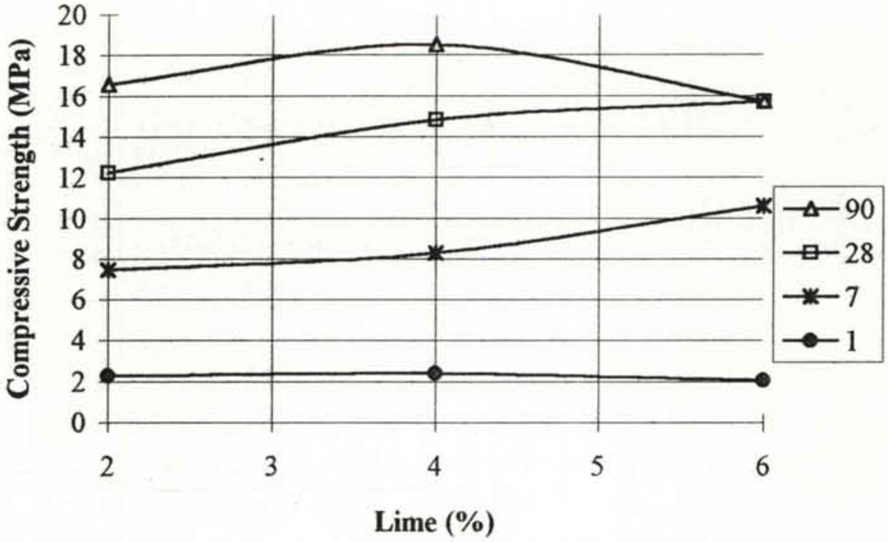

Figure 11 - Compressive strengh against lime content in different ages (2% of gypsum; average of 6 samples)

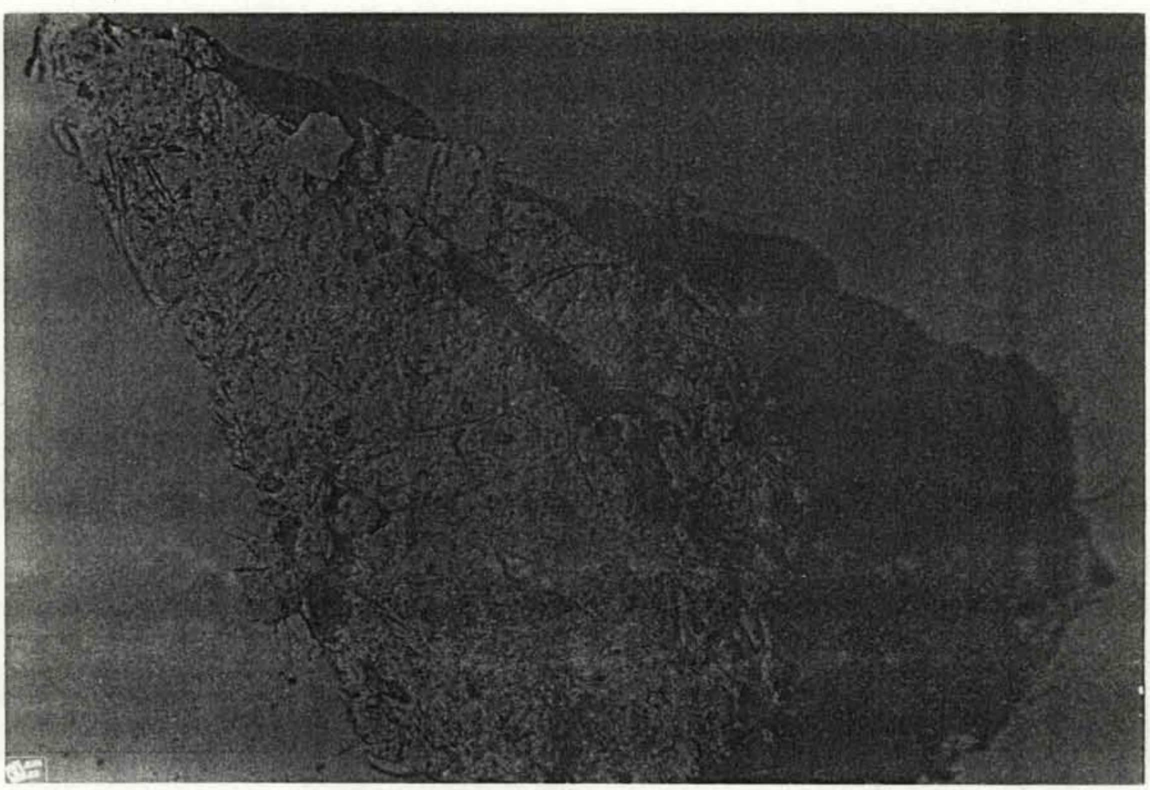

Figure 12 - Sample removed from external wall during the second building inspection

