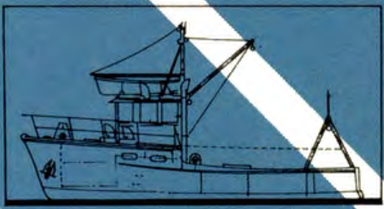
ISSN-0125 1759
Vol. 10, No. 3, July 1980

JOURNAL OF FERROCEMENT



SPECIAL ISSUE

MARINE APPLICATIONS OF FERROCEMENT

IFIC
International Ferrocement Information Center

ISSN 0125–1759

JOURNAL OF FERROCEMENT

JOURNAL OF FERROCEMENT

Volume 10, Number 3, July 1980

CONTENTS

Discussion of the technical materials published in this issue is open until **January 1, 1981** 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over the world, **IFIC** attempts to collect information on all forms of ferrocement applications either published or unpublished.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. IFIC** has also published numerous other books and reports. Enquries 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 Institutional	25.00 50.00
B. Countries other than those listed in Region A.	Individual Institutional	15.00 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 special issue is dedicated to Marine Applications of Ferrocement. The response to our call for papers to be published in this issue was excellent. These articles highlight a number of interesting trends in the use of ferrocement for marine applications.

Contributions have been scarce in the fields of fundamental research activities but many technical papers deal with interesting innovative aspects of ferrocement utilization such as light weight aggregates, fibrous ferrocement, composite lamination with fiberglass, influence of skeletal steel on ferrocement, skeletal free ferrocement for small boats, new methods of construction, etc.

Except for one faithful contributor, "amateurs" have unfortunately not responded to our repeated appeals for their contributions and they are reminded once more that this Journal is also their Journal and that their stories and notes will be most welcomed.

The coverage of the news and notes has been kept in this issue fairly general and not limited to marine applications.

Special efforts have been devoted to preparing this bulky special issue and our grateful appreciation goes not only to the contributing authors but also to the Editorial Board Members who reviewed the manuscripts quickly and also to Mr. V.S. Gopalaratnam, Editorial Assistant who is responsible for putting together the issue in a remarkably efficient way.

Considering the success of this endeavour, another special issue will be published in January 1981 devoted to "Housing Applications". Following our call for papers for this special issue a considerable number of contributions have been promised and some manuscripts already received. Additional contributions will be most welcomed.

As usual comments from our readers aiming at improving the Journal will be deeply appreciated.

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.

Influence of Skeletal Steel on the Flexural Behaviour of Ferrocement

T. Yen* and C.F. Su**

This article is written with a view to clarify certain aspects of the engineering behaviour of ferrocement in relation to the long standing debate of use of ferrocement for fishing crafts, with and without the use of skeletal steel. Theoretically the contribution of skeletal steel to an increase in the cracking moment is negligible. However, in the ultimate condition, this will be stressed due to an upward displacement of the neutral axis from the centroidal axis and thus not only greatly enhance the ultimate moment carrying capacity but also allow for, a greater ductility resulting from increased ultimate deformation. The study experimentally confirms theoretical derivations of the behaviour in flexure of ferrocement with and without the use of skeletal steel.

LIST OF NOTATIONS

A_{si} = cross-sectional layer of steel in the ith layer (mesh or skeletal steel).

A_{sk} = cross-sectional area of the skeletal steel.

b = width of the specimen.

C_c = compressive force taken by the mortar.

C_{si} = compressive force taken by steel in the ith layer (mesh or skeletal steel).

d = thickness of the specimen.

E_c = modulus of elasticity of composite in compression

E_t = modulus of elasiticity of composite in tension.

f'_c = ultimate compressive strength of mortar.

f_r = modulus of rupture of mortar.

f_{si} = tensile stress of mesh or skeletal steel in the ith layer.

f_{sky} = yield stress of skeletal steel.

f_{syi} = yield stress of the ith layer of wiremesh.

f_t = tensile strength of mortar.

M_{cr} = cracking moment of the composite.

M_u = ultimate moment of the composite.

T_c = tensile force taken by the mortar.

T_{si} = tensile force taken by steel in the ith layer (mesh or skeletal steel).

x = distance between neutral axis and the top fiber.

Z_i = resisting arm of the ith layer of mesh.

Z_{sk} = resisting arm of the skeletal steel.

β = constant = 0.65 for f'_c = 541.7 kg/cm^2.

INTRODUCTION

Skeletal steel is an indispensible supporting frame-work in most mould-less constructions. Partly due to the difficulty in fixing its location and its meagre contribution to the cracking moment [1] research studies in the past have ignored the influence of skeletal steel on the mechanical behaviour of ferrocement.

*Professor, National Chung-Hsing University, Taiwan, Republic of China.
**Manager, Taiwan Fisheries Consultants, Inc., Taiwan, Republic of China.

As expressed in an earlier text [2] the position of the skeletal steel often coincides with the centroidal axis of the cross-section of a ferrocement element. If the layers of wiremeshes are evenly placed in such a section, theoretically the presence of the skeletal steel will have no effect whatsoever on the behaviour of the section in flexure, until cracking is initiated. However, in practice placing of the skeletal steel and meshes do not in most case follow the designed locations for these components. One of the objectives of this article is to highlight the effects of such deviations in steel placement on the moment carrying capacity of the section.

Furthermore, when loaded to the ultimate condition, the neutral axis of the cross-section will move away from the centriodal axis and the skeletal steel will now begin to share the stress. This will greatly increase the load carrying capacity of the section. The other object of the study, hence, is to derive a formula for the ultimate moment carrying capacity and compare the results thus obtained, with experimental results.

For flexural behaviour of ferrocement sections, most often two methods of analysis have commonly been adopted;

a) ferrocement section is transformed into an equivalent reinforced concrete section and conventional theory of reinforced concrete is then applied to predict the behaviour of the ferrocement section,

b) equilibrium of forces and moments based on conventional stress-block analysis is carried out to predict behaviour of the ferrocement section in flexure.

For this study, the later method with the effects of skeletal steel duly accounted, is adopted. For the test specimens prepared wiremesh content was relatively lower than those normally specified. Specimen thicknesses vary from 2 cm—6 cm. Compressive strength of the mortar prepared was around 500 kg/cm^2 (49.0 N/mm^2).

EXPERIMENTAL PROGRAMME

Mortar

Type I Potland cement manufactured by the Taiwan Cement Corporation was used in the mortar used for preparation of the test specimen. Water-cement ratio of 0.4 (by weight) and

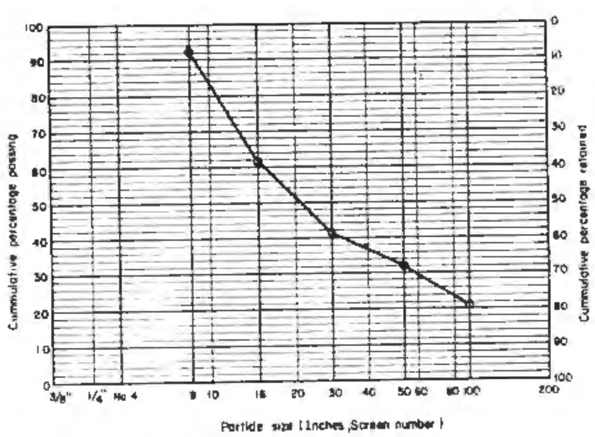


Fig. 1. Gradation curve of sand.

sand-cement ratio of 1:2 were maintained for all the specimens prepared. Fig. 1 shows the grading of sand used for the purpose, as proposed by Yen et. al. [3] Test result on the control specimens of the mortar prepared are presented in Table 1

Table 1. Mechanical Properties of Mortar

Water-cement ratio (by weight)	Cement-sand ratio (by weight)	Compressive strength at 28 days* kgf/cm^2 (N/mm^2)		Modulus of elasticity kgf/cm^2 (N/mm^2)	
0.4	0.5	504.8	Average	3.39×10^5	Average
0.4	0.5	552.2	541.7	3.79×10^5	3.71×10^5
0.4	0.5	568.1	(53.1)	3.94×10^5	(0.364×10^5)

* Specimen dimension : 7.5 cm diameter, 15 cm height.

Skeletal Steel and Wiremesh

Mild steel bars of 5.3 mm diameter were used as skeletal steel for the test specimens. The configuration of the skeletal steel bars are presented in detail in the next sub-section.

Fig. 2 shows the profile dimensions of the hexagonal mesh used. Wire diameter of the mesh used was 0.7 mm. Table 2 present the mechanical properties of the reinforcing materials used.

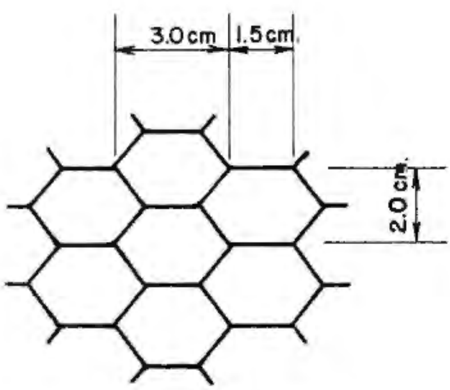


Fig. 2. Wiremesh dimensions.

Table 2. Mechanical Properties of Reinforcing Materials

Item	Diameter (cm)	Tensile strength kgf/cm^2(N/mm)^2	Yield strength kgf/cm^2(N/mm^2)	Modulus of elasticity kgf/cm^2(N/mm^2)
Wire in the mesh	0.07	4,560 (447.1)	3,250 (318.6)	1.29×10^5 (0.126×10^5)
Skeletal steel	0.53	5,465 (535.8)	4,140 (405.9)	3.10×10^5 (0.304×10^5)

Test Specimen and Testing

Two sets of specimens were prepared for determining the effect of the use of skeletal steel on the flexural behaviour of ferrocement. The set of specimen using skeletal steel will hereafter be referred to as Group A while the set without skeletal steel will be referred to as Group B. 12 Specimens (F1-F12) were prepared for Group A while 9 specimens (F13-F21) were prepared for Group B. Table 3 and 4 present essential characteristic of the reinforcing system used for each of these specimen.

Meshes and skeletal steel bars were tied up in required numbers and locations. A 5 mm layer of mortar was placed in the mould prior to placing the reinforcing system (earlier prepared). This was done to ensure a 5 mm cover to the bottom-most layer of mesh. Mortar was placed again and the mould vibrated to achieve proper compaction and a void-free specimen. The specimens were finished so as to give a 5 mm mortar cover to the top layer of mesh and later covered with a polyethelyne sheet. The specimens were demoulded after 24 hours and placed in a curing room for 28 days prior to testing them.

Table 3. Reinforcement specifications for the Specimens with Skeletal Steel

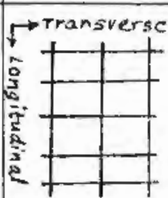
Specimen Number	Arrangement	Skeletal Steel				Number of Layers of Wire Mesh	
		Longitudinal direction		Transverse direction			
		Bar Diameter (mm)	Spacing (cm)	Bar Diameter (mm)	Spacing (cm)	Above the Skeletal Steel	Below the Skeletal Steel
F1-F3		5.3	10.0	5.3	7.2	2	1
F4-F6		5.3	6.1	5.3	4.5	2	3
F7-F9		5.3	7.2	5.3	10.1	3	3
F10-F12		5.3	6.5	5.3	4.8	4	4

Table 4. Specimen Dimensions and Reinforcing Details

Specimen number	Specimen dimension width × thickness (cm)	Reinforcement content (cm^2)		Reinforcement ratio* (%)		Location of skeletal steel from the bottom (cm)	Number of layers of wiremesh	
		Wiremesh	Wiremesh + skeletal steel	Wiremesh	Wiremesh + skeletal steel		Above the centroidal axis	Below the centroidal axis
F1	18.1 × 2.2			0.191	1.19	1.04		
F2	18.0 × 2.2	0.076	0.472	0.192	1.20	1.11	2	1
F3	19.0 × 2.2			0.182	1.13	0.78		
F4	18.4 × 3.2			0.260	1.39	1.16		
F5	18.1 × 3.3	0.154	0.816	0.258	1.36	1.16	2	3
F6	18.1 × 3.3			0.258	1.36	1.04		
F7	17.8 × 4.3			0.212	0.79	1.51		
F8	17.7 × 4.4	0.162	0.603	0.215	0.78	0.96	3	3
F9	17.8 × 4.2			0.217	0.81	1.43		
F10	18.0 × 5.1			0.202	0.93	2.66		
F11	18.4 × 5.0	0.185	0.847	0.201	0.92	1.92	4	4
F12	17.9 × 5.0			0.207	0.95	1.98		
F13	14.7 × 2.3			0.319	0.319	-		
F14	14.8 × 2.3	0.108	0.108	0 317	0 317	-	2	2
F15	14.9 × 2.3			0.315	0.315	-		
F16	14.9 × 4.2			0.259	0.259	-		
F17	15.0 × 4.3	0.162	0.162	0.251	0.251	-	3	3
F18	14.9 × 6.3			0.253	0.253	-		
F19	15.1 × 6.1			0.235	0.235	-		
F20	14.9 × 6.3	0.216	0.216	0.230	0.230	-	4	4
F21	15.0 × 6.2			0.232	0.232	-		

* Ratio of cross-sectional area of reinforcement to cross-sectional area of the composite.

After the curing period, electrical strain gauges were fixed at two locations on the tension face of each specimen as shown in Fig. 3a. A universal testing machine was used to load the specimen. The test set-up is presented in Fig. 3b.

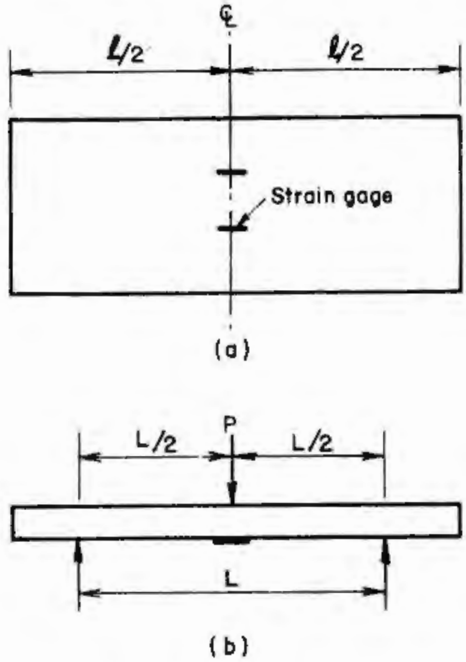


Fig. 3. Details of location of strain gauge and test set-up for the bending test.

Loading was gradually increased from zero until the specimen failed. Strain gauge readings were recorded for each loading. Increments of load were decided so that a representative load-strain curve could be realized. Visual observation of the tension face provided with a rough estimate of the first crack load. This could also be graphically estimated from the load-strain curve, or from knowing the tensile strength and the modulus of elasticity of the mortar ($f_t = f'_c/14$ gives a useful approximation). Table 5 presents the complete results obtained from the testing of the 21 specimens.

THEORETICAL ANALYSIS

The object of the theoretical analysis is to derive acceptable equations that predict the cracking and ultimate moment of a ferrocement section subjected to flexure. This is done by equating the compresive and tensile forces for the ferrocement section in the crack initiation and ultimate stages using analytical stress-block calculations normally applied to ordinary reinforced concrete [4].

Cracking Moment.

Prior to the first crack stage the stress-strain curve of a ferrocement section is elastic and during this stage Walkus [5] determined that the modulus of elasticity in compression (E_c) equals that in tension (E_t).

Table 5. Results from Test and Theory for Cracking and Ultimate Moments of the Specimens

Specimen number	Reinforcement ratio (%)		Cracking moment kgf-cm (N-m)		$M_{cr}(theory)/M_{cr}(test)$	Ultimate moment kgf-cm(N-m)		$M_u(theory)/M_u(test)$	$M_{cr}(test)/M_u(test)$	$M_{cr}(theory)/M_u(theory)$
	Wiremesh	Wiremesh+ skeletal steel	$M_{cr}(test)$	$M_{cr}(theory)$		$M_u(test)$	$M_u(theory)$			
F1	0.191	1.19	-	655	-	2475	2870	1.16	-	0.23
F2	0.192	1.20	750	635	0.85	2213	2512	1.13	0.34	0.25
F3	0.182	1.13	844	700	0.83	2888	3360	1.16	0.29	0.21
			(82.7)	(68.6)		(283.0)	(329.3)			
F4	0.260	1.39	2038	1485	0.73	8963	7780	0.87	0.23	0.19
F5	0.258	1.36	2000	1490	0.75	8938	8325	0.93	0.22	0.18
F6	0.258	1.36	2000	1500	0.75	9000	8383	0.93	0.22	0.18
			(196.0)	(147.0)		(882.0)	(821.5)			
F7	0.212	0.79	3000	2570	0.86	10800	9944	0.92	0.28	0.26
F8	0.215	0.79	3500	2600	0.74	11900	11025	0.92	0.29	0.24
F9	0.217	0.81	3250	2500	0.77	10900	9770	0.90	0.30	0.26
			(318.5)	(245.0)		(1068.2)	(957.5)			
F10	0.202	0.93	3500	3525	1.01	12450	12760	1.02	0.28	0.28
F11	0.201	0.92	3500	3560	1.02	13850	14440	1.04	0.25	0.25
F12	0.202	0.95	4000	3515	0.88	14800	14270	0.96	0.27	0.25
			(392.0)	(344.5)		(1450.4)	(1398.5)			
F13	0.319	0.319	656	580	0.88	1150	1250	1.09	0.57	0.46
F14	0.317	0.317	700	610	0.87	1213	1290	1.06	0.58	0.47
F15	0.315	0.315	656	610	0.93	1220	1290	1.06	0.54	0.47
			(64.3)	(59.8)		(119.6)	(126.4)			
F16	0.259	0.259	2250	2000	0.89	3900	3970	1.02	0.58	0.50
F17	0.251	0.251	2120	2180	1.02	4100	4270	1.04	0.52	0.51
F18	0.253	0.253	2075	2105	1.01	4050	4130	1.02	0.51	0.51
			(203.4)	(206.3)		(396.9)	(404.7)			
F19	0.235	0.235	4500	4410	0.98	8050	8680	1.08	0.56	0.51
F20	0.230	0.230	4750	4625	0.97	8500	9040	1.06	0.56	0.51
F21	0.232	0.232	4750	4510	0.95	8100	8860	1.09	0.59	0.51
			(465.5)	(442.0)		(793.8)	(868.3)			

If the skeletal steel is placed at the center of the section and wiremesh layers are evenly placed above and below it, than the neutral axis of the section in the elastic range will coincide with the centroidal axis. Otherwise, it is necessary to compute the location of the neutral axis prior to determining the stresses and the resisting moment. Theoretically the tensile strength and the modulus of rupture of the mortar are taken as $f_t = f_c'/14 = 38.7$ kg/cm^2 (3.79 N/mm^2) and $f_r = 1.99\sqrt{f_c'} = 46.3$ kg/cm^2 (4.54 N/mm^2) respectively, thus the strain at initial crack should be around 105×10^{-6}. Using the stress and strain blocks shown in Fig. 4, it is possible to compute the cracking moment thus.

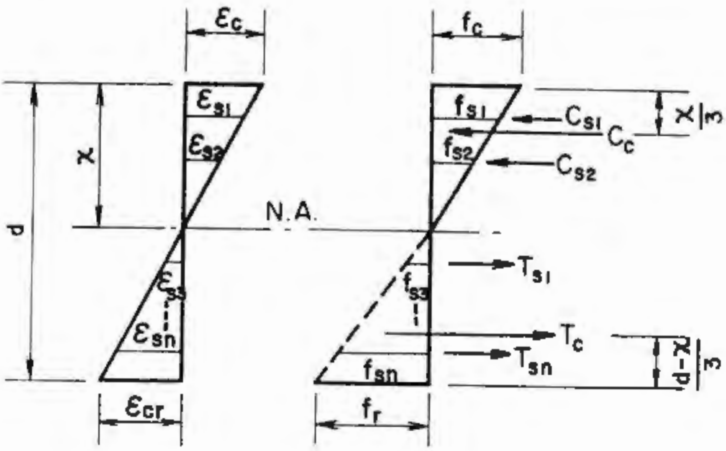


Fig. 4. Strain and stress blocks at initial crack.

$$C_c + \Sigma C_{si} = T_c + \Sigma T_{s(n-i)}$$

$$C_c + \Sigma C_{si} = T_c + \Sigma A_{s(n-i)}\, f_{s(n-i)} \qquad \ldots\ldots\ldots (1)$$

$$M_{cr} = T_c Z + \Sigma T_{sn} Z_i$$

$$M_{cr} = \frac{f_r}{2}\, b(d-x)\left(d-x-\frac{d-x}{3}\right) + \Sigma A_{s(n-i)}\, f_{s(n-i)}\, Z_i \qquad \ldots\ldots\ldots (2)$$

where the notations used have been defined earlier.

Ultimate Moment

Between the first crack and ultimate conditions there will be a gradual shift of the neutral axis, towards the top fiber, as bottom layers of steel yield. Using the stress and strain blocks shown in Fig. 5, it is possible to determine the neutral axis and thereby compute the ultimate moment of the section.

$$C_c = T_c + \Sigma T_{si}$$

$$C_c = T_c + \Sigma A_{si}\, f_{syi} \qquad \ldots\ldots\ldots (3)$$

$$M_u = T_c Z + \Sigma T_i Z_i$$

$$M_u = \frac{1}{2} f_r b(d-x)\left(d-\frac{\beta x}{2}-\frac{d-x}{3}\right) + A_{sk} f_{sky} Z_{sk} + \Sigma A_{si} f_{syi} Z_i \qquad \ldots\ldots\ldots (4)$$

Only because the strength of mortar mix designed for this study is high, it is taken into account in equations (3) and (4).

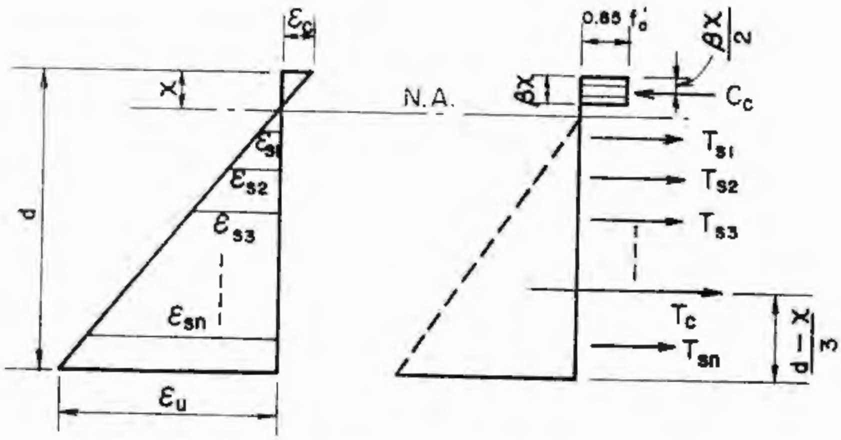


Fig. 5. Strain and stress blocks at the ultimate condition.

DISCUSSION

From Table 4 it can be observed that although the wire mesh contents in the two groups are comparable, total steel reinforcement for Group A is 4 to 7 times of those in Group B. The skeletal steel location is more towards the tension face in specimens F3, F6, F8 and F12 and as seen from Table 5, this yields a higher cracking moment than specimen F2, F4, F5, F7, F9-F11. This proves that displacement of the skeletal steel from the centroidal axis influences the cracking moment of the section, although not appreciably. Comparing the cracking moment of Groups A and B one can conclude that the contribution of skeletal steel to the cracking moment is minimal.

The ultimate moment of Group A is, however, greater than that of Group B by at least two folds. This confirms the upward shift of the neutral axis and consequent yielding of the skeletal steel.

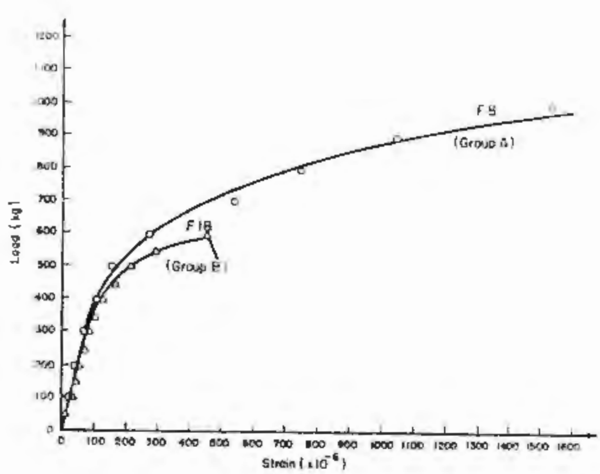


Fig. 6. Typical load-strain relation for Group A and Group B specimen.

Load-strain curves have been drawn for one representative specimen from each group, F8 from Group A and F18 from Group B (Fig. 6). The curves follow a more or less similar pattern until crack initiation. Subsequently the disparity until ultimate is ever increasing. F8 fails at a larger strain than F18 confirming that skeletal steel lends more ductility to ferrocement. This fact makes it suitable for service where the structure is exposed to seismic loadings [6].

