ISSN-0125 1759
Vol. 10, No. 1, January 1980

# JOURNAL OF FERROCEMENT



IFIC

International Ferrocement Information Center

ISSN 0125–1759

JOURNAL OF FERROCEMENT

ISN = 3365

JOURNAL OF FERROCEMENT

Volume 10, Number 1, January 1980

**CONTENTS**



---

Discussion of the technical materials published in this issue is open until **July 1, 1980** for publication in the Journal.



All correspondences related to manuscript submission, discussions, permission to reprint, advertising, subscriptions or change of address should be sent to: **The Editor, Journal of Ferrocement, IFIC/AIT, P.O. Box 2754, Bangkok, Thailand.**

# ABOUT IFIC

The **International Ferrocement Information Center (IFIC)** was founded in October 1976 at the **Asian Institute of Technology** under the joint sponsorship of the Institute's Division of Structural Engineering and Construction and the Library and Regional Documentation Center. The IFIC was established as a result of the recommendations made in 1972 by the U.S. National Academy of Sciences's Advisory Committee on Technological Innovation (ACTI). IFIC receives financial support from the **United States Agency for International Development (USAID)**, the **Government of New Zealand** and the **International Development Research Center (IDRC)** of Canada.

Basically, IFIC serves as a clearing house for information on ferrocement and related materials. In cooperation with national societies, universities, libraries, information centers, government agencies, research organizations, engineering and consulting firms all over the world, IFIC attempts to collect information on all forms of ferrocement applications either published or unpublished. This information is identified and sorted before it is repackaged and disseminated as widely as possible through IFIC's publication and on request through IFIC's reference and reprographic services.

A quarterly publication, the **Journal of Ferrocement**, is the main disseminating tool of IFIC which is published in collaboration with the **New Zealand Ferro Cement Marine Association (NZFCMA).**

IFIC has also published numerous other books and reports. Enquires about IFIC publications are to be addressed to: **The Director, IFIC/AIT, P.O. Box 2754, Bangkok, Thailand.**

**SUBSCRIPTION RATES**

The annual subscription rates in US$ for the Journal of Ferrocement (inclusive of postage by **surface mail**) are as under:

| Region | Status | Rate |
|---|---|---|
| A.* North America, Europe, Australia, New Zealand and Japan | Individual | 25.00 |
| | Institutional | 50.00 |
| B. Countries other than those listed in Region A. | Individual | 15.00 |
| | Institutional | 30.00 |

* Rates for Region A subscribers who are members of the New Zealand Ferro Cement Marine Association (NZFCMA) are as shown in Region B.

We **strongly advise** all parties to subscribe to the Journal of Ferrocement through **air mail,** in which case the following extra charges in US$ are to be added to the annual subscription rates as specified above:

| Region | Additional charge |
|---|---|
| North America, South America, Africa and Europe | 8.00 |
| Asia and Pacific | 6.00 |

# EDITORIAL

This issue of the Journal of Ferrocement includes some papers presented at the Concrete Ships and Floating Structures Convention held in Rotterdam last November sponsored by Thomas Reed Publications Limited. The Editors wish to express their thanks to the Organizers of that convention for allowing us to reproduce some of the presentations dealing with ferrocement which no doubt will be of great interest to our readers involved in boat building. This is in fact an interesting preamble to our July special issue which will be entirely dedicated to "Marine Applications of Ferrocement" and for which we renew our call for papers, be it sophisticated technical papers or simply short notes or news items from "amateurs". All type of contributions will heartily welcomed and should now be sent in for possible inclusion either in the July issue or more likely in the October issue.

Despite the emphasis on boat building to be shown in some issues of the Journal, IFIC does not forget terrestrial applications and is devoting now considerable efforts to publish in a near future three additional booklets in its "Do it yourself" series that started with "Ferrocement Grain Storage Bin" (No. 1). The three following issues will be: No. 2 "Ferrocement Water Tank", No. 3 "Ferrocement Biogas Holder" and No. 4 "Ferrocement Canoe".

Through all its activities IFIC attempts and hopes to meet the information needs of the whole, so broad and diversified community of ferrocement users. As always IFIC will appreciate receiving from its users any comments or suggestions aiming at improving and developing its services.

**The Editors**

## ADVERTISING RATES

| | |
|---|---|
| Full page ........................................ | US$70 |
| Half page ........................................ | US$40 |
| Quarter page ........................................ | US$25 |

These rates are for one number and include the cost of plate making. A reduction of 20 per cent for two numbers and 30 per cent for four or more numbers will be allowed.

All enquiries relating to advertising in this Journal should be addressed to:

The Editor, Journal of Ferrocement
International Ferrocement Information Center
Asian Institute of Technology
P.O. Box 2754
Bangkok, Thailand

---

## FEES FOR IFIC SERVICES

The fees for photocopying are:

| | Subscribers to the Journal | Others |
|---|---|---|
| A. Photocopy | | |
| Xerox | US$0.15/page | US$0.20/page |
| Microform/Printer | US$0.20/page | US$0.25/page |
| B. Microforms | | |
| Microfiches (60 page) | US$2.00/fiche | US$4.00/fiche |
| Microfilm | US$0.007/page | US$0.015/page |

The fees for Reference Bibliography Services will be based on the following hourly rates.

| | | |
|---|---|---|
| Hourly fee | US$3.00 | US$6.00 |

| | |
|---|---|
| AIT M.Eng. Thesis & Doctoral Dissertation: | US$20.00/copy |
| AIT Research Report: | US$ 8.00/copy |

(For each request a service charge of US$2.00 will be added)

Surface postage is free.

# Impact Resistance of Ferrocement Boat Hulls

**P. Nimityongskul*, Chen Bor-Shiun+ and P. Karasudhi†**

*Although numerous studies have been conducted in the past to define and evaluate the impact resistance of ferrocement, there still exists no well defined criteria for predicting it. This article presents a method for predicting single strike impact resistance of ferrocement boat hulls. Experimental results of 49 panels tested, have been discussed with reference to the mechanism of failure and the essential reinforcing parameters namely, steel content and specific surface of reinforcing mesh. It has been concluded that the method suggested can be used to accurately predict the single strike impact resistance of ferrocement. The results also highlight the fact that an increase in steel content and/or specific surface increases resistance to impact. It was observed, however, that beyond a practical maximum steel content, impact resistance does not always increase with increase in the specific surface.*

## INTRODUCTION

Since ferrocement is a versatile material, its use in marine applications has been adopted for many years. In boat hull construction ferrocement is made up of several layers of steel mesh, sandwiching steel reinforcing rod thoroughly impregnated with a stiff, very rich mortar of sulphate-resisting Portland cement and clean fine sand. The steel content of ferrocement is generally greater than 20 pounds per cubic foot of material with sand to cement ratios ranging between 2 to 1 by weight. A water to cement ratio of 0.35 by weight is a generally accepted norm for attaining a stiff ferrocement mortar with acceptable workability.

The failure of ferrocement boat hulls very often results from impact, whether it be from striking a submerged object, colliding with another vessel or moving against a piling while moored. Although, the factors affecting the impact resistance of a ferrocement boat hull have been clearly identified, still a relevant design chart for impact resistance, from which the designers can conveniently look into the appropriate thickness, steel content and mortar compressive strength, etc. is not available. The purpose of this investigation is to determine experimentally the impact resistance of ferrocement panels and assess the effect of specific surface on both different and equal steel content basis. Based on the test results obtained, a design curve for impact resistance is plotted.

## HISTORICAL BACKGROUND

Investigators on the impact resistance of ferrocement boat hulls have recommended various impact test methods and different testing results were reported. Bezukladov, et al. [1] compared the impact strength of reinforced concrete and ferrocement plates by using falling weight. They concluded that the dispersion of reinforcement promotes increase in the impact strength. While reinforced concrete plates had large cleavings, the crushed concrete in ferrocement was held back by the meshes from distintegrating. They also proposed a classification of ferrocement

* Assistant Professor of Structural Engineering and Construction, Asian Institute of Technology, P.O. Box 2754, Bangkok, Thailand.

+ Graduate Student, Division of Structural Engineering and Construction, Asian Institute of Technology P.O. Box 2754, Bangkok, Thailand.

Professor and Chairman, Division of Structural Engineering and Construction, Asian Institute of Technology P.O. Box 2754, Bangkok, Thailand.

based on the specific surface which is defined as the ratio of surface area of steel wire to the volume of composite. A rational approach to the problem was suggested by Shah and Key [2]. Instead of measuring the width of cracks due to total potential energy of the blows, the effect of a constant potential energy was measured in terms of flow of water through the damaged area of the panel at a constant water head. Greenius and Smith [3] found that the provision of rod reinforcement along with mesh reinforcement improved the strength and deformability characteristics under flexure and impact. Ellen [4] examined the mechanical behaviour of different types of steel mesh from a series of impact test. The thickness of the hull is a vital factor affecting the impact resistance of ferrocement as reported by Burgess and Allen [5]. For the range of slab thickness investigated it was concluded if the slab thickness was doubled the impact resistance would approximately double.

The type of impact failure most usually reported in the literature involved fracture of mortar on the back face as a result of reflected tensile waves. This failure involves spalling of the inside surface and if the cross connection between mesh layers is not properly fixed, internal delamination can occur. Bezukladov, et al. [1] reported a second type of failure where if sufficient energy was available a punch-out failure would occur. The resistance of ferrocement to this type of failure would depend on its resistance to transverse shear.

Based on Gibbs and Cox Inc.'s [6], Shah and Key's [2] and Christenson's [7] studies, Snyder [8] introduced a rational definition of impact resistance. The impact resistance is defined as the single strike impact energy required to produce the critical damage condition in the panel. The critical damage condition of any ferrocement boat hull is considered to exist when the flow of water under a two feet head leaks through the damaged area at the rate of six gallons per hour. It was felt after careful consideration of the literature that the best impact resistance would be a single strike impact of such force as to provide a quasi-quantitative comparison of the reinforcements. Snyder declared that the determination of the single strike impact resistance of any ferrocement boat hull was desirable in terms of being more meaningful to the designer. As a result, the determination of the single strike impact resistance for a series of ferrocement panels will be adopted in this study.

## EXPERIMENTAL PROGRAMME

### General

All tests were conducted on ferrocement plates 2 feet by 2 feet having a thickness of $1\frac{3}{8}''$, which is the normal thickness for a 80-feet vessel. The reinforcement consists of layers of wiremesh on both sides of skeletal steel. The only variable in the test program was the steel content and specific surface of reinforcement. Pertinent details of these test specimens are shown in Table 1. The letters A,B,C,D,E,F and G in Table 1 denote the specimen groups.

A total of 49 ferrocement panels, 10 from each group of A,E,F and G and 3 from each group of B,C and D were made and tested. Groups of A,E,F and G were tested in order to determine the single strike impact resistances. Groups of B, C and D were tested by applying the identical single strike impact energy determined from group A in order to assess the effect of specific surface on equal steel content basis.

The volume fraction referred to in Table 2 is defined as the effective volume of the skeletal steel or of the wiremesh in one direction divided by the total volume of the composite material.

Table 1 Configurations of Panels

| Specimen Group | Specimen Size Inch | No. of Specimens | Reinforcement details (from the top to the bottom side) |
|---|---|---|---|
| A | $24 \times 24 \times 1\frac{3}{8}''$ | 10 | 4 layers of No. 20 gauge – $\frac{3}{4}''$<br>6 mm. $\phi$ steel rod at 3″ centres<br>4 layers of No. 20 gauge – $\frac{3}{4}''$ |
| B | $24 \times 24 \times 1\frac{3}{8}''$ | 3 | 1 layer of No. 25 gauge – $\frac{3}{8}''$<br>4 layers of No. 21 gauge – $\frac{3}{4}''$<br>6 mm. $\phi$ steel rod at 3″ centres<br>4 layers of No. 21 gauge – $\frac{3}{4}''$<br>1 layer of No. 25 gauge – $\frac{3}{8}''$ |
| C | $24 \times 24 \times 1\frac{3}{8}''$ | 3 | 4 layers of No. 25 gauge – $\frac{3}{8}''$<br>1 layer of No. 20 gauge – $\frac{3}{4}''$<br>6 mm. $\phi$ steel rod at 3″ centres<br>2 layers of No. 20 gauge – $\frac{3}{4}$"<br>3 layers of No. 25 gauge – $\frac{3}{8}$" |
| D | $24 \times 24 \times 1\frac{3}{8}''$ | 3 | 5 layers of No. 25 gauge – $\frac{3}{8}''$<br>6 mm. $\phi$ steel rod at 3″ centres<br>1 layer of No. 20 gauge – $\frac{3}{4}''$<br>5 layers of No. 25 gauge – $\frac{3}{8}''$ |
| E | $24 \times 24 \times 1\frac{3}{8}''$ | 10 | 3 layers of No. 20 gauge – $\frac{3}{4}''$<br>6 mm. $\phi$ steel rod at 3″ centres<br>3 layers of No. 20 gauge – $\frac{3}{4}''$ |
| F | $24 \times 24 \times 1\frac{3}{8}''$ | 10 | 2 layers of No. 20 gauge – $\frac{3}{4}''$<br>6 mm. $\phi$ steel rod at 3″ centres<br>2 layers of No. 20 gauge – $\frac{3}{4}''$ |
| G | $24 \times 24 \times 1\frac{3}{8}''$ | 10 | 1 layer of No. 20 gauge – $\frac{3}{4}''$<br>6 mm. $\phi$ steel rod at 3″ centres<br>1 layer of No. 20 gauge – $\frac{3}{4}''$ |

**Material and Preparation of Test Specimens**

The skeletal grids used for all the specimens were identical. They were made of 6 mm diameter mild steel rods spaced at 3″ c/c in both directions. Three different sizes of steel mesh were used in this test, namely, No. 20 gauge - $\frac{3}{4}''$, No. 21 gauge - $\frac{3}{4}''$ and No. 25 gauge - $\frac{3}{8}''$ hexagonal steel wiremesh. The wiremeshes used for all seven groups were galvanized. Layers of wiremeshes were placed on both sides of the skeletal grid for all seven groups. They were laid in alternate directions to achieve equal amount of steel in both directions and were tied firmly to the skeletal grid. The galvanizing effect of the wiremesh was removed by accelerated weathering, i.e., placing the wiremesh in the fog room for 8 hours and then drying it under the sun for 2 days.

Table 2 Volume Fraction and Specific Surface of Reinforcement of Test Panels

| Specimen Group | Volume Fraction: Skeletal Steel $V_s$ | Volume Fraction: Wiremesh $V_w$ | Total Volume Fraction of Reinforcement $V_f = V_s + V_w$ | Specific Surface of Wiremesh $K$ in$^2$/in$^3$ |
|---|---|---|---|---|
| A | 0.0106 | 0.0149 | 0.0255 | 6.46 |
| B | 0.0106 | 0.0149 | 0.0255 | 7.75 |
| C | 0.0106 | 0.0141 | 0.0247 | 8.88 |
| D | 0.0106 | 0.0141 | 0.0247 | 10.04 |
| E | 0.0106 | 0.0112 | 0.0218 | 4.85 |
| F | 0.0106 | 0.0075 | 0.0181 | 3.23 |
| G | 0.0106 | 0.0037 | 0.0143 | 1.62 |

**Note:** The specific surface, **K**, is calculated by

a) $K = \frac{2\pi dn}{at}$, for square welded mesh.

b) $K = 5.65 \frac{dn}{at}$, for woven wire mesh.

where $d$ = diameter of wire
$n$ = number of layers
$a$ = wire spacing
$t$ = thickness of panel

Type I Portland cement (ASTM standard C150) and natural fine sand having a gradation shown in Table 3 were used throughout the investigation. The cement mortar with sand cement and water cement ratios 1.75 and 0.38 by weight was used for all test specimens. The water cement ratio is based on the sand being in the saturated surface dry condition.

Table 3. Gradation of Sand

| Sieve Size | Individual % Retained on Sieve | Cumulative % Retained on Sieve |
|---|---|---|
| 3/8 in. | 0 | 0 |
| 3/16 in. | 0 | 0 |
| No. 7 | 0 | 0 |
| No. 14 | 12 | 100 |
| No. 25 | 32 | 88 |
| No. 52 | 40 | 56 |
| No. 100 | 13 | 16 |
| PAN | 3 | 3 |
| TOTAL | 100 | 263 |

Wet mixing of mortar was done in a pan type mixer for about 3 minutes and the mortar was applied manually inside the mould which was subsequently vibrated for 90 seconds during placement to obtain uniform compaction. Two specimens were made in each batch and three 2" cubes for compressive testing were made for each batch as control specimens. All specimens were removed from their moulds after 24 hours and were continuously cured in a fog room and tested after 28 days.

**Apparatus**

The equipment used for impact testing was self-devised and is schematically shown in Figs. 1,2 and 3. The projectile was a 3″ chromium steel ball (annealed) welded to two 107″ long ½″ diameter steel bars as shown in Fig. 2. The weights were commercial standard weights. The projectile alone weighed 11.41 lbs. Total projectile weight could be varied from this value to 191.5 lbs. within an accuracy of ± 1 lb. The projectile was suspended from a steel frame and was raised using two sets of pulley. Leakage tests was done using a wooden water box with a foam rubber gasket attached to the specimen by C-clamps. Applied water head was 2 feet.

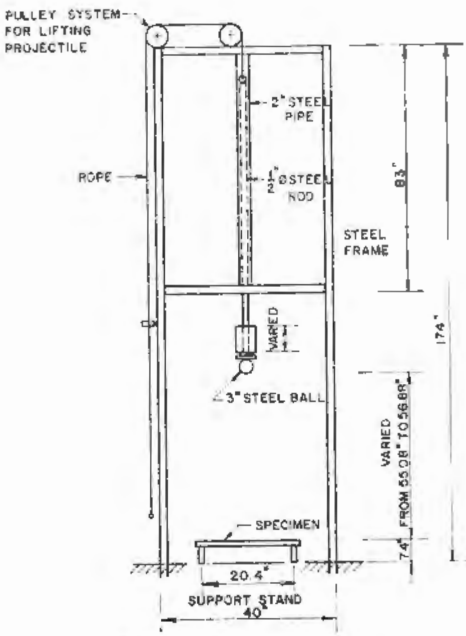


Fig. 1. Impact test set up.

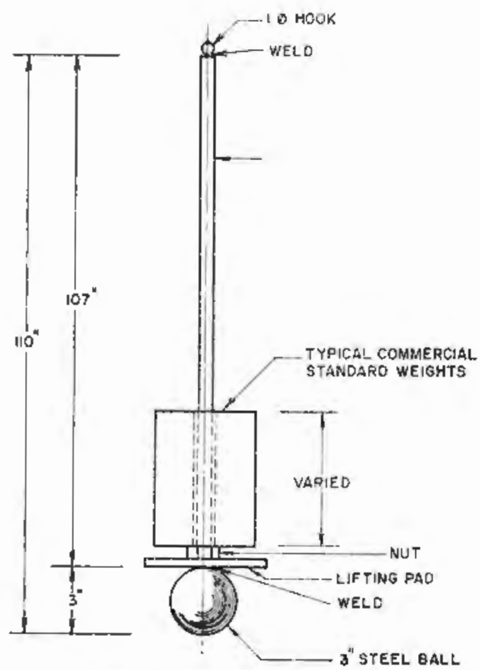


Fig. 2. Projectile Details.