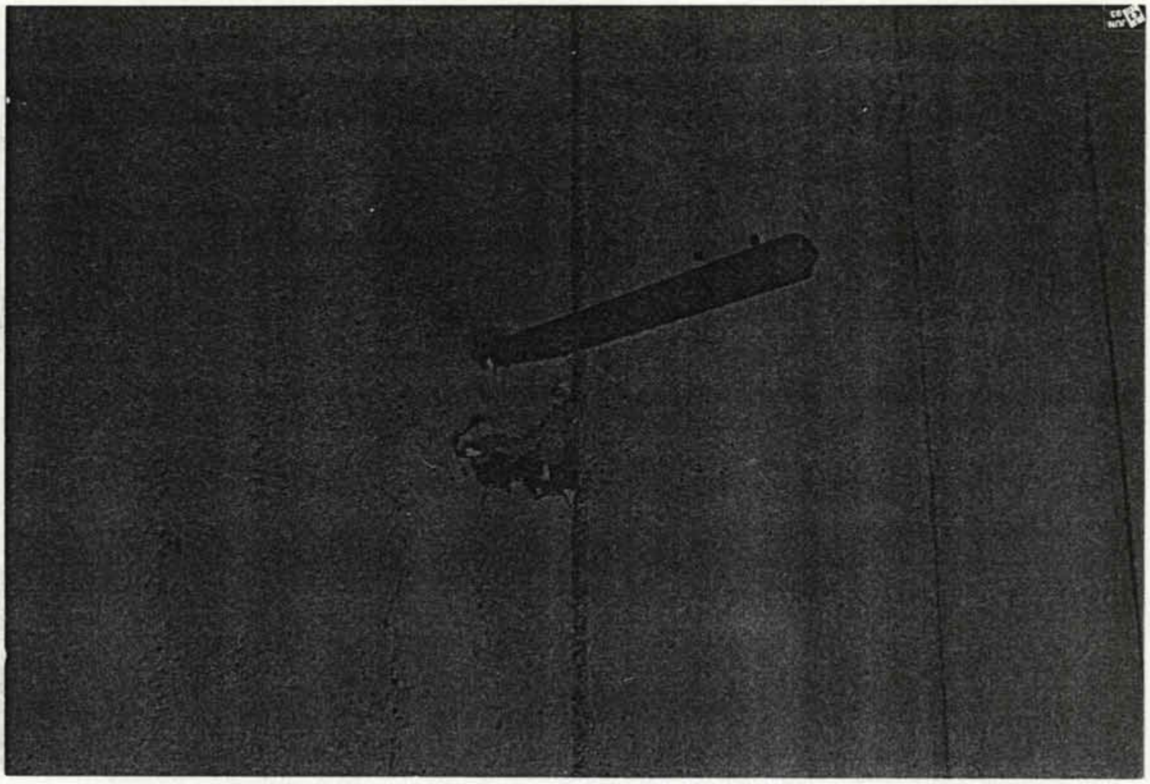

Figure 13 - Chisel strongly attached to the wall.