The effect of skeletal steel was also studied with respect to specimen thickness and associated cracking and ultimate moments (Table 6 and Fig. 7). While the curve for M_{cr} for both groups is relatively closer and of comparable slope, the curve for M_u is markedly different. The difference between the M_u curves of the two groups is comparable for smaller specimen thicknesses while it increases greatly for larger specimen thicknesses. This can be explained as following: After the upward shift of the neutral axis the advantage of a higher reinforcement ratio (as in Group A) greatly increases the resisting capacity of the section [7]. It can also be observed from Table 5 that for the same group, the ratios of M_{cr} to M_u for both theoretical computations as well as experimental values relatively same and are not affected by specimen thickness.

Table 6. Thickness of the Specimens Compared with Associated Experimental Cracking and Ultimate Moments.

Specimen number	Reinforcement ratio (%)		Specimen thickness (cm)	Cracking moment M_{cr} kgf-cm (N-m)	Ultimate moment M_u kgf-cm (N-m)
	Wiremesh	Wiremesh+ skeletal steel			
F1-F3	0.188	1.17	2.2	797 (78.1)	2525 (247.5)
F4-F6	0.259	1.37	3.3	2000 (196.0)	8967 (878.8)
F7-F9	0.215	0.80	4.3	3250 (318.5)	11200 (1097.6)
F10-F12	0.202	0.93	5.0	3667 (359.4)	13700 (1342.6)
F13-F15	0.317	0.317	2.3	690 (67.6)	1194 (117.0)
F16-F18	0.254	0.254	4.3	2150 (210.7)	4017 (393.7)
F19-D21	0.232	0.232	6.2	4667 (457.4)	8217 (805.3)

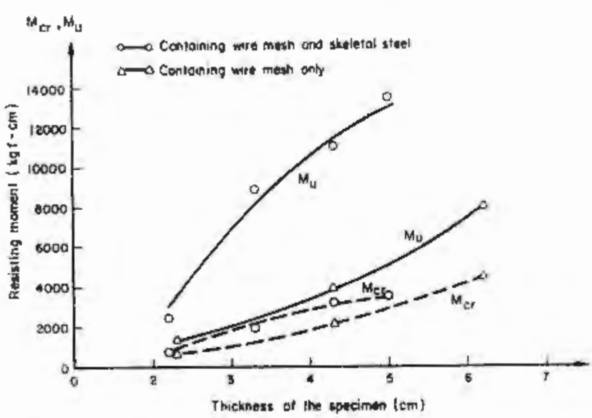


Fig. 7. Influence of thickness of specimen on the cracking moment and the ultimate moment.

Table. 7. Percentage Sharing of Load Between Skeletal Steel and Mortar at Ultimate Loading.

Specimen number	Specimen thickness (cm)	Reinforcement ratio (%)		Load sharing at ultimate loading (%)	
		Wiremesh	Skeletal steel	Skeletal steel	Mortar
F1	2.2	0.191	1.19	65	25
F2	2.2	0.192	1.20	65	27
F3	2.2	0.182	1.13	69	24
F4	3.2	0.260	1.39	69	21
F5	3.3	0.258	1.36	68	18
F6	3.3	0.258	1.36	71	20
F7	3.4	0.212	0.79	55	33
F8	4.4	0.215	0.79	58	32
F9	4.2	0.217	0.81	55	32
F10	5.1	0.202	0.93	55	35
F11	5.0	0.201	0.92	60	30
F12	5.0	0.202	0.95	60	31

Comparison of theoretical and experimental values of cracking and ultimate moments suggest that the earlier suggested equations predict these to a fairly accurate extent.

Table 7 presents the percentage of tensile load sharing between steel and mortar at the ultimate condition. For smaller specimen thicknesses, the tensile load shared by the mortar is smaller compared to specimens of larger thickness. Thus the thinner a ferrocement section, the influence of skeletal steel on the ultimate moment capacity will be appreciable.

CONCLUSIONS

1. Skeletal steel in the vicinity of the centroidal axis will have practically no influence on the cracking moment although it greatly increases the ultimate moment capacity.

2. Besides increasing the ultimate moment capacity, the skeletal steel also increases the ductility of the section resulting from increased ultimate deformation.

3. The increase in ultimate moment capacity of a section containing skeletal steel is more significant in case of thicker sections. This leads to the fact as explained earlier that the skeletal steel plays a decisive role in the ultimate capacities of thinner sections.

4. Analytical equations derived for cracking and ultimate moments of ferrocement sections with and without the use of skeletal steel (subjected to flexure), is fairly accurate. Characteristic feature of these equations are that, due consideration has been given to the tensile load sharing by mortar.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. T.T. Huang, Assistant of the Civil Engineering Department of the National Chung-Hsing University. Thanks are also due to the Taiwan Fisheries Consultants, Inc. who financially supported the above research work.

REFERENCES

1. YEN, T., "Ferrocement, A Type of Thin Wall Reinforced Concrete with Layers of Wire Mesh", Journal of Civil Engineering Department, National Chung-Hsing University, No. 5, June 1978, pp. 5-10.
2. PAUL, B.K. and PAMA, R.P., "Ferrocement", published by the International Ferrocement Information Center, Asian Institute of Technology, Bangkok, Thailand, IFIC Publication No. 5/78, August 1978, 149 pp.
3. YEN, T., SU, C.F. and CHANG, M.F., "A Possibility to Increase the Mortar Strength of Ferrocement", Journal of Ferrocement, Vol. 9, No. 2, April 1979, pp. 53-64.
4. WINTER, G. and NILSON, A.H., "Design of Concrete Structures", 9th Edition, McGraw Hill Book Company, New York, 1979, pp. 113-130.
5. WALKUS, B.R., "State of Cracking and Elongation of Ferrocement Under Axial Tension Load (I) and (II), Buletinul Institutului Politehnic Din Iasi, Tonsul XIV, 1968, pp. 653-664 and Tonsul XVI 1970, pp. 53-60.
6. PARK, R. and PAULAY, T., "Reinforced Concrete Structures", New Zealand, 1975, pp. 195-203.
7. WANG and SALMON, "Reinforced Concrete Design", 3rd. edition, The Southeast Book Company, New York, 1979, pp. 46-49.

Some Improved Methods for Building Ferrocement Boats

Martin E. Iorns*

Ferrocement boat building has been handicapped by overweight, voids, corrosion, poor impact resistance, and high labour requirements. This article outlines some principles and procedures which can overcome those handicaps both in one-of-a-kind and series building. How to design and prepare a high strength mortar which will inhibit corrosion and improve penetration is discussed, together with the most cost-effective ways to use rods, expanded or perforated metal, and welded or woven wire fabrics to increase impact resistance. Shotcrete, laminating, and cavity moulding techniques can improve appearance, eliminate the need for skilled finishers, and drastically reduce labour costs in series production. Important economies can be obtained in one-of-a-kind construction by building both the deck and hull inverted and by use of precast ferrocement bulkheads, frames, floors, soles, and tanks.

INTRODUCTION

The purpose of this article is to suggest some principles and procedures which will help the custom builder overcome the problems of overweight, voids, corrosion, poor impact resistance, and high labor requirements which have handicapped ferrocement progress.

By following these suggestions, a one-of-a kind builder should obtain a structurally sound hull with a minimum of labor at less than one fourth the cost of a fiberglass (GRP) hull of the same dimensions. Furthermore, the ferrocement hull will be superior to GRP in long-term durability; it will be fireproof, less likely to rip open in a collision, and much easier to maintain and repair.

The same principles and some of the procedures mentioned here are incorporated in a process [1-3] for series building, but efficient commercial production requires more sophisticated equipment and methods than can be described in the space available here.

PROBLEM AREAS IN CONVENTIONAL CONSTRUCTION

By conventional construction the author means to include all methods in which an armature of mesh tied to rods is fabricated and then impregnated with mortar. Tying mesh to rods is very time consuming and some builders report spending more than a thousand hours on this phase. Too few ties will permit the layers of mesh to spread apart when the mortar is forced though, resulting in a thick, overweight hull. Overweight may also occur if the rods are not supported by closely spaced station frames or are not of sufficient diameter and stiffness to prevent sagging under the weight of wet mortar. Even if the armature is strong enough to support the mortar, it may still be pushed out of shape by the pressure used to apply the mortar. Sometimes this escapes notice when the builder, under the mistaken impression that the mortar must be placed in one continuous operation, does not finish until dark. Filling concave spots

* Ferrocement Consultant, Fibersteel International Company, P.O. Box 661, West Sacramento, California, U.S.A.

with additional mortar adds weight and such unreinforced areas will crack and spall off under strain.

The obvious solution to the tying problem is to staple the armature to a solid backing. Such a system was advocated by John Samson [4] until it was discovered that the closed mould prevented visual control of penetration to the inner face and resulted in too many voids. This "cedar mold" method was superseded by the now widely used open mould in which the armature is stapled to longitudinal wood planks spaced several inches apart. In 1968 three men, under the direction of a naval architect and the author, built a 12 meter (40 foot) hull in one week by this method with the help of a professional plasterer called in to apply the finish coat [5]. The principal objection to this method is that the framework must be removed, has a limited salvage value, and the areas hidden by the planks must be back plastered.

The presence of rods within an armature introduces another problem in that rods may act as stress concentrators and promote cracking under impact. Tests by the US Navy [6] demonstrated a "remarkable increase in strenth-to-weight ratio by the use of mesh only". Some designers, though, feel that a network of high tensile rods makes a worthwhile contribution to the structural integrity of a hull in a severe collision. It is much cheaper to use rods than to obtain the same result by the use of an equal weight of high tensile mesh, so rods are acceptable provided they are of small diameter relative to the hull thickness, run in two directions at approximately 90 degree angles, and are covered on both sides by two or more layers of heavy gauge mesh.

Construction systems using only longitudinal rods covered by a few layers of (chicken wire) hexagonal mesh are now generally recognised as obsolete but lest owners of boats so built become unduly alarmed, it should be noted that hudreds of such hulls are giving satisfactory service providing the owners are careful to avoid severe impact situations. The curved parts of even a poorly reinforced hull can resist normal seaway stresses, but flat sections near the bow are vulnerable to wave impact if permitted to flex. Any areas in a hull which are found to deflect even slightly when pounding into waves should be stiffened by adding frames, shelving, berths or other substantial cabinetry, leaving access to the hull surface as unimpaired as possible. The bow compartment should also be isolated from the rest of the boat by a watertight bulkhead.

Another problem inherent in coventional construction is that impact resistance must be compromised to achieve a void-free hull. Impact resistance depends on steel content, the type of steel, its distribution, and its surface area. As steel content increases, mortar penetration becomes more difficult and voids more prevalent, weakening the section in which they occur and exposing the reinforcing to corrosion.

Three approaches to solving the void problem are worth considering:

1. Use a mesh with more open space between wires, but increase the diameter of the wires. This maintains ultimate tensile strength but does not provide the fine distribution and high bond surface which enables good ferrocement to deflect without cracking.
2. Make the mortar fluid so it can flow into all tiny crevices where wires touch and cross If a typical sand and cement mortar were watered down to achieve this, it would be both weak and porous. The water-cement ratio must never be more than 0.4 by weight for water retaining structures and should be kept below 0.35. If higher water-cement ratios are used which still meet strength requirements, make sure that the

hull is well sealed with an impervious coating. A sufficiently fluid high-strength mortar can be readily obtained at the 0.35 ratio by adjusting the amount and gradation of the sand or with the use of other fine aggregates.

Strength and permeability are directly related to the water/cement ratio, whereas the sand/cement ratio is relatively unimportant except in mass concrete where the sand is used to economically fill the spaces between larger aggregates and plays an important role in controlling shrinkage cracking. Cracking in ferrocement is controlled by the closely spaced reinforcing so the sand becomes mostly an adulterant by which the fluidity of the mortar can be regulated. With less sand, more cement is needed, but the extra cost is small compared to the gain in strength and durability and the investment in the completed boat.

3. Devise a laminating method whereby the reinforcing is embedded layer by layer into preplaced mortar. This embedding concept is basic to the patented process [3] offered to series builders, but it can also play an important role in the one-off methods described here. Laminating permits the placement of any amount or type of reinforcing material in any hull section without creating voids but requires the use of a solid surface to hold the mortar while the reinforcing is being positioned.

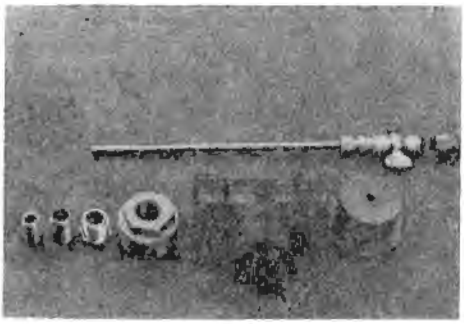
TOOLS AND EQUIPMENT FOR ONE-OFF CONSTRUCTION

A myth has arisen that ferrocement mortar must be placed and finished in one continuous operation. This has resulted in the marshaling of a crowd of skilled and unskilled workmen at the site on plastering day, and the procurement of expensive equipment, often in duplicate, for fear of a breakdown. All mortar prior to the finish trowel coat can be applied by conscientious laborers using methods and mixes which would be considered highly unconventional by professional plasterers.

The Fibersteel Company of West Sacramento, California, built a 10-meter (32-foot) tow boat in 1964 using strips of mesh tied to rods in the conventional manner. Plastering was done in three stages. On the first day the two hands built the armature, applied a rich fluid mortar, worked it well into the armature with gloved hands, rechecked the hull for fairness, scratched the surface, and allowed it to harden. The operation was then turned over to two professional plasterers who trowelled on what they called a "brown" coat, followed a day or two later by a final coat of commercial swimming pool finish plaster. The white hull needed no coating until many years later when it was converted to a pleasure boat and painted for cosmetic reasons. The boat was still in service in 1980, with no sign of any spalling or deterioration. Further evidence that continuity of mortar application is not necessary may be found in the hundreds of successful boats built by the "two shot" method advocated by Hartley [7].

Freed from having to rush the plastering phase, fewer workmen can be more efficiently employed and less expensive equipment can be used. Mortar can be mixed in any watertight tray with a hoe, carried to the job in a bucket, and applied with gloved hands, brush, roller, spray, or trowel. Or the mortar can be mixed in a drum with a paddle chucked in a low speed electric drill. Either method can provide enough mortar to impregnate the armature of a 12-meter (40-foot) hull in one day.

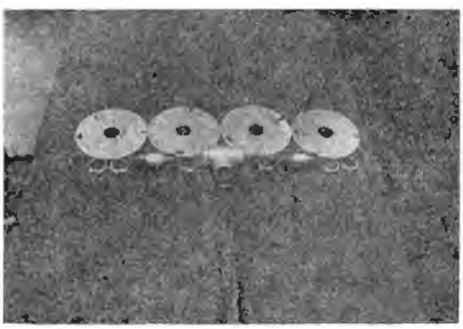
Spray equipment, while not essential, is desirable for multi-coat work, or the laminating techniques to be mentioned later, because mortar applied at moderate to high velocity seems to bond better to the substrate than when applied by trowelling. There are numerous commercial spray rigs costing $2,000 and up, sold in the U.S.A., but the one-off builder can rent a one horse power electric air compressor and use a hopper gun. Hopper guns, sometimes called pattern pistols, cost about U.S. $100 new but a serviceable one can be assembled using a funnel-shaped container holding about ten liters and pipe fittings costing under US$10 (see Fig. 1). The roller tool used to embed mesh is show in Fig. 2.



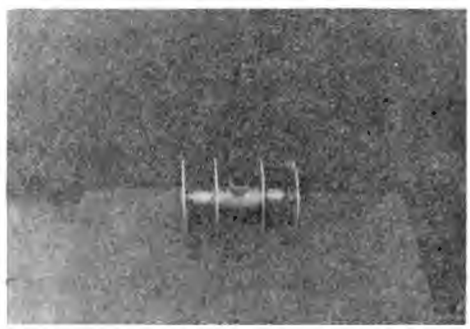
(a)

(b)

Fig. 1. Details of a hopper spray gun.
(a) Parts from a mortar spray gun. Select one of the three fittings show on the left which best suits air and mortar supply. Flatten one end if fan pattern is desired. A "Y" fitting is better than the black "T" shown, if mortar is from pump hose instead of hopper. Adjust air tube in and out to find the best operating position.
(b) Nozzle attachea to 19 liter (5 U.S. Gallon) can, to make a hopper gun.



(a)



(b)

Fig. 2. Details of the laminating roller used for embedding mesh strips in each layer of mortar.
(a) Parts of a roller laminating tool as purchased from a retail electrical/plumbing store for less than US$5.00. The electrical cover plates are 4 inches in (10 cm) diameter. Larger discs would be even better, if available.
(b) Parts shown in (a) have been assembled to form the roller. Lock nuts should be left loose so that the discs are able to rotate freely. More discs may be coupled on if wider tool is needed (for flat surfaces).

MATERIALS

Reinforcing mesh

This is the most expensive component in ferrocement, so deserves the most careful cost analysis. Of the three types of mass-produced mesh commonly available, welded wire fabric, expanded metal, and woven wire fabric, the first two are the most cost-effective. Welding anneals wire and limits the tensile strength of welded fabrics, so a more expensive high tensile ungalvanized woven fabric may be required in high performance planing hulls where thin ferrocement panels are subjected to severe tensile loadings [6]. High tensile mesh is not needed for displacement type hulls. When the same grade of steel is used, welded fabrics are superior to woven fabrics because their wires run straight and load up instantly under strain, whereas the undulating wires in woven fabrics straighten out and may allow the cement cover to crack before being fully loaded.

Woven fabrics with square openings are clearly superior to those woven with hexagonal openings, commonly referred to as "hex mesh" or "chicken wire". Most designers now recommend a widely available square mesh woven with 19 gauge (1 mm) diameter wires spaced about 13 mm (1/2 inch) apart. Galvanizing, like welding, anneals wire and precludes high tensile applications. It may also react with ungalvanized rods to produce hydrogen bubbles unless passivated by adding chromium trioxide to the mixing water at the rate of 200-300 parts per million. A better choice is 16 gauge (1.6 mm) square welded mesh with wires on half inch (13mm) centers. Benford [8] reports tests showing two layers of the 16 gauge mesh are stronger than three layers of the 19 gauge material.

A 14 gauge (2 mm) square welded fabric with wires spaced one inch (25 mm) apart and known in the trade as "Weldmesh 1114" provides the most strength for the money of any of the commonly available welded fabrics suitable for ferrocement. The wide spacing of its wires makes it ideal for deck to hull and bulkhead to hull joints, where penetration is often a problem. One commercial builder used it extensively for bulkheads, decks, foam core construction, or in any place where tensile loading governs, and equal strength is needed in two directions. Its openness and low specific surface makes it inferior for crack control purposes, so a layer of fine mesh or expanded metal plaster lath should be interposed between the Weldmesh 1114 and any surface subject to strain or wide temperature variations. A companion product with half as many wires in one direction costs less and can be used wherever equal strength is not required in both directions.

Expanded metal plaster lath is ideal for boat hulls because it presents a much greater bond surface than wire fabric and costs less, so provides the most economical way to obtain a ferrocement hull which can accept considerable strain on impact without cracking. The suitable types of expanded metal and the precautions to be observed in their use have been fully discussed in [2], so will not be repeated here.

There are many proprietary reinforcing materials being advertised for ferrocement, including steel and glass fibers. Fibers should never be used for boat hulls except in conjunction with some more continuous form of reinforcing. Fibers, because of their random orientation, are not as effective as welded fabrics or expanded metal lath, yet cost about the same per unit of weight. The author believes that the most efficient way to use fibers is not to add them at the mixer but to spray alternate layers of mortar and fibers on a solid surface or closely spaced mesh lattice. Random orientation would then be confined to one plane. Any reinforcing fabricated from ordinary mild steel can be evaluated by comparing its cost per pound or kilo with Weldmesh and expanded metal plaster lath. Weldmesh 1114 in January 1980 costed about fifty cents a pound (.4536 kg) or two dollars a square meter in the USA, and slightly less in England.

Expanded metal plaster lath made from 24 gauge (.023 inch or .584 mm) sheet steel expanded to weigh 3.4 pound (1.54 kg) per square yard (.9144 meter) can be purchased in the

USA from building supply stores for about $1.50 a yard ($1.80 a square meter). A similar three pound lath is manufactured in England.

Equivalent mesh may be obtained from sources outside the US and UK at lower cost, but be sure to check gauges and weights against the standards just given. There are many expanded metals on the market which are too flimsy for consideration. On the other hand, there are many stronger expanded metals made from thicker sheet steel by a more expensive process which are used for machinery guards, catwalks, and other heavy duty applications. Some of these heavier materials may be well worth their cost for those parts of a hull subject to high impact loads.

Cement

This is the second most costly component in ferrocement, but price and quality are fairly standard worldwide. The one-off builder may select the least expensive local cement that meets his government's specifications for compressive strength. If several brands are available at the same price, select the one with the lowest C_3A percentage as it should have the best resistance to the sulfates in sea water. There is no need to pay a premium for Type V sulfate resisting cement because the same protection can usually be obtained by pozzolans or coatings at less cost. A rich, nonporous mortar is adequately sulfate resistant even if made from common cement.

Be skeptical of claims for expensive ultra high compressive strength cements and mortar mixes. A rise in compressive strength is usually accompanied by a rise in the modulus of elasticity (brittleness) which must be controlled by the reinforcing mesh. Any mortar prepared from sound materials with a water-cement ratio below 0.4 and sand-cement ratio less than 2 to 1, should be strong enough for all normal ferrocement use.

Aggregates

Ferrocement designers have tended to specify the use of a sharp, well-graded silica sand without mentioning the relative merits of many alternatives which may be locally available at lower cost. Hardness, sharpness, and gradation are minor considerations if the water/cement ratio is kept between 0.3 and 0.35. The sand must be completely free from organic materials, particularly animal droppings, and should be relatively free from silt or clay. Some parts of the world have aggregates which react with the alkali in cement, so before using a new and untried source of sand, check with a local concrete authority and have mortar bar tests made if in doubt.

Particles larger than about 1 mm (one twenty fifth of an inch) should be screened out to aid in penetration. Woven wire fly screen makes a suitable sieve.

A fine, clean river or beach sand may be suitable for ferrocement, although its poor gradation may make it unsuitable for mass concrete.

There are many suitable aggregates which are lighter than sand, and some of these have a beneficial pozzolanic action as well. Check on the availability and cost of flyash, volcanic ash, slag, diatomaceous earth, expanded shale fines, perlite, pumice, vermiculite and inert alkali-resistant plastics. The plastic micro balloons used in synthetic foams may be too expensive, but low cost styrene beads and granules of scrap rigid urethane foam or styrofoam are worth investigating. Most lightweight aggregates reduce mortar strength proportionally more than they reduce weight, so mortars containing them must be tested for structural adequacy before use.

Water

Everyone agrees that potable water makes good concrete, but water containing enough salt and minerals to be unpalatable may also be used in a rich mortar. Steel will not rust if it is completely coated with a highly alkaline mortar whose pH exceeds 13. A Portland cement slurry meets this requirement but the sand and mixing water must be free from organic matter or other acidic materials which would reduce the pH. There is some experimental evidence [9] to indicate that water with some degree of salinity could be used in a rich fluid mortar without serious adverse effects on the reinforcing, but this practice is not recommended. Water from swamps and jungle ponds is likely to contain acids from rotting vegetation and should be tested before use to be sure the pH is 7 or above.

Admixtures

Anyone reviewing concrete literature encounters a bewildering array of reports and advertisements about admixtures. Most have little application to ferrocement although some play an important role in conventional concrete. Plasticizers and air entraining agents permit workable mixes to be made with higher sand contents but only a large-scale ferrocement builder might find it worthwhile to get involved in the intricacies of their use. Some advertised "waterproofing" admixtures would seem to have value for a boat hull, but all are superfluous in any workable (low sand-cement ratio) mortar whose water-cement ratio is under 0.4.

A retarder can be very useful in hot weather by enabling a small crew to take time to do a thorough job and avoid having to discard mortar because of premature set. There are many proprietary retarders on the market, but the least expensive and most readily available is ordinary sugar. Preliminary tests should be made on trial batches of mortar to determine the upper limit (20-60 grams of cane sugar per 43 kgs of cement) of amounts to use because only a small amount is needed and an overdose can be ruinous. Properly used, a retarder should have no adverse effect on ultimate strength and may even increase it.

Pozzolans are recommended additives which contribute to sulfate resistance and the long-term durability of concrete exposed to water. Some pozzolanic concrete placed by the Romans has withstood immersion in sea water for 2000 years. No one expects that length of service from a boat, so, if a pozzolan is not readily available at a reasonable price, it may be omitted and the hull protected by coatings. Even an unprotected hull should last several lifetimes if made with the non-porous mortar that has been discussed.