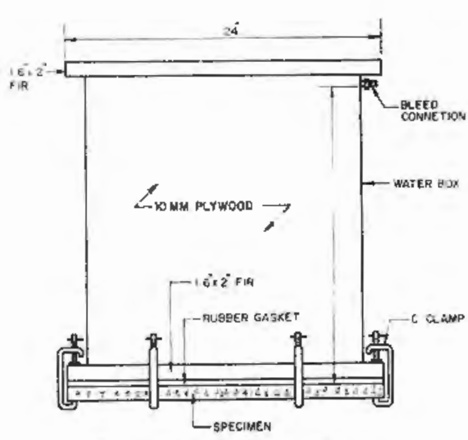


Fig. 3. Leakage test set up.

**Testing Procedure**

In the determination of the single strike impact resistance, three series of impact loading with different load increments were adopted as follows:

load increments for Series 1: 25, 50, 75, 100 .........ft-lbs
load increments for Series 2: 50, 100, 150, 200 .........ft-lbs
load increments for Series 3: 100, 200, 300, 400 .........ft-lbs

The energy of each strike is obtained by multiplying the height of the drop mainly by the weight of the projectile. The energy was varied by changing the projectile weight while keeping the height virtually constant. Heights varied between 4.59 and 4.74 feet. Impact velocity was calculated as 17.33 fps or 10.26 knots which is the same order as the speed of any displacement vessel. For the 25 ft-lbs impact, the minimum projectile weight required a lower drop height of about 2.19 feet. And for the 50 ft-lbs impact, the minimum projectile weight required a lower drop height of about 4.38 feet.

After each strike the dimensions of the damaged area were measured and recorded. If the damage is deemed large enough to cause a measurable leakage, the specimen were attached to the bottom of the water box using C-clamps filled with water, and leakage measured. Leakage was measured for the first 15 minutes after water was introduced into the box, and the result multiplied by four to obtain the hourly rate. The rate of leakage varies inversely with time due to the fact that the loosened particles (spalls) were reoriented by the flow and thus reduced the rate of leakage.

At the outset it was desirable to determine the critical single strike impact energy required to place the panel in the defined condition of failure (6 gallons per hour leakage). To achieve this 10 specimens of each configuration were fabricated and tested. Each of the first three specimens of panels A,E,F and G would be subjected to one of the above impact series. Then by a process of cross plotting the resulting curves of cumulative energy versus leakage and cumulative energy versus number of strikes, the first predicted value of the critical single strike impact energy could be found and applied to the fourth specimen. The damaged fourth specimen were then subjected to leakage measurement. If the leakage rate was less than six gallons per hour, this specimen would be subjected to two or three drops of impact series 3 loading too, and the results of the cumulative energy would be plotted versus leakage and number of strikes. Then the second predicted value of single strike impact energy could be found and applied to the fifth specimen. This damaged fifth specimen was again subjected to leakage measurement and compared with the critical damage condition. If the leakage rate was still less than six gallons per hour, this process would be repeated until the single strike impact energy was accurately found. This process is illustrated in detail in [9].

In the assessment of the specific surface of reinforcement on equal steel content basis, each of the three specimens of panels B, C and D would be subjected to the identical single strike impact energy of panel A. Hence the effect of specific surface with respect to leakage rate under the same impact loading condition could be assessed.

## DISCUSSIONS

It can be seen from all the test specimens subjected to impact loading that the damage was localized at the point of contact and that no large fragments fall out from the specimens, since the multiple layers of mesh hold the fragments together. It is observed that the failure mode can be classified into two groups, i.e., for panels with two to four layers of mesh and for panels with six or more layers of mesh.

For panels with two to four layers of mesh, i.e., panels F and G, a compression failure would usually occur on the upper surface at the point of contact. The reflecting tensile stress wave in the lower surface would cause shear spalling around the ring cracking and would cause disruption in the internal bond between mortar and wiremesh prior to breaking the reinforced steel mesh. Under this laminated condition, it would reduce the effective width of the panel, the strength of material, and hence the impact resistance.

For panels with six or more layers of mesh, i.e., panels A,B,C,D and E, a compression failure was found on the upper surface at the point of contact and several visible radial crack openings, broken wiremesh and a shear cone were observed in the lower surface. Since the increase in steel content will induce an increase in shear strength, the lamination in this group was not found. Since this type of failure was controlled by punching shear, the higher the steel content, the higher the observed impact resistance.

It was observed that the diameter of the base of punch shear cone in the lower surface of all test specimens was around 7 to 7.5 inches. The standard damage of the panel for upper and lower surfaces is shown in Figs. 4 and 5.

Fig. 4. Standard damage of upper surface.

Fig. 5 Standard damage of lower surface.

It is found from a series of testing and cross plotting [9] that the single strike impact resistance of a ferrocement boat hull can be predicted accurately from the method stated in this study. The single strike impact resistances predicted for panels A,E,F and G are tabulated and shown in Table 4.

It can be seen from the impact resistance versus steel content curve in Fig. 6 and from the impact resistance versus specific surface curve in Fig. 7 that the impact resistance increases with the increase in steel content or in specific surface of steel mesh reinforcement.

It is interesting to compare the surface damage of panels A,E,F and G under defined critical damage condition. It is observed that although the leakages of panels A,E,F and G under the critical damage condition are of the same order, the deflections and the crack openings in panels F and G are much less than that of panels A and E, since panels F and G was laminated at low load prior to breaking the steel mesh reinforcement. It is felt that the deflection and crack width measurements cannot indicate accurately the damage to the ferrocement boat hull. And, it can be concluded that for impact testing of the ferrocement boat hull, the flow measurements are a better indication of the damage suffered by the specimens.

Table 4 Result of Impact Test for Determining the Single Strike Impact Resistance

| Specimen Group | Steel Content (%) | Specific Surface $in^2/in^3$ | Single Strike Impact Resistance ft-lbs. | Leakage gal/hr. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Speci-men (1) | Speci-men (2) | Speci-men (3) | Speci-men (4) | Speci-men (5) | Mean |
| A | 2.55 | 6.46 | 567 | 6.182 | 5.875 | | | | 6.029 |
| E | 2.18 | 4.85 | 515 | 6.12 | 5.67 | 5.84 | 6.83 | | 6.12 |
| F | 1.81 | 3.23 | 425 | 6.07 | 5.429 | 6.266 | 5.907 | 5.641 | 5.863 |
| G | 1.43 | 1.62 | 385 | 5.74 | 6.28 | 5.91 | 6.17 | | 6.025 |

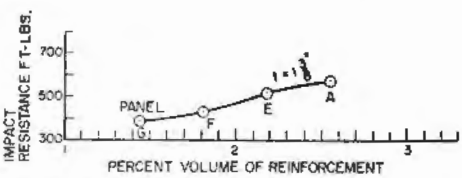


Fig. 6. Impact resistance vs. steel content (Panel A.E.F.G.)

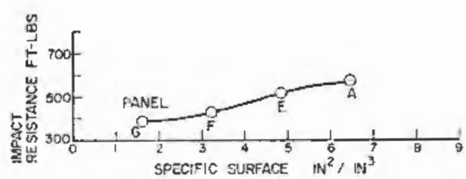


Fig. 7. Impact resistance vs. specific surface (Panel. A.E.F.G.).

Table 5 Results of Impact Test for the Assessment of Specific Surface of Reinforcement on Equal Steel Content Basis

| Specimen Group | Specific Surface $in^2/in^3$ | Impact Energy ft-lbs. | Leakage gal/hr. | | | |
|---|---|---|---|---|---|---|
| | | | Specimen (1) | Specimen (2) | Specimen (3) | Mean |
| B | 7.75 | 567 | 5.74 | 5.389 | 5.231 | 5.453 |
| C | 8.88 | 567 | 6.41 | 9.11 | 5.84 | 7.12 |
| D | 10.04 | 567 | 7.647 | 14.53 | 9.42 | 10.54 |

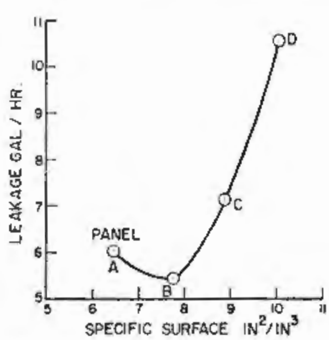


Fig. 8. Leakage vs. specific surface on equal steel content basis (Panel A.B.C.D.).

The test results for the assessment of specific surface of reinforcement on equal steel content basis are shown in Table 5 and Fig. 8. It can be seen from leakage versus specific surface curve that under an almost practical maximum steel content condition the impact resistance does not always increase with an increase in the specific surface. The specific surface of panels B,C and D are 7.75, 8.88 and 10.04 $in.^2/in.^3$ respectively. Since the specific surface in panel B is slightly greater that the optimum value 7.6 $in.^2/in^3$. [1], it still gets the benefit of an increase in impact resistance. For panels C and D, because the specific surfaces are much greater than optimum value, their compressive strengths were reduced due to stratified layers of weakness associated with many superimposed layers of mesh and poor penetration which in turn, led to a reduction in impact strength.

## CONCLUSIONS

On the basis of this study the following conclusions are drawn:

1. The method stated in this study can predict accurately the single strike impact resistance of a ferrocement boat hull.

2. Under critical damage condition, the assessment on different panels becomes more meaningful, or in other word the determination of single strike impact resistance for corresponding panels are quite important to the designer.

3. Instead of measuring the qualitative surface damage, the measurement of the water flow through a damaged panel is a better indication of the damage suffered by the specimen.

4. Impact resistance increases with the increase in the steel content or in the specific surface of steel mesh reinforcement.

5. Under an almost practical maximum steel content condition the impact resistance does not always increase with the increase in the specific surface of steel mesh reinforcement.

## REFERENCES

1. BEZUKLADOV, V.F., et al., "Ship Hulls Made of Reinforced Concrete", NAVSHIPS Translation No. 1148, AD 680042, Shipbuilding Publishing House, Leningrad, 1968.

2. SHAH, S.P. and KEY, W.H., "Impact Resistance of Ferrocement", Journal of Structural Division, Proceedings of the American Society Engineers, Vol. 98, No. ST1, January 1972, pp. 111-123.

3. GREENIUS, A.W. and SMITH, D., "Ferrocement for Canadian Fishing Vessels", Vol. 2 Project Report No. 48, Industrial Development Branch, Fisheries Service, Department of Environment, Ottawa, January 1972.

4. ELLEN, P.E., "Practical Ferrocement Design—Reinforced and Post-Tensioned", FAO Investigates Ferrocement Fishing Craft, edited by John Fyson, Fishing News (Books) Ltd., Surrey, England, 1972.

5. BURGESS, W.M. and ALLEN, D.C., "Impact Resistance of Reinforced Concrete as a Problem of Containment", Research Report No. R251, University of Sydney, August 1974.

6. GIBBS & COX, INC., "Marine Design Manual for Fiberglass Reinforced Plastics", McGraw Hill, 1960.

7. CHRISTENSON, K.A., "The Impact Resistance of Laminated Steel Mesh Impregnated with Portland Cement Mortar", Graduate Student Report, University of California, Berkeley, July 1971.

8. SNYDER, P.G., "The Impact Resistance of Modified Ferrocement Panels", Thesis for the Degree of Master of Science in Naval Architecture and Marine Engineering, Massachusetts Institute of Technology, September 1973.

9. CHEN BOR-SHIUN, "Resistance of Ferrocement Boat Hulls Against Impact", Thesis for the Degree of M.Eng., No. ST 19-8, Asian Institute of Technology, Thailand, 1979.

# Cost Reduction and Quality Control in Ferrocement and Marine Concrete*

Martin E. Iorns+

*The paper describes laminating and shotcrete techniques which decrease labor requirements while increasing quality control and impact resistance; compares costs and other advantages of ferrocement over glass reinforced polyester (fibreglass) in boat hulls; discusses hybrid floating structures of ferrocement in combination with conventionally reinforced concrete which can be built for substantially less than all-steel structures; outlines use of floating moulds which enable large ships and monolithic floating structures to be built directly on the water, thus removing any size limits imposed by available shipways or graving docks.*

## INTRODUCTION

Service experience with ferrocement boats over the past 130 years [1] and with concrete ships for 60 years shows conclusively that reinforced concrete has adequate strength and superior durability for marine use at a lower materials cost than glass reinforced plastic or all-steel construction. Why, then, is concrete not more widely used? The answer lies in its high fabrication costs, and it is the purpose of this paper to outline some new methods which have been tested in practice and found to effect a substantial reduction in the first cost of both ferrocement boats and floating concrete structures.

The application of these methods and materials to vessels under 40 metres (130 feet) and to floating concrete structures is already far beyond the experimental stage. All we have to do now is apply the same principles to larger vessels.

## PRIOR CONSTRUCTION METHODS

For ships, concrete was placed between two forms, much as in concrete construction ashore, but the ultra-thin hull thickness of ferrocement boats required a different approach. An early method was to erect pipe frames, attach longitudinal, and sometimes transverse, rods spread approximately 10 cm. apart, then tie several layers of wire mesh, usually poultry netting, inside and outside the rods.

R.T. Hartley [2], in New Zealand, substituted welded prefabricated truss frames and advocated that mortar be applied in two separate operations.

John Samson [3], in British Columbia, proposed that mesh and mortar be applied over a closed cedar male mould which would be left in place as an interior finish. It was soon discovered that penetration problems required the mould to be removed for back plastering, so this closed mould was quickly replaced by the now widely used open mould in which mesh and rods are stapled to longitudinal wood battens spaced several centimeters apart.

Commercial builders are understandably reluctant to publicize the methods they have developed for series production but most use inverted construction over reusable frames and

* Reprinted with the permission of the pubishers of the proceedings of the Concerete Ships and Floating Structures Convention, Rotterdam, November 12-14, 1979. (Thomas Reed Publications Limited, U.K.)

+ Fibersteel International Company, West Sacramento, California, U.S.A.

jigs. Some builders use spray (shotcrete) equipment to apply the mortar but have found that velocity placement alone does not ensure full penetration of the mesh cage.

## PROBLEMS

Appearance and cost factors have prevented ferrocement from gaining any appreciable share of the pleasure boat market. The few ferrocement boats exhibited at U.S. boat shows have suffered by comparison with glass reinforced plastic (GRP) offerings and attracted few buyers. Many individuals have achieved finishes equal to GRP, but to do so commercially would require so much skilled labour as to price the boats out of the market.

In fishing boats and work boats where appearance is secondary to utility, mass production has made considerable progress in countries with fixed labour costs and a controlled market. The People's Republic of China [4] and Cuba [5] are notable examples.

Up to now, ferrocement has also been handicapped by overweight, voids, and poor impact resistance.

The excessive overweight frequently encountered in conventional ferrocement boats can be due to faulty design or poor workmanship (more often the latter), but some degree of overweight is always present when rods are included in the armature to space and support the mesh.

Engineering studies by the U.S. Navy [6] in connection with the development of high performance (30 knot) ferrocement planning hulls showed rods to be "a very inefficient use of the included steel, principally for three reasons. The surface area bond is not equal to the allowable stress for the rod, so that the rods are not loaded to take advantage of their strength. Because of the spacing of the reinforcing rods, regions of unreinforced mortar exist in the ferrocement which contribute to the material weight but not to its strength. Finaly, the rods act as stress concentrators. Small-scale mechanical property tests of ferrocement have demonstrated remarkable increase in strength-to-weight ratio by the use of mesh only."

Voids obviously weaken the section in which they occur. They may cause leaks or allow sea water to attack the reinforcing. They may-contain pockets of water which can freeze and lead to rapid deterioration of the hull in severe climates.

Careful workmanship can minimize the size and number of voids but cannot eliminate them entirely in any construction method where mortar must be forced through multiple layers of closely spaced mesh.

Voids also represent one horn of a dilemma and impact resistance the other.

Resistance to impact is dependent on the amount of steel, its distribution, and the amount of surface in contact with the mortar. As steel content increases so does the difficulty of obtaining full mortar penetration. To achieve penetration by conventional methods one must reduce the concentration of mesh so that ferrocement, in practice, is usually under-reinforced. As a result, when the hull deflects from a blow, the rods act as stress concentrators [6], and the mesh cover is insufficient to control crack propagation. At least three losses of ferrocement boats from this cause have been brought to the author's attention.

## SOLUTIONS

The ideal ferrocement construction system must be able to produce a lighter , void-free, all-mesh, impact-resistant hull with an appearance equal to GRP, but with lower cost materials and less labour. Such a process has been developed [7] patented, and is now available to any builder.

Finish labour is eliminated and appearance comparable to GRP is obtained by the use of a female mould. GRP builders converting to ferrocement may use their existing moulds, but a new design can use a less costly ferrocement mould. Voids are eliminated by embedding each mesh layer separately in preplaced mortar. The rigid mould supports the mesh and mortar so rods become superfluous, although they may still be used in the keel, stem, and deck edge where they are most cost effective in resisting impact. This all-mesh construction permits a lighter hull with improved impact resistance, yet with much lower labour requirements as discussed below.

## PRODUCTION METHOD AND MATERIALS

The mould is first sprayed with a parting agent followed by a 2 or 3 mm gel coat of portland cement mortar fortified with a polymer to produce a tough, non-porous surface. When this gel coat has hardened sufficiently to resist print-through, a similar thickness of structural mortar is sprayed on and strips of mesh are pressed into the soft mortar by means of a tool designed especially for this purpose. Successive layers of mortar and mesh are applied in an overlapping pattern until the laminate reaches design thickness.

The ability to place any amount of reinforcing in any section must be used with caution because it is now possible to over-reinforce. Attention should first be directed toward reaching an optimum concentration of lower cost, high specific surface types of mesh such as expanded metal plaster lath which laboratory test [5] and service experience have shown to be superior to woven wire mesh in ability to strain without cracking.

In the past, Lloyd's has been reluctant to accept expanded metal ferrocement but the U.S. Coast Guard after extensive tests at California State University in Sacramento [8] fully approved an expanded metal lath laminate for small passenger vessels including integral diesel fuel tanks. Lloyd's and other standards-setting organizations may be expected to do likewise after making similar tests.

## PRODUCTION COSTS

Laminating techniques and spray application of mortar (shotcrete) have drastically reduced ferrocement labour costs.