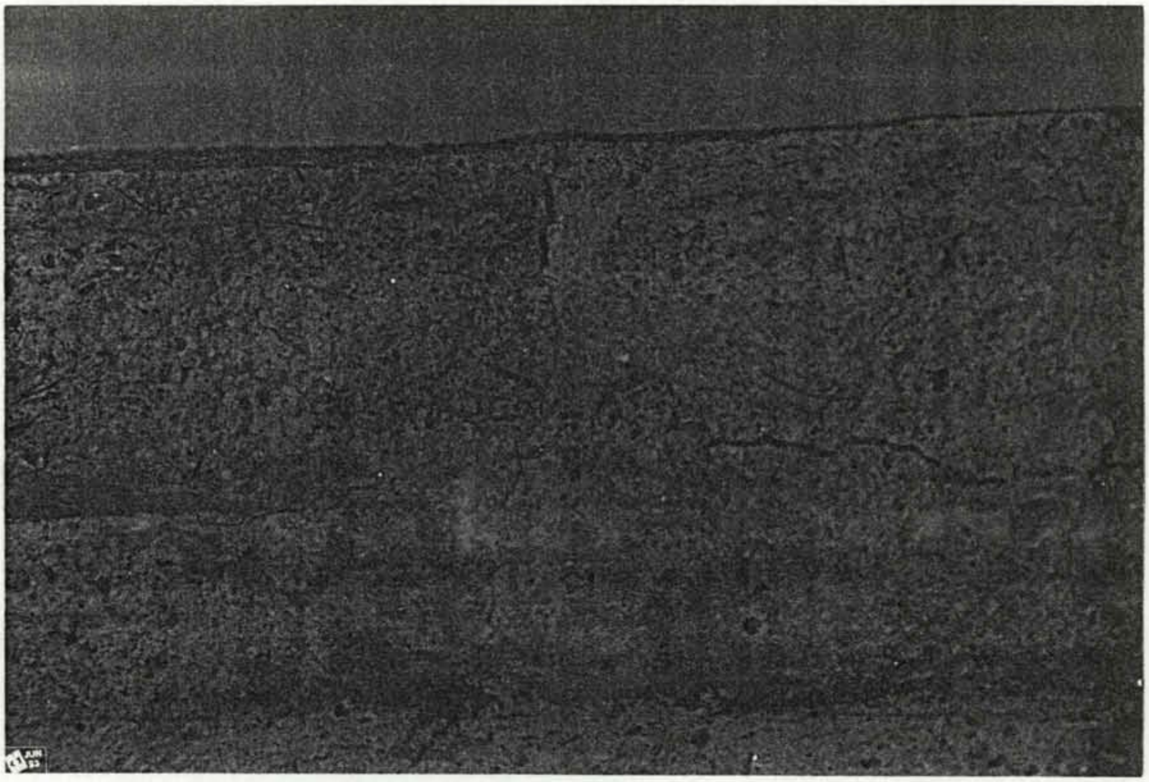

Figure 14 (a) - Multiple cracks in the sample removed from the panel placed over the soil.