Pozzolans are available in several forms. Natural sources include some volcanic materials and diatomaceous earth. Flyash, a waste product of coal burning, is plentiful and much research has been done on its utilization. Pozzolans may contain undesirable impurities, so should be certified for concrete use by a competent authority. There is a common misconception that the pozzolan content of a mortar should not exceed 5%, or at the most 15%, of the cement weight. Pozzolans can replace up to 15% of the cement in most concrete hydraulic structures without affecting ultimate strength, although early strength will be less. Higher pozzolan concentrations are needed to convert all the soluble free lime in cement to an insoluble calcium silicate, so the author's recommendation is to keep the cement content and the water-cement ratio constant but replace 30% to 100% of the sand with pozzolan. The resulting mortar should be tested and compared with mortars of known suitability before being used in a boat.

Some pozzolans absorb considerable water into their interior structure which will not be immediately available for hydration of the cement. This can be checked by weighing a dry sample of the pozzolan, soaking it in water for a day or more, placing it in a warm (not hot) oven until it is surface dry, then reweighing. The completely dry weight is subtracted from the surface dry weight to find how much water was retained in the pozzolan. A proportional amount of water can then be added to the mortar.

MORTAR MIXING

It is assumed that the cement is being delivered in bags known weight and that the mixer will hold at least a one-bag batch, otherwise a container will be needed to hold and measure a known weight of cement. Another container must be marked or cut down to hold an amount of water which will not exceed 35% of the cement weight, and thus provide a 0.35 water-cement ratio. Another container holding enough additional water to bring the w/c to 0.4 can be prepared for use in tempering an overly stiff mortar, but a better practice is to use a retarder or temper with a 0.4 w/c slurry.

The order of mixing, providing it is thorough, does not affect the final strength of the mortar, so the method used will depend on the equipment available. The mortar mixers used throughout the U.S. have paddles rotating on a horizontal shaft inside a stationary drum and may stall if dry materials are added first.

Revolving drum concrete mixers rely on the presence of coarse aggregate to do a thorough job of mixing and permit the dry ingredients to be added first. Revolving drum mixers, while not recommended for ferrocement, are cheaper and can be used if mixing time is lengthened and carefully monitored for thoroughness.

Dry mixing was the rule in older methods which used leaky wood boxes or flat platforms. It is still necessary for some admixtures such as polyethylene oxide, a pumping lubricant that will coagulate if not first mixed with one of the dry ingredients.

In paddle-type mortar mixers water is placed in the mixer first, then the cement, then the pozzolan if used, followed by just enough sand or other aggregate to obtain the desired consistency. If a fluid mix stiffens prematurely, a retarder should be used. The mortar used to impregnate an armature should be of an almost paint-like consistency and applied with a brush or spray so it will run down into all the crevices. The excess can be caught on a plastic sheet and remixed. The fluid mortar application is followed by a stiffer mix containing more sand or reclaimed fluid motar which has stiffened but not finally set.

MATERIAL TESTING

There are two tests which any builder can easily make with simple equipment which will tell whether a hull be structurally sound, and which should be made in every case where the builder departs from conventional methods or uses new mortar mixes and mesh combinations.

First, prepare a series of test panels about one meter long and about 15 cm (6 inches) wide. Dimensions are not critical as long as they are the same for all panels. Make three reference panels with materials known to be suitable and three panels of each of the materials to be tested. Give all the same cure. Support each panel near the ends and load the center through a wood block which will distribute the load over one fourth to one third the span. Compare the test panels to the reference panels with respect to the weight required to bend them and to produce audible or visible cracks.

Second, prepare a series of square reference and test panels one-half meter (19 inches) or larger on a side, place on a frame which will provide a continuous support around and near the edge, drop a heavy blunt weight from a height onto the center of each test panel, and compare the impact behavior of the test panels with the reference panels. Test not only for the amount of force required to produce a measured rate of leakage, but also for complete failure (an open hole). The striking weight can be made by filling a pipe or other container approximately 25cm (10 inches) in diameter with concrete and rounding its end, using a bowl for a form. This impact test is the single most important test which can be made by any builder who wants to evaluate previously untested local materials or who wants to improve the structural integrity of a hull for which other materials such as chicken wire were specified by the original designer.

CONSTRUCTION METHODS

All one-off boats of conventional design can be built more efficiently in the inverted position, including the deck which should be built first. All but the very smallest boats should be launched inverted and turned upright while afloat. A survey of several California builders who righted their hulls out of the water revealed a high rate of damage. Turning while afloat can usually be done with simple equipment and minimum risk.

If the boat is built away from the launching site, consider building it directly on the conveyance which will transport it to the water. Be sure to provide for the insertion of jacks, slings, or rollers, and a crawl space for access to the interior, unless a transom door is included in the design. Such a door leading into a stern cockpit is not difficult to construct in ferrocement and is a great convenience for boarding guests, swimmers, and large fish.

In addition to the open mold method mentioned earlier, the builder has a choice of three other systems, all more efficient than any previously published.

They are: (1) Closed mold, (2) Integral mold, and (3) Precast core. The first, an "all mesh" laminated version of Samson's "cedar mold" [4], will be a good choice for those parts of the hull above the cabin sole which are to have an interior wood finish. The penetration problems which brought the "cedar mold" into disrepute can be solved by embedding the mesh in preplaced mortar layer by layer as described later. Even so, a wood lining in the bilge is not desirable, so another method is recommended for those areas.

Where a wood lined interior is not required, the choice lies between an integral mold and a precast core, with the former favored for amateur use as it is more closely related to traditional methods using rods.

The precast core method has considerable potential but is still in the conceptual stage, so some experimentation would be needed to adapt it to a particular boat design. It is extremely versatile, especially for lightweight sandwich construction, but there are few guidelines available from prior experience.

All methods start construction by procuring enough sheets of thin plywood or other water resistant panels about 6mm (¼ inch) thick to cover the deck area twice. Place half the panels on a flat surface and the other half on top to form a double thickness. Stagger the joints and bond the top and bottom layers with any low-cost waterproof glue, and paint the top surface with a light color or whitewash. Loft (draw) the hull lines full size on this platform and outline the deck openings.

Prepare patterns for making the permanent bulkheads, hull frames and any deck beams needed. If the closed mould method is to be used, these elements, and possibly the deck will probably be made from plywood. The other methods normally use precast ferrocement.

Instead of preparing patterns, precasting may be done on transparent plastic sheeting laid on top of the lofted lines. As soon as the mortar stiffens, the casting can be pulled aside to make room for the next piece. These precast elements should be reinforced with at least two layers of Weldmesh 1114 or equivalent which should be allowed to project about 10 cm (4 inches) from the edge which joins the hull or deck. This projecting mesh will be bent fore and aft when the precast piece is in place and form the core of the joining fillet. The interior edge of frames and any large bulkhead openings should be reinforced with mild steel rod wrapped with mesh which overlaps the Weldmesh core Figs. 3-4.

Fig. 3. Halfway point in casting bulkhead (same method used to precast deck and frames). A layer of mortar is first spread over outline on casting platform. Metal lath is rolled in and then covered with more mortar as shown here. Man in foreground is placing first of the two layers of Weld mesh to form core of fillet where bulkhead join hull. One more layer of metal lath and mortar will complete the precast phase.

Fig. 4. Bending Weldmesh 1214 about rod curved to deck camber to form core for precast deck beam. Crimping is preferable to cutting in order to flatten bulges.

While the precast pieces are curing, prepare the temporary station moulds from plywood or scrap lumber in the usual manner and set aside clear of the deck platform. Place longitudinal stringers at intervals and heights which will bend up the edges of the deck platform to the design camber. The transom will probably have a similar curvature and may be precast at this point. Flat transoms should have been cast at the same time as the bulkheads. Fill the seams in the deck platform and sand smooth or cover the deck area with any low-cost fabric such as burlap, the back of a discarded carpet or any sheet material which a test panel shows will impart a desirable pattern to the deck surface. Nail a mortar stop around the deck edge and around deck openings. Saturate the surface with a proprietary release agent guaranteed to leave a paintable surface, or use diesel oil fortified with upto 50% of any cheap lubricating oil.

Spread or spray a layer of fairly stiff mortar not over 3mm (1/8 inch) thick and allow to harden but not dry out. Spread another similar layer of mortar and roll in sheets of expanded metal lath or closely spaced wire fabric. The purpose of this mesh layer is only to prevent temperature and shrinkage cracks from appearing on the deck surface later, so orientation of the mesh strips is not critical, but overlap all edges at least one open space.

Place as many layers of Weldmesh as are called for in the design and impregnate with a fluid mortar. The Weldmesh should be cut to reach at least 15 cm (6 inches) outside the deck edge and be bent up to provide an overlap with the hull reinforcing. If ferrocement hatch coamings are to be installed later, the Weldmesh can span the openings in the mortar, then be cut and bent up after demoulding.

The precast deck beams and bulkheads are now positioned and bonded to the deck with a fillet of mortar just covering the spread apart layers of projecting Weldmesh. Any wood bulkheads, frames, or beams used in the closed mould method should also be placed and fastened to the deck at this point.

Precast permanent hull frames and temporary station moulds which outline the shape of the hull are now placed and aligned. In the closed mould method the strips of wood or other material which have been selected for the interior finish are then fastened to the permanent frames and bulkheads and then protected on the hull side with a waterproof coating, preferably a high build elastomeric type. Prefinishing the interior face now may save work later. The closed wood mould need only be used for those parts of the boat requiring that interior finish. Other areas, particularly those below the cabin sole, will be more durable and fire resistant if done by one of the other methods.

In the integral mould method, rod (preferably high tensile) of a diameter less than one fourth the finished hull thickness is run fore and aft, spaced at as wide an interval as will accurately maintain the hull shape. No vertical rod is used, unless the designer insists on it and in relatively flat hull sections the spacing can be greater than in conventional construction. Strips of expanded metal lath or perforated metal are tied to the inner face of the rods and snugged tight. Very few ties are needed compared to those used in conventional construction, only enough to hold the mesh tight to the rods against gentle pressure. Wood battens can be used to back up the mesh in any area where the rods are so widely spaced as to permit sagging.

Gently fill the space between rods with a mortar which has been stiffened with enough ultra lightweight aggregate so it will not fall through the holes in the mesh yet will be firm enough to hold staples after it has hardened. This results in an integral mould which can be encased in mesh on the outside now and on the inside after launching and righting.

In the precast core method, planks running the length of the hull are precast on a flat surface with lightweight mortar sandwiched between strips of mesh. One or two rods may also be embedded in the plank if needed. Width and thickness of the planks will depend on the size and curvature of the hull. The planks need only be strong enough to span the gap between station frames and support one layer of laminate, so a wide range of rigid plastic foams or light weight aggregates could be used. One might also experiment with sawdust and cement or with bamboo either whole or split. When structurally weak materials are used for the core of the planks, strips of Weldmesh should be molded in or inserted between the planks for shear ties (see Fig. 5-8).

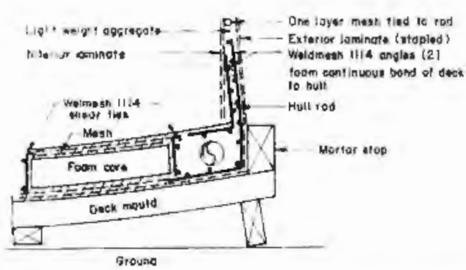


Fig. 5. Hull-deck joint, Integral Mould Method.

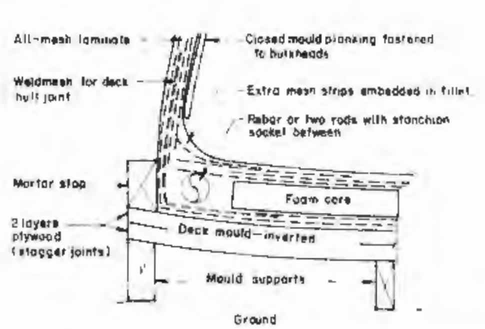
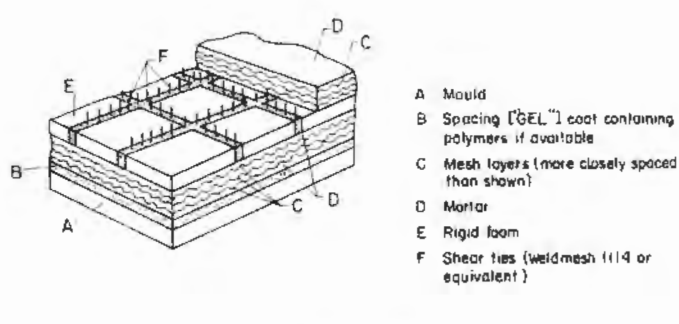
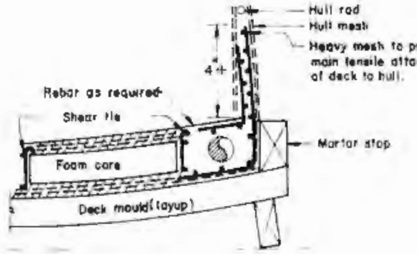


Fig. 6. Cross-section of deck-hull, Closed Mould Method.

(a)





(b)

Fig. 7. (a) Exploded view of foam core ferrocement.

(b) Cross-section of foam, core deck to integral mould hull. Shear ties and mesh upstand can be made from Weldmesh 1114 or equivalent in boats under 20 m. Rebar at deck edge may be replaced by two rods with stanchion sockets between. Foam core may be replaced by deck beams.

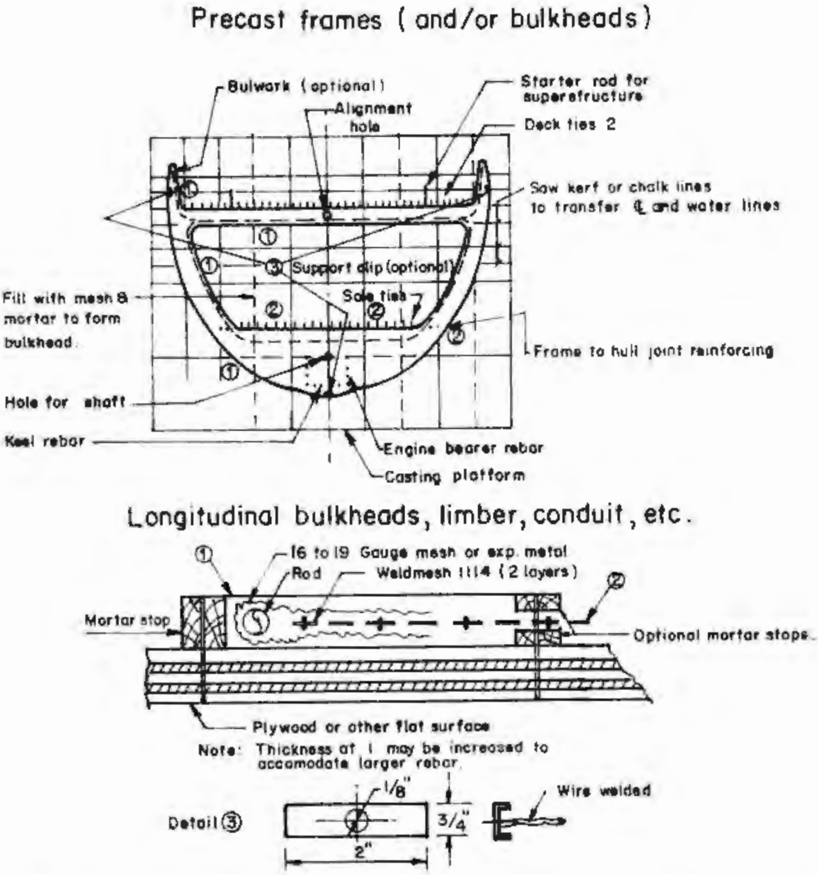


Fig. 8. Details of precast frames, longitudinal bulkheads, limber and conduits.

The precast planks are fitted to the station frames in the same pattern as wood planks would be fitted to a carvel type wood hull. Ties at bow and transom with occasional ties in between should be sufficient to hold the plank against the station moulds. Instead of precasting a garboard plank to fit the keel, it may be simpler to fill that area with solid concrete.

As soon as the closed mould, the integral mould, or the precast planks are in place, a thin layer of high strength mortar is brushed or sprayed on the surface and strips of expanded metal lath are pressed into it and stapled. The preferred pattern is to run the strips about 45 degress on the diagonal with the second layer at 90 degrees to the first. Do not overlap any mesh except along the keel and stem where the extra thickness is needed for impact resistance. Each strip and each subsequent layer must be embedded in wet mortar with no dry spots under any part of the mesh.

While the last layer of exterior mesh is being applied, call in a professional plasterer to apply the finish coat which should not be more than 3 mm (1/8 inch) thick. Tell the plasterer to provide a smooth but slightly rough surface which will make a good bond with any hull coating to be applied later. A slick steel trowel finish needs to be sanded or etched with phosphoric acid before paint will adhere well. Phosphoric acid is also useful for treating rust spots. Never use hydrochloric (muriatic) acid on ferrocement or on any concrete where steel is near the surface.

A word about coatings: Most epoxy formulations resist alkalis, bond well to concrete. and provide watertight, glossy surface. But they become brittle on aging, are considerably stronger than the concrete beneath, and have a much greater coefficient of expansion. They have been successful on hulls which are subjected to only minor temperature changes, but if several coats are built up on decks where daily temperature variations may be extreme, a shear failure can occur in the concrete below the bond line. If an epoxy is needed on deck for its adhesive qualities, it should be a thin coating followed by a tougher, more flexible paint such as a urethane.

As soon as the exterior mesh is cemented in place, work can start on the interior. The bulkhead to hull joint should be filled with mortar up to about the waterline, leaving overhead work until the hull is upright. The Weldmesh projecting upwards from the deck should be encased in at least two layers of mesh embedded in mortar.

After the hull is upright, the interior laminate is completed and the keel is poured in layers heavily reinforced with rod. Short lengths of rebar, strap, and angle iron are sometimes available from steel fabricators at scrap prices, and their elongated shape will arrest cracking much better than punchings or pellets. Ferrocement is an excellent choice for cabin soles and for integral tanks to hold water, sewage, and diesel fuel, although the latter requires special construction techniques and sealing methods to prevent leaks.

The recommendations in this article have been stated in general terms because it is difficult to be specific without a particular design in mind and without knowing what materials are available at the builder's site. Even with all that information at hand it is not possible to say with certainty which of the three building systems outlined here will be the most efficient. Each can be made to work, but some designs may be more easily constructed by one method than by the others. It is conceivable that all three methods might be used during the building of a single boat.

REFERENCES

1. IORNS, M.E., "Fibersteel", Journal of Ferrocement, Vol. 4, No. 5, August/September 1975, pp. 13-21.
2. IORNS, M.E. and WATSON, L.L., "Ferrocement Boats Reinforced with Expanded Metal", Journal of Ferrocement, Vol. 7, No. 1, July 1977, pp. 9-16.
3. IORNS, M.E., "Cost Reduction and Quality Control in Ferrocement and Marine Concrete", Proceedings of the November 1979 Concrete Ships and Floating Structures Convention in Rotterdam, published by Thomas Reed Publications, 36/37 Cock Lane, London ECIA 9BY, U.K. and reprinted in the Journal of Ferrocement, Vol. 10, No. 1, January 1980, pp. 11-17.
4. SAMSON, J. and WELLENS, G., "How to Build a Ferrocement Boat", Samson Marine Design Enterprises, Richmond, British Columbia, Canada, 1968.
5. DAY, J., "New Boats: A Concrete Example", Lakeland Boating, Ann Arbor, Michigan, January 1969, pp. 22-24.

6. DINSENBACHER, A.L. and BRAUER, F.E., "Material Development, Design, Construction and Evaluation of a Ferrocement Planning Boat", Marine Technology, Vol. 11, No. 3, July 1974, pp. 277-296.
7. HARTLEY, R.T., "Hartley's Ferro-Cement Boatbuilding". Broughtwood Printers, Auckland, N.Z., 2nd edition, January 1973.
8. BENFORD, J.R., "Practical Ferrocement Boatbuilding", International Marine Publishing Company, Camden, Maine, 3rd edition, June 1972.
9. SHALOM, R. and RAPHAEL, M., "Influence of Sea Water on Corrosion of Reinforcement", ACI Journal, Proceedings, Vol. 55, No. 12, June 1959, pp. 1251-1268.

Light-Weight Ferrocement Yacht – Criteria, Construction and Service Experience

V. Barberio*

This article describes the design consideration, construction and materials technology adopted for the Maty 1st, a pleasure yacht that has undergone 4 years of successful navigation and marine trials. The hull is constructed in a light-weight ferrocement composite that consists of an exterior sheating of epoxy-glass and an interior coat of epoxy resin. The sandwiched ferrocement laminate consists of several layers of mesh reinforcement and a puzzolona cement based matrix that also contains foamed clay, sand, asbestos fibers and quartz powder. Service experience has proved that the composite meets all the functional and structural requirements for boat hulls and other larger floating structures. It has been concluded that the composite holds a great potential for the construction of hulls and floating platforms.

LIST OF NOTATIONS

i_f = working reinforcement index = $S_s + V_l$ (concept to be as yet perfected)
K = dimensionless coefficient that varies inversely with fiber diffusion ≥ 1
S_s = total specific area cm^2/cm^3
V_{cr} = critical fiber volume (dimensionless)
V_f = volume fraction of fibers (dimensionless
V_l = volume fraction of fibers in the loading direction (dimensionless)
γ = weight of the materials (kg/m^3)
$\gamma_{M/S}$ = weight of the matrix per unit laminate area (kg/m^2)
$\gamma_{M/V}$ = weight of the matrix per unit volume of the composite (kg/m^3)
$\gamma_{S/S}$ = weight of steel per unit laminate area (kg/m^2)
$\gamma_{S/V}$ = weight of steel per unit volume of the composite (kg/m^3)
σ_{mu} = Rupture stress of the matrix in tension (kg/cm^2)
σ_{fu} = yield stress of the fibers (kg/cm^2)

INTRODUCTION

The boat Maty 1st is a pleasure yacht, sail-rigged with an auxiliary motor, having the following features that were actually measured after contruction:

Length (overall)	8.88 m
Buoyant length	7.30 m
Maximum beam	3.20 m
Draft	1.40 m
Displacement	6.00 m.t.
Power (diesel engine)	13.00 h.p.
Standard sail area	45.00 m^2
Ballast	1.50 m.t.

Designed in 1974, the primary object of the study was to observe the in-service performance of a composite laminate hull made from epoxy-glass and ferrocement.

* Consulting Engineer, Strutture Construzioni Idrauliche, Via L. di Breme 94, 00137 Roma, Italy.

DESIGN CONSIDERATIONS

Like ordinary reinforced concrete ferrocement too uses brittle cement based matrix that is prone to cracking under tensile loads. Although the crack arresting mechanism of ferrocement sections under tensile or flexural stresses is markedly superior than ordinary reinforced concrete, for boat hulls it is imperative that stresses as far as possible be compressive. This is mainly because cracks could initiate local corrosion of reinforcing steel and thus threaten the structural integrity of the hull. For the stresses (in-service) to be predominantly compressive, the hull profile should be compoundly curved in all the three fundamental directions.

The compoundly curved hull can thus be analysed as a shell [1]. The structural behaviour in the three principal directions is different because it is a function of the radii of curvature along these directions. The load shared by a section with a smaller radius of curvature is greater than that of a section with a larger radius of curvature. At the same time, from the naval architecture point of view, it is desirable that resistance to propulsion be minimum for economical operation of the boat. It is, hence, clear that frames along the transverse directions have to be strong so as to take a larger share of the load as they have a substantially smaller radius of curvature as when compared to the longerons (sections along the length of the vessel).

With boats that exceed the lengths of 15-20 m, as specified by the Lloyds Register of Shipping, there is a transition of shape from the one shown in Fig. 1 to the one shown in Fig. 2. As a result of this transition boat hulls longer than 15-20 m are subjected to torsional stresses along the longitudinal section in addition to bending and compressive stresses.

With the use of pipe frames as transverse and longitudinal stiffeners, reasonable consideration is to be paid to the membrane effect when external loading against doubly curved shell parts in the hull bottom and sides, is largely transferred as compressive stress in the laminate (Fig. 3) In such cases the ferrocement panel excellently acts as a shell rigidly supported at these edges of stress concentrations. The Det Norske Veritas [2] in an attempt to formulate rules for ferrocement hulls, rightly grants a shape premium that allows a reduction of the hull thickness (Fig. 4), although it inexplicably cancels this allowance by a second limiting formula. In any case the shape does allow for a limited capacity to take on tensile stresses even at reduced hull thicknesses [3-4].