The 16.8 metre (55-foot) boats being built in California to U.S. Coast Guard standards for passenger vessels use five layers of expanded metal lath, which with mortar and admixtures cost approximately fourteen hundred dollars. The hull is built in one work day by five unskilled labourers under the direction of an experienced foreman. Some overtime is required for preparation and cleanup, but one hull was completed in fifty man-hours, and the last few have been built in under sixty manhours each, for an average labour cost of less than five hundred dollars, including insurance and fringe benefits.

It should be noted that the cost ratio of materials to labour applies only to hulls, bulkheads, and soles. The foam core deck and cabin on these 16.8 metre boats use some higher priced meterials, but the installation of bulkhead fillets, floors, soles, integral tanks, and the deck-to-hull joint are almost pure labour. As a rule of thumb, labour costs will about equal the cost of materials in both ferrocement boats and floating structures made by the methods outlined here.

## FERROCEMENT VERSUS GRP

Minimizing overhead expenses is a prime consideration for any builder. Low start-up costs are particularly important. Ferrocement expenses are much lower than GRP.

Ferrocement moulds may cost as little as a tenth as much as GRP moulds and will last indefinitely. With normal curing procedures, production will be one hull each week from each mould. Steam curing can reduce this to three days, but it may be more cost-effective to build additional moulds to secure the production rate needed. In warm climates, use of the floating mould to be described later may increase the production rate to one per day.

The basic equipment needed for ferrocement boats up to 20 metres in length consists of a mortar mixer and mortar pump, an air compressor of five horsepower or more, a small crane or gantry to lift and place bulkheads, machinery, or deck sections, and the usual hand tools used by plasterers and carpenters.

The total investment in equipment should not exceed five thousand dollars unless one plans to build large floating concrete structures, in which case higher capacity shotcrete apparatus and lifting equipment will be needed.

GRP requires controlled temperature and humidity in the production plant, whereas ferrocement construction can proceed at all ambient temperatures above 10° Celsius, and the higher the humidity the better.

Ferrocement needs only to be sheltered from sun, wind, and rain during laminating, and from sun and wind during curing, so a cover for each mould and a storage shed for materials and tools will suffice for commercial production. The author believes that when labour, materials, and all other cost factors are considered, ferrocement hulls above 10 metres in length can be built for less than one-fourth, and possibly as little as one-tenth, the cost of GRP. If not presently at that level, the escalating cost of petrochemicals compared to the more modest rise in the price of cement and steel will soon make it so.

## CUSTOM BUILDING METHODS

Laminating techniques can also be used in one-off construction to obtain better quality control with less labour than in the traditional ferrocement methods.

One method uses all-mesh construction over an inverted open wood male mould. Three men built a 12-metre (40-foot) hull in one week by this method with the help of a professional plasterer called in to apply the finish coat. A sequence of photographs published in a regional magazine clearly ilustrates the method [9].

A more sophisticated approach which dispenses with most of the woodwork, saves labour, permits better quality control, and results in a stronger vessel, is based on the integral mould concept. The method has never been published and has so many variants, depending on vessel shape, size, framing, and site conditions, that only a brief outline can be provided here.

Boats up to 18 metres (60 feet) in length and sometimes larger, depending on design and site conditions, are best built inverted, including the deck, and righted after launching. A platform of plywood or other material is prepared with the designed deck camber and crown, then convered with fabric or matting to produce the desired deck surface texture. A foam core ferrocement deck is then laid down and precast bulkheads or frames are erected and bonded to the deck, thus minimizing overhead work later.

High-carbon wire or rod of a suitable diameter and spacing is placed fore and aft over the frames and bulkheads and covered with lightweight mesh or other fabric, then sprayed with a light-weight mortar. When this flash coat has hardened it becomes an integral mould to which further laminate may be applied either inside or out.

For large ships or where site conditions make inverted construction impractical, the hull is built upright with the integral mould forming the outside surface of the hull. Bulkheads, frames, floors, soles, and deck sections are precast outside the hull, lifted into place, and bonded into the hull laminate with fillets wide enough to prevent concentrated shear zones.

The laminating concept can be applied to ships of any size and, if projections based on small-boat experience hold true, the savings will be substantial. Labour productivity per kilo of displacement rises as vessel size increases and experience has shown that a 15-metre (50-foot) boat can be built with only a few more man-hours than a 10 metre (33-foot) boat, even though more than twice the amount of material is involved. The tighter curves of the smaller boat require more cutting and trimming of mesh and more care in placement. In larger ships, laminating can proceed at a much faster pace.

Reinforcing bar can be laminated into the hull to form the structural frame of the ship. If prestressing is needed to keep displacement within acceptable limits, it can be readily accomplished by post-tensioning. Post-tensioned ferrocement was used for the hull of the Australian-built ocean racing yacht HELSAL which won the gruelling Sydney to Hobart race a few years ago.

## FLOATING MOULDS

In ice-free locations, the construction of ferrocement boats, ships, and floating concrete structures can be greatly facilitated by the use of floating moulds.

A boat or ship mould consists of a hull-shaped cavity recessed into a flush-decked concrete barge slightly wider and longer than the hull, so as to provide a working area around the rim of the mould. The barge surrounding the mould is bulkheaded into four watertight compartments, the after two of which are provided with means to flood or empty, using pumps or compressed air.

As soon as bulkheads and frames are in place and the boat hull has gained enough strength to float without support (which may be only a few hours in hot weather) water is introduced between the mould and the hull, causing the hull to release and float free in the mould cavity. The after barge compartments are then flooded until the transom of the mould sinks below the draft of the vessel which is then floated to an outfitting dock. During this operation the forward part of the barge mould is never completely immersed, thus eliminating the need for the wing walls required by a conventional floating drydock.

If the mould is not kept in full use for production purposes, it can be fitted with removable keel blocks and used as a floating drydock to service boats previously built in it or for repairs to any smaller craft.

## FLOATING CONCRETE STRUCTURES

A floating, integral ferrocement mould can substantially reduce the cost of large floating concrete structures and eliminate the need for graving dock or shipways. Any area of quiet water, sloping beach or tide flat can be used as a building site. Construction can take place directly on the water, so there is no limit to the size of the structure. Building started on a tide flat or in shallow water can be moved to a deeper location as draft increases.

By this method a shallow box is constructed of 3 mm or heavier waterproof plywood or particle board encased in polyethylene or similar film to keep out the water. The inside of the box is lined with another layer of film to act as a release agent. The interior bottom and sides of this floating box are next covered by a ferrocement laminate containing at least two layers of overlapping mesh. A reinforced concrete bottom slab is then placed on which bulkheads are cast flat and tilted into position. Bulkheads may also be precast ashore and lifted into position.

The deck pour can be made with conventional forming and materials or by the use of precast ferrocement deck pans. The bulkheads can be cast with a wide flange along the top edge on which reinforced precast deck panels can rest. The deck panels are cast undersized with projecting reinforcing and form channels in which heavier longitudinal and transverse rebar can be placed in a closing pour. Numerous pitfalls were encountered in early attempts to use this method, but these have now been surmounted and several concrete floats up to 25 metres (80 feet) in length have been built with significant savings in labour.

Except for possible anchorage problems, there seems to be no economic or technical reason why large monolithic floating concrete platforms cannot be built as sites for cities and airports. All the requirements of building ashore-site acquisition, excavating foundations, landscaping and the like are superfluous to marine construction by this method, which by contrast becomes increasingly attractive from an economic as well as an ecological viewpoint, as the land becomes more crowded.

The methods described thus for can be aplied to any hull configuration, but there is another technique which should be considered for concrete structures of constant cross-section where length greatly exceeds beam such as floating breakwaters, ribbon-type wharfs, and pontoon bridges. A patent application is being prepared on a horizontal slipform floating mould which will permit the extrusion of large box girder sections of any length directly on the water at the building site.

Pontoon bridge construction could start on one bank and proceed continuously until connection is made to the far shore. Vehicular traffic could be carried both on the top deck and inside the hull. Where wind and current loads, anchorage problems, or need for opening spans preclude monolithic construction, the bridge would be built in segments. An uninterrupted flow of both land and water traffic can be achieved by building floating detours onto which vehicles would be diverted while the main span was open for ship passage.

## CONCLUSIONS

Laminating techniques and spray application of mortar (shotcrete) against a single surface mould can improve appearance, reduce labour costs, speed production, eliminate voids, permit all-mesh layups, improve strength-to-weight ratios, facilitate foam-core construction, increase impact resistance, and bring overall production costs well below GRP or all-steel construction.

Floating moulds further increase production rates in warm climates and floating integral moulds permit the building of ships or large floating concrete structures without a graving dock or slipway.

Horizontal floating slipform moulds are being designed to permit continuous extrusion of pontoon bridges or other elongated floating concrete structures.

REFERENCES

1. CASSIE, W.F., "A Personal Rediscovery", Concrete (London), November 1967, pg. 280-3.
2. HARTLEY, R.T., "Hartley's Ferro-Cement Boatbuilding", Broughtwood Printers, Auckland, N.Z., 2nd edition, January 9, 1973.
3. SAMSON, J., and WELLENS, G., "How to build a ferrocement boat", Samson Marine Design Enterprises, Richmond, British Columbia, 1968.
4. NATIONAL ACADEMY OF SCIENCES, "Ferrocement Applications in Developing Countries", 2101 Constitution Avenue, Washington D.C., February 1973.
5. UNITED STATES DEPARTMENT OF COMMERCE, INDUSTRY AND TRADE ADMINISTRATION, Washington, D.C., Fishing boat construction bulletin, March 8, 1979.
6. DISENBACHER, A.L. and BRAUER, F.E., "Material Development, Design, Construction, and Evaluation of a Ferro-Cement Planing Boat", Marine Technology July 1974, pp. 277-296.
7. U.S. PATENT NO. 3,652,755, March 28, 1972; Canadian Patent No. 948,834, June 11, 1974; and British Patent No. 1,347, 587, March 17, 1972.
8. IORNS, M.E. and WASTSON, L.K., "Ferrocement Boats Reinforced with Expanded Metal", Journal of Ferrocement, Vol. 7, No. 1, July 1977.
9. DAY, J., "New Boats: A Concrete Example", Lakeland Boating, January 1969, pp. 22-24.

# Design, Series Production and Promotion of Ferrocement Vessels*

**B.J. Spradbrow⁺ and K.M. Wiklund†**

*Ferrocement has not gained widespread acceptance as a construction material for the commercial production of marine structures. There is no technical reason why it should not be able to compete with other boat building materials; it has in fact a number of advantages. The authors, who are engaged in type-certification of small craft, suggest an approach to the production and marketing of ferrocement vessels which is intended to circumvent the boating public's scepticism toward the material. Some general guidelines to boat design are presented. It is suggested that ferrocement can gain a sizeable market in the immediate future, but that this will require a determined effort by interested organisations.*

## INTRODUCTION

"*Any time things appear to be going better, you have overlooked something......*"

Anonymous

Ferrocement has been defined as thin-walled highly reinforced cement mortar. Much has been written about it [1]. Much has been researched: high strength mortars, low weight mortars, additives, alternative reinforcements, surface treatments. It can be strong, light, inexpensive, superior in all respects. Ferrocement boats have been built in all parts of the world for many years. But there is no breakthrough. It is not quite accepted. In the industrial countries plastic, steel and aluminium dominate in boat and small ship production and structural applications. It could well be that something has been overlooked......

The situation in Scandinavia today, and in most of the industrial countries, is that some few companies build ferrocement boats, in spite of apparently overwhelming competition from GRP. production, in spite of a predominately negative public opinion, in spite of a lack of adequate funding and credit.

If ferrocement is to be more than an amateur boatbuilding material in the industrial world and remain a real alternative in the developing countries, it has to meet all demands as to strength, lightness, low cost, lack of maintenance, repairability and suitability for series production. We believe that industrial ferrocement production can meet these demands and also compete in price.

Our objective here is to promote active involvement in well-founded ferrocement projects. It is natural to assume that those organizations most likely to support such projects will have experience in concrete construction. In the following, therefore, we will not go into technical detail regarding ferrocement, but concentrate rather on the peculiarities of boat design and on the steps that might be taken to promote ferrocement in the boatbuilding industry.

*Reprinted with the permission of the publishers of the proceedings of the Concrete Ships and Floating Structures Convention, Rotterdam, November 12-14, 1979. (Thomas Reed Publications Limited, U.K.)

⁺Surveyor, Small Craft Department, Det norske Veritas, Norway.

†Senior Surveyor, Small Craft Department, Det norske Veritas, Norway.

The time has come to stand back a little, to see what has been achieved and what can be achieved, to analyse, to decide, to act.

## PAST AND PRESENT

*"In order to judge properly, one must get away somewhat from what one is judging, after having loved it."*

Andre Gide 1903

The "traditional" method of ferrocement construction consists of plastering concrete mortar over a self-supporting framework of rods and mesh. Meterial costs are low and few specialized boatbuilding skills are required, but the method is time-consuming. It is widely used in the developing countries and by amateur builders. High labour costs make it a hopeless alternative for large-scale commercial production in industrial countries.

An alternative method is to temporarily fasten the reinforcement to a male form. Costs for external (and sometimes internal) finishing are high. A logical development to reduce these costs is to cast in a female mould, as in glass-reinforced-plastic boat building. Difficulties may arise in placing conventional reinforcement, but it is this method which, to date, has proved most suitable for commercial production.

Various techniques and materials have been used to make better use of the mechanical properties of steel and concrete: for example pre-and post-tensioned steel rods, steel fibres, and the use of additives to increase mortar strength and workability and to reduce weight.

In general it appears reasonable to say that the development of commercial production has been limited by a tendency toward 'traditional" thinking with regard to construction methods.

The first ferrocement boats, built by Lambot in France 130 years ago, were 12 ft (3.7 m) dinghies. Since then the material has been used for the complete spectrum of small marine structures; pontoons and barges, buoys, pleasure yachts, and commercial vessels up to almost 30 m long. In many countries ferrocement has gained a degree of acceptability. Why therefore, is it not better accepted in most industrial countries?

Ferrocement is in a number of ways suited to amateur construction. It can be relatively simple to work with; it is inexpensive, the materials are readily obtainable. The amateur can either research the subject and build with great care, or he can sketch up the boat of his dreams, read a book or two on the subject, and set to work......

The boating public (and many suburban communities) have, over the years, been exposed to numerous ferrocement projects that can be described, at best, as unfortunate failures. These failures influence public opinion. Public rejection effectively rules out large-scale series production. A new producer of ferrocement hulls must, therefore, expend considerable effort to overcome public scepticism — in addition to his "normal" sales efforts —and he will need to strive for quality, for perfection.

The information necessary for a technically successful operation can be obtained from (1) existing research data (2) published data and information from presently active companies and the "pioneers" (including some who have tried and failed) (3) related technologies.

Designs for ferrocement construction are available from many sources, and are of highly variable quality—few are intended for, or suitable for, series production. Some may be suited to modification but it is essential to rely on the services of experienced and competent professionals.

Classification societies play a role in improving acceptability of the material by formulating codes for design, materials and construction. In most cases control is carried out on behalf of insurance companies or national authorities. In the special case of type certification in Scandinavia, approval of the design and production, and testing of a completed prototype, amounts to quality control on behalf of the private buyer. An acceptable level of safety is obtained through critical inspection rather than by overdesign.

Det norske Veritas published tentative rules for the construction and classification of ferrocement vessels, based on the "traditional" method, in 1974. These rules have been used for fishing boats and pleasure boats from about 30 to 60 feet, and the boats appear to have had adequate structural qualities. The rules are also the basis for the new edition of rules being prepared by the maritime authorities in the Nordic countries. Further development of rules for ferrocement will assume that boats are series produced and will allow reduced scantlings when especially strong materials are used.

## DESIGN—THE BASICS

"*Certain defects are necessary for the existence of individuality*".

Geothe 1809

Herr Goethe's sentiments have been confirmed by very many builders of ferrocement boats. However, the need for positive economic results leads to a need for series production, which in turn allows little scope for individuality. Neither do consumer protection laws allow a lot of room for defects......

A plea therefore to project instigators: allow adequate funding for professional design and control. In all but the most basic marine structures it is essential that good ship or boat design practice is adhered to, that the result is an aesthetic success, and that the product functions successfully during its planned service life.

One must assume that firms not presently engaged in boatbuilding but which have the capability to carry out cost analysis, reinforced concrete design, sophisticated production, and marketing, will not have the competence to carry out a successful boat design. The design of ships and boats is an iterative process which usually goes through the steps outlined below. The detail in each step will normally increase with each "loop".

a) Design requirements: These may initially be the result of a market analysis—or a guess. Conflicting demands in the following steps may lead to modification of the original requirements

b) Determination of proportions and parameters: Experienced designers will understand and have a record of the influence of hull proportions and parameters on performance. These factors are a non-dimensional measure of various aspects of the hull shape and are quite critical for optimum results.

c) Powering: The required power for a given service speed can be determined by calculation or, if the size of the project allows it, by tank testing of scale models. Range, fuel requirements and propeller design will be based on the continuous motor rating (service speed). For sailing yachts, sail and rig design will assume a wide range of service conditions. The longitudinal placing of the rig is seldom understood, and critical.

d) Lines plan: Hull shape is the "alpha and omega" of boat design. Performance, appearance, functionability, space for accommodation, and suitability for the proposed construction method lie in the hands of the designer at this stage. It may be desirable to manufacture full or part scale models before series production for performance testing or visual study.

e) Hydrostatic and stability calculations: These will include also calculation of trim and of free surface of liquids in tanks (which have a negative effect on stability).

f) Arrangement: Preliminary design will cover accommodation, machinery, electrical and deck layouts whilst detail design may extend to interior layout details, ventilation systems, insulation, anchoring and towing arrangements, tanks, piping systems, steering gear, wiring and electrical system diagrams, and safety equipment.

g) Structural design and method of production: Structural failure stems usually from a detail failure of under-estimation of a loading. We will consider this in more detail in following sections. Additionally it must be kept in mind that even structural details must be produced economically, attention to detail in a highly competitive market will pay dividends.

h) Weight estimation: Naval architecture has been defined as a science of weights and levers. That definition gives a clue to the importance of the detailed weight calculation. Errors in estimation or carelessness in production can seldom be accommodated by the hull shape form parameters.

i) Cost analysis: In this respect boat design is no different from other fields of engineering—the estimated costs of the first preliminary designs invariably fall outside budget limits. When costs have been trimmed to an acceptable level and before production commences it is wise to check market response to the design.

The design (and the production process) should be documented in detail, and a technical specification drawn up from the outset. This will prove invaluable for internal control routines and negotiations with subcontractors, licencees, dealers and marine authorities ...... and for eventual control by classification societies.

## STRUCTURAL DESIGNS

"*Neither smiles nor frowns, neither good intentions nor harsh words, are a substitute for strength*".

John F. Kennedy 1960

Structural design in the marine environment is complex. Ferrocement in itself poses no particular problems: if the loadings and mechanical properties (see Appendix 1) are known, suitable scantlings can be derived. A checklist for common loadings on boats and equipment is shown in Appendix 2. In the following we will comment upon some of the listed points.