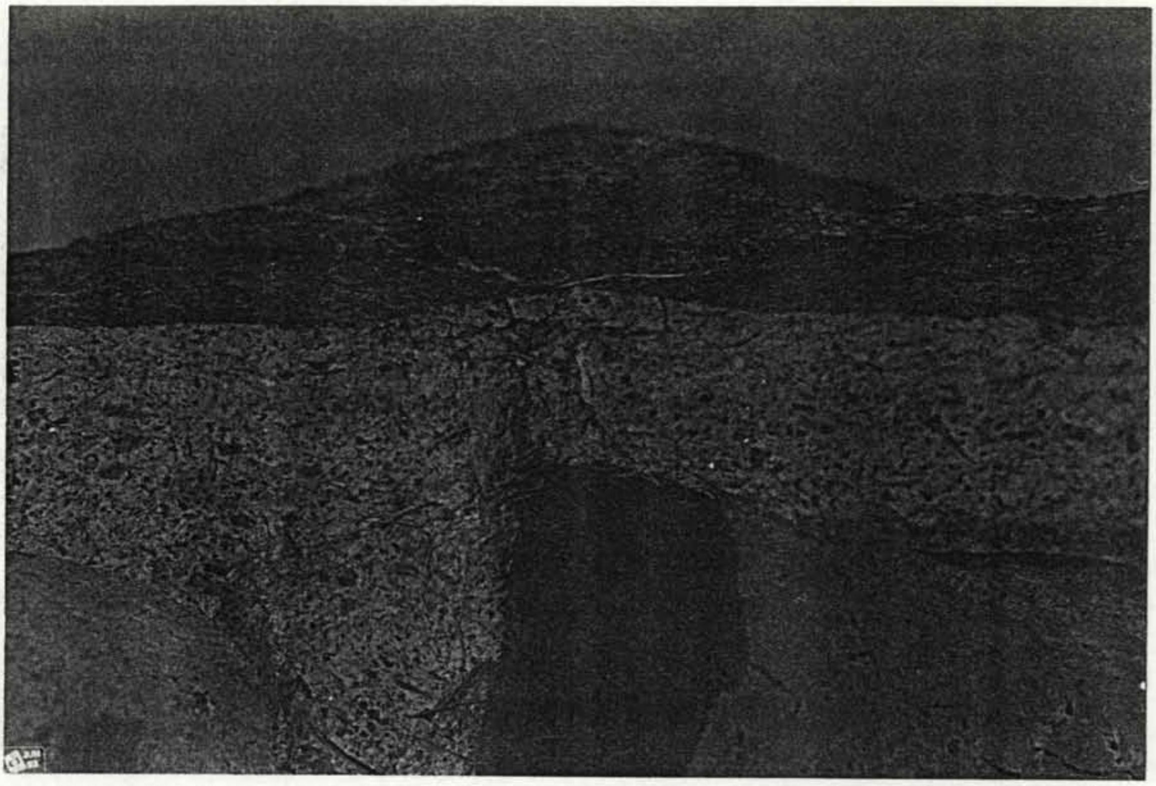

Figure 14 (b) - Multiple cracks in the sample removed from the panel placed over the soil