Based on this design philosophy the following are the structural framing specifications of Maty 1st:

Spacing of transverse frames	: 0.50 m
Transverse frames (galvanized steel pipe)	: 2.67 cm ϕ, 0.23 cm thick
Keel longeron (galvanized steel pipe)	: 4.82 cm ϕ, 0.29 cm thick
Spacing of longitudinal frames	: 0.75 m
Longitudinal frames (galvanized steel pipe)	: 1.70 cm ϕ, 0.20 cm thick
Thickness of ferrocement laminate	: 1.80 cm

MATERIAL TECHNOLOGY

The design of a vessel is greatly influenced upon, by the choice of the material that constitutes the hull. Essentially, ferrocement can be identified as a composite made up of finely dispersed steel reinforcement and a cement based matrix. Compared to other boat-building

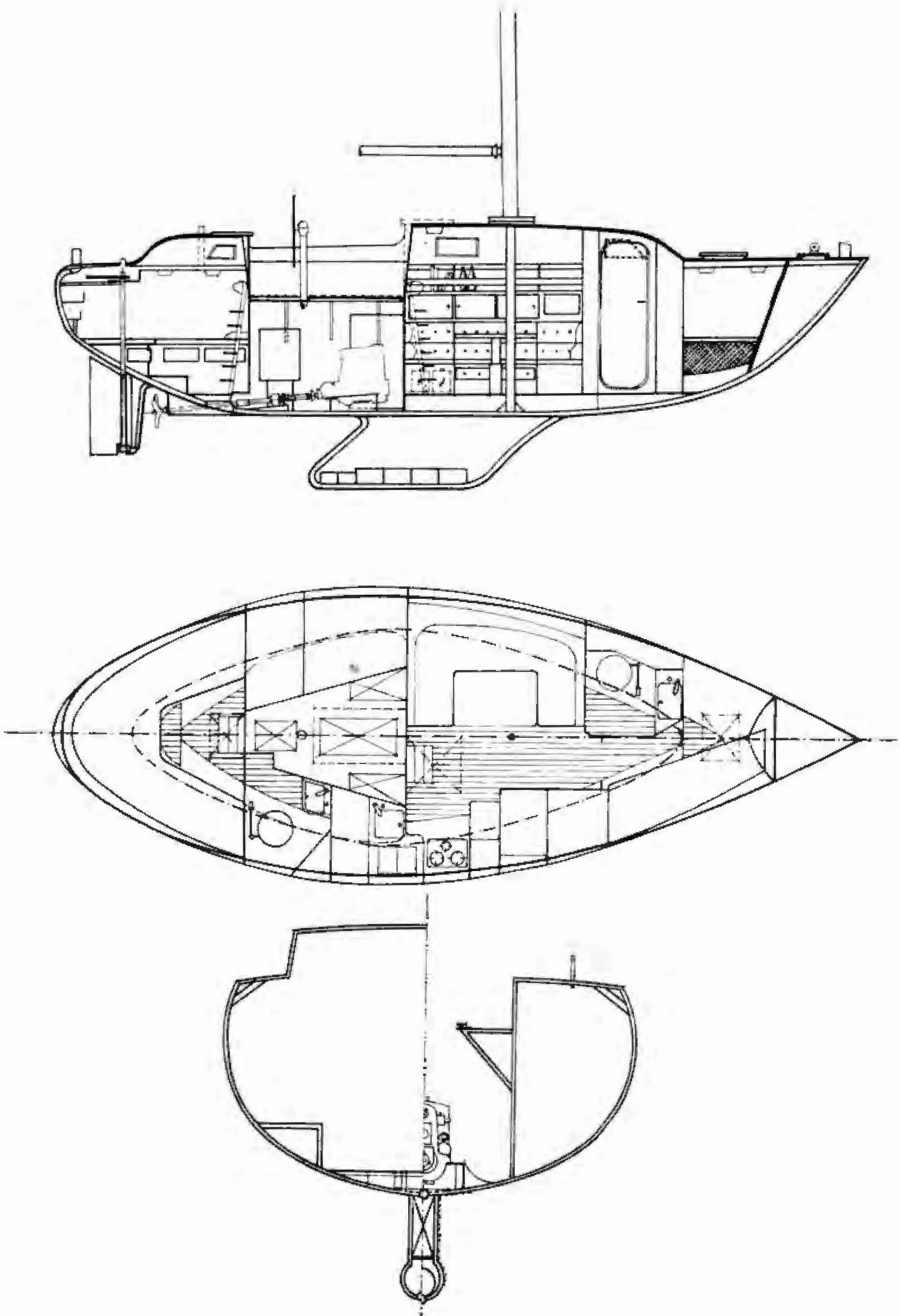


Fig. 1. The yacht "MATY IST"—Typical sections. Note that the surfaces are curved in all the directions.

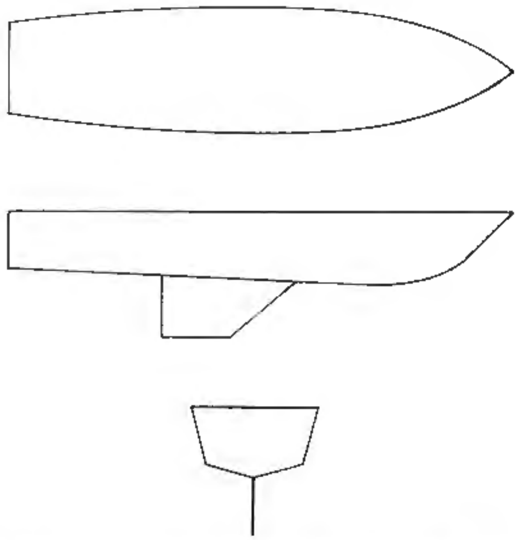


Fig. 2. Unsuitable shapes for ferrocement. If adequately reinforced and corrugated the limitations vanish, but then the weight is increased.

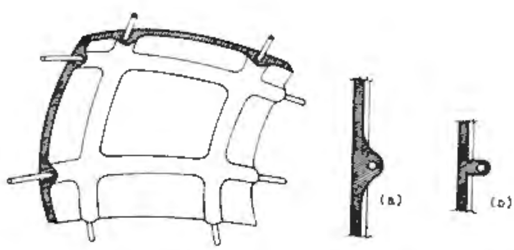


Fig. 3. Single panels of ferrocement constitute curved plates firmly fixed at the joints and filleted to the structural skeleton. Scheme "a" is more suitable than scheme "b".

$$F = \left(1 - \frac{f_1 + f_2}{2\,S_1}\right)\left(1 - \frac{f_3\ f_4}{2\,S_2}\right) = 0.7$$

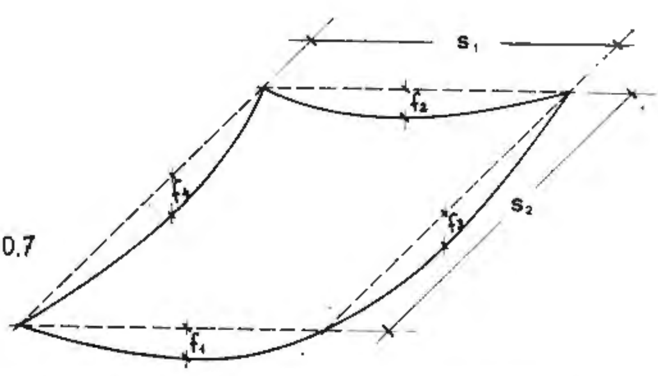


Fig. 4. The correction factor for laminate thickness as suggested by Det Norske Veritas.

materials ferrocement is heavier. Any attempt to reduce the weight would, hence, have to consider the individual and composite behaviour of its two basic components.

Acceptable definitions of ferrocement imply that only beyond a certain threshold of steel content and dispersion does the material enjoy the merits of the often claimed superior engineering behaviour. It can be defined mathematically as,

$V_f \geq KV_{cr}$, where all the notations used are defined earlier.

V_{cr} is a ratio of the ultimate properties of the two components. With the use of high tensile steel to maintain a specified volume content of steel it is, hence, necessary to improve the dispersion and quality of mortar.

If one assumes a σ_{mu} of 50 kg/cm^2 and σ_{fu} of 2,200 kg/cm^2 one obtains

$$V_{cr} = \sigma_{mu}/\sigma_{cr} = 50/2{,}200 = 0.022$$

Adopting $K = 2$, gives $V_f = 0.044$ which is equivalent to a steel content of around 350 kg/m^3 (kg of steel per m^3 of composite) which is in good agreement with the minimum limit specified by Nervi for ferrocement construction.

It is evident that with other types of mesh (configuration as well as quality), both the values for K and of V_{cr} change. For a more uniform distribution of fibers thus, the use of mesh reinforcement (continous fibers) could be complemented with discrete steel fibers in the mortar.

On the other hand, the composition of the mortar could be improved as well, to improve the overall performance of ferrocement. The attempt to reduce weight should not be at the cost of strength or workability.

Based on these considerations, the hull was composed of several layers each with a distinct task to perform. As a composite they were intended to meet all the structural and functional requirements of a boat hull.

(a) An exterior layer of epoxy resin reinforced with a cloth made of glass fibers, weighing 0.20 kg/m^2.

(b) Four layers of welded square mesh (galvanized) with 0.9 mm ϕ wires at 1.2 cm centers (both ways).

(c) One layer of welded square mesh (galvanized) with 2.7 mm ϕ wires at 5 cm centers (both ways).

(d) Three more layers of mesh as described in (b).

(e) One layer of diluted epoxy resin.

For the deck and the super structure, layer (b) contained one less layer of mesh than that provided for the hull. For the hull bottom, the interior coat of (e) was replaced below the water-line by a layer of epoxy-glass as stated in (a), Fig. 5.

The cement based matrix encasing layers (b), (c) and (d) included foamed clay (to reduce weight), sand, asbestos fibers (to improve the tensile behaviour of the otherwise brittle mortar 5% by volume), quartz powder (to improve the aggregate gradation thereby reducing risks of presence of strength impairing voids, 3% by volume) and admixture, (to improve the workability of the mortar while maintaining a reduced water-cement ratio, 0.14% by volume).

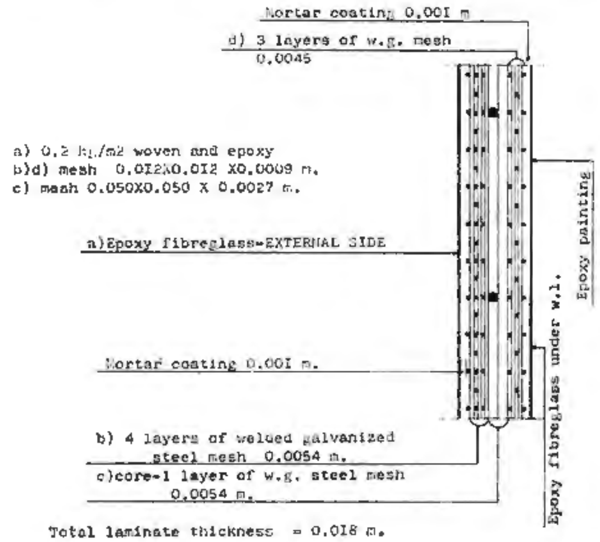


Fig. 5. Section of the ferrocement/epoxy glass laminate showing reinforcing details.

The ratio of cement to inert materials was around 900 kg/m^3 (900 kg of cement per cubic meter of inert materials) while the water-cement ratio was maintained at 0.4 (by wieght).

The bulkheads around the motor pit were built using polymer impregnated mortar (only as a trial experiment). The internal layer of the stern cabin was built in polyester instead of epoxy-glass mainly to reduce the cost (by as much as half).

Table 1 gives the essential physical properties of the composite material. Positive benefits of using such a laminate are discussed in the following sections. Fig. 6 shows staggering of layers of mesh adopted to reduce the effective opening size as well as reducing the overall thickness of the hull.

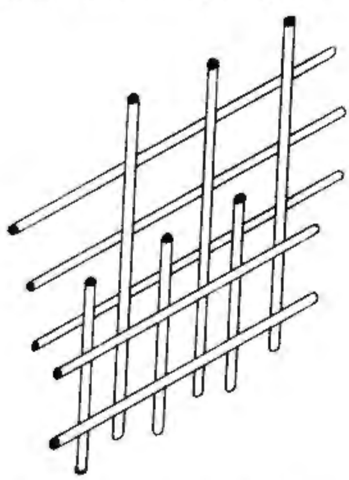


Fig. 6. A possibility for reducing the thickness of the section by staggering of meshes prior to placing onto the skeletal steel.

Table 1. Characteristics of ferrocement laminate.

Component	S_S cm^2/cm^3	V_l %	V_f %	KV_{cr} %	$i_f = S_s + V_l$	$\gamma_{s/s}$ kg/m^2	$\gamma_{S/V}$ kg/m^3	$\gamma_{M/V}$ kg/m^3	$\gamma_{M/S}$ kg/m^2	γ kg/m^2	t mm
Hull											
External layer	2.62	2.95	5.90	2.85	5.57	3.04	475	1800	11.52	13.56	6.4
Core layer	0.63	2.12	4.24	2.85*	2.75	1.85	342	1800	9.23	11.08	5.4
Internal layer	2.46	2.76	5.52	2.85	5.22	2.28	414	1800	9.90	12.18	5.5
Epoxy glass + ...	–	–	–	–	–	–	–	–	–	2.18	0.7
										39.00	18.0
Deck, Bridge House											
External layer	2.46	2.76	5.52	2.85	5.22	2.28	414	1700	9.35	11.63	5.5
Core layer	0.63	2.12	4.24	2.85	2.75	1.85	342	1700	9.18	11.02	5.4
Internal layer	2.46	2.76	5.52	2.85	5.22	2.78	414	1700	9.35	11.63	5.5
Epoxy glass + ...	–	–	–	–	–	–	–	–	–	2.18	0.7
										~37.00	17.1

* Due to the fact that fiber diffusion is low, V_{cr} should be much greater

Note : 28 days compressive strength of mortar = 400 kg/cm^2.

SERVICE EXPERIENCE

The boat has been navigated for about 4 years, both in the summer and winter and has been exposed to adverse sea conditions.

In the summer of 1976, during a storm off the Eolian Isles, the craft had to confront the sea with its engine out of service, its boom broken and its spanker lying against the shrounds. Given the sea condition and exceedingly violent winds, the chances of navigating the boat were nil. A French container freighter sheltered the boat for sometime, allowing emergency repairs to be carried out. The maneuver caused a collision of the yacht with the enormous French vessel. However, beyond some creaking of the hull there were no major dents or other damages, and it never shipped water.

In the winter of 1979 during a storm that played havoc along the coast of southern Italy, causing loss of many sea-going crafts, the boat collided with another yacht that had broken its moorings. Damage was sustained only by the wooden waveboards. Like in the earlier accident, there was absolutely no damage to the ferrocement hull.

The yacht crew wholly amateurs have found themselves in the worst of the sea conditions at many other times and yet the Maty 1st has come through these situations unscathed. It, even today is in excellent shape and its hull structurally strong. This leads one to believe that

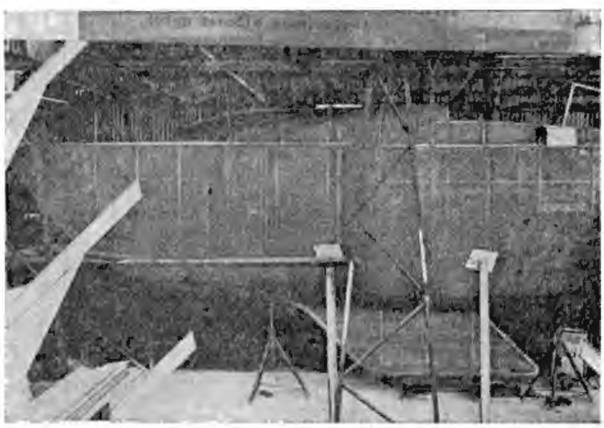


Fig. 7. The hull under construction, Note the structural continuity.

Fig. 8. The hull and the fitting-supports are built at the same time.

the materials and the construction technology (Figs. 7-10) adopted to be sound, and will serve as an invaluable experience for other marine designers as well.

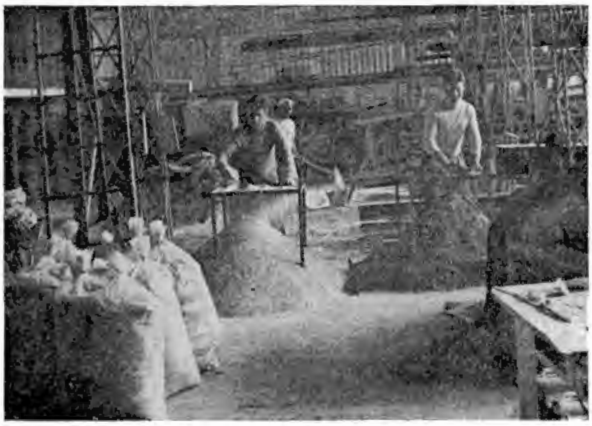


Fig. 9. Sand-grading.

Fig. 10. The yacht "Maty 1st" under sails.

CONCLUSIONS AND POSSIBILITIES FOR THE FUTURE

Study of the engineering behaviour of a composite laminate used for Maty 1st is underway. This along with similar studies on other composite laminates would in all likelihood lead to the evolution of a modified variety of ferrocement that offers greater resistance to adverse marine loading conditions and at the same time is lighter than conventional ferrocement. Quantitative and qualitative studies on polymer impregnated ferrocement, light-weight fibrous ferrocement and composite laminates would identify successful possibilities for the future.

Study of a shape suitable to such composites, that allows maximum structural resistance and at the same time performing well hydrodynamically would open new avenues for design.

For boat hulls of lengths below 15 m, use of a section similar to that shown in Fig. 11 is tentatively proposed, based on the excellent service experience gained from the Maty 1st, and on selective laminate criteria.

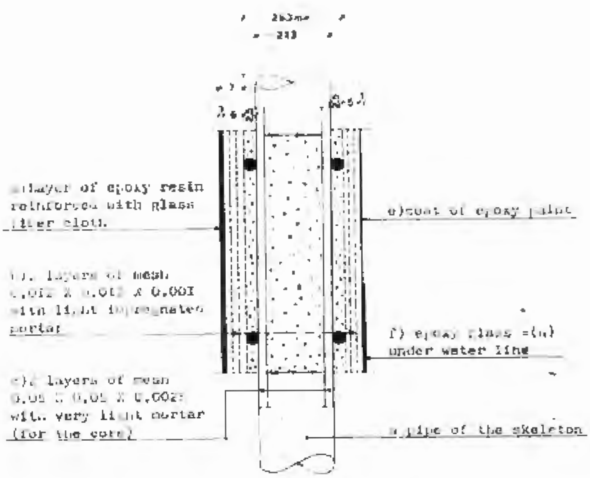


Fig. 11. A proposed section of a sandwich ferrocement section using high tensile steel wire.

Use of expansive cement for ferrocement constructions should be studied. Technically these would induce a small amount of prestressing and reduce risks of micro-cracking. Alternatively high tensile steel wires could be used to induce a small prestressing force. The hull can thus be reduced in thickness and, hence, in weight.

Floating islands and platforms, wharfs, pontoons for aquaculture, and transport vessels for substances stored at very low temperatures are envisaged applications for the future besides work boats, fishing vessels, barges and pleasure crafts.

In conclusion it can be said that light-weight ferrocement composites, if well designed and properly constructed can be cost competitive with many other conventional methods of marine construction, while meeting all the structural and functional requirements. The technology offers enough flexibility for it to be made labour intensive or capital intensive depending upon the need and conditions at any particular location.

REFERENCES

1. SCRIVENER, J.C. and CARR, A.J., "Ferrocement Boat Hull Analysed by Finite Element Method", FAO seminar on the design and construction of ferrocement fishing vessels, October 1972, Wellington, New Zealand, 17 pp.
2. DET NORSKE VERITAS, "Tentative Rules for the Construction and Classification of Ferrocement Vessels", Det Norske Veritas, Norway, 1974, 77 pp.
3. BARBERIO, V., Present Day Treatment of Ferrocement in Boat Construction", (in Italian), L'Industria Italiana del Cemento, Giugno 1972.
4. BARBERIO, V., "Boats in Ferrocement at Wellington", (in Italian), L'Industria Italiana del Cemento, Giugno 1974.

Preliminary Testing for a Composite Ferrocement/Fer-a-lite/Fibreglass Yacht Hull

David C. Lowry*

The hull of a shallow-draft yacht is being built with a conventional steel armature plastered on the outside with cement. The inside will be back-plastered with a mixed polyester resin and light-weight filler ("Fer-a-lite") and covered with glass fibre cloth. Test panels show that the composite to be adopted is about 75% of the weight of pure ferrocement and about twice as strong. This composite has application where the cost of the hull is a small proportion of the total cost of the vessel and where saving hull weight is important.

INTRODUCTION

The author is building a Hartley-designed 13 metre (43 foot) "Fijian" ferrocement yacht. Having chosen the shallow-draft bilge-keel option, there has been emphasis on trying to restore the yacht's righting moment. One tactic has been to save weight in the deck (by adopting Hartley's plywood deck option) and another has been the lowering of the centre of gravity of the ballast (by using external lead ballast). A third tactic was to examine Fer-a-lite; a light-weight hull material described enthusiastically by Bingham [1]. This article describes some experiments with it.

Fer-a-lite is a low density filler formulated by Aladdin Products in U.S.A. It is mixed with polyester resin to obtain a paste which is trowelled onto the steel mesh armature in place of cement mortar. Among its advantages are:

(a) There is a great saving in hull weight.
(b) There is no wet cure to worry about.
(c) It can be trowelled on in small batches by an amateur.

When the author first investigated the material it seemed to have three disadvantages:

(a) It is difficult to obtain a smooth surface because of its stickiness.
(b) It is expensive compared with cement.
(c) Its strength is not well documented.

Test panels were cast to test whether Fer-a-lite produced a hull with strength at least equal to conventional ferrocement. The first three panels constructed (Panels A, B and C) suggested that it did not, but a fourth panel (D) involving cement, Fer-a-lite and fibreglass was much superior to either cement or Fer-a-lite alone.

TEST PANELS

Four test panels were prepared with a steel armature similar to that used in the hull. It consisted of high tensile steel rods (5 mm diameter) at 50 mm spacing, diagonals of 3 mm wire at 75 mm spacing, and 5 layers each side of 22 gauge galvanized hexagonal half-inch mesh.

* Lowry and Associates, Kalamunda, W.A., Australia, 6076.

Panel A was plastered with Fer-a-lite (one bag of filler to 6 pints (3.4 litres) of prepromoted orthophthallic polyester resin). Newspaper was laid over the top to aid smoothing the surface.

Panel B simulated a hull plastered on the outside with cement and back-plastered on the inside with Fer-a-lite. The panel was plastered with cement (see below) and after curing under water and drying, it was back-plastered with Fer-a-lite. The cement mortar penetrated about two thirds of the way through the armature.

Panel C was plastered conventionally with cement mortar. The mix consisted of 10 kg cement, 0.8 kg ground blast furnace slag, 18 kg sand (Readymix Ltd. 's sand blasting sand; it had been washed screened and dried), and water with a trace of chromium trioxide. The mortar was mixed in a conventional rotary mixer with a water/cement ratio of about 0.45. The panel was cured under water for 25 days.

Panel D simulated a hull plastered on the outside with cement, then back-plastered with Fer-a-lite and immediately covered with fibreglass. The armature was plastered with cement (about two-thirds penetration), cured under water, and dried. The panel was back-plastered by trowelling with Fer-a-lite which was covered immediately with fibreglass. The fibreglass consisted of 3 layers of chopped strand mat (225 g/m^2) alternating with 3 layers of woven roving (600 g/m^2), making a total of 2.475 kg/m^2 (8.0z. per sq. ft.).

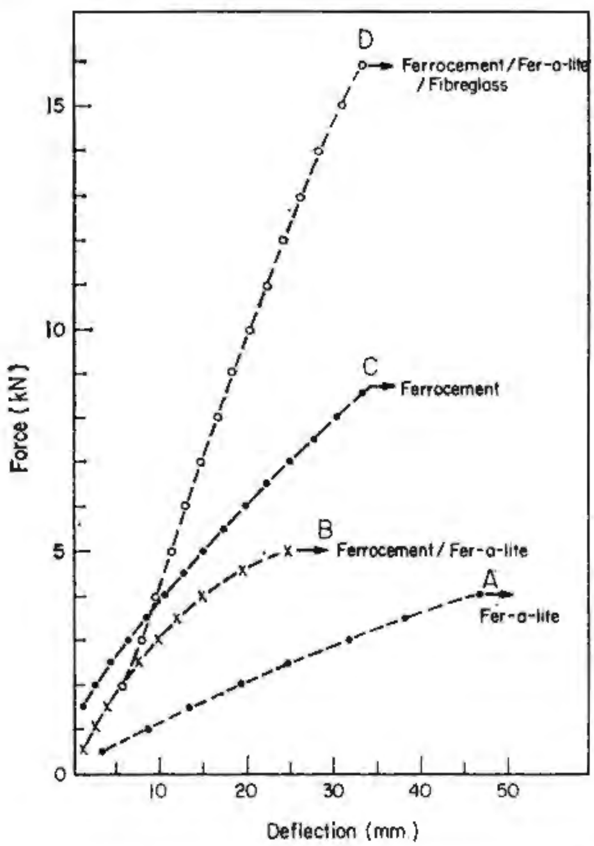


Fig. 1. Force/deflection diagram for panels tested as centrally loaded beams.

The panels were trimmed to 360×800 mm and tested by the Materials Testing Laboratory of the Engineering Dept., University of Western Australia. They were tested as beams (span 700 mm) and centrally loaded until failure. Panels B and D were loaded on the cement face to simulate force on the outside of the hull. Details of the panels are given in Table 1 and load/deflection results are plotted in Fig. 1.

TEST CUBES

Cubes (70 mm along edges) were cast in Fer-a-lite (as used in panel A) and cement (panel C) to determine the compressive strength of the two mortars. The results are listed in Table 1.