The *loading conditions* will be affected by: the size and nature of waves in the intended areas of service; the intended service or maximum speed; limit conditions in bad weather, particularly with regard to accelerations.

The *static loadings* are determined by the weight and position of centre of gravity of the structure which affects in turn, stability, load carrying ability and the vessel's motion in a seaway.

In addition to weight distribution, hull form is a major factor in determining the response of the vessel in waves. *Dynamic loads*, particularly from slamming, can be very high; but theoretical maximum accelerations may not be attainable in practice because they cannot be tolerated by the crew and the passengers. The possibility and consequence of fatigue failures must be borne in mind.

*Propulsion* and *"in-service" loadings* will include calculations of thrust loadings on the structure. The risk of vibrations should also be analysed. Rudder loadings are directly proportional to the square of the speed and can be very much higher than one might expect—failures in rudder stocks and steering gears are not uncommon. Rig failures in sailing yachts stem often from under-designed fittings. If mooring or towing cleats and bollards are inadequate they have a habit of failing when most needed.

*Production loadings* must not be forgotten. As in other structures, built-in stresses, if they are not bargained for, may result in failures through fatigue or overloading.

*Environmental hazards* may take many forms—salt spray, extremes of temperature, and polluted water, to name a few—and may lead to destruction or inferior operation of equipment or hull components. Damage can be extensive and difficult to correct or repair.

*Potential damage* obviously cannot be anticipated with any certainty. It is, however, comforting to know that the design incorporates features which are intended to prevent total destruction .... fires can be restricted, and small boats do not need to sink if damaged or capsized. The placing and type of safety equipment should be determined in the design stage.

Having established the load conditions for the boat, dimensioning of the structure can be determined from basic theory.

Seen from a practical viewpoint, the strength calculations should be as exact as possible in order to produce economic designs and designs of as low weight as possible. The logic behind published classification rules is that the calculations should at the same time be as simple as possible in order that the designer may derive scantlings by the use of a calculator.

In this respect the published scantlings rules are an acceptable tool for "one-off" design although an optimal series production ought to be based on more accurate studies of the individual design. Competition demands optimization in boat construction. Safety factors should be such that the structure has adequate strength at the end of its planned useful life—too little strength may risk the lives of those onboard, whilst too much will price the product out of the market and reduce performance.

# ALTERNATIVE TECHNOLOGIES

*"The beautiful souls are they that are universal, open and ready for all things".*

Montaigne 1580

The various approaches to ferrocement construction have been widely publicised but there is as yet no universally accepted series production method. We feel that there is much merit in a careful study of the competing technologies before opting for any particular technique. I deally this study should extend to the development slikely to occur in each of these technologies in order that they remain competitive. An attempt should then be made to adapt ferrocement production to the most promising, the most effective, of these methods.

GRP is now firmly established as the major boatbuilding material up to 40 feet. From the outset, laminates were laid up by hand in female forms. This method is still favoured by many boatbuilders. A subsequent development was the spraying of the mixture of chopped fibres and polyester instead of hand lay-up—the advantage is greater speed of moulding the disadvantages are reduced mechanical properties and somewhat less control over thickness. The most recent development is in the use of semi-automatic moulding in closed forms. Parting agents and gelcoat are first applied to the forms; reinforcement and core materials are positioned, and the forms are closed; polyester is then pumped or sucked into the form—the major advantages lie perhaps in the interior finish; little or no interior finishing work is required, frames and stiffeners can be moulded in situ, and additional moulded components fit exactly. For larger GRP boats sandwich structures are widely used to reduce weight and to provide better insulation. Thermoplastic materials are used more and more for the smallest sizes of boats and have shown very good results in service. These materials are particularly suitable for large-scale series production.

Traditional wooden boatbuilding has lost its position in most parts of the world because of the labour-intensive methods requied. However, newer techniques, principally involving laminated and/or epoxy-impregnated timbers, have proved highly suceessful and competitive.

Optimisation of steel construction methods has led to automatic burning of plates, the use of jigs, and improved welding and painting systems. Aluminium boatbuilding for series-production involves also the use of extruded profiles, and sometimes of pressed plates and glued connections.

From the above, one might expect that ferrocement materials can, or should, be adapted to one or more apparently suitable techniques. For many types of production, the injections of a suitablemortar intoclosed forms may prove superior. One would expect that a combination of prestressed reinforcement and fibre-reinforced concrete with suitable additives could be used in such applications. It is also conceivable that plates and profiles could be cast and extruded, and that glues or bedding compounds could be used for bonding of components.

## COMPOSITE STRUCTURES

*"There is no more lovely, friendly and charming relationship, communion or company than a good marriage."*

Martin Luther 1569

Many of the arguments put forward for not buying boats of a particular material are ill founded—steel is heavy, aluminium is noisy, plastic is weak, concrete is for buildings. It is no easy matter to overcome such biases, and one is usually left with two alternatives: extensive promotion of the product (equivalent to education of the potential customer), or presentation of the product in a form which the customer can accept.

Changes in attitude can be effected with promotion, but some of the biases are well-founded and it is then up to the producer to conform, to accept that the customer is right. Plastics are fine for building hulls and decks, but the interior has to be, or has to look like, wood. We may find that ferrocement can be accepted for building hulls and decks, but it will have to look like plastic and the interior will still have to be, or look like, wood.

We cannot make much headway with various claims about ferrocement if the customer is determined that he wants somethings else. The line of least resistance will probably dictate the use of composites. It is likely that plastic impregnated surfaces will be demanded, that plastic mortars will be accepted in a "change-over" period.

The ferrocement producer will have a cost advantage over his competitors. He would investigate the advantages (lower weight or improved appearance) of using other materials for deckhouses, decks and interior compartments. Additionally, the differing requirements in the design of hull, deck and bulkheads may demand the use of different materials or techniques.

Boat production in the future may well be based on fibre-reinforced-concrete/plastic hulls, with thermo plastic accommodation mouldings and buoyancy compartments, and sandwich bulkheads and deck with PVC core and plywood surfaces.

Care must be taken in the design and surface finishing of composite structures. Some plastics in particular suffer a considerable decrease in mechanical properties after a period of exposure to water or high humidity. Similarly, dissimilar metals in contact in the marine environment may corrode rapidly. Obviously these are minor problems which can be solved easily if one is first aware of them.

## MARKETING

*"A man without a smiling face must not open a shop".*

Chinese Proverb

In the foregoing we have put forward our view that the present image of ferrocement is not such as to encourage large scale commercial projects. There appears to be an economic case for the material, and no serious technical impediment. The need is, therefore, for a change of image and of public opinion. Marketing must be given the same high priority as design.

The advantages of the material must be hammered home. It must be stressed that the sum of new cost and maintenance costs is less than or equal to the equivalent product in GRP., that performance, aesthetics, resale value, repair possibilities and insurance rates are equal or better. Marketing will define the needs for design and production. Ferrocement must compete as an equal.... or better.

It is a rather sad fact of modern life that the consumer is subjected to a barrage of superlatives in the promotion of new products. A product will not normally sell well if it is not superior, or if it is not somehow related to a product which is superior. One might expect, intuitively, that ferrocement needs dramatic results—success in competition—to assist in its promotion. The new producer of, for example, family cruising boats will need to be able to show that his "regatta machine", his "GT version", can compete successfully.

"What's in a name?"—Shakespeare was not trying to sell ferrocement boats when he asked that question. His public did not have to comprehend that concrete can in fact float. A comparison might be made with glass reinforced plastics. It was not easy to sell boats called "plastic" when the GRP industry was in its infancy. It was something soft and flexible, second rate, whilst "glass fibre" had a ring of quality, of technological advance that eventually became accepted. "Ferrocement" is a name accepted by users and advocates of the material. But will it sell? Possibly, in time. We are inclined to think that alternative tradenames would have a wider public acceptance.

Marketing is, like design, a job for experts and one of the keys to business success. It is vital, and expensive. Mistakes can lead rapidly to failure of the venture. The importance of correct marketing of the *end product* must be made clear to all involved in the product—designer, builder, subcontractors, raw material suppliers, financiers—and all should be given the opportunity to participate in its promotion. Many of those involed will have an obligation to assist—the promotion of ferrocement as a boat-buiding material appears singularly difficult and it seems unreasonable that the producer/builder alone should carry all of the promotional costs.

## THE CATALYST

*"With money in your pocket you are wise and you are handsome and sing well too"*.

Yiddish Proverb

A number of apparently unrelated international developments may have a significant influence on the future of ferrocement: the energy crisis and the rising price of plastics; increased cooperation between industrial and developing countries; redistribution of fishing limits.

The direct consequences of these developments would appear to be, respectively: GRP boat production must be optimized or new construction materials employed; the materials and techniques used in new projects must be available and suitable in developing countries, and the finished product should (if desired) be acceptable for export to the industrial countries; there will be a need in many regions for vastly increased coastal fishing fleets. The thread that goes through these thoughts is a potentially enormous market for which ferrocement (or a ferrocement composite) is suitable.

We are aware of the significant progress being made in the developing countries. We believe also that the ferrocement cause will be greatly assisted by an attempt to break into the potential markets of the industrial countries. How can this be achieved?

It is obvious, it has been shown, that excellent boats can be built from ferrocement. It should also be obvious that public acceptance of the material requires a concerted effort by all interested organisations. The cost of a new development can only be justified if the new market is significant. It is essential therefore that large scale projects are proposed, and that these are supported, technically and financially, by material suppliers research institutions, classification societies and international aid organisations. The catalyst, will, as usual, be money—for research, design, production and promotion.

Circumstance appears to have given ferrocement technology an opportunity to advance. Whether the apparent impediments can be overcome, and whether an intensive effort will give economically rewarding results, is difficult to say with absolute certainty. We believe that they can, and will.

## REFERENCE

(1) INTERNATIONAL FERROCEMENT INFORMATION CENTER, "Ferrocement and its Applications — a Bibliography, Volume I" IFIC, Asian Institute of Technology, Bangkok, Thailand, 1979.

## APPENDIX 1: PROPERTIES AND COSTS

The mechanical properties of ferrocement are very much influenced by the constituent materials and construction techniques. As an illustration, typical flexural stresses for a number of alternatives are listed in the following table.

*Typical flexural (yield) stresses to first crack ($N/mm^2$)*

| | |
|---|---|
| Hexagonal mesh, steel rods | 7 |
| Welded square mesh | 10 |
| Welded square mesh, steel rods | 20 |
| Expanded metal | 20 |
| High tensile square mesh | 40 |
| Steel fibres, high tensile rods | 60 |

*Typical yield stresses for other materials ($N/mm^2$)*

| | |
|---|---|
| Mild steel | 240 |
| Aluminium (5083) | 220 |
| Glass-reinforced-plastic (mat, rovings) | 120 |

*Typical densities ($kg/m^3$)*

| | |
|---|---|
| Ferrocement | 2700 |
| Mild steel | 2860 |
| Aluminium | 2700 |
| Glass-reinforced-plastic | 1540 |

**Moment Capacity**

In the following we have made a simplified comparison of the weights of different materials to withstand an applied unit moment. Note that design *stresses will be reduced by load factors which are not necessarily equal.* The comparison applies only to the case of bending/yield strees, and does not apply to other (realistic) design conditions.

Stress = moment/section moulus
$\alpha$ moment/(thickness)$^2$
Thickness $\alpha$ (moment-stress)$\frac{1}{2}$
Weight $\alpha$ thickness $\times$ density

Weight of material to withstand a given moment (based on yield stresses)

| | Stress | Thickness | Weight |
|---|---|---|---|
| Ferrocement | 60 | 1.00 | 1.00 |
| Mild steel | 240 | 0.50 | 1.45 |
| Aluminium | 220 | 0.52 | 0.52 |
| Glass-reinforced-plastic | 120 | 0.71 | 0.40 |

**Material Cost**

A fair comparison of costs would have to be based on knowledge of the particular construction methods for a particular design. Prices of materials will depend on local supply and demand, quantities ordered, etc. Our figures are based on approximate prices to producer in Norway, mid-1979, and on the weight factors derived above.

Cost of material to withstand a given moment

| | Weight factor | Cost factor | Cost |
|---|---|---|---|
| Ferrocement | 1.00 | 1.0 | 1.0 |
| Mild steel | 1.45 | 1.83 | 2.7 |
| Aluminium | 0.52 | 8.75 | 4.5 |
| Glass-reinforced-plastic | 0.40 | 7.38 | 2.9 |

Costs for a finished product will depend on production time and techniques. The difference between aluminium and steel, for example, is much less than indicated by material costs alone. The point we would like to make here is that material costs for ferrocement are relatively low-if production times approach those for other materials, the final product will be cost competitive. The above cost figures do not apply to other design conditions.

APPENDIX 2: GUIDE TO LOADINGS ON BOATS & COMPONENTS

100 *General, loading conditions*
110 Weather & wave conditions
120 Use of the boat

| | |
|---|---|
| 200 | *Static* |
| 210 | Light weight condition |
| 220 | Equipment & cargo weights |
| 230 | Docking, winter layup, lifting |
| 300 | *Dynamic* |
| 310 | Hydrostatic |
| 320 | Accelerations |
| 330 | Slamming |
| 340 | Deck waves |
| 350 | Ship motions |
| 360 | Waves in tanks |
| 400 | *Propulsion and "in-service"* |
| 410 | Motor & propeller |
| 420 | Steering |
| 430 | Rig |
| 440 | Towing, mooring, anchoring |
| 450 | Crew |
| 500 | *Production loads* |
| 510 | Shrinking/stretching |
| 520 | Deformation |
| 530 | Prestressing |
| 540 | Laminating |
| 600 | *Environmental hazards* |
| 610 | Direct sunlight |
| 620 | Ice |
| 630 | Hot, moist air |
| 640 | Organisms and small creatures |
| 650 | Chemicals |
| 660 | Noise and vibration |
| 700 | *Potential damages* |
| 710 | Fire and explosion |
| 720 | Collision, impacts |
| 730 | Abrasion |
| 740 | Falling weights |

# A Review of Marine Applications of Ferrocement in Asia*

V.S. Gopalaratnam+, R.P. Pama† and J. Valls‡

*Ferrocement is a kind of composite material in which the filler material (usually brittle in nature), called the matrix, is reinforced with fibres dispersed throughout the composite, resulting in a better overall structural performance than that of its original components. This paper summarizes the developmental work undertaken in the Asian region to promote the use of this versatile low-cost material for specific marine applications. While it dwells on the most common marine use of ferrocement (namely boat-building), it also attempts to outline other marine applications of this material besides presenting a glimpse of its future potentials for other floating or submarine ferrocement structures.*

## INTRODUCTION

Ferrocement is considered as a highly verstile form of composite material made of a cement mortar matrix and layers of wire mesh or similar small diameter steel mesh closely bound together to create a stiff structural form [1]. This material, which is a special form of reinforced concrete, exhibits a behaviour so different from that of conventional reinforced concrete in performance, strength and potential application, that it must be classed as a separate material. In rationally designed ferrocement structures, the reinforcement consists of small diameter wire mesh in which the proportion and distribution of the reinforcement are made uniform by spreading out the wire meshes throughout the thickness of the element. This dispersion of the fibres in the brittle matrix offers not only convenience and a practical means of achieving improvements in many of the engineering properties of the material but also provides advantages in terms of fabrication of products and components.

More recent research [2] has investigated the use of a single layer of high tensile steel mesh reinforcement with a fibrous cement mortar matrix, to ensure a more even spatial dispersion of the steel. This method of construction, using also a small prestressing force, is claimed to offer superior material properties. It would however require a more mechanized approach during plastering and consequently is of less relevance to Asia.

Though the earliest use of ferrocement dates back to 1848, it has only in the past two decades gained acceptance in Asia as a boat-building material. As a result of some of its successful applications in a marine environment, commercial builders have shown some interest in the material as applied to working vessels. Experience shows that ferrocement in its present state of development is most suitable for boats longer than 10 m (33 ft) when a speed of between 6.5 and 10 knots is required.

---

* Reprinted with the permission of the publishers of the proceedings of the Concrete Ships and Floating Sructures Convention, Rotterdam, November 12-14, 1979. (Thomas Reed Publications Limited, U.K.)

+ Senior Information Scientist, International Ferrocement Information Center, Asian Institute of Technology P.O. Box 2754, Bangkok, Thailand.

† Associate Director, International Ferrocement Information Center, Asian Institute of Technology, P.O. Box 2754, Bangkok, Thailand.

‡ Director, International Ferrocement Information Center Asian Institute of Technology, P.O. Box 2754, Bangkok, Thailand.

Ferrocement is a relatively heavy material for boat-building, compared to the traditional wooden boats used in this region. This disadvantage has led researchers in the region to think about the economics of ferrocement construction in the light of the quality of the product desired, of the location and of competitive materials available. Consequently, ferrocement is being tried out for the construction of stationary or semi-mobile marine structures like buoys, floating docks and dry docks, floating breakwaters, floating oil reservoirs, caissons and platforms besides rectangular and cylindrical pontoons. The following sections review some of the most common marine applications of ferrocement in Asia.

## BOAT-BUILDING

During the past two decades, researchers and officials in the fisheries departments of most of the Asian countries have been looking for a viable aternative material to replace traditionally used materials for country fishing craft. In most cases the need to find a replacement for wood (commonly used in most local craft) is urgent because of the ever escalating costs, as well as the added danger of excessive deforestation. The sizes, types and numbers of boats built in the different Asian countries under study are presented in Table 1.

A brief round-up, country by country, is given in the next few sub-sections which in specific cases (wherever details are available) include the salient construction features of the various types of boats built in the countries referred to, in Table 1.

Table 1 Ferrocement Boats built in Asia.

| Country | Number of boats built | Sizes of boats (m) | Types of boats | Number of ferrocement boat-building yards |
|---|---|---|---|---|
| Bangladesh* | 30 | 10-14 | Transport/Fishing | 1 |
| China† | 2,000 | 12-15 | Transport | 30 |
| Hong Kong | 4 | 15-27 | Fishing | 1 |
| India* | 9 | 5-12 | Fishing | 1 |
| Indonesia* | 20 | 10-12 | Barges | 1 |
| Korea | 11 | 10-25 | Fishing/Barges | 1 |
| Malaysia* | 3 | 12-22 | Transport | 2 |
| Philippines | 3 | 12-30 | Fishing/Coast | 2 |
| Sri Lanka+ | 40 | 7-17 | Fishing | 2 |
| Thailand | 30 | 5-24 | Transport/Fishing/Pleasure | 2 |

*Note:* 1. *1978 figures, +1979, figures. All others are 1974 figures.
2. †Estimated in 1974
3. Table based on Ref. [3] and updated information available from the International Ferrocement Information Center.

