FERROCEMENT BOATBUILDING FOR ROYAL NAVY APPLICATION

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ABSTRACT

Ferrocement boatbuilding has a very long and successful history but in the passing of time, little application of this material has been made in boats beyond the fishing and leisure industries. This article examines the feasibility of manufacturing naval craft from ferrocement using new production techniques and materials based on the work of:

- The Naval Ship Research and Development Center, Bethesda, Maryland, U.S.A.
- Fibersteel International Company, West Sacremento, California, U.S.A.
- The author's own work from an undergraduate project for an Honours Degree in Ship Science at Southampton University.

Background

For many, the merest mention of boats made from concrete brings laughs of derision and disbelieving glances, but it is in fact the case that concrete boats have been created in a variety of maritime forms for over 140 years. As a production method, ferrocement (as the material is generically known) can provide a great many advantages over wood, steel or even Glass Reinforced Plastic (GRP) of organisations to determine the optimum type of mesh to use as ferrocement reinforcement. A census of opinion favours the half inch 19 gauge galvanized welded square mesh, as this has the greatest strength to surface area ratio.

The major bulk of ferrocement comes from the mortar. Mortar is different from concrete in as much as:

- Concrete is a mixture of cement, sand and gravel hardened by chemical reaction when a controlled amount of water is added.
- Mortar implies a mixture of cement and sand alone, hardened similarly to concrete.

A number of materials can either be added or used as partial replacement for the cement or water to further enhance the properties of the mix.

In its most simplistic terms, ferrocement has been defined as:

> 'A number of layers of closely spaced steel mesh into which the concrete, in the form of mortar, is forced by hand and the strength of which is usually considered to come entirely from the steel with the concrete simply operating to keep out the water.'[1]

Whilst this is a very simplistic definition and whilst it must be stated that the mortar matrix does provide a degree of strength to the material, this description is representative. As such, if it were possible to produce a matrix material like mortar which had the same strength and bonding properties, retained its water-tight properties but had a greatly reduced density, then ferrocement would genuinely become a viable alternative to aluminium and GRP.

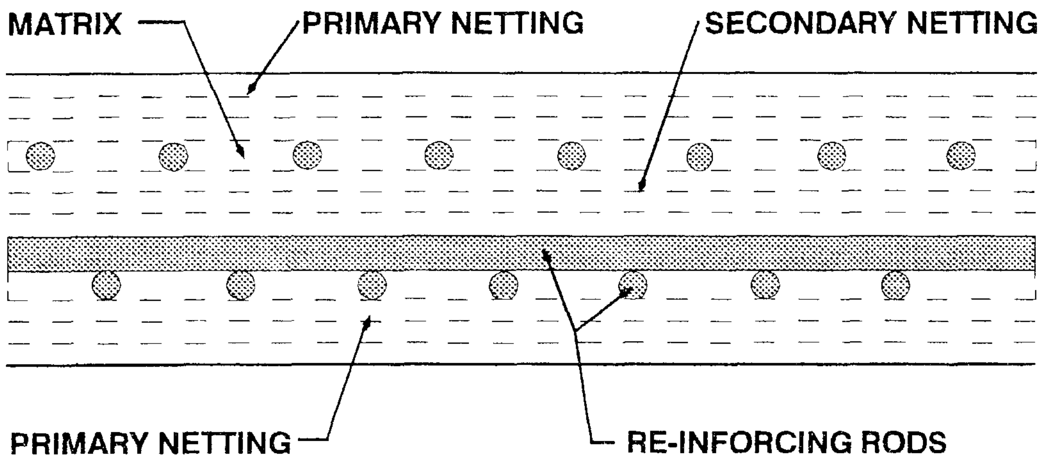

FIG. 1—CLASSICAL FERROCEMENT CROSS SECTION

Standard Fabrication Method

Traditionally ferrocement boats have been manufactured using a 'skeletal' framework (FIG. 1) of steel rods laid at a set spacing in a longitudinal and transverse orientation. To this framework are tied a number of layers of wire or steel mesh on both the inboard and outboard faces. To this meshed framework the mortar is applied by hand and forced in to provide a void free matrix. The surface mortar is then plastered to provide a smooth finish.