IMPACT TESTING

Primitive impact tests were made on the panels to compare the relative damage that could be expected from localised impact on the hull. The ends of the panels (360 mm wide) were supported on two rows of bricks transverse to the longitudinal reinforcement to give as 360 mm span. A steel weight (17 kg) with a spherical striking surface of 140 mm diameter was dropped 96 cm onto the centre of the supported area. The damage after three blows is described in Table 2.

DISCUSSIONS

(1) The deflection tests show that the Fer-a-lite panel A can bend further than the cement panel C before rupture, but rupture occurs at only about half the load. Panel B has intermediate characteristics. However panel D was twice as strong as the cement panel C and was about 75% of the weight.

(2) The compressive strength of the Fer-a-lite measured here (33.7 MPa ; 4,900 p.s.i.) was less than half that measured for the cement (74 MPa; 10,700 p.s.i.). Bingham [1] reports the compressive strength of Fer-a-lite as 8,000 p.s.i. This difference could possibly be attributed to variations in the mix as well as the age of the specimen.

(3) The impact test show that the cement/Fer-a-lite/fibreglass panel D is superior in impact resistance to pure Fer-a-lite A and greatly superior to cement C.

(4) These tests do not necessarily condemn pure Fer-a-lite as a hull material but they do suggest that the whole hull should be designed taking into account the much lower density and somewhat lower strength. It would appear to be unwise simply to replace the cement with a weaker material when the overall weight (about 17 tonnes in the case of the "Fijian") must be maintained to get the boat to float on its designed water line.

(5) The composite cement/Fer-a-lite/fibreglass is suited to upright truss frame style of construction where fibreglass can be laid on the inside of the hull. Presumably it would be impossible to fibreglass the overhanging outer surface.

(6) The composite makes good use of the materials; the cement being on the outside where its abrasion resistance is valuable and where it can be trowelled fair. The resin is on the inside, protected from ultraviolet light.

Table 1. Data on test panels and cubes.

	A	B	C	D
Composition of mortar	Fer-a-lite	Cement/Fer-a-lite	Cement	Cement/Fer-a-lite/fibreglass

Test Panels in flexural test

Dimensions of panel	360 × 800 × 19.5 mm	360 × 800 × 22.1 mm	360 × 800 × 23.6 mm	360 × 800 × 22.4 mm
Weight	6.5 kg	12 kg	17 kg	13 kg
Weight per unit area	22.6 kg/m^2 (4.6 lbs/sq. ft.)	41.7 kg/m^2 (8.5 lbs/sq. ft.)	59 kg/m^2 (12.1 lbs/sq. ft.)	45 kg/m^2 (9.3 lbs/sq. ft.)
Span between supports	700 mm	700 mm	700 mm	700 mm
Ultimate load	4.05 kN	5.05 kN	8.7 kN	15.8 kN
Deflection at ultimate load	47 mm	25 mm	33 mm	34 mm

Test Cubes in compression test

Load	16.5 kN	–	36.3 kN	–
Strength	33.7 MPa (4,900 psi)	–	74 MPa (10,700 psi)	–

Table 2. Results of impact tests. Cumulative damage after third blow.

Panel	Damage on impact side	Damage on reverse side	Permanent deflection	Potential leakage
A (Fer-a-lite)	None visible	Radial cracks all less than 1 mm wide.	About 4 mm	None
B (Cement/Fer-a-lite)	Large crack across panel; cement flaking off impact area	Large crack across panel 2 mm wide; also radial cracks	14 mm	Minor
C (Cement)	Major impact crater 100 mm across and 12 mm deep	Mesh punched out; major spalling of cement over an area 160 mm across	None	Major
D (Cement/Fer-a-lite/fibreglass)	Minor cracking and flaking of cement making a crater 60 mm across and 3 mm deep	Area 140 mm across deflected outwards 3 mm. No cracking of fibreglass, but paleness suggests minor delamination	None	None

(7) Panel B showed that it is difficult to get good penetration when back-plastering Fer-a-lite with a trowel. However Panel D had excellent penetration because the addition of fibreglass involved vigorous rolling with a small roller.

(8) The fibreglass surface of Panel D was much fairer than the surfaces the author achieved with a trowel on either cement or Fer-a-lite. This was partly due to inexperience with a trowel but was also due to the ease of fairing the fibreglass surface with a roller. If the armature is fair, then any lumps of Fer-a-lite between the mesh and the fibreglass can be smoothed out with the roller used for impregnating the cloth with resin.

(9) The bonds between the three layers of Panel D were very good. The contact between the cement and Fer-a-lite was intensely crenulated because the mortar had been forced through the mesh, while the joint between the Fer-a-lite and fibreglass was continuous polyester resin.

(10) It is interesting to speculate on the merits of a hull plastered both sides with Fer-a-lite and fibreglass. It would involve rolling the hull during construction. It would in effect be fibreglass sandwich with a Fer-a-lite and steel core.

(11) In this project it was assumed that the conventional ferrocement hull was adequately strong, and the aim was to improve the righting moment without loss of hull strength. Thus the hull has been back-plastered with cement below the level of the cabin sole where weight is advantageous and the composite of Panel D will be used only above that level.

(12) The main drawback to the Panel D layup is the added cost when compared with back-plastering with cement. The extra cost in 1979 prices for covering about 80 m^2 of hull is expected to be about A$2000 - 3000 with a further A$ 1000 needed for additional lead ballast to compensate for the saving in weight. It was noted with Panel D that after failure under flexure there was no rupture of the fibreglass. Presumably the cost could be reduced by reducing the amount of fibreglass until it failed at the same time as the cement.

CONCLUSIONS

A composite of cement/Fer-a-lite/fibreglass produces a material that is lighter and stronger than if the same armature was plastered solely with cement. Because of the extra expense and labour involved this approach probably has application only where saving of hull weight is important and where the extra cost of the hull is not a large proportion of the total cost of the vessel.

ACKNOWLEDGEMENTS

I gratefully acknowledge the help of Mike Neal of Cockburn Cement (Western Australia) for advice and for testing facilities. I also thank W. Johnston of Canberra who provided very useful advice on the use of resins and fibreglass on ferro-cement hulls.

REFERENCE

1. BINGHAM, B., "Ferro-cement-design, techniques and application". Cornell Maritime Press, Cambridge, Maryland, U.S.A., 1974, 444 pp.

The Use of High Tensile Wire Reinforced Fibrous Ferrocement in Marine Applications

D.J. Alexander*

High tensile wire reinforced fibrous ferrocement is a comparatively recent variation of the traditional mesh reinforced ferrocement. The material has been developed by the writer's practice and has been the subject of several articles published, in which the theory underlying its practice is given. This article describes the applications of the material in the marine field to which it is singularly appropriate on a cost benefit basis, and in its resistance to corrosion which is a property it shares with the family of ferrocements.

INTRODUCTION

The essential difference between mesh reinforced ferrocement, with which most readers will be familiar, is the replacement of multi layers of fine mesh with a single layer of coarse high tensile wire (UTS 1,800-2,050 MPa) and wire fibre. All the strength of the reinforcement is concentrated at the outer layer and is therefore a great deal more effective than wire, and mild steel wire at that (480-560 MPa) which is located at diminishing lever arm and diminishing stress levels. The crack regimes are similar in both forms of ferrocement.

Mesh reinforced ferrocement requires an average 25% by weight of steel in the composite compared with 12% with high tensile wire reinforcement inclusive of wire fibre.

This point of comparison was dealt with in the paper "High Tensile Wire Reinforced Fibrous Ferrocement—Its Theory and Practice", published in the April 1980 issue of the Journal of Ferrocement. A table from that article is presented here to highlight the effectiveness of using fibrous ferrocement.

Table 1. Comparitive Study of Mesh Reinforced Ferrocement With High Tensile Wire Reinforced Fibrous Ferrocement.

Property	Mesh reinforced ferrocement	High tensile wire fibrous ferrocement
Yield moment capacity	7,950.00 lb.in.	30,674.00 lb. in.
Working moment	5,110.00 In.in.	10,000.00 lb. in.
Weight of steel employed per sq.ft	2.88 lb.	2.82 lb.
Cost of steel employed per sq.ft	\$2.56	\$1.02
Cost of equivalent strength steel (nearest size)	\$3.85 for $\frac{3}{8}''$ plate	\$5.00 for $\frac{1}{2}''$ plate
Comparative cost of ferrocement per sq.ft	\$2.84	\$1.31

(Cost data derived from current New Zealand prices as listed in [1]).

* Alexander and Poore Consulting Engineers, Auckland, New Zealand.

Both the fibre and the high tensile wire are purchased at approximately US$800.00 per tonne while the galvanised mesh commonly employed in ferrocement costs in the vicinity of US$2,000.00 per tonne. So there is both a weight and cost advantage accruing to high tensile wire reinforced fibrous ferrocement which is decisive in its effect on total material requirements.

METHODS OF CONSTRUCTION

The method of construction of fibrous ferrocement vessels does not vary greatly from those used in mesh reinforced ferrocement ones, except to adopt the technique to the more open reinforcement assemblages.

The size of high tensile wire used is either 2.5 mm or 2.0 mm pitched at 25 mm centres which replaces the multiple layers of wiremesh which usually has a 12 mm aperture and uses 19 gauge wire. The fabrics resulting from the assemblages of these wires are designed to match the calculated service moments in terms of crack width which results in a stress level which is approximately one third ultimate so that the reserve strength of the composite is large.

Boats

In boats the basis of construction is truss framing (as in mesh ferrocement) onto which skeletal steel rods and fabric steel are tied. However, the amount of steel used is substantially less and tieing less frequent so the labour content is reduced. Generally, the exterior of the vessel is completely sheathed after completion of the attachment of the fabric in low cost thin ply sheets which are tied onto the fabric with suitable spacers on the inside face designed to give the correct cover of mortar to the steel. Thereafter, fibrous mortar is applied from inside the hull with the aid of spud type vibrators. The progress of mortaring can be discontinued provided location and restart requirements are closely observed. It is worth commenting here that few types of fibres are suitable for ferrocement work due to balling or uneveness of distribution which is characteristic of many of them.

Upon completion of mortaring the exterior ply is stripped off leaving a virtually finished surface except for cutting back and patching ply tie-back wire points and healing spacer marks preparatory to stoning the surface and painting it. The accompanying photographs clearly demonstrate the techniques described above (Fig. 1-14).

Barges and Pontoons

Barges and pontoons are a special case of marine structures which consist chiefly of flat surfaces. This permits precasting of components usually in the form of prestressed planks of any length and width consistent with handling. These are formed in flat stressing beds and the resulting planks or panels are fingered together at the joints and post tensioned to improve the overall integrity of the vessel. In smaller barges meshing up similar to that used in boats is employed.

Current production of barges and large pontoons use methods akin to mass production in which reinforcing mats are prefabricated, often in 6 m × 6 m size, hundreds of which may be required for a single barge. Planks up to 80 feet long, formed in multiples in a single casting bed 240 feet long are being used in construction of barges and in many cases these represent

Fig. 1. Setting up frames and skeletal steel for 55′ vessel. This and subsequent photos (unless otherwise specified) are taken in the Sabah Shipyard.

Fig. 3. View downshop of progress in the construction of 55′ vessels. A head of these is a 72′ purse seining fishing vessel being scantled.

Fig. 4. Outer ply sheathing being stripped from the hull after casting from interior.

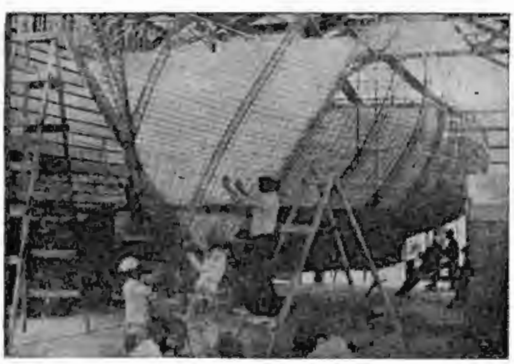


Fig. 2. Progress with fine reinforcement. Vertical steel being placed. Note bulkheads in position.

Fig. 5. Keel area showing ply ready for stripping. Rudder horn bar shown in the plate is cast in fibrous ferrocement.

Fig. 6. Vessel with ply sheathing removed and ready to shift downshop for finishing the super-structure.

Fig. 7. General view of shop showing small vessels being constructed to the side of the main down shop production line.

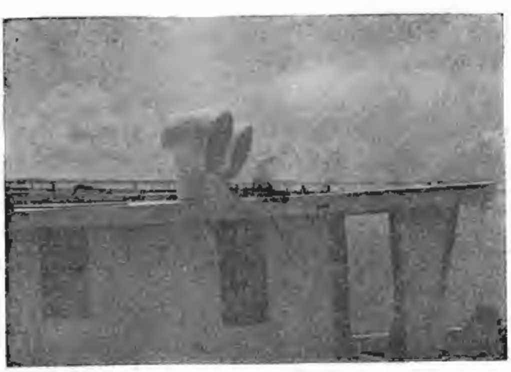


Fig. 8. Detailing of the super-structure in fibrous ferrocement. The vent cowls are formed in fibrous ferrocement.

Fig. 9. A close up of a large vent cowl.

Fig. 10. A finished hull now at launching position.

Fig. 11. A 13 meter fishing vessel recently constucted in New Zealand. These vessels, of which there are several are used in violent ocean conditions. This vessel has already been driven ashore in storm condition and refloated totally without damage although this generally results in total loss for timber or fibreglass vessels.

Fig. 12. A stern view of the vessel (Fig. 11) prior to launching.

Fig. 13. Finished view of a 55′ tug for coastal towing of log rafts.

Fig. 14. A 72′ tug for coastal towing of log rafts and palm oil barges.

the full length of the barge or pontoon under construction. The accompanying photographic record shows a segment of the construction of barges and pontoons (Fig. 15-23).

Journal of Ferrocement : Vol. 10, No. 3, July 1980

Fig. 15. 410 tonne cellular cast palm oil barge now in service for 5 years. A second 500 tonne barge is currently under construction.

Fig. 16. View of a 120 tonne section of a 230′ × 58′ × 10′ floating wharf being constructed in Jakarta. The total weight of the pontoon structure is 840 tonnes. The 72′ shore anchors and access bridges are also cast in high tensile wire reinforced fibrous ferrocement. This structure probably represents the largest marine structure yet undertaken.

Fig. 17. A close up of the pontoon sectional structure prior to casting the deck.

Fig. 18. A close up view of the section jacked off its building slab.

Fig. 19. A view of multiple production of 12 meter self powered barges under consturction in Jakarta.

Fig. 20. A 65 tonne fuel oil barge under construction in Sabah. This is a rib slab design. Hull length is 62′ and features a typical high tensile wire reinforcing lay-up. The barge is to be powered by a 265 HP diesel engine. Duty is coastal and river.

Fig. 21. Depicts the stern section of the fuel oil barge.

Fig. 22. This shows a close up of the ribs and clearly shows the shear steel used to connect these to the hull fabric.

Fig. 23. Typical detail of rib slab construction of 55 tonne dwt. self propelled barges using precast elements by way of bulkheads, ribs and beams. The wire fabric is pre-assembled in 6 meter square fabrics. The current series consists of a group of vessels.

CONCLUSIONS

As a concluding note it has been observed that construction costs would be of the order of 80% of current steel prices and weight surcharge less than 25% This surcharge is not for strength purposes as the flexural strength of the composite far exceeds that of mild steel plate, but to increase the ill defined property of piercing resistance.

It is thought that the future construction should include large tankers using a cellular construction similar to that currently being employed for palm oil tankers of admittedly modest size.

This type of construction leads to a totally unsinkable ship either as its whole or its parts which may result from breakup at sea. Such a construction would be virtually impracticable to achieve in steel.

REFERENCES

1. ALEXANDER, D.J., "High Tensile Wire Reinforced Fibrous Ferrocement—Its Theory and Practice", A Report prepared by Alexander and Poore Consulting Engineers, Auckland, New Zealand, 34 pp.

Skeletal Free Ferrocement for Building Small Craft

G.K. Nathan* and P. Paramasivam**

In this paper, a skeletal free ferrocement suitable for small craft, a method of modification of lines diagrams of a timber hull to that of a ferrocement hull, and results and capability of computerization of stability analysis of the ferrocement hull are presented. Also, this paper includes a brief discussion of the provisional rules for construction of ferrocement boats and construction techniques for building small craft. It is shown that the skeletal free ferrocement meets the strength requirements of Lloyd's provisional specifications. Cost and man-hour estimates for the construction of a ferrocement hull and an approximate cost comparison with other types of construction are given. Viability of the proposed method and use of this type of ferrocement for small boat building have been established by the construction and testing of a 7.01 m (23 ft) sailing boat.

INTRODUCTION

The advantages and use of ferrocement as a material for construction of boats are well documented [1 – 3]. In the last two decades, a few developed countries have increasingly been using ferrocement as a building material for boats of sizes between 10 m and 30m [4]. In developing countries there are different types of boat in use, which are smaller than 10 m length and built with timber. It will be advantageous to build these boats using ferrocement material; and some successful attempts have been reported [5], however, the technique of building small craft is not freely available. The common type of ferrocement has mortar matrix, skeletal steel reinforcement and mainly hexagonal wire mesh to arrest the crack propagation [1]. This method of construction has a major drawback in that it cannot be used in application where a thinner section is desirable to overcome the weight problem for smaller craft. A type of ferrocement without skeletal steel was developed at the University of Singapore, which has only woven square wire mesh. This material could be made with thinner cross sections to obtain the same strength. This paper presents the technique of building small craft using skeletal free ferrocement.

The new type of ferrocement has been extensively tested to ascertain the mechanical properties under tensile, flexural and impact loading, and expressions have been obtained to predict its properties [6, 7]. Using this type of material, secondary roofs, circular and rectangular water tanks [8], sunshade, silos and bus shelter have been successfully designed and tested at the University of Singapore. Also, other methods of predicting mechanical properties of ferrocement have been reported [9]. In this paper the properties of the proposed type of ferrocement vis-a-vis Lloyd's specifications for ferrocement yachts [10] are briefly discussed and their application to small craft have been established by construction and testing of a 7.01 m (23 ft) sailing boat. The method of construction, procedure for transferring lines diagrams of an existing wooden hull to that of a ferrocement hull and some results of the stability analysis are presented. The construction details of a small craft which are different from that of a large ferrocement boat are briefly described. The technique of construction and analysis are illustrated with figures and a cost estimate is given.

* Senior Lecturer, Department of Mechanical Engineering, University of Singapore, Singapore 0511.
**Senior Lecturer, Department of Civil Engineering, University of Singapore, Singapore 0511.

DESIGN OF FERROCEMENT HULL

The design procedures are briefly outlined which can be easily adapted to replace timber with ferrocement as a building material of small craft. This method has the advantage that a proven and available timber hull shape can be readily selected for construction using ferrocement without elaborate design and testing of hull shapes. Also, proven hull shapes may find customer acceptability more readily.

Modification of Wooden Hull

The weight of a hull constructed with ferrocement can be lighter than that with timber when the length of a boat is 10 m or more, even though the specific gravities of ferrocement and timber are about 2.5 and 0.8 respectively, because thicker sections and heavy framework are required for timber hulls to achieve a required strength. This is due to timber having high strength in the longitudinal direction and being discontinuous in the transverse direction. But, for craft of length less than 10 m the opposite is true i.e., timber hulls are lighter than the ferrocement hull. Therefore, when ferrocement is used as a construction material for small craft, the timber hull has to be modified to account for the heavier hull which needs increased displacement, and there are two alternatives possible:

(i) the first is to keep the draught the same by widening the beam about 10% and this value would depend on the length of hull, and

(ii) the second is to increase the freeboard, anticipating a deeper draught.

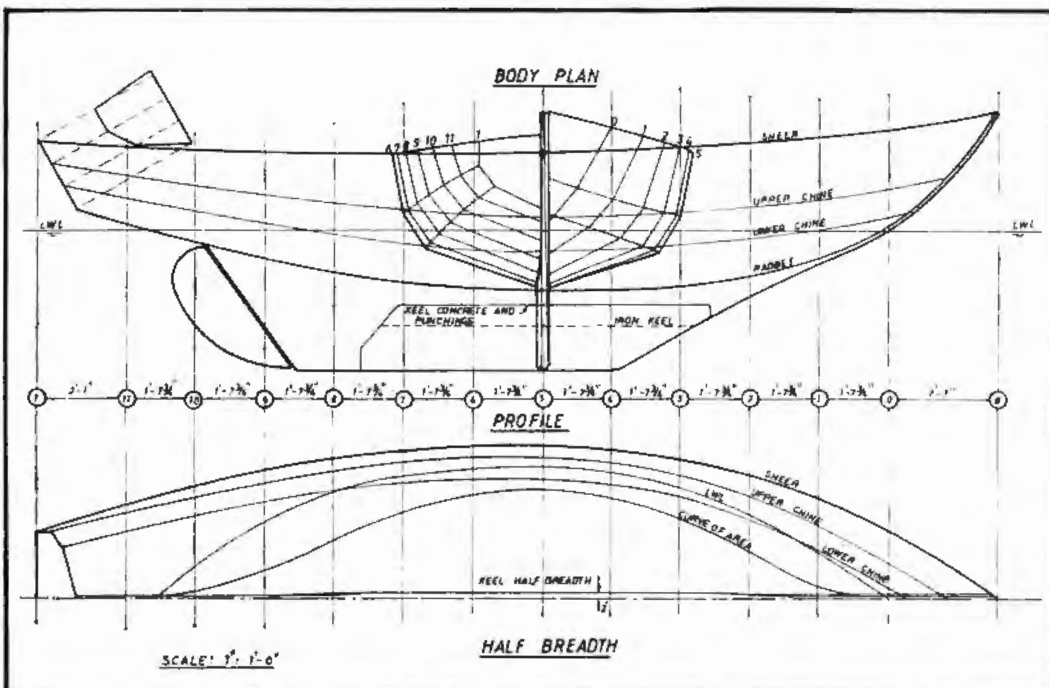


Fig. 1. Lines diagram of 7.01m (23 Ft) chine wooden hull.

Either of the two methods may be used, the selection of anyone would depend on the type and use for which the craft is intended. In this case, the first method was used because for a sailing boat, it is better to have a lower centre of gravity. Fig. 1 shows the lines diagrams of the hard chine wooden boat which has been modified to a knuckle free, double curve ferrocement hull (Fig. 2). Ferrocement curved surface is preferable because shell effect contributes towards the strength and has less resistance to motion than the hard chine hull. The comparison of the two figures shows that with only a little modification a ferrocement hull can be obtained, and these figures have no use beyond this observation.

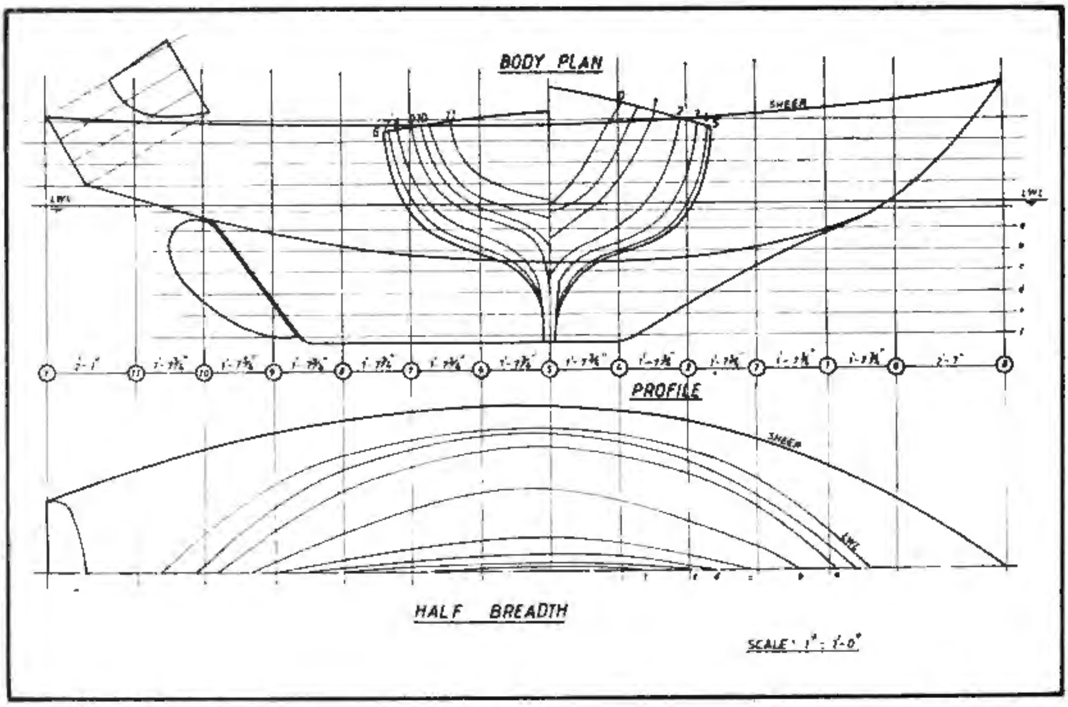


Fig. 2. Lines diagram of 7.01m (23 Ft) double curvature ferrocement hull.