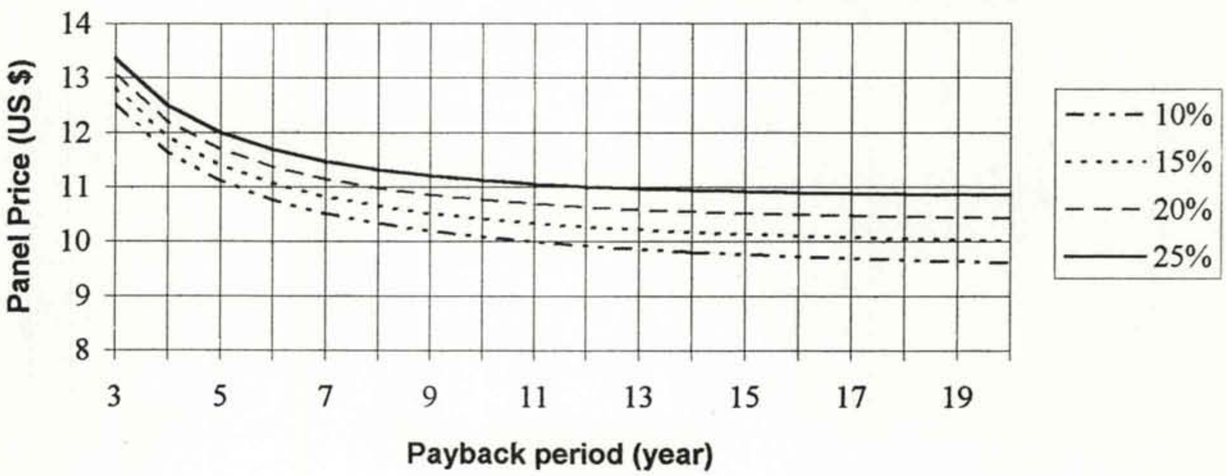

Figure 15 - Minimum panel price at diferent discout rates and payback periods

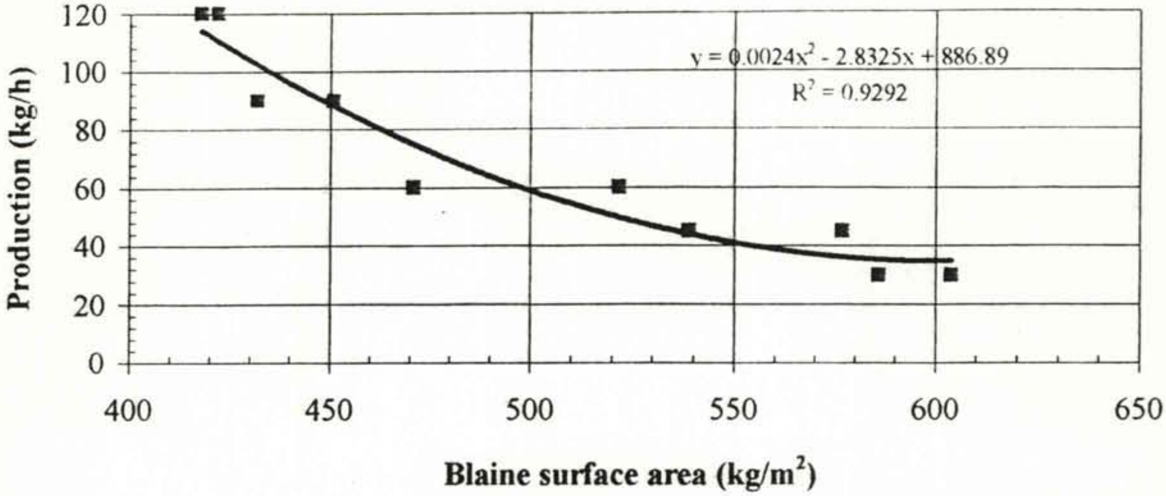

Figure 16 - Mill's grinded BFS production *versus* surface area

Figure 17 - Outdoor placard in front of International Airport of Vitoria - ES

IPT

Instituto de Pesquisas Tecnológicas

O Instituto de Pesquisas Tecnológicas — IPT — nasceu de um núcleo agregado à Escola Politécnica de São Paulo. Esse núcleo, sob a denominação de Gabinete de Resistência dos Materiais, foi criado pelo Prof. Francisco de Paula Souza, em 1899. No início, os objetivos principais eram servir de apoio ao ensino dessa Escola e desenvolver um programa de ensaios, visando determinar as principais características físicas, químicas e mecânicas dos materiais em uso corrente nas construções. Em 1931, sob orientação do Prof. Ary Torres, o Gabinete passou a denominar-se oficialmente Laboratório de Ensaio de Materiais. Esse novo nome simbolizava uma significativa reestruturação do antigo Gabinete, caracterizada pela ampliação e renovação do aparelhamento técnico, pelo aumento e seleção do pessoal, pela divisão de trabalho por seções especializadas e, como fator dos mais importantes, pela aplicação progressiva de tempo integral aos seus funcionários.

A rápida expansão das atividades do Laboratório justificou a sua transformação em Instituto de Pesquisas Tecnológicas, anexo à Escola Politécnica, em 1934, quando também foi fundada a Universidade de São Paulo.

O IPT começou, então, a criar novas áreas de capacitação tecnológica, desempenhando um papel sempre crescente em diversos campos: no desenvolvimento da pesquisa tecnológica, na formação de recursos humanos, na organização de um sistema de metrologia legal e de sistemas de padrões industriais, na criação e desenvolvimento de um centro de documentação tecnológica, no controle e proteção de marcas e patentes, e na captação e difusão da informação tecnológica.

O desenvolvimento da industrialização brasileira, acelerado pela II Guerra Mundial, conduziu o País a realizar pesados investimentos em grandes obras como barragens e usinas hidrelétricas, rodovias, pontes, edifícios públicos, conjuntos habitacionais etc.

Todo esse esforço exigiu ampla participação do IPT e sua transformação em entidade autárquica do Estado de São Paulo, em 1944, possibilitava dinamizar significativamente essa participação, mantendo sempre estreitos vínculos culturais com a Escola Politécnica e a Universidade de São Paulo.

Em resumo, a história do IPT tem como característica marcante um processo de desenvolvimento natural, quer de instalações como de recursos humanos. Cada fase de sua existência significou, antes de mais nada, um processo de acompanhamento do desenvolvimento do País.

Em 1976, o IPT passou a ser uma Empresa Pública com a denominação de Instituto de Pesquisas Tecnológicas do Estado de São Paulo S.A. — IPT. Atualmente, os seus recursos instrumentais e humanos distribuem-se por nove Divisões Técnicas: Divisão de Construção Civil, Divisão de Economia e Engenharia de Sistemas, Divisão de Geologia de Engenharia e Mecânica de Rochas, Divisão de Geologia e Recursos Minerais, Divisão de Mecânica e Eletricidade, Divisão de Metalurgia, Divisão de Produtos Florestais, Têxteis e Couros, Divisão de Química e Divisão de Transportes.

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e Desenvolvimento Econômico