This method of manufacture is fraught with problems; the largest being the inclusion of voids in the framework, which is largely due to the method of forcing the mortar into the framework. No perfect method exists to ensure that full penetration is achieved with no voids. Voids create weak areas where they occur. In addition they may allow water in, which can then corrode the reinforcement or may result in water pockets freezing in sub-zero temperatures hence causing the mortar to rupture. In a vain attempt to design for these failures, naval architects have in the past tended to specify section thicknesses in excess of what is actually required, hence further adding to the weight penalty of these vessels.

Using this production method also results in an inefficient use of the skeletal steel. This is because the strength of the material depends upon the amount of steel used compared to its surface area in contact with the mortar. Relatively large diameter steel rods have a small ratio of bond area to steel content and result in the rods not being stressed to their design loading, before the material fails through separation of mortar from the rods.

In addition to this, the large spacing that exists between the rods results in large areas of mortar remaining unreinforced. Effectively these are areas which contribute to weight, but provide nothing to material strength. Yet another disadvantage of this type of construction, is the way in which the large rods act as stress concentrators. The compounded effect of all of these shortcomings has led to a material which is:

- Inadequately reinforced.
- Prone to voids and rupture.

Hence it has been manufactured with excessively large cross sections to compensate. This leads to a poor design which increases material mass, whilst not increasing its strength.

Cement River Assault Boat

In 1970 the U.S. Naval Advisory Group in Vietnam initiated a ferrocement boat building programme; with design and development being undertaken by the Naval Ship Research and Development Center, Bethesda, Maryland, U.S.A.[2] The programme was to design and build a Cement River Assault Boat (CRAB) which would have a design displacement (with a crew of five and full equipment) of 2.9 tonnes and be capable of 30 knots.

The design was to deviate from the traditional construction methods by eradicating the need for the large diameter reinforcing rods that had so hindered the designs of previous vessels, instead designing the CRAB with an all mesh construction (FIG. 2).

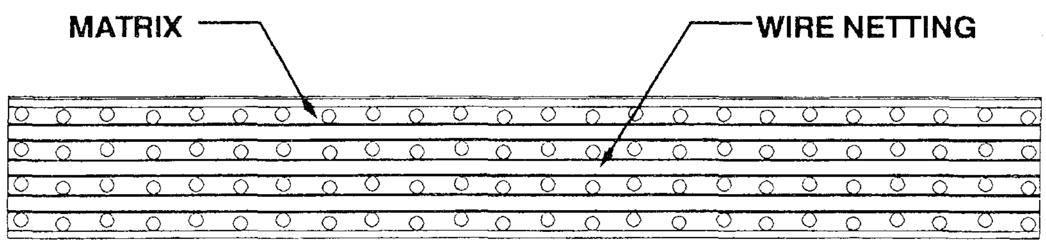

FIG. 2—FERROCEMENT CROSS SECTION (POST DINSENBACHER AND BRAUER)

The manufacture of the CRAB was undertaken on a male mould which was open on both sides for ease of hand plastering. The design required five layers of ungalvanized, half inch squared, 19-gauge wire mesh to be tied together over the male mould. This was then plastered with mortar to provide a very thin structure of the order of 1cm thick. Hence a vessel was built which had no steel reinforcing rods as part of the composite material. It was however, still a fairly labour intensive and laborious process as, even though the wire and reinforcing rod tying had been reduced, still a large degree of mesh wire tying remained and the process still relied upon hand plastering.

The CRAB was nevertheless still a major evolutionary step in ferrocement design as it provided a vessel that could withstand the rigours for which it was designed, namely loadings caused by:

- Impact of the bottom on the water surface.
- Propulsion,
- Hoisting
- Side impact with other boats or piers

Yet it was thinner and 'supposedly' less reinforced than any of its predecessors.

The CRAB was specifically designed for inland high speed assault duties in Vietnam but due to the cessation of hostilities, the programme was never progressed beyond the prototype stage. However, the CRAB and two similar design vessels were produced and handed over to the Korean Marine Corps. Here they have subsequently seen many years of active duty and to the authors knowledge are still operationally used with no recorded problems.