Stability Analysis

It is important that the modified ferrocement has statical stability. The statical stability of a floating body is the tendency it has, to return to the upright position when inclined away from that position. It is quantified in terms of righting lever at any angle of inclination of hull forced upon it and when this is multiplied by the corresponding buoyancy force, the product gives the righting moment.

There are two types of statical stability that have to be determined, namely transverse stability and longitudinal stability. For small boats transverse stability should be such that it has a positive righting moment even when on its beam.

There are different methods available for determination of statical stability curves. In this investigation Barnes' method [11] has been selected as it is easily amenable to computer programming. Computerization of stability analysis of a ferrocement hull is much easier, because it is

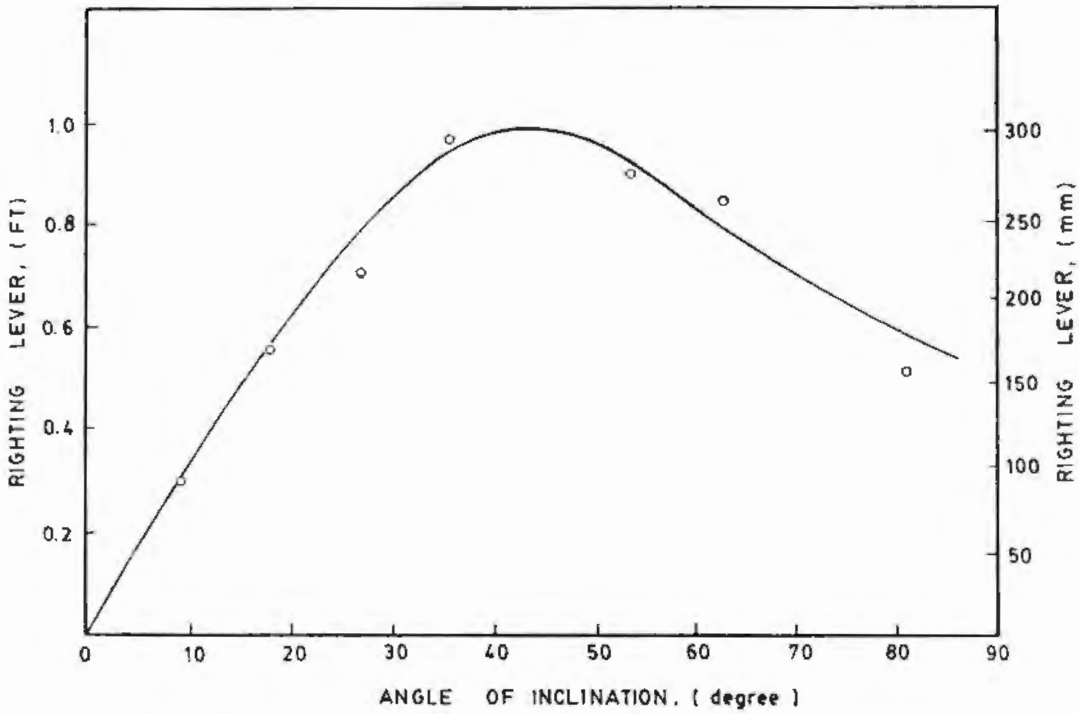


Fig. 3. Transverse stability curve of monolithic ferrocement hull determined using a computer program.

Table 1. Important Paramaters of Ferrocement Sailing Boat

Description	m	Ft
Length overall (L.O.A.)	7.01	23
Length on water line (L.W.L.)	5.49	18
Breadth moulded (Bmld)	2.29	7.5
Depth moulded (Dmld)	1.83	6
Draught moulded (Hmld)	0.99	3.25
Overall height keel to cabin top	2.29	7.50
Centre of gravity above keel (kG)	1.08	3.53
Transverse metacentre above keel (kM)	1.54	5.05
Longitudinal Metacentre above keel (kM_L)	5.26	17.27
Centre of buoyancy above keel (kB)	0.71	2.32
Longitudinal centre of buoyancy aft (LCB)	0.18	0.58
Tons per cm Immersion (TPC)	0.194 t/cm	
Moment to change trim 1cm (MCT 1 cm)	0.018 t.m/cm	
Displacement in Tonnes (△)	2.25 t*	
Surface area of hull	20.83 m^2	
Surface area of deck, cabin & cockpit	12.49 m^2	
Accommodation (number of persons)	4	

*t = metric tonne

a shell structure with uniform thickness all around. Fig. 3 shows the transverse stability curve for the ferrocement hull determined by using a computer program. The curve is determined assuming a constant centre of gravity and trim for different angles of inclination, and a series of curves may be determined for varying parameters, if necessary. Also, all the other statical stability curves can be determined using this program. Some of the major dimensions of the sailing boat which were calculated using this computer program are given in Table 1.

SPECIFICATIONS AND FERROCEMENT MATERIAL

Lloyd's provisional rules of 1973 [10] for construction of ferrocement yacht states the specifications of constituent materials such as cement, sand, water content and types of rein forcement. However, no minimum stress requirement is stated even though it is stipulated that tensile and flexural strength, modulus of elasticity and impact resistance of the ferrocement should be determined. The properties of the cement-sand matrix and the reinforcement should be such that the final product i.e., the ferrocement material should be impermeable to water, least susceptible to sulphate attack in a highly alkaline environment and have required cracking stresses to withstand the forces a boat would be subjected to in the sea.

There are semi-empirical expressions which have been estabished to predict the strength of ferrocement [6, 7, 9] and these expressions can be used in the selection of the constituents of ferrocement. Nevertherless, it is advisable to conduct standard tests to determine the cracking stresses under different types of loading.

Matrix: Cement, Sand and Water Content

The three constituents which form the matrix of ferrocement determine the impermeability to water and contribute towards the strength of ferrocement. Also, the amount of water determines the workability of the matrix during plastering of the skeleton hull.

The cement Type I or Type V is recommended [10] and the latter is least susceptible to sulphate attack and it is also slow setting, allowing a longer period for plastering and smoothening of the hull. However, availability of a fresh supply of cement Type V and its cost are two important factors which are against using this type of cement in some developing countries. In this project, cement Type I is used, as it is intended to cover the finished hull surface with a protective coating.

Sand should be free of contaminating materials that would affect the strength of the matrix, also the grading and size of aggregates are important because of their effect on strength, workability, porosity and shrinkage. The Lloyd's specification states that all the sand passing through an apperture size of 4.7mm (3/15") and not more than 10% passing through an apperture size of 150 microns (100 Mesh) should be used in the matrix of ferrocement, and for finishing of the hull surface coarser sand should be omitted and all the sand should pass through an apperture size of 2.36mm (1/8").

The water content in the matrix will affect the strength, permeablity and workability of the matrix [2]. Lower water content increases the strength and reduces the workability but the opposite is true with higher water content.

The specification states that the sand to cement and water to cement ratios should be 1.5 to 2.5 and 0.25 to 0.35 respectively. The authors' experience shows that it is very difficult to work with such low water content. Even with an admixture at increased cost at least a water to cement ratio of 0.4 is required for plastering.

Ferrocement Material

An important requirement in the construction of a ferrocement boat is to have satisfactory workability during the plastering of a hull, in order to ensure that consistent mechanical properties are obtained throughout the entire hull. Permeability, if there is any, can be overcome by treating the finished surface with a coating formulated for ferrocement boats.

It has been reported that seagoing ferrocement boats which have been built with certain properties have been granted 100 A.1 insurance classification by Lloyd's [2]. It has also been reported that the maximum stress that would act due to either sagging or hogging of a ferrocement hull 22.86m (75 ft) is about 6.89 N/mm^2 (100 lb/in^2) [12].

Table 2. Mechanical Properties of Ferrocement and Comparison with Lloyd's Approved Strength

Strength (Stress)	Ferrocement*		Lloyds**	
	lb/in^2	N/mm^2	lb/in^2	N/mm^2
a) Tensile: First crack	1200	8.27	1300	8.97
: Ultimate	1680	11.58	1690	11.66
b) Flexural: First crack	2030	14.00	1900	13.10
: Ultimate	3350	23.10	3600	24.83
c) Modulus of Elasticity	2.21×10^6	1.52×10^4	1.3×10^6	0.89×10^4

*Material used in the construction of sailing boat
**Ferrocement material approved by Lloyd's [2].

Table 3. Properties of Constituent Materials and Physical Properties of Ferrocement

Plain Mortar		
Cement:Sand:Water (by weight)	1:1.5:0.4	1:1.5:0.4
Crushing Strength	37.9N/mm^2	5500 lb/in^2
Tensile Strength (direct tension)	1.04 N/mm^2	151 lb/in^2
Modulus of Elasticity	2.2×10^4N/mm^2	3.19×10^6lb/in
Wire Mesh		
Grid Size	8.5mm×8.5mm	0.33inx0.33 in
Diameter	0.92mm	0.034 in
Tensile stress at 0.01% strain	276N/mm^2	40,000 lb/in^2
Ultimate Tensile stress	358N/mm^2	52,000 lb/in^2
Modulus of Elasticity	2.0×10^5N/mm^2	29.0×10^6lb/in^2
Ferrocement		
Thickness of ferrocement	12.5mm	0.5 in
No. of Layers of Wiremesh	5	5
Percentage of reinforcement	3.27%	3.27%
Specific gravity	2.6	2.6

Taking into account various considerations and the authors' experience working with ferrocement, cement Type I and fine aggregate all passing through B.S.S. No. 14 and less than 10% passing through B.S.S. No. 100 were selected. The mechanical properties of the ferrocement used in the construction of the sailing boat were determined as described in an earlier work [6] and are given in Table 2. The properties of the constituent materials and characteristics of ferrocement are given in Table 3.

A comparison of the mechanical properties of the proposed ferrocement with that of Lloyd's insurance, in Table 2, shows that the proposed material meets established standards. Also, the proposed ferrocement hull, deck and cabin is a monolithic structure which would add to the design strength.

CONSTRUCTION TECHNIQUE

The construction of a ferrocement hull by the use of a traditional method has three main parts: (i) lofting and pipe bending (ii) assembly and laying of wire mesh and (iii) plastering and curing.

Lofting and Pipe Bending

Lofting is the process of drawing of plans and profiles of a boat to full size on a suitable plane surface using the offset tables. Fairing is done to eliminate any deviations not apparent on a small scale drawing. Details of lofting could be found in any book on boat building [3] and it is usually done to the outside of the hull surface.

The lofted drawing of a ferrocement hull consists of a body plan, sheer profile, half breadth plans etc. Using the inside of the half breadth plans, framework was made for all the stations with 19.1mm ($\frac{3}{4}''$) diameter pipe of thickness 2mm (1/16 in). Also, using 50.8mm (2") diameter pipe and thickness 3mm (1/8 in), the keel shape was formed.

The pipe bending was done using a hydraulic bender with frequent comparison between the bent pipe and lofted breadth plan, to ensure that the required shape is free from kinks and localized deformation. A chalk line drawn on the pipe before commencing to bend, acts as a reference line, and twisting of the pipe during bending can be avoided. A numbering system is useful to assist in the final assembly of the pipe framework and each station frame was made in three parts, two half breadths and one for the deck line camber. These three pieces were tied together to form the station framework. This was done for all the stations shown in Fig. 2.

Assembly and Laying of Wire Mesh

The keel pipe was first laid on concrete blocks with a wooden plank on the top. Steel stirrups of diameter 6.3mm ($\frac{1}{4}''$) were tack welded on the bottom stem at positions where assembled station frames are to be placed. Then framework of each station was placed along the keel pipe and the pipe framework was temporarily assembled by tack welding and supported in position using a scaffolding. Then, the framework was checked for fairness using a batten. This is important to avoid grinding after the plastering is done. Once this was done the framework was permanently welded together to obtain a skeleton of the hull. Then the required number of pipe frames for the cabin and cockpit were tied to the hull frame work. Tying is usually preferrable to welding but initial tack welding provides a little rigidity during assembling of station framework. Fig. 4 shows the assembly and laying of wire mesh.

Wire mesh comes in standard rolls of 0.91m × 15.23m (3 ft × 50 ft). Five layers of wire mesh were cut about 300mm longer than the keel block and tied together before being slipped. under the keel, and these five layers were wrapped around the keel rectangular frame and tied. The mesh was draped in double layers from the deck downwards and pulled constantly to maintain tension, hence a fair shape of the hull was obtained. At joints, at least 75mm (3") of overlapping was provided. Two layers were placed inside and three layers outside the pipe framework, and, in all five layers were tied together at 75mm (3") spacing vertically as well as horizontally. The mesh for the deck cabin and cockpit were similarly laid, with allowances for hatch, portholes etc, but this was done after the hull was plastered.

Fig. 4. Assembled pipe framework forming the hull and laying of wire mesh.

Provisions were made for bulkheads, floor supports, mast supports and other fittings, and these were made as integral parts of the hull (Fig. 5). This approach of having a monolithic hull is preferable because it is stronger, and also additional wire mesh or steel reinforcement can be provided in areas subjected to the additional loading of the components. Also, the other advantage is that it is ready for fitting without the necessity to hack or drill the completed hull which is rather an expensive and a laborious task. The completed skeleton hull has enough rigidity for plastering.

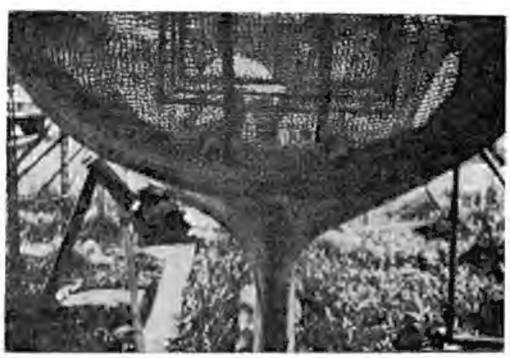


Fig. 5. Hull after laying of wire mesh with drain pipes and rudder shaft.

Casting and Curing

The cement, sand and water matrix of ratio 1 : 1.5 : 0.4 respectively was made in batches depending on the quantity required. Plastering was started from the keel bottom and frequently a portable pencil type vibrator was used in difficult corners to effect compaction, otherwise the matrix was always pushed from outside to inside to ensure complete penetration, as seen in Fig. 6. Then both surfaces were smooth finished maintaining the thickness of the plastered surface at 12.5mm. The hull was plastered continuously in a day, before laying the wire mesh on the deck, cabin and cockpit, this was done to have enough working area during the plastering of the hull. The completed hull was cured for seven days and then laying of wire mesh was done on the unfinished part (Fig. 7) and plastering completed on a later date.

Fig. 6. Plastering of ferrocement hull.

Although, plastering was done in two parts, the curing for the plastered part was continued for 28 days by covering with wet sacks. Experiments conducted to determine the strength of a specimen made in two parts with a time interval showed that the strength is not affected. Hence, the method of plastering and curing of a ferrocement structure in parts is preferable, as the work on a structure can be done at a reasonable pace ensuring that the plastering is done well. Unsatisfactory plastering is the main cause of defect in any ferrocement structure.

Fig. 7. Laying of wire mesh to form the ferrocement deck and cabin.

COST ANALYSIS

It is difficult to make a precise cost comparison of hulls constructed with different types of material because cost would depend on the life span, depreciation, cost of labour, annual maintenance, method of manufacturing etc; however, it is known that these factors are more favourable to ferrocement hulls than the others [1]. In this investigation, an approximate cost comparison of ferrocement, timber and fiber glass hulls in made. For the purpose of comparison, hulls of displacement about 2.5 metric tonne and about 7m length have been selected. The cost estimates are for only labour and material, and they are based on January 1980 prices in Singapore (US$1 = S$2.15).

The itemised labour and material costs for building of ferrocement hull are as follows:

Labour cost	No. of Man hrs	Cost S$
1. Pipe Bending	100	175
2. Assembly of framework	300	525
3. Setting of scaffolding	80	140
4. Lofting	60	105
5. Placement of Mesh	440	770
6. Plastering	100	245
7. Miscellaneous	60	100
Total	1140	2060

In places where labour cost is escalating, mechanization and modern methods have to be used to reduce the total cost.

Materials

1. Woven square wire mesh	S$ 1,200
2. Cement, sand, steel pipe	S$ 400
Total cost of material and labour	S$ 3,600

The cost of materials are based on retail prices and it can be reduced by about 30%, if whole sale prices are used. For a timber hull, the material and labour costs are S$4,500/= and S$2,200/= respectively making a total of S$6,700/=. This total cost is based on Chenghai, a type of timber used in the local boat building industry.

The cost of fiberglass hull is more difficult to assess as a large amount of capital is invested in making the permanent mould. A motor boat of fiberglass hull and timber cabin with fittings but without engine would cost $18,500. It can be safely estimated a bare hull and cabin would cost more than that of a timber boat.

Comparing the cost of hull, for the three types of construction, ferrocement works out to be the cheapest. Also one should take into account that fiberglass and timber hulls need additional framework and material for deck, cabin and cockpit which would increase the cost further when compared with a monolithic ferrocement hull.

DISCUSSION AND CONCLUSIONS

A ferrocement hull is subjected to various stresses during handling on land more than in water, as seen in Fig. 8 and necessary allowance should be made while designing a ferrocement hull. Fig. 9 shows the hull being towed for fitting and it can be seen that the load water line mark is just above the water surface which shows that the method of designing and construction

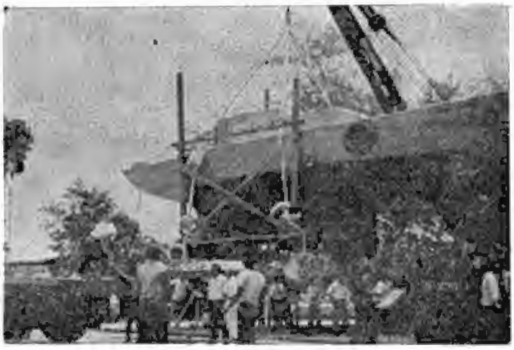


Fig. 8. Method of handling ferrocement boat prior to launching.

have been carried out to the expected specifications and standards. The thickness of the hull has been maintained at 12.5mm, and if it had been increased by 2.5mm the weight of the hull would have increased by 20% and affected the design load water line. Also, testing for transverse and longitudinal stability showed that the expected results were obtained.

Fig. 9. Testing of ferrocement boat and position of load water line.

The investigation establishes the viability of using skeletal free ferrocement for building of small craft and shows that this material meets Lloyd's specification on strength but slightly differs from the others, such as, type of reinforcement and aggregates. It is timely that considerations are given to existing specifications [10,13] and new specifications are drawn for building of small craft, which incorporates the progress that has been made with ferrocement.

The technology for building of a ferrocement hull can be easily acquired as it has been shown in this project. The procedures to convert lines drawings of a wooden boat to that of a ferrocement and, design and construction method can be used for converting the existing wooden boats. However, before any attempt is made, the correct amount of reinforcement should be selected to provide the required strength and statical analysis should be conducted to determine the stability of the modified hull.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to students, technical staff and others who in one way or another helped in conducting this investigation.

REFERENCES

1. 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, pp. 13-54.
2. SAMSON, J. and WELLENS, G., "The Ferrocement Boat", Samson Marine Ltd, Richmond, B.C., Canada, 1972.
3. JACKSON Jr., G.W. and SUTHERLAND, W.M., "Concrete Boatbuilding", George Allen and Unwin Ltd, London, 1969.
4. GOPALARATNAM, V.S., PAMA, R.P. and VALLS, J., "A Review of Marine Applications of Ferrocement in Asia", Journal of Ferrocement, Vol. 10, No. 1, January 1980, pp. 31-45.
5. MACALISTER, G., "Ferrocement and the Development of Small Boats", Journal of Ferrocement, Vol. 10, No. 1, January 1980, pp. 47-50.
6. NATHAN, G.K. and PARAMASIVAM, P., "Mechanical Properties of Ferrocement Material", Proc. of First Australian Conf. on Engg. Mat., University of New South Wales, Sydney, 1974, pp. 309-331.
7. NATHAN, G.K. and PARAMASIVAM, P., "Tensile and Flexural Cracking Stress of Ferrocement", Engineering Journal of Singapore, Vol. 3, No. 1, 1976, pp. 11-17.
8. PARAMASIVAM, P., NATHAN, G.K. and LEE, S.L., "Analysis Design and Construction of Ferrocement Water Tanks", Journal of Ferrocement, Vol. 9, No. 3, July 1979, pp. 115-128.
9. PAUL, B.K. and PAMA, R.P., "Ferrocement", IFIC, AIT, Bangkok 1978, pp. 34-117.
10. LLOYD'S REGISTER, "Provisional Rules for the Construction and Classification of Yachts 1973", Part F, Ferrocement Yachts, London, 1973.
11. RAWSON, J.J. and TUPPER, E.C., "Basic Ship Theory", Longmans, London, First Edition, 1968, pp. 93-138.
12. JAMES, W., "Materials for Construction of Small Craft-Ferrocement Construction", Proc. of the Symp. On Small Craft RINA, Southampton, Sept. 1971, pp. 41-43.
13. ALEXANDER, D.J., "The Widening Applications of Ferrocement", Coroprint-Coromandel, New Zealand, 1979, pp. 6-80.

Some Thoughts on Methods and Materials for Ferrocement Boat Construction

PART II – SUPPORT SYSTEMS

Larry Mahan*

Positive positioning as well as adequate support should be incorporated in the armature system. Many ferrocement armatures that I have visited and ever worked at have had only limited support and usually inferior scaffolding.

Uneven or inadequate support while building can cause more problems than seem readily apparent at first glance. Distortion has a way of migrating to other areas. Take bulkhead stations as an example.

Without proper support, bulkhead stations, the primary structural zones of the boat, will forced out of line and cause fastening problems after the plastering phase. I have measured bulkhead positions of several boats before and after plastering. The armatures without internal and external supports and bracing have each proved to have some degree of distortion. Some have even had whole sections sag due to mortar weight alone.

I have seen twisted sheer lines (deck edge), stems askew and bulbous body sections, mostly due to improper support. Of course some were casued by inadequate steel content and unfair moulding but for the most part, even these could be kept reasonably fair and in correct alignment with the proper support.

There are several ways to support the armature yet still provide ample room for proper working conditions on plastering day.

When building upright the support system is more involved than the inverted position. Not only do you have the sheer to contend with but for the most part the bulk of the weight rests on the keel. I have used a very simple, strong yet easily adjustable keel support system for my boat LARINDA.

LARINDA is a sixty foot modified replica of a 1767 coastal schooner and because of this type of design, the hull is very large and consequently heavy (60 ton designed displacement.) By utilizing various weldments this method can be used for any moulding technique: wood, truss or pipe frame.

At the bottom of my removeable pipe frames I welded a galvanized, five eights inch diameter, coarse threaded nut. A 5/8 inch diameter galvanized rod approximately ten inches in length, is threaded into the welded nut just far enough to utilize all of the threaded surface of the nut. At this position, when plastering day arrives, the cement pushed into the keel cannot lock onto any exposed rod threads creating problems of the rod's removal at a later date.

Another galvanized nut is positioned at a lower point of the threaded rod and under it is placed a large flat washer or steel plate. The washer or plate acts as a bearing surface for the adjusting nut. The whole unit is duplicated for the adjacent frame and the two units fit into holes drilled in the support block.

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

By raising or lowering each nut a like amount, proper support and balance is maintained. With this support system set up at each frame station perfect alignment can be maintained.

The method I used to keep the keel line perfectly straight involved the use of file index cards. After punching a one inch hole on center in both directions, each card was taped between the supporting rods with the top edge just touching the bottom of the keel.

Sighting from either end of the keel any uneven areas will immediately show as a blockage in the index card view holes. Alignment is quickly rectified with the simple nut adjustmet.

During the three years that passed in LARINDA'S armature construction, the keel support system was only corrected twice and both of these corrections were made just after frost season. The reason for so few adjustments caused by frost is due to the fact that all scaffolding and armature was enclosed in a six mill polyethelene covering. Each pair of threaded rods rested on a wood block which in turn, was supported by a six foot long, four inch by four inch oak timber. The oak timbers were liberally coated with used crankcase oil to prevent premature rot.

Fig. 1. The LARINDA on the plastering day showing extensive external scaffolding.

During plastering day and after the keel was fully penetrated, additional wood blocking was positioned under the keel next to the threaded rods as added insurance of proper support.

Before leaving the keel bolts topic I should mention that I waxed the threaded ends that penetrated the keel and keel nuts. This prevents the cement from bonding to the rods and allows removal at a later time. The opening left by the rod can easily be filled with an epoxy grout thus sealing against water intrusion.

Overhead support for LARINDA'S frames consisted of one quarter inch diameter steel rods fastened to the pipe frame on each side. Sixteen rods to a side provided the necessary support along the sheer. The rod ends were supported overhead by two inch by eight inch crossbeams. The top section of rod were threaded and by loosening or tightening, accurate adjustments could be made.

The original scaffolding was set up with this support system in mind and during the interval of seven years time, very little repair work was needed. I think the guy wire system, set up to steady the overall scaffold, contributed a tremendous amount of structural support.

Fig. 2. A sign-board fixed to the scaffolding indicates the mix-proportions for each batch of mixing.