### Bangladesh

Construction of ferrocement country boats was initiated in 1972 under a Canadian Hunger Foundation Project, by Ferocem International Ltd., Canada [4]. Under this pilot project in collaboration with Bangladesh Jatiya Matshyjibi Samabaya Samity, four indigenous designs were chosen for conversion to ferrocement construction all of which were primarily used for fishing or transportation of the catch.

The wooden "Balam" craft is a class of mechanized boat for which formal design calculations or drawings are claimed to be pracitically non-existent. The wooden 'Cox's Bazar' boat is believed to have evolved, in several identifiable stages, from a dugout craft with stiched top sides to a relatively modern mechanized one, engaged in fishing in the Bay of Bengal. It is by far the most popular of the four versions converted to ferrocement. The 'Chandi' is a general purpose non-mechanized country boat. It is an undecked open boat used for fishing in rivers and estuaries. The modified ferrocement version is costly and in its present form not viable commercially. The 'Jele Noaki' also a non-mechanized country boat which is the smallest of the four designs attempted is used for fishing in smaller rivers.

While 'Balam' and 'Cox's Bazar' boats are constructed right—side up, an up-side down method of construction is adopted for 'Chandi'. Unlike these three bigger boats an unframed mode of up-side down construction is adopted for 'Jele Noaki'.

The 'Balam' is constructed of a nominal 2.5 cm (1 in.) thick skin with 7.5 cm (3 in.) frames on 0.6 m (2 ft) centres. The frames are fabricated in moulds with one mould for each frame station. The frames are webs of 9.5 mm (3/8 in.) steel bars covered on both the sides with 2 layers of mesh. The full layup consists of #4 hard drawn steel bars on 5.0 cm (2 in.) centres running longitudinally with 2 interior layers of 12 mm ($\frac{1}{2}$ in.), 20 gauge hexagonal mesh on each side of the skeletal steel plus 1 layer of 6 mm x 6 mm ($\frac{1}{4}$ in. x $\frac{1}{4}$ in.), 20 gauge woven mesh on either side of this. The frame, hull layup and mesh reinforcement for the 'Cox's Bazar' boats are similar to that for 'Balam' except for small variations. The frames for 'Chandi' are 7 cm ($2\frac{3}{4}$ in.) deep on 0.6 m (2 ft) centres and fabricated of #4 hard drawn steel bars on 7.5 cm (3 in.) centres with 3 layers of 12 mm ($\frac{1}{2}$ in.), 20 gauge hexagonal mesh on either side of the skeletal steel. In 'Jele Noaki', in the absence of frames and stringers, a core of 9.5 mm x 19 mm (3/8 in. x 3/4 in.) wooden battens on 12 mm ($\frac{1}{2}$ in.) centres are used to provide the necessary stiffness. Here too, 3 layers of 12 mm ($\frac{1}{2}$ in.), 20 gauge hexagonal mesh is used on either side of the skeletal steel. The 'Jele Noaki' is made on a permanent open male mould which is reusable. Fig. 1 shows a completed 'Cox's Bazar' boat on its supports.

**China**

While China remains the only country in the world where ferrocement boat-building has been taken up on a large scale, little detail is available on the design and developmental work undertaken there. The construction technique adopted since 1964 is believed to be simple with direct conversion into ferrocement of indigenous hulls designed for smooth water uses. Such boats called 'Sampans' are built by the thousands in the People's Republic of China . Information available from the National Academy of Sciences [5] suggests that the most common sizes are 12 m (40 ft) 'Sampans' of a 6-ton cargo capacity and 15 m (50 ft) 'Sampans' of a 10-ton cargo capacity. In 1971 plans were underway to build a 60-ton capacity boat equipped with a diesel engine. All smaller boats are towed or poled along still canals.

In a well laid-out building (Fig. 2), the vessels are built up-side down over a pit. This facilitates better plastering of the inside. Several areas in the building are allotted for prefabrication and assembly of units like the bulkheads, afterdecks and foredecks. When hull construction starts, high tensile wires are positioned along the turn of the bilge and the centre-lines of the

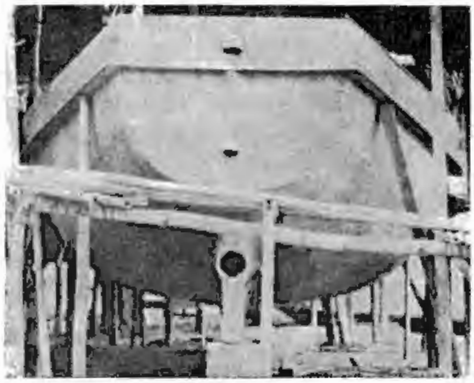

Fig. 1. Cox's Bazar boat in Bangladesh.

hull. They are held taut with a windlass and pass over temporary wooden spalls (cross pieces which hold in place bulkheads and frames of the hull to come). Precast bulkheads and frames are then postioned and attached to these wires. 'New moon' shaped frames are spaced about 1 m (3.34 ft) apart. They are approximately 2.5 cm (1 in.) thick, 5 cm (2 in.) wide at the ends (deck level) and 15 cm (6 in.) wide at the center (keel level). Once in place, these outline the hull profile and provide support for mesh and mortar. 3 layers of mesh, 1 on the inside and 2 on the outside are placed along with reinforcing rods that run along the length of the hull. Extra layers of mesh are used at potential stress areas. The urgent need for a large number of new hulls is believed to have forced China to adopt mass production techniques and ferrocement has allowed them to do this.

Fig. 2. Precast ferrocement parts for a new boat are made in front of a boat that is curing. Note pit under the hulls and rail tracks used when the completed craft is moved.

## Hong Kong

The use of ferrocement for the construction of fishing vessels in Hong Kong is believed to have been launched in 1969. Most of the crafts constructed are used as fishing trawlers that are fully mechanized. The designs basically conform to western standards unlike most Asian countries which adopt indigenous designs with slight modifications.

The first known vessel to be constructed is the 'Pak Tak', a 16 m (54 ft) craft built by Ferro Cement Marine Construction Ltd., Hong Kong (Fig. 3). Periodic examination of the vessel has proved it to be much more economical to operate than a wooden vessel and has revealed no faults. One feature of the vessel which is of particular interest is that despite operation in tropical waters, the bottom is not as susceptible to marine growth as in the case of wooden vessels [6]. Due to the better thermal insulation property of ferrocement less ice is used in the fish hold than in a comparable wooden vessel.


Fig. 3. The Pak Tak, a 54-footer mechanized fishing trawler built in Hong Kong (before deck installations were fitted).

Following the success of this vessel, other 86 ft ferrocement stern trawlers were made in 1971; their salient features are LOA 26 m (86 ft), LBP 22.5 m (75 ft), Breadth extreme 6.6 m (22 ft), Depth amidships 3 m (10 ft), and Designed mean draft 2 m (7 ft). The hull, deck, bulkheads floors, engine beds, fuel and water tanks of these vessels are made of ferrocement. They have a designed endurance of about 20 days or 4,8000 miles.

**India**

Ferrocement crafts are only recently gaining popularity in India. The first craft built was a 9.75 m (32.5 ft) long mechanized fishing trawler with a displacement of about 6.75 tons. After extensive trials, the Cochin Port Authorities have registered this boat built in 1971 and it is successfully carrying out fishing operations off the west coast near Kerala [7]. Additionally, the Fisheries Department of the Government of Tamil Nadu (South India) have already successfully built over half a dozen trawlers ranging from 5 m (16.67 ft) to 12 m (40 ft) (Fig. 4). Developmental work is still beginning on a cautious note, the main aim being to generate local interest and to establish the profitability of using ferrocement boats.

Besides mechanized trawlers numerous inland fishing rowboats have also been built by the Government of Tamil Nadu. Additionally, the 'Coracle', a common type of circular country craft made of split bamboo covered with buffalo skin used locally to cross rivers or for fishing in inland waters, has been successfully fabricated in ferrocement [8]. The 'Coracle' which costs as little as US $ 65.00 has attracted much attention and proposals are under way to build many more such crafts.

**Indonesia**

Unlike most Asian countries, Indonesia has to date attempted the building only of small ferrocement boats that are not mechanized. The use of wood for building small vessels is a widespread custom in Indonesia. As a result of increasing timber costs, the Government looked for viable alternaives and launched a ferrocement boat construction project in 1977 at the Development Technology Center [9]. Since then it has completed a few 4-6 m (13.34-20 ft) "dugout" canoes to replace traditional wooden designs. Following this successful attempt bigger crafts have also been tried out (Fig. 5). It is claimed that Indonesia, in collaboration with foreign firms has undertaken construction of about 20, 10-12 m (33.34-40 ft) barges for cargo hauling duties.

Fig. 4. A 38-footer ferrocement trawler built by the Department of Fisheries in Tamil Nadu (South India).

**Korea**

The Kyung Dong Shipbuilding and Engineering Company Ltd. is the only ferrocement boat-building yard in Korea. Most of the technical research is undertaken in collaboration with the Korea Institute of Science and Technology. The boats built to date are mechanized and between ½ ton to 30 tons displacement. More recently a 600 DWT oil barge has also been constructed.

The 30-ton fishing boats [10] are built on integral 2.5 cm (1 in.) diameter pipe frames at 4.5 m (15 ft) centres. Skeletal reinforcing of 6 mm (¼ in.) diameter rods at 5 cm (2 in.) centres vertically and 10 cm (4 in.) centres longitudinally is provided. 12 mm × 12 mm (½ in. × ½ in.), 20 gauge meshes are used in addition to 12 mm (½ in.) hexagonal mesh. The average hull thickness is 2.5 cm (1 in.) above DWL and 3.0 cm (1.2 in.) below it. Powered by a 150 HP diesel engine the refrigerated hold capacity is given as 35 $m^3$ (1.240 $ft^3$) run off the main engine. The principal dimensions are LOA 19.3 m (64.34 ft), LBP 17.5 m (58.34 ft), Beam 4.2 m (14 ft), Depth moulded 1.85 m (6.16 ft), Draft (DWL) 1.45 m (4.84 ft).

Fig. 5. A bigger version of a country craft being constructed at the Development Technology Center Bandung, Indonesia.

The 600 DWT hull for the oil barge is constructed with full ferrocement bulkheads dividing the interior into eight separate cargo oil tanks and void tanks fore and aft. The hull is stiffened additionally by deep intermediate transverse webs as well as longitudinal members at 0.7 m (2.34 ft) centres in the hull bottom and underdeck. Timber belting protects the barge against impact damage. The principal data are LOA 18 m (60 ft), Breadth 6.8 m (22.67 ft), Depth 2.7 m (9 ft), DWT 600 (Fig. 6).

Fig. 6. The 600 DWT oil barge launched in Korea in 1974.

## Malaysia

Not much work on the promotion of ferrocement has been undertaken by Malaysia. However, recently Alexander & Poore of Auckland, New Zealand have launched a few 22 m (73.34 ft) high tensile wire reinforced fibrous ferrocement tugs for log hauling and general cargo duties in Sabah where they were constructed [2].

It is interesting to note the several new techniques adopted in the construction of these vessels. Firstly, the traditional mesh form of dispersing steel is absent. It is replaced with a layer of 10 gauge high tensile wire encased in a fibrous (steel) mortar matrix. The resultant material is claimed to be decisively stronger in flexure and piercing resistance than conventional ferrocement and is also more economical. Plastering the mortar onto the meshes is replaced by a technique of vibrating the fibrous mortar from the inside of the vessel against thin plywood facings. This inexpensive external moulding technique can be applied to vessels of all sizes but especially large ones. The vessels are also post-tensioned within the skin to give a final stress of approximately 4 Mpa. Post-tensioning is believed to have the effect of stiffening the ferrocement in its working range without adversely affecting its impact resistance (unlike in conventional ferrocement). It also has better abrasion resistance. Most of the components of the vessel have been constructed of fibrous ferrocement, including the deckhouse, rudder plate, funnel, mast, ventilator cowls, bollard belting and even the anchor.

Ferrocement oil tanks with a 20-ton capacity occupy the bilge areas in the fore hold engine room areas and fresh water is carried in the after hold bilges. The commodious cargo holds are designed to stow 30 tons of general cargo at which load the draught aft is 2.75 m (9.17 ft) and the free-board 1 m (3.34 ft) (Fig. 7).

Fig. 7. Launching of a 22 m high tensile wire reinforced fibrous ferrocement tug for long hauling duties Sabah, Malaysia.

Material costs compare more than favourably with other materials, averaging US$ 13.4/m$^2$ including painting. This is about a third of the cost of plate, scantlings, gas, electrodes and paint requirements of a comparable steel vessel.

**Philippines**

Ferrocement boat-builing is known to have begun in 1968 with the construction of a 3 m (10 ft) punt at the Cavite Naval Shipyard [11] 4.75 mm (3/16 in.) rebars are used as skeletal steel reinforcement along with 3 layers of 12 mm ($\frac{1}{2}$ in.) hexagonal mesh on either side of this to form the hull reinforcement.

Subsequently, for a 12 m (40 ft) coastguard cutter, a pipe frame method of construction was adopted, under advice from Ferrocement Ltd. of Auckland, New Zealand. Water-proofing additives are mixed in the cement mortar and a four day steam curing has greatly improved the performance of this vessel, which is in a sound condition even after running aground once. A 15 m (50 ft) fast patrol craft also uses a pipe frame approach. The rebars of this vessel are however welded (in the 12 m coastguard cutter they are tied), and no water-proofing admixture is used. It is observed that a thin epoxy coating renders the craft water-proof. Even after three accidental 3 m (10 ft) drops, the hull is reported to be in perfect seaworthy condition. A 30 m (100 ft) fishing research vessel inadvertently launched after 3 days of steam curing without application of epoxy coating was observed to be quite permeable and highly susceptible to sulphate attack (Type 1 Portland cement was used for hull construction). This resulted in corrosion of the reinforcing steel rods and mesh and eventual deterioration of the hull. However, a 6 m × 3 m × 0.9 m (20 ft × 10 × 3 ft) houseboat with a barge type hull using welded wire fabric made of #3 hard drawn steel wire, 5 cm × cm (2 in. × 2 in.) was construtecd. Performance of this vessel after 3 days of steam curing proved satisfactory.

However, unlike the 30 m craft, pozzalan was used as an additive after using a better graded sand for the cement mortar matrix.

Pozzalan is observed to render the mortar practically immune from sea water attack and makes the aging mortar stronger.

The Philippines is the only country that is known to have tried out ferrocement craft for speeds as high as 20-25 knots. Also interesting is their very encouraging study of gun-fire impact damage to thin ferrocement slabs.

**Sri Lanka**

The Research and Development Division of the State Engineering Corporation of Sri Lanka have developed a process designated Wirecon [12] which is quite similar to the one developed by Alexander & Poore Ltd. (earlier described as fibrous ferrocement). Investigations show that short pieces of steel wire mixed with cement mortar are suitable for ferrocement construction; the resultant material also offers better structural properties.

Boat-building using the Wirecon process started in 1967. 8.4. m (28 ft) fishing boats to 14.4 m (48 ft) harbour launches have been built to date. After investigation of a number of alternative methods of costruction including wooden mould, lattice frame and pipe frame, the last was selected as the most suitable. Use of wire mesh was reduced by about 50% by using chopped wire (28 SWG and 2.5-3.75 cm (1-1½ in.) long) mixed with cement mortar for plastering the skin. In the case of the 14.4 m boat, the actual cost observed was almost a half of a comparable boat made of teak.

Updated information obtained recently show that the Cey-Nor Development Foundation Limited is fast developing to be a pioneering organization in the region, in the construction of ferrocement fishing trawlers. To-date they have built over 30 vessels in lengths ranging from 9 m (28 ft) to 17 m (55 ft). Design of these vessels are based on readily available boat plans. Outside China, the Cey-Nor Boatyard probably ranks high on both its production rate as well as range of designs and sizes.

**Thailand**

Under a FAO sponsored project stern trawlers of LOA 16 m (52.5 ft) were built at the Rayong Marine Fisheries Station for the Fisheries Department of Thailand [13] in 1968. On the basis of earlier recommendations a cement content of 480 kg/m$^3$ (30 lb/ft$^3$) is used for the vessel hull. The principal specifications are LOA 16 m (52.5 ft), length (DWL) 14.5 m (47 ft 7 3/4 in.), Beam (maximum) 4.54 m (14 ft 10 3/4 in.), Beam (water-line) 4.42 m (14.5 ft), Depth 2.25 m (7 ft 4 3/4 in), Displacement to DWL 34.5 m$^3$ (12.18 ft) (Fig. 8). Based on local availa-

Fig. 8. 16 m ferrocement stern trawler for a FAO sponsored pilot project to study economic and technical viability of using ferrocement in Thailand nearing completion.

bility of materials 6 mm (1/4) in.) wire rods are used to construct the framework of longdituinal rods at 7.5 cm (3 in.) centres joined by vertical rods at 10 cm (4 in.) centres. 4 layers of 12 mm (1/2 in.), 19 gauge hexagonal mesh is used on both sides of the skeletal steel for the compound curvature of the hull and 12 mm (1/2 in.), 19 gauge welded mesh for the flatter surfaces of deck and bulkheads. Use of two types of mesh is mainly a consequence of the non-availability of enough stocks of 12 mm, 19 gauge hexagonal mesh at the time of construction. Modified Portland cement-Type II (which possesses resistance to sulphate attack) and natural fine river sand passing through ASTM seive #8 was used for the cement mortar matrix. A cement/sand ratio of 1 : 1.75 (by weight) and a water/cement ratio of 0.36 is used. Additionally, a lignosulphate based plasticizer is added at 7 $cm^3/kg$ (0.9 $in.^3/lb$) of cement to improve workability. All steel connections for the skeletal steel are welded to offer extra rigidity and plastering is undertaken right-side up. After moist curing a check for voids is made by tapping the hull with a light hammer on the mortar. When a void is located the plaster is broken and the surface cleaned before replastering with a mortar to which vinyl-polymer bonding agent is added. After one coat of clear epoxy priming, three coats of epoxy gloss paint are applied. The inside of the bilges is also coated with a diesel oil resistant tar-epoxy coating to prevent attack of the concrete surfaces by spilt fuel. The total material cost of the hull, deck and fish-hold of the 16 m ferrocement trawler is about US$2,500.00 (1968 figures).

Additionally, ferrocement has also been successfully tried out based on indigenous long tailed boat designs (uses a portable diesel engine that is connected when desired—Fig. 9).

Fig. 9. A ferrocement long tailed boat, Thailand. These are sometimes mechanized using a portable diesel engine.

## MISCELLANEOUS MARINE APPLICATIONS

Due to unfavourable construction conditions and limitations in the budget of the breakwater project of Hsin-Kang Fishing Harbour, Taiwan, caissons of the composite-type breakwater were partly fabricated with ferrocement [14]. The caissons, 10 m (33.34 ft) long, 12 m (40 ft) wide and 6.7 m (22.34 ft) high, were composed of sandwhiched-type sidewalls of reinforced concrete and ferrocement, ferrocement partitions, and a reinforced concrete base plate protected by a corrugated ferrocement shell on the bottom surface. Corrugation increased the frictional coefficient between the ferrocemet shell and the rubble bed and the width of the caisson as a result could be considerably reduced. The weight of such a caisson is only 40% of a comparable reinforced concrete caisson. Consequently, launching facilities required are a mobile crane and a tug only (Fig. 10). The cost is remarkably less although the performance is comparable.