All corners, as well as at the telephone pole positions were stayed with well tensioned steel cable.

As each building phase progressed, new scaffolding was constructed and fastened directly to the initial scaffold work. All interior scaffolding was supported from the overhead crossbeams, and with careful positioning, none of the beams or planks touched or pressed on

Fig. 3. A freshly plastered section of the LARINDA hull.

any part of the armature. All areas could be reached for work and on plastering day, no one had to struggle at awkward positioning.

Steel angle members connecting my removeable pipe frames provided the stiffness needed to prevent distortion that could arise on plastering day. The web frames or truss method should be braced in a like manner. Two or three crossmembers and one vertical should be enough. If in doubt add more just before plastering.

My internal bracing held up very well and I will add that during the fairing phase, the armature had to stand the punishment of a twelve pound sledge hammer. Also, just before plastering, all overhead supports were disconnected for the purpose of checking heights, keel line and overall hull plumb and level. While the overhead supports were loose, thirty feet of keel support was also slacked off.

Not only was the armature fair, plumb and level, but the unsupported keel stayed straight and true with the still supported fore and aft sections. The internal bracing and pipe moulds were strong enough to support approximately five tons of armature, moulds and internal bracing.

A support system not usually thought of but just as important is the wire tie system. Most amatuer builders seem to think that the wire ties only purpose is to keep the mesh taut and compacted and some only place enough ties to do just that.

A visit to a few armatures under construction will immediately show the support problem created by insufficient wire ties. Place your hand against a "finished" section and push in and out. At the same time, watch the mesh and rods on the surrounding areas. You may notice movement of both rods and mesh and you might even see mesh layer separate a bit.

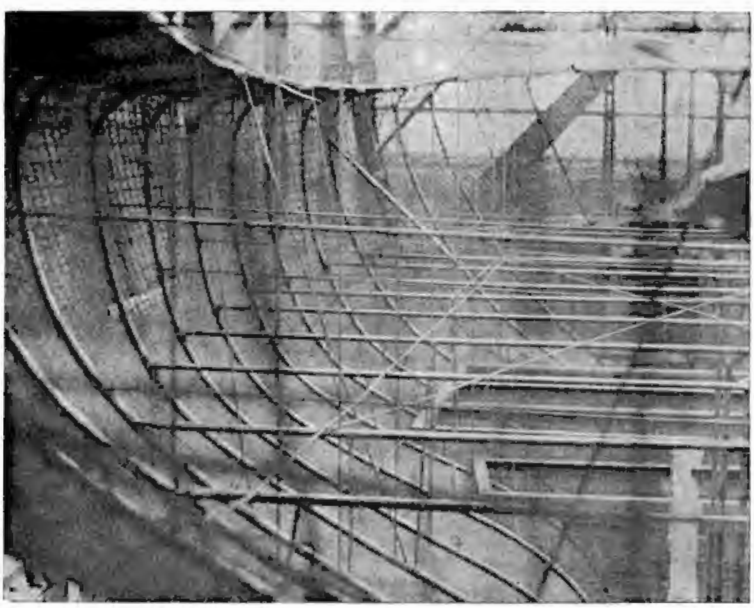


Fig. 4. Photograph above shows a hull of Benford design, utilizing removable pipe frames.

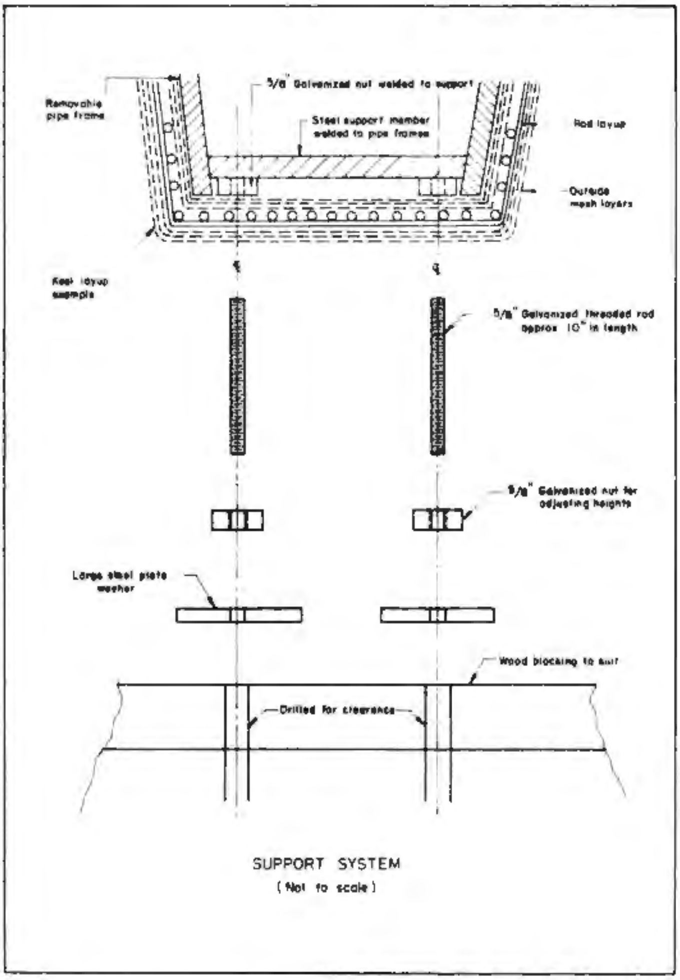


Fig. 5. The support system is detailed in the figure above, as used for LARINDA. This system ensures a high degree of flexibility in adjusting the supports even while work is in progress.

The armatures with proper wire ties will not exhibit this movement. Instead, you will find that it is very difficult to deflect the mesh/rod matrix. The armatures with wire ties at every rod intersection and with each of these ties passing through all layers of mesh will provide a uniform support system of its own through ridgidity.

Plastering a properly tied armature, as compared to the less carefully tied armature, will prove out this lesson. As a before and after check, take a long fair wooden batten and laying it on edge, sight down the edge and note the fairness of the steel work. After curing go back to the same area and with the batten, check and note the differences in fairness.

Do this for both types of armatures, the 'carefully tied' and the 'just tied enough'. Now you can see what I mean. The ties really do provide an important support system.

Inverted armatures done over a battened wood mould present less problems in the wire tie support system but even here, any areas not supported by battens should be properly tied. Don't forget to use a like amount of staples in all battened support areas.

Just because the batten does supply the necessary support it does not leave you room for improper compacting. The mesh and rods in these areas still have to be compacted and held to prevent excessive movement or build up.

When placing final wire ties, even if a rod intersection already has a tie because of earlier mesh placement, unless the tie passes through all mesh layers another tie will be required.

LARINDA has over 360,000 wire ties in the hull armature exclusive of bulkheads and decks, which are also constructed with ferrocement. Each one of the ties played an important part in supporting the overall armature.

Just the fact that it took repeated blows with a twelve pound sledge hammer during final fairing proves this, Would you dare take a twelve pound hammer to your armature?

(*Due to reasons beyond our control, this article which was to appear in the April 1980 issue of our Journal had to be carried over to this issue. The article will be continued in the forthcoming issues of the Journal.*)

The Introduction of Ferrocement Fishing Boats to Lake Malawi

Gowan MacAlister*

In September 1977 MacAlister Elliott & Partners (ME & P) were approached by the Anglican Diocese of Malawi to investigate the possibility of building low cost fishing boats on Lake Malawi.

The Republic of Malawi is a small landlocked country covering an area of some 114,250 sq. kilometres in Central Africa. It's dominant feature is a long deep rift valley running from North to South on the Eastern side of the country, containing Lake Malawi which covers an area of about 45,000 sq. kilometres. The population is estimated to be about 5 million, making it one of the most densely populated countries in Africa, with an average density of 42 people per sq. kilometre.

The economy of Malawi is overwhelmingly dependent on agriculture, and fishing plays a large part in the national diet. Of about 100,000 tonnes of meat and fish protein consumed annually, 80% is locally caught fish. However, the per capita income is low (about U.S.$180 per annum in 1975), so that only extremely low cost boats are attainable by the fishermen.

The existing artisanal boats in Lake Malawi are of two sorts.

1. The traditional dugout canoe which obviously has very limited carrying capacity and stability. It is difficult to arrive at an accurate price for a dugout canoe, as the existing fleet is usually old and replacement boats are not available due to the lack of suitable trees near the lake shore.

2. Flat bottomed planked wooden boats between 4.3 m. and 6 m.

Two Government yards and a number of individual carpenters produce wooden boats based originally on FAO designs. The Government boats are sound but production is low due to shortage of suitable timber and skills. The other boats are poorly built and have a short life.

Various materials were considered for building the new boats. Glass Reinforced Polyester and steel proved too expensive as all materials had to be imported. There were insufficient skilled carpenters to expand the wooden boat building industry, and the shortage of timber made the boats expensive. Ferrocement appeared to have the most potential as the materials are inexpensive and readily available, and the skills are easily assimilated.

ME & P produced a brief proposal to investigate the manufacture of small ferrocement boats and in 1978 Barclays International Development Fund commissioned a feasibility study to enable an assessment to be made of building sites, local materials, labour and skills, boat designs and markets.

The study located and analysed all materials necessary for ferrocement. Analysis of the sands in the U.K. laboratories identified an excellent lakeshore sand.

*MacAlister Elliot and Partners Ltd., 6 Highfield Lymington Hampshire, SO4 9GB England, U.K.

The report produced proposals for suitable 4.3 m. and 5.8 m. boats, specified all building, plant, equipment and labour and costed the boats for regular production. Potential locations visited were assessed and the market was analysed, and discussions with the Department of Fisheries and the National Bank layed the groundwork for finance schemes for fishing boat purchase. The report included the detailed planning for an implementation project quantifying costs and time schedules.

The Diocese of Malawi runs the Malindi Rural Centre, encompassing a number of rural activities including a workshop, a pottery and a carpenters' shop making simple furniture. The Study recommended that the boat building yard should be an autonomous section of the Malindi Rural Centre.

After long discussions with the Diocese and Barclays International Development Fund, the Project was approved in two phases. Phase I included the detailed design and full size templates for the boats, the design of the buildings and the organisation of all plant, equipment, materials and labour to start building boats. Phase I would be supervised by a ME & P Project Manager for 5 months. The targets for Phase I were as follows:-

1. At least 6 servicable boats must have been produced by the Yard.
2. At least 3 must be in use fishing effectively by artisanal fishermen.
3. There must be a future order book for at least 6 boats.

If these targets were achieved Phase II would continue for a further 7 months to enable local managers to be trained, and 'Malindi ferrocement Boats' to become a self supporting long term rural industry.

The Project started in June 1979 with the detailed design of the boats. The constraints on the design were many. The boat needed to be suitable for paddling, outboard motors, inboard motors and sail; they needed to be easy to build in ferrocement and easy to fit out in local timber. They also have to be delivered by lorry or trailer and to be dragged up the beach.

ME & P have developed a method of laying up boats on simple male moulds. In this patented process the meshes are stretched over the mould with simple tensioning devices and finally clamped at the gunwale. For the process to work all curves on the hull must be positive, but it is extremely quick and easy, requiring no tying or stapling. Positive curves are desirable anyway on small craft as it ensures that all external loads are compressive. Rods can be included in the lay up, held in place by the top layers of mesh.

A simple transomed hull shape was chosen with fine lines for rowing or paddling, and a slight knuckle at the chine to give good stability. The gunwale in plan was designed to simplify a substantial gunwale capping in local timber.

Fig. 1 shows the 4.3 m. general arrangement. All curves are positive and the ferrocement gunwale system is indicated. After meshing the hull a timber batten is attached to the mould along the sheer and the mesh stapled round it. After plastering the bare hull has a substantial beam along the gunwale, producing a very stiff boat.

The layout shows a deck forward and a working deck aft. These enclose buoyancy chambers filled with scrap polystyrene material, readily available in Malawi from importers of goods such as electronic equipment.

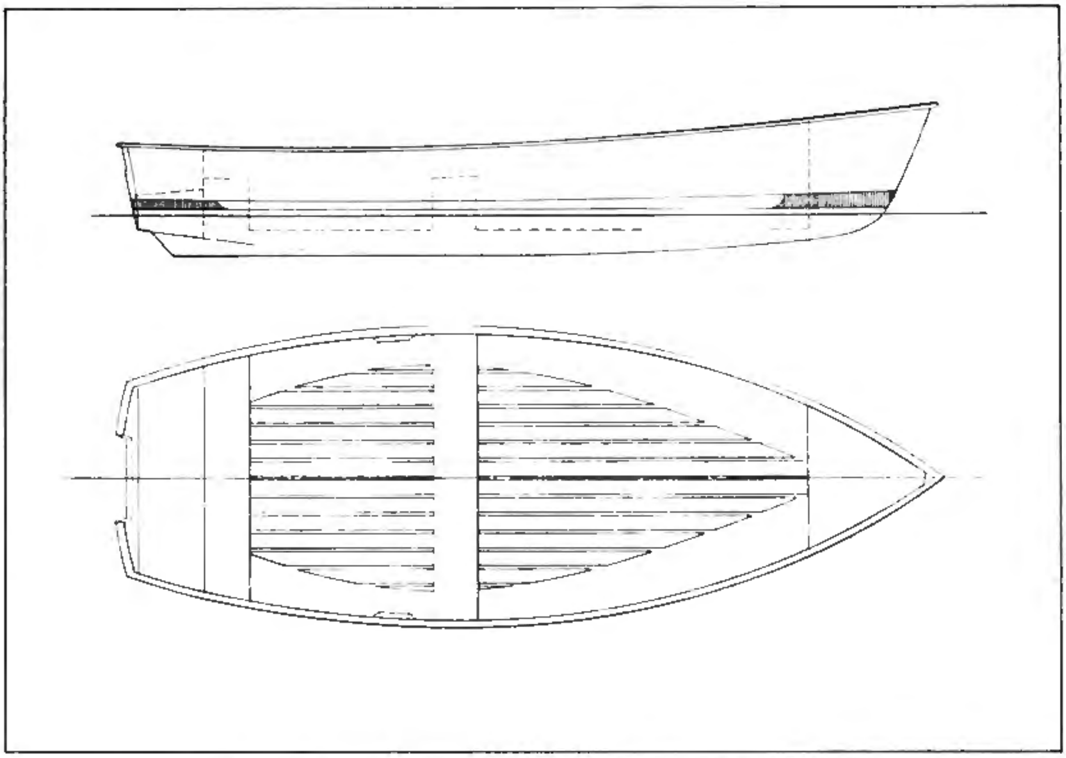


Fig. 1. A 19′ (4.3m) general purpose launch (general arrangement).

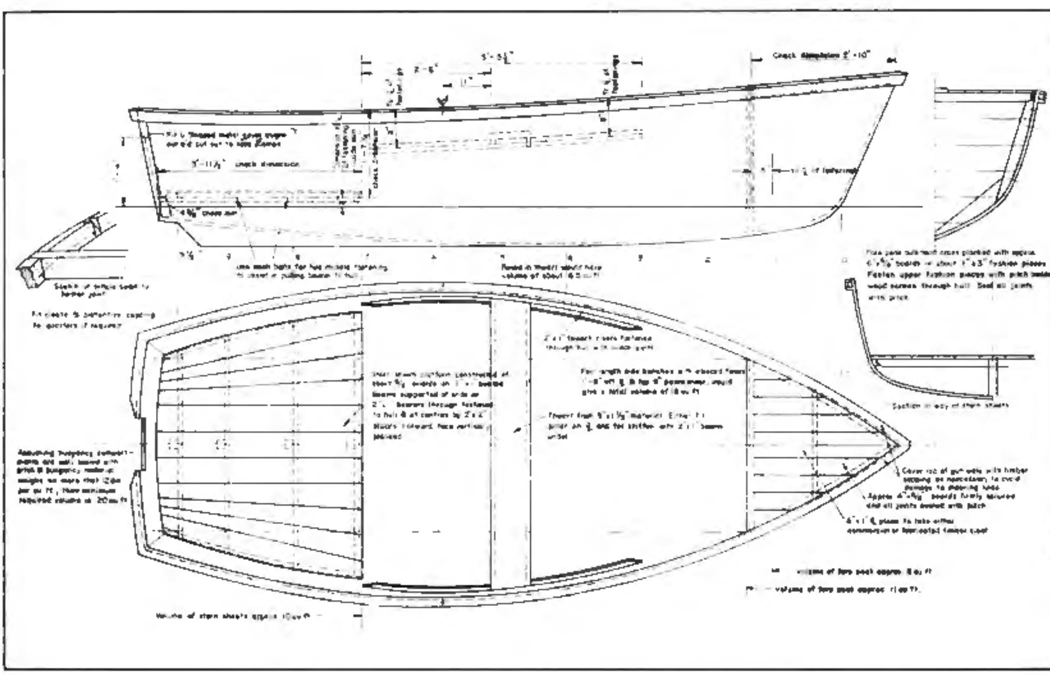


Fig. 2. A 15′ Outboard Launch (general arrangement).

The ME & P Project Manager arrived in Malindi in July 1979. Most of the equipment necessary, mainly hand tools, buckets, etc. was purchased in Blantyre. Cement mixers are available for purchase or rent. The largest single investment was a 30 mm petrol driven poker vibrator which was flown out from the United Kingdom.

Production of the first 4.3 m. mould started before any buildings were erected (see Fig. 3). The moulds are planked to give the general surface contour and need not be very elaborate. The mould is covered with a layer of hexagonal mesh and polythene sheet is used for a release layer. Six local people were employed including a foreman. None of these people had any previous experience of boat building or ferrocement.

The first hull was layed up and plastered in about 1 week and cured under wet sacks and polythene on the mould. The lay up was 6 layers of 22 gauge 12 mm. hexagonal mesh (square welded mesh is not avaiable in Malawi) with 6 mm rods between.

Fig. 3. Mould for 4.3 m boat.

Fig. 4. Plastering first hull.

The various keels necessary for the variety of uses are added during meshing. A wooden former of suitable keel shape is placed onto the inside mesh. The outer mesh and reinforcing is then stapled to the former and tensioned over the rest of the hull as normal. Some back plastering is necessary after removal from the mould over the keel. On inboard installations the keel former is hollow, containing the stuffing box. After removal from the mould the inside mesh is folded into the box and plastered so that the timber is again completely encapsulated. Ferrocement engine beds are cast in place by setting simple shutters into the mould. These holes can be spanned by the polythene when not required.

Plastering is achieved using vibrator boxes. Mortar is placed in these open ended boxes, which are pressed against the hull with the vibrator in the mortar. The boxes are placed against the gunwale and the hull is plastered upwards in vertical strips. With care the wet edge of the mortar can be observed running up the polythene barrier layer on the mould and a completely void free hull results. (see Fig. 4.)

After curing the hull is painted, and hull and mould rolled over. The mould is then pulled out of the hull with block and tackle from a convenient tree. It appears that with some maintenance the moulds are good for about 50 boats before overhaul. (see Figs. 5-7).

Fig. 5. Rolling over 5.8.m hull and mould.

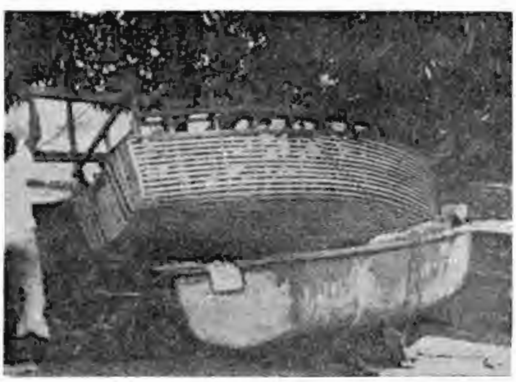


Fig. 6. Removing mould from hull.

Fig. 7. 4.3m ferrocement boats on lakeshore.

Fitting out was completed by carpenters from the Rural Centre with new operatives being trained. The quality was poor to start with but quickly improved to a creditable standard. (see Fig. 8.)

The first few boats were used for testing and demonstration. No. 1 boat suffered some damage on rocks, indicating weakness in the mortar. The curing technique was subsequently improved, which has cured the problem. The boats were stable and dry and performed well. Two or three people can pull a 4.3 m. boat up the beach, using logs as rollers.

Fig. 8. Fitting out 5.8 m hull.

There was immediate interest from both local and distant communities and Malindi Ferrocement Boats started taking deposits for new boats.

A simple building was erected and the 5.8 m. mould produced (see Fig. 9.). By now the Project was employing 12 people, who through their extended families were supporting over 120 people. Two people were employed as sawyers, felling and hand sawing trees into planks for fitting out.

Fig. 9. Malindi ferrocement boats building shed.

The larger capacity of the 5.8 m. boat proved more popular than the 4.3 m. and several orders were taken for boats with small inboard diesels.

Despite problems in Malawi such as a desperate shortage of fuel and the unprecedented high level of the Lake, the targets for Phase I were exceeded and Phase II is now underway.

Fig. 10. 5.8 m with outboard.

Fig. 11. 5.8 m gaff cutter with locally made mast, spars and sails.

To date about 20 boats have been built including two sailing boats, one a 5.8 m. Gaff Cutter (Figs. 10-11) and the other a 4.3 m. with a simple dipping lug rig. Sailing trials indicated a good performance. With the scarcity and cost of fuel in Malawi the development of acceptable sailing rigs is of the utmost importance. Most of the boats are used for fishing though some are working as general transports and passenger launches.

Inflation is high in Malawi but a recent costing for a 5.8 m. boat was as follows.

Ferrocement hull, including labour	$490
Fitting out for outboard version, including labour	$250
Overhead, mostly material transportation (excluding ex-patriates)	$180
	U.S. $920

This is considerably cheaper than any wooden boat of similar size produced in Malawi.

Production is about 4 boats per month and can be increased by building extra moulds when the market justifies it. During 2 weeks leave by the Project Manager it is encouraging to note that production continued as normal.

The Department of Fisheries and various other organisations have purchased boats and such is the success of Malindi Ferrocement Boats that projects on other parts of the Lake are being investigated.

Many enquires are being received for larger boats for offshore and passenger work and an 8.5 m. design is on the drawing board. To organise this and some of the many other uses for this versatile material a further year of management by ME & P personnel is being negotiated.

Perhaps the most significant fact is that 9 months after starting from nothing Malindi Ferrocement Boats is now producing 4 substantial durable boats per month, (now the largest producer in Malawi) with a total investment in plant and equipment, including the building, of less than $4,400. The yard employs people with no previous experience of boat building and uses locally available materials. It is hard to see how this could be achieved using any other material.

ME & P are working on small boat projects in many parts of the Developing World and have found Ferrocement particularly advantageous in countries where skills and timber are in short supply. The spread of this technology would be of great assistance in areas where artisanal fisheries expansion is desirable.

NEWS AND NOTES

AUSTRALIA

Swimming Pools and House Boat From Ferrocement

Although swimming pools have known to be constructed out of ferrocement in the early 70's in New Zealand, it hasn't been until recently that it has gained commercial acceptance in Australia. A typical size of a small swimming pool is 9m x 4.8m (plan) with depths ranging from 1.1m at the shallow end to 1.6m at the deep end.

Mr. Jim Dielenberg of Victoria, Australia has patented the construction method for such pools (Fig. 1). Following photographs highlight some of the construction aspects of building ferrocement swimming pools. Figs. 2-4 illustrate the various stages in the construction of the pool shown in Fig. 1. Figs. 5-7 present close-ups of the pool to illustrate web stiffeners, piping and drainage details of another pool (a slightly modified design from the one shown in Figs. 2-4). The Journal of Ferrocement will soon be publishing a more detailed article on the subject, authored by Mr. Dielenberg.

Mr. Dielenberg is also building a 40 ft. houseboat. Typical of such boats is its 'flat bottomed' similarity with barges. Figs. 8-11 show some of the stages in the construction of

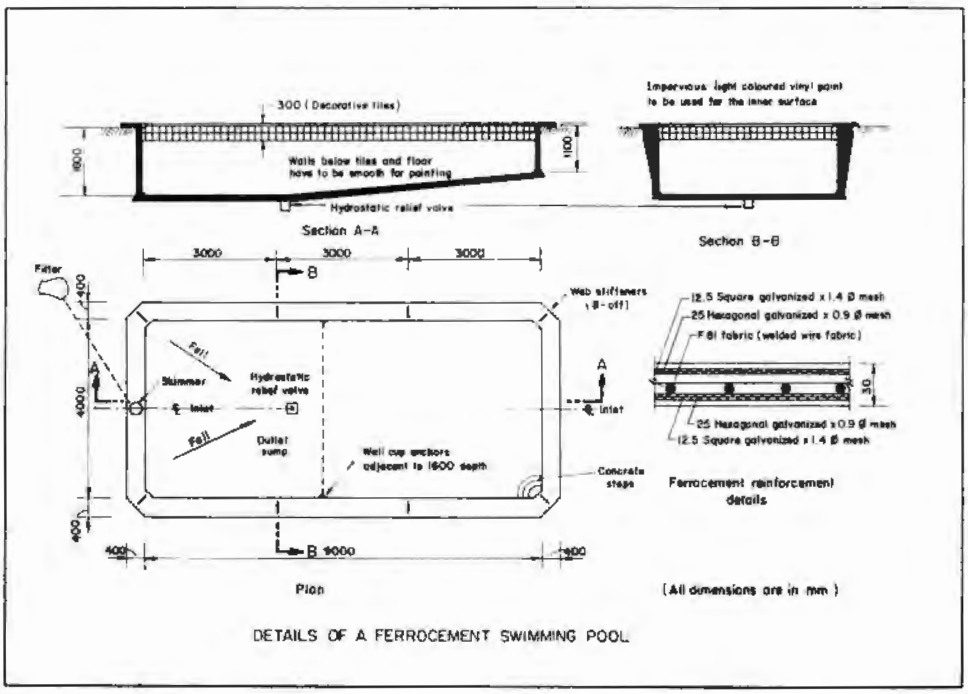


Fig. 1. Plan, sectional elevations and reinforcing details of a domestic swimming pool.

the house-boat. The upside-down construction uses a frameless male mould technique.