Fig. 10. Setting up pre-cast ferrocement elements of the caisson. Note projections of skeletal steel in panels, which ensure stronger joints. Joints are grouted after skeletal steel is welded in position.

During a 4 month 'Ferrocement Technology' training programme conducted at the Asian Institute of Technology, Bangkok, Thailand in 1978 for a group of practicing Indonesian engineers, the construction of ferrocement rectangular and cylindrical pontoons was undertaken, as well as a 6 m (20 ft) dugout canoe and a 4.8 m (16 ft) Sampan. The rectangular pontoon serves as a floating pumping station (Fig. 11). The wall thicknesses are 2.5 cm (1 in.) and skeletal reinforcement consists of 9 mm (3/8 in.) diameter bars used as ribs for all edges and a grid of 6 mm ($\frac{1}{4}$ in.) diameter bars at 15 cm (6 in.) centres for all walls. 4 layers of 12 mm ($\frac{1}{2}$ in.), 19 gauge hexagonal mesh are tied 2 on each side of the skeletal steel cage. The principal dimen-

Fig. 11 Flotation test of a rectangular pontoon designed to serve as a floating pumping station.

sions are 1.2 m (4 ft) length, 1.2 m (4 ft) width and 0.75 m (2.5 ft) depth with a square opening at the centre along the depth to accommodate the inlet or suction pipe (opening of 0.35 m x 0.35 m x 0.75 m or 1 ft x 1 ft x 2.5 ft). The pump is mounted atop the square opening. Minus the pump and other installations, the pontoon weighs 580 kg (1,276 lb) and it is estimated to cost US$ 190.00. With an imposed load of about 200 kg, it is designed to float 35 cm (14 in.) above water level.

The cylindrical pontoon of diameter 0.9 m (3 ft) is 6 m (20 ft) long and is desinged with hemispherical caps at eiher ends (Fig. 12). Designed for use as a floating bridge along with similar such units (two of these placed alongside with their longer axes parallel and with wooden planks over them to form the road) it can carry a load specified for Kelas III A (Class III A) roads in Indonesia. The weight of one such unit is about 510 kg (1,020 lb) and the estimated cost is about US$165.00. The reinforcement consists of 8 mm (1/3 in.) diameter bars forming circular grids for diaphragms which are placed at 1.6 m (5.34 ft) centres, transverse circular rings of 6 mm (¼ in.) diameter bars at 20 cm (8 in.) centres and 6mm (¼ in.) diameter longitudinal bars at 20 cm (8 in.) centres. 4 layers of 12 mm (½ in.), 19 gauge hexagonal mesh, 2 on each side of the skeletal steel cage are tied. Plastering is carried out through small sectors left unmeshed until completion. These sectors are plastered later. For convenience of fixing planks over such pontoons it is preferable to flatten the top and also provide projecting bolts along the length of the flattened top while fabricating the skeletal steel cage. Hooks provided at the hemispherical ends allow connection of such pontoons in a series, to form a bridge or to tug these pontoons while they are hauled to the site. Flotation tests conducted at AIT proved success ful even without the use of any painting or of any additives in the cement mortar. However, these would undoubtedly ensure better waterproofing properties under service conditions

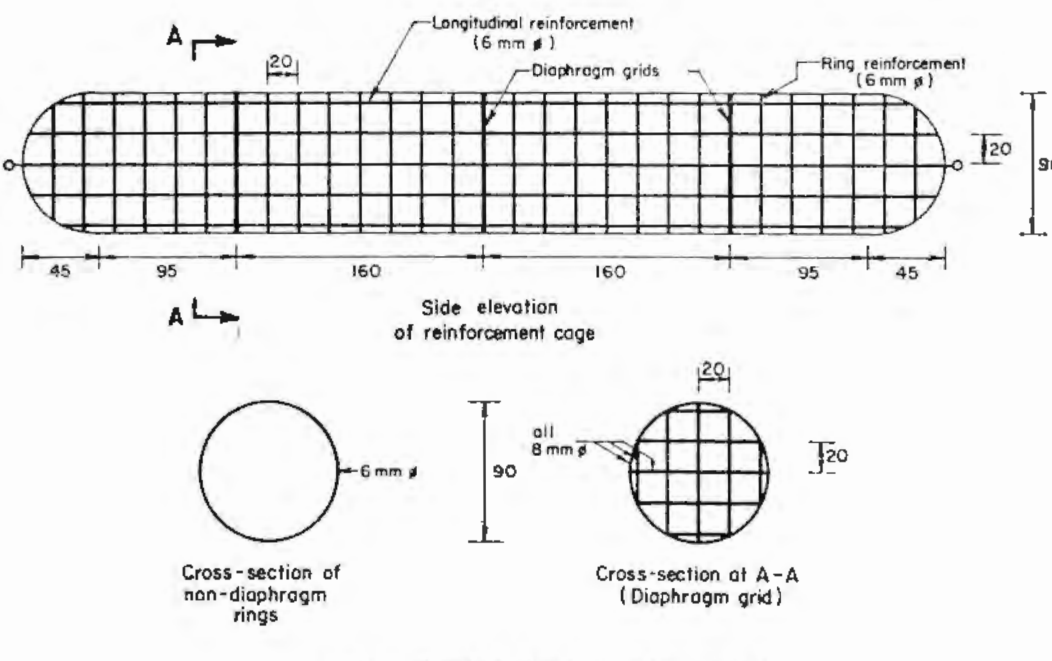


**Fig. 12.** Details of the skeletal steel cage for a cylindrical pontoon.

Fig. 13. First prototype buoy fabricated by the southeast Asian Fisheries Development Center, Philippines for a flotation system used in the culture of green mussels.

Similar ferrocement buoys have been used by the Aquaculture Department of the Southeast Asian Fisheries Development Center, Philippines for a flotation system in the culture of green mussels (Mytilus Smaragdinus) [15] (Fig. 13).

Although details of other applications are as yet unavailable there is evidence that ferrocement has been used for the construction of floating oil reservoirs, small size floating dry docks and raft homes.

## POTENTIALS FOR THE FUTURE

While ferrocement has been successfully proven to be a viable alternative to traditional materials used for boat-building, it has only in the recent past been realized that it could be more effectively used for stationary or semimobile marine structures. The disadvantage of excessive weight (compared to timber or steel structures of a comparable capacity) is thus eliminated while other advantages of superior material properties, economy, labour intensive construction techniques, material availability and maintenance-free service are made use of, to the fullest extent.

Although mechanized methods of mass production of ferrocement elements (like processes developed in eastern Europe and Israel) are unsuitable economically for Asian conditions, they are likely to improve product reliability and finish, thus securing a niche for the new material at least during the initial stages of propagating this relatively new technology.

Floating wharves, marina floats, submarine research vessels and tanks, submarine pipelines for handling oil from wells and floating foundations for drilling rigs are some of the new avenues where ferrocement could possibly be used.

## CONCLUSIONS

Though ferrocement marine applicaions have come to stay, in Asia, as a cheap alternative to other building materials and methods, it is far from being utilized to its fullest potentials. The reasons for this are manifold. Imaginative researchers and boat-builders have enthusiastically advocated the material as an extraordinary material and consequently projected the better properties of ferrocement out of proportion, while at the same time not adequately specifying its negative aspects. There have been specific instances in Asia and elsewhere where this overplaying has led to a disenchantment. Inadequate expertise and lack of knowledge of elementary engineering properties of the material could have been the cause of such disasters. Unlike other conventional materials for which codes of practice are available, there exists no National Building Code for construction of ferrocement structures.

Although ferrocement is undoubtedly a promising material, the earlier discussed demerits should be publicised clearly, in presenting ferrocement technology as an ideally suited technology appropriate to Asian condition. Codes of practice should be formulated by countries in the region as quickly as possible, before the entire technology is abandoned as a result of setbacks and lack of confidence. In fact since most Asian users lack adequate finances for entering into such ventures, a National Building Code for ferrocement structures would be an indispensable document in getting financial agencies interested in such projects.

In addition, the already established (1976) International Ferrocement Information Center (IFIC) at the Asian Institute of Technology is a step in the right direction and Asiaerience could obtain substantial benefits from IFIC services ,especially in learning from the expn users of other users of this relatively new technology.

## REFERENCES

1. PAUL, B.K. and PAMA, R.P., "Ferrocement", International Ferrocement Information Center, Asian Institute of Technology, Bangkok, Thailand, August 1978, 149 pp.
2. ALEXANDER, D.J., "Launching of a 22-Meter High Tensile Wire Reinforced Fibrous Ferrocement Tug for Log Hauling Duties", Journal fo Ferrocement, Vol. 9, No. 1, January 1979, pp. 41-42.
3. PAMA, R.P., LEE, S.L. and VIETMEYER, N.D., Edited "Ferrocement, a Versatile Construction Material: Its Increasing Use in Asia", A report of the Workshop on Introduction of Technologies in Asia—Ferrocement, A Case Study, (November 5-8, 1974), Asian Institute of Technology, Bangkok, Thailand, 1976, 106 pp.
4. BIGG, G.W., "Ferrocement Boats for Bangladesh: Appraisal for the Future", The evaluation of a two-year pilot project for the construction of ferrocement fishing vessels and the introduction of ferrocement technology in Bangladesh with recommendations for future development, Ferocem International Ltd., Canada, December 1975, 84 pp.
5. NATIONAL ACADEMY OF SCIENCES, "Ferrocement: Applications in Developing Countries", A Report of an Ad Hoc Panel of the Advisory Committee on Technological Innovation, BOSTID, Washington, D.C., February 1973, 93 pp.
6. FERRO CEMENT MARINE CONSTRUCTION LTD., "The Advent of 86 ft Ferro Cement Stern Trawlers in Hong Kong", A brochure published by Ferro Cement Marine Construction Ltd., Hong Kong undated, 4 pp.
7. VISVESVARAYA, H.C., "Ferrocement Developments and Applications in India", Part of Ref. [3], pp, 96-99.
8. KANAKASABAPATHY, T., "Ferrocement Research and Development in Tamil Nadu, India", Part of Ref. [3], pp. 22-33.
9. DJAUSAL, A., "Ferrocement Project in West Java", News and Notes, Journal of Ferrocement, Vol. 8, No. 3, July 1978, pp. 213.

10. KYUNG DONG SHIPBUILDING AND ENGINEERING CO. LTD., "Ferrocement in Korea", Journal of Ferrocement, Vol. 4, No. 5, August/September 1975, pp.49.

11. PROTACIO, A.C.,"Figures Showing Typical Section of Keel & Frame Made of Pipes and Truss Type Framing for Ferrocement Hull", Naval Shore Establishment, Philippines, 1971, 4 pp.

12. KULASINGHE, A.N.S., "Development and Application of Ferrocement in Sri Lanka and Malaysia", Part of Ref. [3], pp. 92-95.

13. FYSON, J.F., "Construction of a 16-Metre Ferrocement Fishing Boat", FAO Fisheries Technical Paper 95, Rome, 1970, 58 pp.

14. SU; C.F., LEE, Y.H. and CHANG, R.H., "The Design and Construction of Ferrocement Caissons with. Corrugated Frictional Base Plates Used in the Breakwater of Hsin-Kang Fishing Harbour", Journal of Ferrocement, Vol. 9, No.2, April 1979, pp. 63-74.

15. TOLOSA, R.T., "Ferrocement Buoys for Mussel Culture", To be published in the Journal of Ferrocement, Vol. 9, No. 3, July 1979.

# Ferrocement and the Development of Small Boats*

**Gowan MacAlister+**

*Ferrocement has been in existance for over one hundred years and a wide range of vessels ranging from yachts to liberty ships have been built. However apart from the earliest experiments most of the boats built have been above about ten metres giving rise to the idea that small ferrocement boats are not possible. This paper outlines some of the author's research with small boats and illustrates the results of some projects involving boats under ten metres. This paper concludes that small ferrocement boats are both cost effective and efficient within certain limitations and that current research may soon reduce these limitations.*

## INTRODUCTION

Ferrocement is a surprisingly old material. Lambot's original idea in about 1847, to use steel rods to strengthen a cement mortar, is a very early example of reinforced concrete. Lambot produced a thin shell material and used it to build a boat—ironically a very small one. In spite of primitive mortars the boat still survives and is one of the oldest remaining in existance not built in wood.

After the early work of the pioneers, little progress was made until the shortage of steel during the Wars turned designers' attention to reinforced concrete. Several ships were built in the First and Second World Wars which performed relatively successfully. Concrete vessels and barges, relics from this period, are a familiar sight around the coasts of Europe, many of them in remarkably good condition.

Little more work was done on thin shell possibilities until Professor Nervi built his famous boats Irene and Nenelle 100 years later. Reinforced concrete, on the other hand, had become the world's major structural material enabling undreamed of architectural innovation such as Manhatten.

Since Nervi, thousands of boats have been built by amateurs and the number increases steadily. Commercial yards have been producing boats for many years though not on the scale of GRP production. The merits of the material has encouraged some national building policies, notably in the Republic of China with their sampan production and Cuba where a large proportion of their fishing fleet, numbering several hundred boats, is ferrocement.

Development thus far has evolved the building methods that are considered "orthodox", namely some sort of framing technique, rods and mesh applied by hand and manual plastering.

These methods can produce yachts and fishing boats of the highest quality with excellent finish and it is only the relative (and costantly changing) costs of labour and materials which gives GRP its present diminishing advantage.

* Reprinted with the permission of the publishers of the proceedings of the Concrete Ships and Floating Structures Convention, Rotterdam, November 12-14, 1979. (Thomas Reed Publications Limited, L.K.)

+ MacAlister Elliot and Partners, Lymington, Hampshire, England.

## SKINNING

Another valuable ferrocement technique worth mentioning is the skinning of old wooden hulls. Steel meshes are stapled to the planking and plastered with mortar resulting in a strong durable shell which will last for years. This process, used extensively by MacAlister Elliott and Partners, has particular relevance in much of the developing world where damage to boats by marine borers is particularly severe.

Fig. 1. 48-Foot smack meshed and ready for skinning.

Fig. 2. The completed (skinned) 48-foot smack.

## PROBLEMS FOR SMALL BOATS

None of this development has overcome the basic disadvantages of ferrocement, namely weight, labour intensiveness and difficult quality control.

Amateur builders tend not to cost their own labour too carefully and usually accumulate hundreds of hours of free help from friends. They usually build larger yachts where weight is not a problem, although quality control difficulties, normally concerning voids in the structure or surface fairness, have scuppered many projects.

Apart from the early innovators, all subsequent building has been with relatively large boats from about ten metres upwards. Is it therefore impossible to build small ferrocement boats?

The author has been developing techniques for building small boats for many years and has overcome many of the problems. Current research with fibres may soon make significant improvements to the techniques.

The parameters which define the properties of a ferrocement panel are steel content, steel cross section (i.e. geometric dispersion), specific surface of steel, quality of mortar and compaction. Steel content and cross section are self-evident when considering stresses in a particular direction. Specific surface measures the dispersion and fineness of the reinforcing and its ability to control cracking.

A good ferrocement membrane therefore has a high percentage of finely disersed reinforcing (usually meshes) well compacted with high quality (and therefore dense) mortar.

These requirements are mutually contradictory. Fine meshes take up more space than an equivalent weight of heavier mesh causing thicker panels and as the meshes get finer, impregnating the matrix with mortar becomes more difficult.

## SMALL BOAT PRODUCTION

The author designed and produced a run of 4.5 metre launches using new methods aimed at overcoming the physical building problems. The idea was to design a robust launch with reasonable displacement, built so as to optimise the thin ferrocement panels. This was achieved with a reusable male mould and a lay-up of small diameter rods and 1 mm meshes, stretched accurately and tightly over the mould. Flow vibration techniques overcame the mortar penetration problem and the resulting hull was about 13 mm thick with a steel content of about 16% by weight.

These little boats have been used for fishing, passenger ferries and general workboat duties and most are still in service after many years.

In spite of the efficiency of the moulding techniques, which enabled the boats to be built in about a week, it was still more labour intensive than a similar though probably less robust boat in GRP, which requires no painting. The recent stagering price increases in polyester and polyurethane resins may soon give a new impetus to ferrocement boat building in the industrial nations.

## ARTISANAL BOATS IN THE DEVELOPING WORLD

MacAlister Elliott and Partners was set up to promote ferrocement building in the developing world. The economics of cost and labour in the developing world make FerroCement particularly attractive. The technology is simple and the materials are basic and often available locally which is seldom ture with other materials—even timber nowadays. The labour intensive nature of the process is an advantage in many countries where large amounts of unskilled labour is available.

Most of the traditional boatbuilding in the developing world is artisanal with small boats being built for fishing or river transport. Of these many are developments of the dugout, ranging from the magnificent 25 metre Senegalese transport pirogues to the small oddly shaped dugouts on Lake Victoria.

Social upheaval in recent generations and the paucity of suitable tress has put the traditional builders into decline, while the need to expand the artisanal fisheries is vital.

## WEST AFRICA PROJECTS

MacAlister Elliott and Partners were approached by the Swedish International Development Agency to design and build a series of 9 metre pirogues for testing and eventual local production in their Fisheries Development Programme in Guinea Bissau. Techniques were developed to produce simple dugout type boats quickly and easily in ferrocement. The log

Fig. 3. Fitting wooden sides to ferrocement pirogue bottoms.

Fig. 4. Ferrocement pirogues on the island of Bubaque.

shape is surprisingly suitable with positive curvature ensuring compressive hydrostatic and impact loading.

Hulls are built on a male mould using a patented method of tensioning and clamping. Production takes about two man-weeks for a 9 metre 'dugout' including stripping and preparing the mould. The 'dugout' bottoms are completed using traditional timber trim and colours and have been accepted enthusiastically by local fishermen.

Fishing trials with the boats showed them to be robust, stable and watertight — the latter being a new experience for the Guinean fishermen. Positive buoyancy can be a problem though scrap packaging material is often available and certain kinds of seed pods are being tested.

Plans are now in hand for large scale production in Guinea Bissau and a similar project is soon to start in Senegal.

## MALAWI PROJECT

Quite a different kind of boat is being produced on Lake Malawi. There, in a project sponsored by the Anglican Diocese of Malawi and funded by Barclays Bank Development Fund, we are manufacturing 4.6 metre and 5.9 metre outboard powered boats of conventional design. These are again built using a male mould with the mesh and reinforcing clamp over it.

It is significant to note that the Project is producing about one boat per week at extremely low cost and with a capital investment in plant and equipment of about $1,600. All materials are obtained locally including an excellent sand from the lake shore. The boats are built by local labour. It is hard to see how this could be achieved using any other material.

Fig. 5. 12.8 m Transport vessels for Guinea Bissau.

Fig. 6. 15-Foot ferrocement fishing launch produced on Lake Malawi.

## CONCLUSIONS

Small boats can be built in Ferrocement.

Our present methods restrict us to simple shapes and to displacement boats. It will be some time, if ever, before we can compete with lightweight materials such as GRP and aluminium for planing boats though our present research with stainless steel fibres may enable a substantial reduction in the necessary skin thickness. We are also designing a simplified spray process, developed originally for our skinning operations, but which will inevitably lead to the use of female moulds and a challenge to the near nonopoly of GRP for small boats.

# Some Thoughts on Methods and Materials for Ferrocement Boat Constrution

## PART I

by Larry Mahan*

Selecting the design would seem to be the locigal starting point but after thinking awhile, one has to consider several other items before deciding on a particular plan.

'On site' inspections of several ferrocement boats is the first step. Try and discover other builders near you and if the approach is correct, most builders will stop and pass on either advice (good and bad) or answers to your basic questions. Each builders usually knows where other ferrocement boats are under construction, consequently, your information sources continue to expand.

While at these 'on site' projects ask the builder his impressions of materials, layups moulding methods (upright or inverted) problems, sources of materials and costs. Soon you will gain a wealth of information that can be cross referenced to derive conclusions.

Assisting other ferrocement boatbuilders will be your best investment. Whether it is in the early lofting stages, placing and tightening wire ties, plastering or just general scaffold work, you will learn most of the basics in ferrocement boat construction. 'Hands on' experience will teach you so much more than a shelf full of boatbuilding text books.

Plan on spending three to six months at this 'on site' inspection and work program. These early efforts, seven before selecting your design, will clarify most areas and may even change your whole outlook as to choice of design and building method.

Once you realize that your ferrocement boat cannot be built during a few weekends but will probably consume the better part of several years of part time work (depending on design), investigative and preplanning efforts will become a part of your life. Even while working your regular 8-5 job, your brain will continously solve or log notes pertaining to the boat.

Keep a large lined notebook with you at all 'on site' inspections for jotting notes. It is an easy habit to get into once you try and when the day is over and the easy chair by the stove or open window contains your weary body, the day's notes or ideas can be reviewed and everything stays fresh in your mind.

When you examine each armature, notice how the rod and mesh network is tied or stapled together. You will find in some instances, poor workmanship. Loose, baggy mesh and wide spaced rods combined with improper rod end overlap contribute to an unfair, lumpy and structurely unsound hull. The armatures with correct or close rod spacings, tigthly tied or stapled mesh, properly staggered joints and ends will look and feel sound. Of course fairness comes with all these factors only as long as the initial mould is correct.

Some of my own personal observations have led to these conclusions:

1. 35 feet and under — build inverted. The small sizes are easily turned over and most work is down-hand. Gravity helps instead of wearing you down. Inverted armatures are

* IFIC Correspondent and Editor of Seaworthy Dreams, Mass., U.S.A.

easily checked for fairness at all stages. Scaffolding is at a minimum. Another side benefit is that all rubbish falls to the ground.

2. Hulls larger than 40 feet tend to become a problem for turning over if built inverted. Building upright solves the turning problem but instigates many others. An elaborate scaffolding is needed. Any protective shed construction needs to be larger than the inverted hull. This results in extra materials, costs and time.

3. Build on an area that allows adequate drainage. Plastering and curing could pose problems if drainage is not adequate. Shock hazards surface if you are standing in puddles of water while using electrical tools.

4. Whether your mould is wood, pipe or welded truss, keep it as open as posible. Narrow strips of widely spaced wood are best if using a wood mould. Every boat that I have helped plaster has had some void areas behind each batten, ribband, or station mould. Keeping these areas down to a minimum makes for structural continuity and less work back plastering later. Pipe frames pose this same void problem. The welded truss mould proves to be least troublesome in this respect, but if accurate lofting techniques are utilized this is the best method.

5. When purchasing the reinforcing rods order steel that has a tensile strength of between 80,000 and 110,000 pounds tensile strength. This range of strength allows panel beating with a heavy maul yet is still stiff enough to maintain fairness on its own. One thing to keep in mind about panel beating—unless one end of the rod is free (not welded) the distorted area will just move to another spot. The easiest solution to this is to only weld the rods at the stem or stern, never both. After panel beating and fairness is true, then you can weld the opposite ends. This holds true for the verticle rods as well. Only weld the ends at the keel. Let the rods run wild at the sheer.

6. When choosing rod sizes, if not designated on your plans, it is far better to use two layers of closely spaced ($1\frac{1}{2}''$—$2''$) small rod than to use large rod at realitively distant spacings ($6''$—$9''$). Most boats that I have seen using the large rods with distant spacings have had load cracks form later when blocked and left to sit a year or more. These cracks do not physically seem to penetrate very deeply but the boats with the close small rods do not seem to exibit this same cracking or crazing problem. The small closely spaced rods carry and spread the load more uniformly.

7. Mesh selection. This is where the biggest bone of contention seems to lie. My preference is of the $\frac{1}{2}''$ square galvanized weldmesh. I have worked on boats that have used many different types of mesh and I still recommend the $\frac{1}{2}''$ square weldmesh. If you just compare some individual samples it becomes immediately apparent that the square weldmesh even feels the best.

Of course I am speaking of the high tensile strength square weldmesh. The hexagonal mesh cannot be obtained in high strengths simply because of the fact that the high strength wire cannot be twisted onto itself without severe strains put upon it or at worst, breaking. Push your hand onto a section of hexagonal mesh and you will see how readily it deforms. This is because it only has a tensile strength of about 30,000 pounds. I admit that the hexagonal mesh can be formed around a ball much easier than the square mesh but this, along with the initial cost, is the only advantage it has over the square weldmesh.

When cutting a section of the hexagonal mesh you will have hundreds of mesh ends that never seem to stay out of the way. They always manage to get caught on an adjoining mesh layer or protrude to catch either the hand or trowel when plastering. On the other hand, when you cut a section of the square weld mesh, because it is welded at each wire intersection, the cut can follow close to the wire and leave no ends to catch the hand, mesh layer or trowel.

The square woven mesh is even more difficult to work with than the hexagonal mesh. It is prone to unravel at the cut ends and each cut end leaves hundreds of hard sharp wires to catch and hinder the job. If used over compound surfaces and in full width sections (salvage on both edges), the square woven mesh works well and forms a fair even flow.

As far as expanded metals or wall lathing is concerned, I have had no experience with either therefore I cannot give any pros or cons regarding these materials.

While still on the mesh subject I should relate that my boat, LARINDA, has over 3,200 square feet of hull surface and square weldmesh was utilized throughout. Even in compound curve areas we found no great difficulty in placing the mesh. I might also mention that all of the inside mesh layers were placed horizontally in 15′ to 20′ sections. Each section overlapped the next by 4″ to 6″ on all edges and ends. Each suceeding layer ends and edges were staggered by one foot. The outer layers were placed vertically in one continous piece from keel to sheer and all edges were butted. Each suceeding layer edges were stagered one foot. As the work progressed for and aft, the mesh strips would lay slightly on the diagonal. The further fore or aft we went the more severe the angle. Without this diagonal positioning the mesh would bag and darts would have to be cut to keep the mesh flat. At the extreme ends of the boat the mesh strips had to be cut in the form of long pie shaped slices. Even here, using the vertical diagonal placement, full length pieces could be placed and without dart cuts.

When choosing mesh it is of utmost importance, then working outside with only a partial or marginal cover, that you purchase galvanized mesh. The plain steel mesh even the wire copper flash coated type) rusts too quickly and causes a marked decrease in strength. The wire weakened by rust, also has poor bonding qualities with the plaster because of the rust coating. If you are building in a tight structure and it is going to be more than two years before you plaster, I also recommend that you use galvanized mesh. After one year the humidity of the air starts rusting plain steel mesh. *(To be continued in the next issue of the Journal).*

# NEWS AND NOTES

## CHINA

### Ferrocement Boats Popular in China

Due to the nationwide shortage of timber (in the People's Republic of China) and Chaiman Mao's program of massive reforestation of the entire countryside, ferrocement boats are being produced in nearly every province. The Ying Chow Factory near Nanking produces 20,000 ferrocement boats per year; these boats are usually approximately 10-m long with 20-m thick shells. They are cast in molds, finished off with hand plaster and steam cured. The boats are mainly used for the transportation of farm products.

In the beginning, peasants were skeptical of these boats as they were concerned over their lack of knowledge of cement. However, after providing extra cement to each boat user and instructions on patching, the government was able to convince people that ferrocement boats were superior to timber craft. The production cost of ferrocement boats is approximately one-half that of comparable wooden vessels, and today nearly 90% of all boats on the canals and rivers of China are of that material.

Experience has proven that ferrocement boats are less expensive to maintain, more durable, faster to build, easy to repair, unsinkable (because their fore and aft hatches are constructed watertight), and provide greater hull strength and impact resistance. They also incur less hull surface friction in navigation and therefore move at a faster speed due to the smoother concrete surface. The ferrocement boat technique has also been applied to the construction of floating platforms, petroleum barges, piers up to 35-m long, self-propelled tankers, river boats, barges, platforms and tankers.

*(The above new item has been reprinted from Civil Engineering-ASCE, August 1979 which is an extract from Alfred A. Yee's paper entitled "Current Engineering and Construction Practices in China.")*

## HOLLAND

### Concrete Ships and Floating Structures Convention

Use of concrete for construction of offshore platforms, pontoons, barges and boats is evidently undergoing a meteoric—if little recognized—rise in popularity. This was evident from the presentations at the Concrete Ships and Floating Structures Convention that was held in Rotterdam last November. Organized by Thomas Reed Publications Limited of U.K., the successful Convention had a modest participation of around 130 delegates, more than two-thirds of whom were from overseas. During the three days of delibrations at the Rotterdam Hilton, a total of 22 papers were presented in subjects ranging from selection of materials for the aggressive marine environment to, the history of concrete marine structures; from structures for energy generation to use of concrete for floating LNG/LPG storage tanks; and from goliath semisubmersible oil production platforms to small boats and pontoons.

Bound volume of the Proceedings of this Convention can be ordered from the organizers of the Convention.

For the first time in such a convention, an entire session was devoted to ferrocement. Four of the five papers presented on ferrocement are reproduced elsewhere in this issue. The fifth paper on experiences of Ferro Cement Marine Services (U.K.) in Seychelles and Sudan is likely to be included in one of the forthcoming issues of the Journal.

An impressive display of the activities of the various international companies involved in marine engineering works was arranged during the conference. 'De Zeemeeuw' (the Seagull), a 4.2 m long ferrocement sloop built in 1887, the first known use of ferrocement for boat building in the Netherlands, was also on display. The Netherlands Cement Industry, the present owner of the sloop, which was earlier in use at the Amsterdam Zoo, more than made a point regarding the durability of concrete. Apparently the wooden and iorn parts of the sloop deck, have since worn off, leaving behind a ferrocement hull that is still in an excellent condition. Another display that drew a lot of interest was a slick 6 m ferrocement canoe that bagged the first prize at a Concrete Canoe Race. The hull claimed to be a little over 3 mm in thickness (3 layers of steel mesh) weighed only 38.5 kg (GRP advocators —here comes your competitor!)

Discussions during the ferrocement session essentially dwelt on aspects like minimum cover requirements (2 mm in ferrocement as when compared to 50 mm in conventional reinforced concrete was highly debated!) exact delineation between ferrocement and conventional reinforced concrete, the need for a cautiously documented code of practice for ferrocement construction and some of the envisaged marine applications suggested in the IFIC paper (mainly ferrocement caissons, fibrous ferrocement and submerged ferrocement pipes).

As a grand finale the organizers of the Convention also arranged for a visit to Europort 79—an exhibition held in Amsterdam concurrently, that was particularly oriented to propulsion and electronic side of the world's maritime industry.

The Convention successfully achieved its prime objective of initiating delegates from the marine and concrete industries into a free and frank exchange of views and also assessing each other's requirements and opportunities through the various technical sessions. Ferrocement for one, did definitely make inroads into the materials market for marine structures, if the enthusiasm or interest in ferrocement at the Convention was any indicator.

*(Report compiled by Mr. V.S. Gopalaratnam, Senior Information Scientist, IFIC)*

## IFIC NEWS

### Lecture Series by Indian Correspondent

A Series of 8 lectures on Ferrocement Technology and its Applications has been delivered during the past year or so, in western and northern India by Mr. P.C. Sharma, Correspondent to the Journal of Ferrocement. Specially prepared with a view to create an awareness, amongst practising engineers and architects about the suitability of use of ferrocement in varied engineering and architectured applications, these lectures were also used for publicising activities and services of IFIC. These lectures included slide shows and were well attended.

### Staff on the Move

Mr. V.S. Gopalaratnam was back at IFIC after a month-long official visit to India and the Netherlands. Visiting various organizations and research establishments during the tour to India he gathered valuable insight into recent developments in the applications of ferrocement as well as their commercial production (feature article to be published in the next issue of the Journal). At the Netherlands, he presented a paper entitled "A Review of Marine Applications of Ferrocementin Asia" at the Concrete Ships and Foating Structures Convention, (Rotterdam, November 12-14, 1979) organized by Thomas Reed Publications Limited.

Mr. P.C. Sharma, Correspondent to the Journal who was on a second assignment at IFIC as a Technical Specialist, while on a visit to Singapore took the opportunity to see research work conducted at the University of Singapore. A report based on his visit is also likely to be published in the next issue of the Journal.

## INDIA

### Developments of Ferrocement Products for Rural Areas

The Appropriate Technology Unit of the Allahabad Polytechnic has done a commendable amount of work in actually transfering this promising appropriate technology to the rural areas in India. Among the rural utility items developed are ferrocement boats for inland transport, shell roofs for village houses, roofing tiles for low-cost housing, irrigation channels and pipes, fodder trays for cattles and small capacity water tanks and grain storage bins. Masons from the rural areas have now been adequately trained to manufacture these items and fabrication yards in villages adjoining the Allahabad Polytechnic have supposedly been set up.

Our Correspondent from Roorkee reports that plans are also underway to develop larger boats for picnickers and pilgrims for use at Sangam (point of confluence of three rivers near the holy city of Allahabad).

Fig. 1

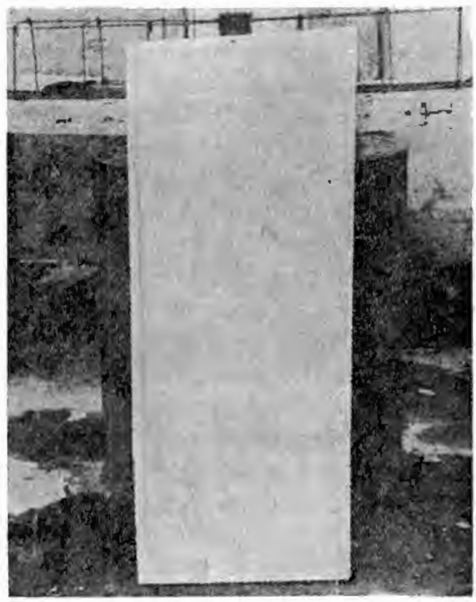

Fig. 2

Fig. 1 shows a 25-$m^2$ ferrocement shell roof of 3.5 cm thickness with a central rise of 0.6 m. Reinforcement consists of 8 mm bars at 25 cm centers both ways along with a layer of 20 g hexagonal mesh ($\frac{1}{2}$ inch opening) and a layer of 20 g square woven mesh ($\frac{1}{4}$ inch opening). The shell is supported by a reinforced concrete edge beam over brick columns. Fig. 2 presents a ferrocement roofing tile 1.5 m x 0.65 m with two 4 cm ribs (not in view) along its length. Fig. 3 illustrates a small capacity (300 kg approx.) grain storage bin. The cylindrical bin is 60 cm in diameter and 1 m high and also includes a flat ferrocement lid.

Fig. 3

### Ferrocement Domes Using Split Bamboo at Ahmedabad

Two ferrocement domes using a basic bamboo frame that is left in place after plastering have been constructed by the Sarabhai Technological Development Syndicate in February 1979. Circular in plan these domes are of approximately 5 m in diameter and serve as roofs for a toilet and store room at an institution for the mentally retarded in Ahmedabad. The skeleton for the dome is made up of 2" x 3/8" split bamboo strips that are bolted at all intersections to form a quare grid. First fixed in position on the floor this frame is proped into place by tempo~rary supports of predetermined lengths to give the dome its curvature. Two layers of 24 g 3/8" hexagonal mesh placed over this bamboo framework acts as the reinforcement for the 15 mm thick dome. Bamboo strips are left in place, even after finishing the underside of the dome, so as to lend a beautiful grid pattern to the interior. The bamboo strips are treated for resistance to termite attacks. The photograph below (Fig. 4) shows the dome being fabricated. Cost estimates of this dome that is supported by a circular reinforced concrete edge beam are encouraging (around US$ 6.00 per square meter covering area).

Fig. 4

### Training Course in Ferrocement Technology for Polytechnic Lecturers

The first ever training course in ferrocement technology for polytechnic lecturers was organized jointly by the Structural Engineering Research Centre (SERC), Roorkee and the Curriculum Development Centre (CDC), Allhabad Polytechnic from June 11-23, 1979 at Roorkee. Participants included teachers of polytechnical colleges from the various states in India. The curriculum for the course covered theory and laboratory work that included field applications and testing of various ferrocement structures.

The eminent Indian structural engineer who was also the Vice Chancellor of the University of Roorkee, Dr. Jai Krishna inagurated the training course. Prof. S.C. Jain of the Allahabad Polytechnic and Dr. V.P. Narayanaswamy of the SERC coordinated the various aspects of the course. The IFIC published text, "Ferrocement" (by Paul and Pama) and a specially prepared

Lecture Notes (by Dr. V.P. Narayanaswamy, G.V. Surya Kumar and P.C. Sharma) were provided as course material for the participants. Based on the encouraging feedbacks of the course, the CDC envisages to organize similar courses in different parts of the country, in collaboration with the SERC. According to reports from our Correspondent, the CDC also envisages to introduce ferrocement technology in the diploma courses in Civil Engineering at all polytechnics in India.

The below photographs show participants in the course undertaking casting and testing of some of the items that were designed. Fig. 5 shows the course participants casting a ferrocement folded plate roofing element. Fig. 6 shows one of the participants learning to use the SERC developed semi-mechanized process for producing ferrocement cylindrical units. Fig. 7 illustrates the testing of a folded plate roofing element. Deflections are being recorded while the specimen is being water-loaded.

Fig. 5

Fig. 6

Fig. 7

INDONESIA

**More Recent Developments in Application of Ferrocement**

Further to our earlier report in the News and Notes section of the October 1979 issue of our Journal of Ferrocement, we now have more recent information on developments in Indonesia.