(Report compiled based on information and photographs provided by Mr. Dielenberg).

Fig. 2. Broad external flanges border the periphery of a ferrocement swimming pool, dimensional details of which is presented in Fig. 1.

Fig. 3. A full view of the pool shown in Fig. 2. Note that the pit excavated prior to construction of the pool wall has been backfilled creating a natural mound for drainage of area adjoining the pool.

Fig. 4. A close-up of the pool that has been finished on the inside. Decorative tiling along the periphery lends better aesthetics to the pool besides being functionally effective in concealing the watermark along the walls.

Fig. 5. A close-up of the outside of another ferrocement pool showing web-stiffeners that help support the wide flange on the top.

Fig. 6. Skimmer details have been highlighted in this photograph.

Fig. 7. Photograph shows details of the piping arrangements for a ferrocement pool. Note also the steps provided on the top of the left hand corner of the photograph.

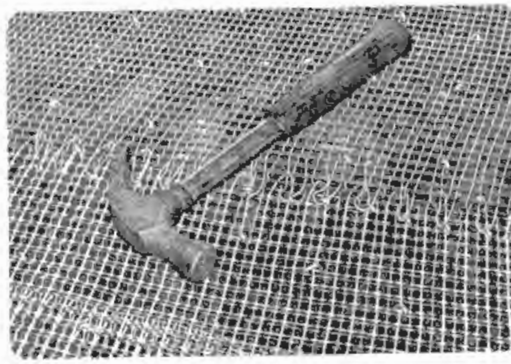


Fig. 8. Close-up of the house-boat armature showing details of mesh overlap and staples driven into the plywood mould below.

Fig. 9. The armature of the house-boat ready for plastering, is sheltered under a temporary tarpaulin shed.

Fig. 10. Plastering of the stern of the house boat is under progress. Wooden strips nailed along the mid-rib makes plastering to the proper profile easier.

Fig. 11. One half of the hull is plastered while the other half is yet to be attended to.

CYPRUS

First Ferrocement Vessel Built

Mr. Alkaeos P. Petrides of the Alkaeos Petrides Ltd., Larnaca Cyprus has recently completed a R.O.R.C. 39. Based on our records at IFIC this is probably the first ferrocement vessel to be constructed in that country. It is a 39 footer and the photograph below (Fig. 12) shows the completed hull prior to construction of the deck and the super structure. Interesting to note is the sturdy steel framed support for the vessel which facilitates easier handling of the hull during and after construction.

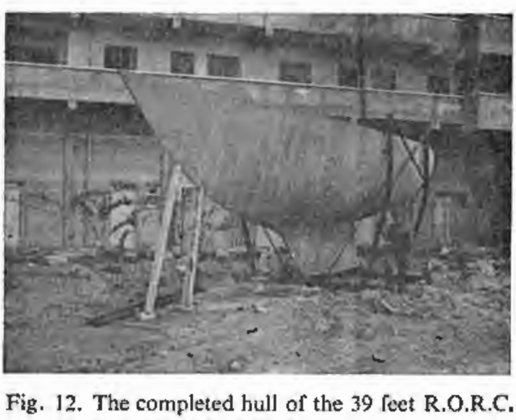


Fig. 12. The completed hull of the 39 feet R.O.R.C. 39 ready to be launched.

(Photo : courtesy Mr. Petrides)

INDIA

Ferrocement Products Exhibited at Trade Fairs

India International Trade Fair (IITF) 1979 and the National Trade Fair (NTF) 1980 were two recent exhibitions held in New Delhi that included an up-to-date display of ferrocement products. The main attention at the Structural Engineering Research Centre (SERC) stall in the Science and Technology Pavilion and the National Building Organization Pavilion were several ferrocement rural utility structures. While SERC Roorkee displayed water tanks, grain storage bins, roofing units, cattle feeding trays and two types of biogas holders, SERC Madras exhibited ferrocement service core unit, rectangular tanks and fiber reinforced concrete manhole covers.

The displays (Figs. 13-16) at both these fairs included several charts and posters tracing back the historical background of ferrocement and highlighting the varied applications of the material. NTF-80 which was organised in concurrence with the UNIDO-80 conference in New Delhi, attracted a

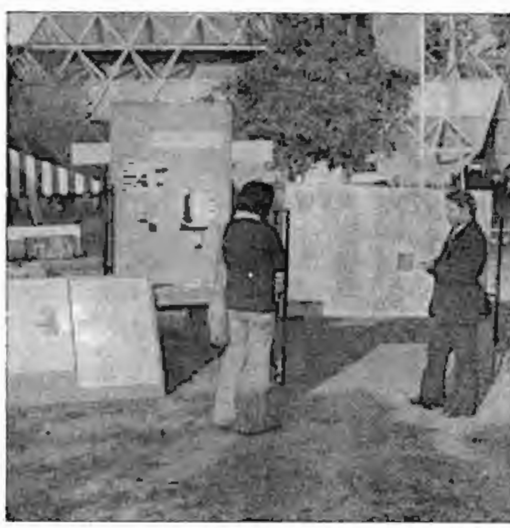


Fig. 13. Display stands on ferrocement research and applications at the SERC stall, IITF-79.

Fig. 14. Ferrocement folded plate roofing panels erected for demonstration at the exhibition, showing laps with adjacent panels.

Fig. 15. IFIC display stand sheltered under ferrocement roofing elements, NTF-80.

lot of UNIDO 80 delegates who were enthusiastic about the potentials of ferrocement. The Journal's India Correspondent arranged a display of IFIC publications and attended to several enquires of IFIC activities and services.

Fig. 16. Ferrocement service core units for housing on display at IITF-79 and NTF-80.

Ferrocement Research at the Indian Institute of Science

Investigation on ferrocement has been a continuing topic of research at the Civil Engineering Department of the Indian Institute of Science, Bangalore since 1971 and it has received an impetus with the sanction of a research scheme on studies on ferrocement precast products for housing by the Department of Science and Technology, New Delhi, in 1977. The investigation team consists of Prof. Prakash Desayi and Mr. C.S. Vishwanatha.

Studies conducted so far have been on (a) Ferrocement wall elements subjected to axial loading, (b) Lightweight ferrocement wall elements, (c) Ferrocement wall elements subjected to loads at small eccentricities and (d) Ferrocement roofing elements. Some of the results obtained have been published as journal articles and the various findings have been incorporated in four reports (DST-FC-RR 1-4) submitted so far to the Department of Science and Technology. In the studies on wall elements, variables included in the investigation are, three different shapes of the specimens (giving three different slenderness ratios), types of meshes used and amounts of mesh and mild steel reinforcement. In the case of lightweight ferrocement, sand was replaced by foamed blast furnace slag. For specimens tested under eccentricity, the magnitude of eccentricity was also a variable. The analytical studies have been mainly towards developing suitable methods of computing the ultimate load capacity of the ferrocement wall elements. Fig. 17 shows the crack pattern of a wall element after test.

Fig. 17. Ferrocement wall element designed at IISc, after a load test showing failure pattern. Photograph to be actually viewed with A-II right-side up.

In the studies on roofing elements, the variables included are three different proportions of a trapezoidal shape, different types of meshes, different span/depth ratios and different amount of mild steel reinforcement. Analytical work has been towards developing methods of estimating cracking load, ultimate flexural strength, ultimate shear strength, short-time deflections and an examination of the load factors with respect to limiting deflection and limiting crack width and how they compare with the load factor on ultimate strength. Fig. 18 shows the cracks pattern of a ferrocement roofing element after test.

Fig. 18. Folded plate elements for roofing designed at IISc, after a load test showing crack pattern and development.

The results of the study are expected to lead towards development of rational methods of design of ferrocement walls, roofing and other elements of housing constructions.

Ferrocement Service Core Units

Provision of serviced land and housing has not kept pace with the needs, particularly for low-income groups in India. It is estimated that the slum population of the Madras metropolitan area alone is increasing by some 14,000 households annually. The problem is still more acute in the cities of Calcutta and Bombay. The earlier plan for slum clearance by housing the slum dwellers in multi-storeyed buildings has not found much favour due to high cost and limited financial resources. Hence the present thinking is for the 'Site and Services' schemes where the low income groups will be provided with developed plots for construction of houses with separate service facilities like bath and w.c. The scheme also covers core housing, where partially completed houses with service cores are given, which can be competed or expanded in stages by the owners. The Government of Tamil Nadu is implementing an urban development project for improving the Madras Metropolitan area with financial assistance from the World Bank. This Rs. 9-crore project consists of forming about 13,500 serviced plots at three selected sites, namely, Arumbakkam, Villivakkam, and Kodungaiyur, on the periphery of Madras covering a total area of 168 hectares.

With a view to reducing the construction cost of service core units, the Structural Engineering Research Centre (SERC), Madras, has developed service core units in ferrocement for use in 'Site and Services' schemes.

The side walls of the core units as well as the floor and roof slabs are 3 cm thick (Figs. 19-20). The reinforcement consists of 2 layers of 26 gauge 13mm × 13mm chicken wire mesh tied on to a central layer of 10 gauge 150 mm × 150 mm welded wire mesh. Cement mortar

Fig. 19. A precast-ferrocement service core unit under erection at SERC, Madras.

Fig. 20 A view of the ferrocement service core units at Villivakkam, Madras.

1 : 3 (by volume) is applied manually using temporary plywood pieces as formwork on one side. The plywood pieces can be removed immediately after applying the mortar. The units can be cast at site or can be precast at a central casting yard. The guniting technique can be advantageously used for mass production. For precasting, the units can be combined as 2 bathroom units and 4 w.c. units which can be erected side by side for row housing schemes. The maximum weight of a precast unit will be about 2.4 tonnes. The units can directly rest on levelled ground with compacted sand or on 4 pedestals of 300 mm $\times$ 300 mm size in brick mansory, thus reducing the foundation cost. Three types of full-scale, service core units with various combinations of bath rooms and w.c.'s were cast at SERC and the performance of the units was observed over twelve months with satisfactory results.

A set of 4 bathrooms and 4 w.c.'s with an overall size of 6.00 m $\times$ 1.90 m can be constructed in 7 days by 3 masons. The fabrication of the reinforcement cage can be done in 3 days by 2 bar benders. The total cost of the set will be about Rs. 3,000/ - excluding the cost of service fixtures. The cost of 1 bath and 1 w.c. works out to Rs. 750/ - The cost of 1 bath and 1 w.c. including service fixtures will be Rs. 900/ - The Tamil Nadu Housing Board is presently constructing 80 service core units at Villivakkam.

More Commercial Production Units Established

Two more factories in Northern India started commercial production of ferrocement components. M/s. Ashok and Associates, Lucknow and M/s. Indian Concrete Products, Meerut have been provided with the know-how and designs by SERC, Roorkee under licence from the National Research and Development Corporation (Government of India), New Delhi for producing ferrocement bins, water tanks, dust bins, garbage drums, tree guards, irrigation channel linings, fodder trays and roofing units. Scientists at the SERC have trained the staff of these two units in acquiring the basic skills required in ferrocement construction.

(All the news briefs from India have been reported by our Correspondent at SERC, Roorkee, Mr. P.C. Sharma).

SOLOMON ISLANDS

Fisheries Development Project

In Solomon Islands, 10 pole and line ferrocement fishing vessels are being built with a \$3.6 million loan from the Asian Development Bank. A shipyard set up for the purpose by National Fisheries Development Ltd. at Sasapi, on Tulagi, an island some 32km from Guadalcanal across the notorious Iron Bottom Sound, graveyard of scores of Japanese American and Australian warships.

General manager of the Sasapi shipyard is Trevor Homes, a UK fisheries expert from Grimsby, who is convinced that building in ferrocement is the most advantageous method for a developing nation. In his opinion, building of the hulls can start more or less immediately, using locally available labour and very little equipment, provided one has a ferrocement expert supervising the initial stages of the project.

Building in ferrocement is usually a labour-intensive method, and thus expensive in a country where wages are high. But it can be very economical where labour is easily available and cheap. The Solomons were ideally suited for it, as there were a few welders, metal workers and plasterers available, who had worked in ferrocement before, and even some shipwrights who had learned their trade on locally built timber boats.

According to Trevor Holmes, one of the ferrocement hulls should cost only 60% of the price of a similar hull built in steel, fibreglass or timber.

The project started in August 1978 on the site of a former boatyard. By the end of 1979 the first hull was ready for launching, while the second hull was reaching the plastering stage. The boats will have a typical Japanese look about them, with an elongated beak and fishing platforms all around. They will carry Japanese skippers and fishing masters from Okinawa. But the entire crew of 23 will be made up of Solomon Islanders. The fishing method employed by these boats will be the proven Japanese technique of spraying the chosen area first, followed by pole and lining with live bait.

Designed by Auckland naval architect Jerry Breckveldt, the boats will be 24m LOA the hull having a length of 20m, breath 6m, draft 2.73 m. They will have an ice capacity of 27.5 m^3, but no refrigeration, as they will be used as day boats only, returning to base each night to land the catch and load the bait for the next day's fishing. Propulsion will be provided by a 450 hp Caterpillar engine, giving a speed of 10.5 knots. Each boat will be equipped with two generators to provide electricity, drive the pumps etc, a G & M of 34 KVA, and a smaller Yanmar of 4 KVA for emergency use.

Aware of one of the major shortcomings of a ferrocement hull - poor lateral impact resistance - Trevor Holmes is trying to build the boats as strong as possible, but without making them too heavy in the process. Watson's mesh is used throughout, with two layers inside and three outside. The side decks will be of ferrocement, but superstructure and interior will be timber. The estimated fishing weight will be about 130 tonnes.

The shipyard has a large building shed in which two hulls can be finished side by side (Fig. 21-22). Projected time from hull laying to commissioning is 12 months (four months for lofting and armature work, four months for plastering, curing, painting and launching, plus a final four months for the fitting-out, to be carried out afloat).

Obviously the first two boats are taking longer: the first will be 17 months, the second 15 months. But the next eight hulls should be rolling off every four months after that, so that the projected 10 vessels should take only four years to build.

Fig. 21. Pole and line skip jack tuna fishing vessel that has been completed is shown in the foreground. At the background is another such vessel whose armature is ready for plastering, Solomon Islands.

Fig. 22. A Stern view of the vessel shown in Fig. 21. The photograph also shows a general view of the timber trussed shed, Solomon Islands (LOA = 24 m; displacement fully laden = 134 m.t., 450 BHP, 10 knots).

Besides the general manager, three foreign experts - a ferrocement specialist, an engineer and a shipwright - are also employed by the yard, all provided by either British or New Zealand aid.

A total of 120 local men work at the shipyard, about 75% of them employed on the boats under construction, the remaining doing general work as the Sasapi shipyard also offers maintenance and repair facilities for private commercial shipping, which cannot use the government shipyard, also based at Tulagi. Two slipways up to 80 tonnes are available at Sasapi, the shipyard being capable of carrying out all basic repair work. Plans are also underway for a larger 350 tonnes slipway to be built soon.

The shipyard will also build 20 bait-catching boats, two for each catcher boat. The bait catchers will be 8m long, breath and a draft of 1m. Two have already been built in ferrocement (Fig. 23), but as this material tends to be too heavy for this size, the remaining boats will be probably built of GRP. The shipyard also has on order 15,8m plywood fishing boats for the Solomon Islands Development Bank, which will sell these on credit to local fishermen.

Fig. 23. A smaller vessel (LOA = 7.8.m displacement = 3.0 m.t.; 20 BHP; 6.5 knots) built for training the staff at the boat yard, Solomon Islands.

The boatyard at Sasapi is already operating two line and pole fishing boats of similar dimensions to those under construction. Built in Japan, one of steel, one of fibreglass. They have already proven to the management that neither of these materials is suitable for the Solomons, as major structural repair work cannot be carried out in the islands. In case of serious hull damage as has already happened, the boats had to be sent to Japan for repair.

Both the existing boats and the projected 20 will be operated by National Fisheries Development Ltd and will sell their catch to Solomons Taiyo, whose freezing and canning factory is also on Tulagi.

(Report based on article in Pacific Islands Monthly-April 1980 and information provided by Mr. Ian Baugh, our Associate Editor who serves as the ferrocement expert for the project.)

U.S.A.

ACI Committee 549 meets in Las Vegas

A recent meeting of ACI Committee 549 took place during the ACI annual convention in Las Vegas, March 2-6, 1980. Among the items discussed were the future directions of committee activities. The following activities were proposed in order of priority:

(a) Immediate completion of the state-of-the-art report on ferrocement upon return of the review from the Technical Activities Committee.

b) Preparation of a recommended practice guide for ferrocement.

c) Organization at a future ACI convention of a combined symposium on fiber reinforced concrete and ferrocement to be sponsored by ACI Committees 544 and 549.

Other items of interest were also discussed among which, 1) the need to assess the fire resistance of ferrocement as its application in the U.S. housing industry is greatly hindered by fire code requirements, 2) the need to assess existing technologies of the production of ferrocement and define most efficient techniques to encourage its use in industrialized nations, and 3) the need to optimize and standardize mesh geometry, types of meshes and the required mechanical properties of the mesh reinforcement.

Committee 549 will also attempt to establish closer contact and communication with other technical committees (of ACI or other organizations) particularly the RILEM and the IASS Committees on ferrocement to coordinate research needs and combine expertize. Most of the above items will be addressed in more detail at the next committee meeting, during the ACI fall convention in Puerto Rico, September 1980.

(Report by Dr. A.E. Naaman, Chairman, ACI Committee 549 on ferrocement.)

Homely Sculptures Afloat

Miles away from the conventional applications, are the New Age Sundial Structures designed by Harold Meeske. Extravagantly innovative ideas recreate the "castle-in-a-moat" concept in these structures which are nothing but modern-day castles (costing no less than a million dollars!), which float and rotate in oversized swimming pools or lakes.

New Age Sundial Structures (Fig. 24)

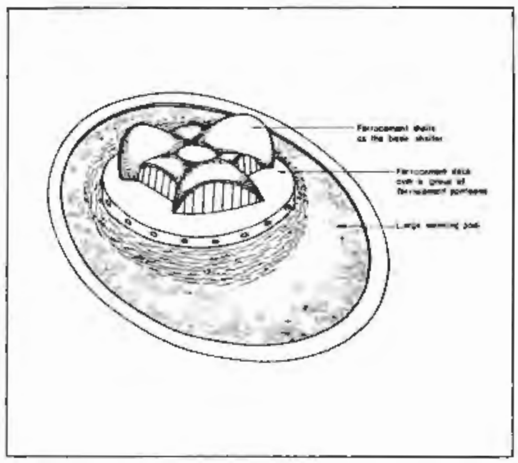


Fig. 24 An artists impression of a New Age Sundial Home

according to the company by the same name (706 S. Sail, Santa Ana, California, U.S.A.) are designed to be unique and luxurious homes built on floating pontoons varying in width from 12 m to 30 m. The homes vary from 280 m^2 to 2300 m^2 depending upon individual requirements and the architectural design As floating structures they can be rotated a full 360 degrees, either continously at different speeds or intermittently. This allows a panoramic view of the landscape from any room at any time. Hilltops are obviously the most ideal locations for these homes. Each home is expected to have some of the most advanced technology in solar energy, electronics and interior design. Ferrocement would be used along with some other conventional materials for the construction of the basic structure.

These units centered 20-30 feet from the sides of the pool will have access bridges that are operated hydraulically.

The company brochure goes on to describe other options like a subterranean parking under the swimming pool with an elevator coming up the center of the structure and a guest house or an office in an adjoining pool. Sitting here in Asia, the amazing concept seems too extravagant even to fantasize!

The firm plans to build the first homes in Los Angeles, Orange country and Palm Springs areas and later envisages to build 500-1000 such structures in other parts of the world in the next 10 to 15 years.

(Report compiled by V.S. Gopalaratnam from a brochure forwarded to the IFIC by Dr. G.L. Bowen, an ex-member of the Journals' Editorial Board).

INTERNATIONAL MEETINGS

Forthcoming Events

International Conference on the Performance of Concrete in a Marine Environment, St. Andrews, Canada, August 17-21, 1980. For further information, contact: Mohan Malhotra, Conference Chairman, CANMET, 405 Rochester Street, Ottawa, Ontario, Canada KIA OGI.

Sixth International ERMCO Congress, Brussels, Belgium, September 22-26, 1980. For further information, contact: APBP-BVSB, Mechelsesteenweg 363, 1950 Kraainerm, Belgium.

Session on Experimental Wind Engineering on Structures, Florida, U.S.A., October 27-31, 1980. For further information, contact: Prof. Leon R.L. Wang, Department of Civil Engineering, Rensselaer Polytechnic Institute, Troy, New York 12181, U.S.A. or 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. For further information, contact: Polymer Concrete Congress 1981, Secretariat, c/o Dr. Yoshikho Ohama, Department of Architecture College of Engineering, Nihon University, Koriyama, Fukushima-ken 963, Japan.

Second International Conference on Superplasticizers in Concrete, Ottawa, Canada, June 10-12, 1981. For further information, contact: Mohan Malhotra, CANMET, 405 Rochester Street, Ottawa, Ontario, Canada KIA OGI.

Call for Papers

Second Australian Conference on Engineering Materials, University of New South Wales, Australia, July 6-8, 1981.

The University of New South Wales is organizing the Second Australian Conference on Engineering Materials which incorporates an one-day session on materials of construction for developing countries.

Abstracts for the above conference are solicited on topics relating to the research, development and application of engineering materials. Abstracts are also invited on topics relating specifically to low-cost materials and other similar construction material for use in the developing countries.

Closing date for receipt of the abstract is August 15, 1980 while full manuscripts are expected to be submitted by January 15, 1981.

For further information, contact:

Dr. D.J. Cook
School of Civil Engineering
University of New South Wales
P.O. Box 1, Kensington, NSW 2033
Australia (Tel. (02) 662 3009)

The Nervi International Symposium on Ferrocement, Bergamo, Italy, July 22-24, 1981.

The International Union of Testing and Research Laboratories for Materials and Structures (RILEM), the American Concrete Institute (ACI), and the International Association for Shell and Structures (IASS) are planning an International Symposium on Ferrocement in Bergamo, Italy on July. 22-24, 1981. The goal of the symposium is to synthesize information on:

- Materials Properties
- Structural Design
- Technology of Production
- Cost Evaluation
- Applications
- Recommendations for Code of Practice

Prospective authors wishing to present a paper are invited to submit an abstract of about 200 words by November 30, 1980. The manuscript of accepted papers must be mailed by March 31, 1981. The preprints will be distributed before the symposium. The final proceedings of the symposium will be published by RILEM. Please submit the abstracts to either of the co-chairmen of the symposium:

Professor Ing. Guido Oberti
Istituto Sperimentale Modelli E Strutture (SPA)
Viale Giulio Cesare, 29
24100 Bergamo
Italy

or

Professor S.P. Shah
University of Illinois at Chicago Circle
Department of Materials Engineering
P.O. Box 4348
Chicago. IL 60680 USA

Abstract

JFP25 INFLUENCE OF SKELETAL STEEL ON THE FLEXURAL BEHAVIOUR OF FERROCEMENT

KEYWORDS: Analysis, First Crack, Flexure, Testing, Ultimate Moment.

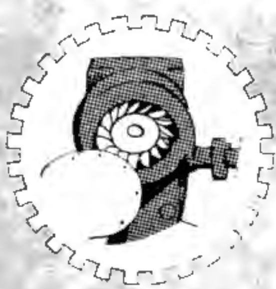
ABSTRACT: This article is written with a view to clarify certain aspects the engineering behaviour of ferrocement in relation to the long standing debate of use of ferrocement for fishing crafts, with and without the use of skeletal steel. Theoretically the contribution of skeletal steel to an increase in the cracking moment is negligible. However, in the ultimate condition, this will be stressed due to an upward displacement of the neutral axis from the centroidal axis and thus not only greatly enhance the ultimate moment carrying capacity but also allow for, a greater ductility resulting from increased ultimate deformation. The study experimentally confirms theoretical derivations of the behaviour in flexure of ferrocement with and without the use of skeletal steel.

REFERENCE: YEN, T. and SU, C.F., "Influence of Skeletal Steel on the Flexural Behaviour of Ferrocement", Journal of Ferrocement, Vol. 10, No. 2, Paper JFP25, July 1980, pp. 177-188.

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.