Reporting for us, on his activities, Mr. J.B. Manga who works for a rural development project in South Sulawesi sent us a few photographs of the stages in the construction of a dome for a mosque.

Seated atop a reinforced concrete and brick masonary structure, the dome is 6 m in diameter and has a central rise of 4.5 m. Fig. 8 shows details of the skeletal steel

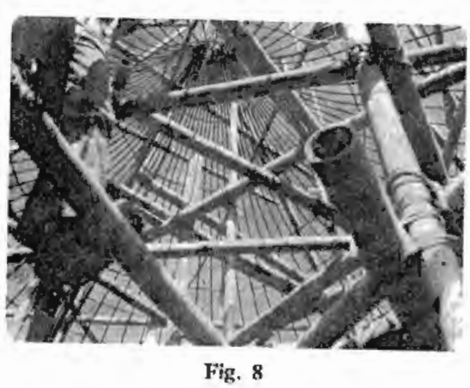

Fig. 8

framework of the beautifully shaped dome with extensive bamboo scaffolding in the foreground. Fig. 9 shows workmen fixing up layers of wiremesh onto the basic steel framework. Fig. 10 shows the completed dome covered with hessian, undergoing moist curing.

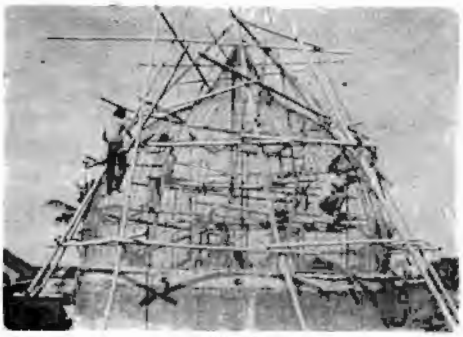
Fig. 9


Fig. 10

SRI LANKA

**Ferrocement for Cyclone-Resistant Construction**

The Building Research Institute of the State Engineering Corporation of Sri Lanka has developed a number of ferrocement building components such as ferrocement corrugated roofing sheets, ferrocement long tile, ferrocement door and window sashes, and partition walls, has also experimented with its use in cylone-resistant constructions. The ferrocement house design developed for cyclone-prone areas has the following features:

(1) A prismatic folded-plate in the form of an inverted hopper-bottom made of ferrocement is the principal cladding unit for walls and roof. These units are placed side by side, contiguously and tied with binding wire. They can then be plastered using the known ferrocement techniques to form a monolithic wall and roof. (Fig. 11).


Fig. 11

(2) The wall units are embedded in a 150 mm (6") reinforced concrete slab-on-the-ground at the bottom and the skeletal steel in the wall unit is spot-welded to skeletal steel in the roofing unit at the eaves level. This ensures a truly monolithic construction.

(3) At eaves level a series of openings in the form of an inverted—V exists rightround the house. This yields an "equally permeable four walls" thus reducing considerably the internal pressure developed within the building by wind storm.

(4) At window openings, the skeletal steel (which could be a 50 x 50 x 3.15 mm welded mesh) is continued. The window sashes could be of sliding type and installed inside. Thus the continued skeletal steel mesh protects the window sashes from flying debris.

(5) The R.C. slab-on the ground floor is heavy enough to resist uplift and sliding caused by wind pressure.

(6) The ferrocement wall units together with the R.C. slab-on the ground provides a truly watertight compartment which could safely sustain a storm surge which normally accompanies cyclones.

(7) The ferrocement folded plate shell is of 10 mm (3/8") thickness. But ferrocement could assure a construction which has adequate resistance to damp penetration, even under flood conditions.

(8) For added thermal comfort, the walls and roof could be provided with an internal timber cladding which could entrap an air cavity for insulation.

(9) The erection of such a ferrocement building can be done as follows: The skeletal steel is bent to the prismatic shape and wiremesh reinforcement laid over it and tied perhaps, in the factory and transported to the site. They are then erected and connections welded on the site and plastered. The mortar can be applied manually or, if necessary, pneumatically.

(10) The monolithicity is essential for a structure such as a house to transfer the uplift forces through walls to the foundation. In the present ferrocement design, this is ensured by a large number of spot-welds at skeletal steel connections. Since there is a very large number of such connections, much more than the number required to ensure the monolithicity, there will be a safe margin of failure due to constructional error.

The prismatic folded-plate unit, provided with diaphragms along its length for buckling and warping strength, is designed to withstand safely the uplift and positive pressures caused by a wind storm of 62 m/s (140 mph) over a span of 4.6 m (15 ft).

As load tests have shown the folded plate unit has considerable resistance to uplift forces. The resistance of walls and roof to in-plane stresses is ensured by the continuous diaphragms in the assembled folded plate units.

The folded-plate shell has undoubtedly higher resistance to concentrated loads such as those arising from flying debris and are also easy to construct than the equivalent curved shells.

Load tests simulating the positive and uplift wind forces, impact loading and the support conditions have been carried out on separate cladding units. These tests have shown that:

(a) The folded plate ferrocement unit could withstand the design load before the appearence of first cracks.

(b) the ultimate load corresponds to a wind speed of several times more than the design wind speed.

(c) the failure is local exhibiting multiple fracture behaviour of ferrocement. Therefore, any damaged units (wall or roof) even caused by flying debris can be repaired easily and put into use.

An estimate of cost has shown that this construction which can be built even on high wind and storm-surge hazard areas costs as much as an equivalent reinforced concrete construction.

*(Reprinted from Sri Lanka Building Research, Vol. 1, No. 3, July 1979, from an article by M.A.U.G. Fernando, Chief Engineer of the Building Research Institute).*

U.S.A.

**Student Project**

Students trying to kick the concrete canoe habit might want to experiment with a project similar to that successfully completed by ASCE Student Chapter members at the

University of Illinois, Chicago Circle campus a few years ago. That project was a ferrocement shell planned and erected on campus to serve as an information center for student activities. Here's how and what Chicago students did, as reported by faculty adviser Dr. Antoine E. Naaman.

The ferrocement shell consists of four hyperbolic paraboloids covering an area about 400 ft$^2$ (37 m$^2$) and rising approximately 22 ft (6.7 m) above ground

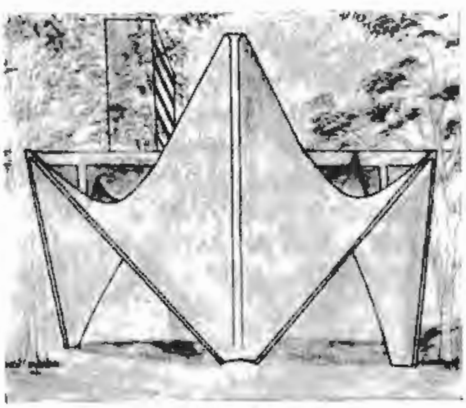

Fig. 12

Completion of the shell required three major phases: the first involved design and feasibility studies; the second consisted of securing permits and commitments for supplies and funds from various sources; and the third phase was actual construction.

Generally, each phase required the participation of a different group of 10 to 15 students (with some students participating in two consecutive phases in order to insure continuity).

During construction, which took place in spring 1977, the following steps were taken: pouring the concrete footing and attaching the base plates of columns; forming the skeleton of the structure by using square steel tubes welded at one end to the base plates (these tubes formed the sides of the hyperbolic paraboloids). Next came attachment of 1/8-in. diameter steel strands between the sides in two opposite directions, forming a grid with openings of about 1 by 1 ft each (and giving the preliminary shape of the shell). Then came cutting, placing and attachment of four successive layers of steel wiremesh ($\frac{1}{4}$-in. opening, gauge 23), two on each side of the skeletal structure; placement of the mortar by shotcreting; finishing and curing. (The intended design thickness of the shell was a half-inch, however, due to difficulty in controlling thickness during shot-creting, actual thickness varied in places up to one inch.)

The project was financed by contributions from firms and individuals in the Chicago area. *(The above news item has been extracted from Civil Engineering—ASCE, September 1979).*

# BOOK REVIEWS

## FERROCEMENT

*By Charles Buhagiar*
*Published by New University of Malta, Civil Engineering and Architecture Department, Malta.*

This is a well compiled dissertation submitted in partial fulfillment of the requirement for the Degree of Bachelor of Civil Engineering and Architecture at the New University of Malta. Divided into three parts—Development of Ferrocement, Properties of Ferrocement and Experimental Investigation of Ferrocement Water Tanks, this is a good review of the historical development and more recent wide ranging applications of ferrocement. Although the dissertation is basically a literature survey, it is likely to be a forerunner as a well prepared state-of -the-art review. The publication is recommended to curious beginners who would find it handy and well illustrated.

| | | |
|---|---|---|
| *165 pp. + vi* | *295 mm x 210 mm* | Flexicover Edition |
| *English* | | *June 1979* |
| | | *Cost: Not mentioned* |

## LECTURE NOTES FOR THE FERROCEMENT TECHNOLOGY TRAINING COURSE

*By V.P. Narayanaswamy, G.V. Surya Kumar and P.C. Sharma*
*Published by Structural Engineering Research Centre, Roorkee, Uttar Pradesh, India.*

Prepared specially for a training course sponsored by Curriculum Development Centre, Allahabad Polytechnic, Allahabad for training teachers from Polytechnics on Ferrocement Technology, this publication is a must for similar short courses on the subject. The amply illustrated book contains a basic introduction on the material besides chapters devoted to the historical development, constituent materials, mechanical properties, concepts of analysis and design, notes on construction techniques and a review of ferrocement applications. The material for the book is drawn from numerous research reports of specific interest to the Indian situaton, besides the IFIC published text "Ferrocement" by Paul and Pama. The list of references cited for the chapter on mechanical properties is very exhaustive and even includes an article published as late as April 1979.

| | | |
|---|---|---|
| *129 pp.* | *285 mm x 225 mm* | *Flexicover Edition* |
| *English* | | *June 1979* |
| | | *Cost: Not mentioned* |

## THE WIDENING APPLICATION OF FERROCEMENT

*By Douglas Alexander*
*Published by the author himself. Copies can be ordered from D.J. Alexander, Box 28265, Remuera, Auckland 5, New Zealand.*

This timely publication is an appraisal of the state-of-the-art and allied papers on the various applications of ferrocement. It also presents a variation of conventional mesh reinforced ferrocement, a development initiated by the author's consulting practice. The author's effort in attempting to compile into one volume all his published work on high tensile wire reinforced fibrous ferrocement is commendable. The compendium contains excellent colour prints of the various projects that were completed using fibrous ferrocement. Besides comprehensively comparing the engineering properties of this new variation, the book also includes discussions on the effect of prestressing ferrocement. The book being a compendium, cannot be expected to present continuity and uniformity of presentation both in the text as well as illustrations. Improved reproduction of some of the considerable number of photographs and sketches would be well worth the effort. This informative and useful publication is highly recommended to the entire body of ferrocement users—expecially commercial manufacturers and researchers.

*120 pp. + 7 drawings*
*English*

*225 mm x 160 mm*
*ISBN: 0-473-00168-3*

*Hard Cover Edition*
*August 1979*
*N.Z.$ 22.00 (air mail)*

# INTERNATIONAL MEETINGS

**Symposium on Wood, Ferrocement and Plastics in Shells and Spatial Structures, University of Oulu, Oulu, Finland, June 9-14, 1980.**

The IASS Symposium 1980, organized by the International Association for Shell and Spatial Structures in collaboration with, the Finnish Academy of Technical Sciences will be devoted to two trends both central in the present development of thin-walled and spatial structures. The first half of the Symposium will concentrate upon the use of wood material in shells and spatial systems, the latter half dealing with more modern materials such as ferrocement and plastics.

The symposium is organized in three sessions each one offering ample scope for discussion. The first session treats wooden shells and spatial structures, and the appropriate theory. Although the Symposium will place most weight on the ingredients of a good structural solution, design fabrication and constructional technique, opinions about future development are also welcome. The second session is devoted to concrete-like composites such as fine-aggregate concrete with various binders or cement paste. These almost entirely thin-walled shell structures make use of microreinforcement, asbestos, glass, metal, plastics, etc. In this session the properties of the composites form an interesting part. The third session is reserved for structures of plastics, without more accurate specifications.

For details regarding the Symposium and further information, contact:

Prof. Dr. Paavo A. Tupamäki
Chairman, IASS Symposium 1980
Department of Civil Engineering,
Kasarminite 8
University of Oulu
90100 Oulu 10, Finland

**The International Congress in the Chemistry of Cement, Paris, France, June 30-July 5, 1980.**

The following themes have been selected for the above Congress: Influence of raw materials, fuels and manufacturing processes on clinker structure and properties; hydration of pure Portland cements; structure of slags and hydration of slag cements; structure of pozzolanas and fly-ash-hydration of pozzolanic and fly-ash cements; special cements' pastes-rheology; interface reaction between cement and aggregate in concrete mortar.

For further information, contact:

CERILH
23, rue de Cronstadt
75015 Paris, France

**Session on Experimental Wind Engineering on Structures, Florida, U.S.A., October 27-31, 1980.**

The Committee on Experimental Analysis and Instrumentation will sponsor a session at the ASCE Annual Convention, October 27-31, 1980 in Hollywood, Florida. The theme is "Experimental Wind Engineering on Structures".

For further information, contact:

Prof. Leon R.L. Wang
Department of Civil Engineering
Rensselaer Polytechnic Institute
Troy, New York 12181
U.S.A.

Prof. James Colville
Department of Civil Engineering
University of Maryland
College Park, Md. 20742
U.S.A.

**Third International Congress on Polymers in Concrete, Nihon University, Fukushima-ken, Japan, May 13-15, 1981.**

Nihon University along with some other institutions will sponsor this Congress to be held in Japan in 1981. The main objective of the Congressis to provide for the dissemination of information on polymers in concrete through presentation of papers, and discussion related to the process technology, properties, and existing potential applications of polymer-modified concrete, resin concrete (or polymer concrete), polymer impregnated concrete, gypsum-polymer composite, concrete-sulphur composite, polymeric admixture for concrete, and adhesives and coating used in concrete work.

A number of he papers contributed related to polymers in concrete will be accepted for oral presentation. In addition to these, other papers will be considered for publication in the proceedings. Potential authors are invited to submit an abstract (in English) of about 300 words by July 1, 1980.

Papers or discussion comments may be presented at the Congress in either English or Japanese. Manuscripts of papers, however, should be written in English.

Further details concerning the final Congress Program and accommodations will be available early in 1981.

Further information can be obtained from:

Polymer Concrete Congress 1981
Secretariat
c/o Dr. Yoshihko Ohama
Department of Architecture
College of Engineering, Nihon University
Koriyama, Fukushima-ken 963
Japan

# Abstract

JFP19 IMPACT RESISTANCE OF FERROCEMENT BOAT HULLS

KEYWORDS: Hull, Impact, Specific Surface, Testing, Volume Fraction.

ABSTRACT: Although numerous studies have been conducted in the past to define and evaluate the impact resistance of ferrocement, there still exists no well defined criteria for predicting it. This article presents a method for predicting single strike impact resistance of ferrocement boat hulls. Experimental results of 49 panels tested, have been discussed with reference to the mechanism of failure and the essential reinforcing parameters namely, steel content and specific surface of reinforcing mesh. It has been concluded that the method suggested can be used to accurately predict the single strike impact resistance of ferrocement. The results also highlight the fact that an increase in steel content and/or specific surface increases resistance to impact. It was observed, however, that beyond a practical maximum steel content, impact resistance does not always increase with increase in the specific surface.

REFERENCE: NIMITYONGSKUL, P., CHEN BOR-SHIUN and KARASUDHI, P., "Impact Resistance of Ferrocement Boat Hulls", Journal of Ferrocement, Vol. 10, No. 1, Paper JFP19, January 1980, pp. 1-10.

---

JFP20 COST REDUCTION AND QUALITY CONTROL IN FERROCEMENT AND MARINE CONCRETE

KEYWORDS: Boat, Construction, Cost, Mould, Pontoon, Production.

ABSTRACT: The paper describes laminating and shotcrete techniques which decrease labor requirements while increasing quality control and impact resistance; compares costs and other advantages of ferrocement over glass reinforced polyester (fibreglass) in boat hulls; discusses hybrid floating structures of ferrocement in combination with conventionally reinforced concrete which can be built for substantially less than all steel structures; outlines use of floating moulds which enable large ships and monolithic floating structures to be built directly on the water, thus removing any size limits imposed by available shipways or graving docks.

REFERENCE: IORNS, M.E., "Cost Reduction and Quality Control in Ferrocement and Marine Concrete", Journal of Ferrocement, Vol.10, No.1, Paper JFP20, January 1980, pp. 11-17.

---

JFP21 DESIGN, SERIES PRODUCTION AND PROMOTION OF FERROCEMENT VESSELS

KEYWORDS: Classification, Cost, Design, Load, Material Property, Production.

ABSTRACT: Ferrocement has not gained widespread acceptance as a construction material for the commercial production of marine structures. There is no technical reason why it should not be able to compete with other boat building materials; it has in fact a number of advantages. The authors, who are engaged in type-certification of small craft, suggest an approach to the prroduction and marketing of ferrocement vessels which is intended to circumvent the boating public's scepticism toward the material. Some general guidelines to boat design are presented. It is suggested that ferrocement can gain a sizeable market in the immediate future, but that this will require a determined effort by interested organisations.

REFERENCE: SPRADBROW, B.J. and WIKLUND, K.M., "Design, Series Production and Promotion of Ferrocement Vessels", Journal of Ferrocement, Vol. 10, No. 1, Paper JFP21, January 1980, pp. 19-29.

In a world of mounting crisis over energy!

# The Power Guide

**brings you up-to-date information on small-scale energy sources commercially available throughout the world.**

**Hydro-Electric Systems**

Wind power,
Solar power,
Hydro-electric systems,
Heat pumps,

as well as more conventional steam, petrol and diesel engines — control equipment and instrumentation.

The guide includes a select bibliography and an index of manufacturers as well as agents and distributors.

Comprehensive introductions to each section provide the pros and cons of the various power sources as well as the criteria for selecting the right one.

**Solar Power**

This directory contains a mine of carefully assembled material in a handy catalogue. Published at this critical period of power shortages, it should prove a bestseller — in the technology, engineering and do-it-yourself fields.

All rights enquiries to C. & J. Wolfers Ltd, 3 Regent Square, Bloomsbury, London WC1H 8HZ, U.K.

**Wind Power**

Order from Intermediate Technology Publications Ltd, 9 King Street, London WC2E 8HN, U.K.
Telephone 01-836 9434.

**Heat Pumps**

ISBN 0 903031 59 0

Paperback. 240pp.
Fully illustrated. £7.50*.

Publication date:
October 22, 1979.

* Originally advertised at £5.95 for 166 pages. Now a bigger and better book of 240 pages for £7.50.