This vessel was designed to operate at speeds up to and including 30 knots. However, the designed operation was for inshore waters and as such the vessel would not have been subject to the intense loadings attributed to wave interaction with the boat. On the other hand, it must not be overlooked that ferrocement already has a proven history of use at sea where innumerable fishing boats and trawlers manufactured from the material are daily subject to the worst of weather conditions, suffering no more problems than their steel contemporaries. What must not be underestimated also, is that ferrocement has a longer and therefore more proven history at surviving such conditions than GRP vessels do.

Work of the Fibersteel International Company

In an attempt to reduce the labour intensive nature of ferrocement boat manufacture, the Fibersteel International Company of Sacremento, California, U.S.A. developed a new method of manufacture[3]. This production method was patented in its own right in 1972 (British Patent Number 1 347 587, March 17, 1972), but drew much of its philosophy from GRP manufacture.

The principles of this method necessitate the use of a female mould. This may be manufactured from either GRP or ferrocement. The mould, following coverage with a parting agent, is layered with a 2 to 3 mm mix of mortar fortified with a polymer. This gives a tough, non-porous surface which offers a GRP like surface finish and requires no surface finishing upon release from the mould. Like GRP, pigments can be used at this stage to give the hull a permanent colour. Onto this skin is **sprayed** a further 2 or 3 mm layer of mortar into which strips of mesh are pressed, using a steel roller to ensure full mortar penetration is achieved. Subsequent layers are undertaken in an identical manner, ensuring that the mesh overlaps in such a way as not to leave any areas without reinforcement. This process is continued until design thickness is achieved. Upon completion of the mortar curing, the hull is removed from the mould in much the same way as is done with GRP. It is then ready for fitting out.

The build up of mesh layers in this manner ensures that no large scale voids exist within the mortar, as the mesh is forced into the mortar rather than the vice versa method of previous construction. Furthermore, using mortar spraying devices, the composite can be built up in faster timescale than is possible for GRP lay-up. Additionally, this material scores over GRP in that the manufacturing skill requirement is less and the atmospheric conditions are 'friendlier' and less explosive!

Like GRP, this production method takes on many of the advantages not offered by steel or aluminium production; most notably, the ability to allow the naval architect to specify varying material thicknesses for different areas of the vessel as dictated by the design loadings. For a material such as ferrocement, this gives further vital weight savings.

Here then, is a fast and relatively simple manufacturing method for ferrocement boat production, on either a small or large scale, that at the same time allows vessels to be built which are adequate in strength and impact resistance but are significantly cheaper than GRP or steel equivalents. The only handicap the ferrocement boat has is its excess weight penalty.

Silica Fume Concrete

Silica fume concrete is a relatively new innovation in the construction industry, first used commercially in the 1980's. It is claimed that silica fume concretes have greater strength and densities than Ordinary Portland Cement (OPC) and that they have greater resistance to abrasion and chemical attack.

Silica fume is a mineral composed of ultra-fine, solid, amorphous glassy spheres of silicon dioxide. The average silica fume particle size is 0.15 microns or put another way, each microsphere is 100 times smaller than a cement grain; in a typical concrete mix with 10% silica fume, there will be 50,000 to 100,000 silica fume particles for each grain of portland cement. Because of the nature of the silica fume admixture, it is claimed that the silica fume concrete is stronger than an OPC mix for two reasons:

1. The ultra fine silica spheres act like ball-bearings in the slurry (silica fume is usually provided in a slurry form due to its fly-away nature) and form part of the pore water solution. They are easily dispersed in the spaces between and around each cement grain when the concrete is freshly mixed. In a typical 10% silica fume concrete mix, the distribution of the fume particles results in a dramatic improvement of the fine pore structure of the hardened concrete which then leads to more densely packed, stronger and less permeable concrete.
2. The highly reactive microsilica, with a specific surface of around 20,000 m^2/Kg (OPC = 350-500 m^2/Kg, tobacco smoke = 10,000 m^2/Kg) alters the cement paste structure dramatically. During the binder phase of hydration, the silica fume reacts with the liberated calcium hydroxide to form secondary Calcium Silicate Hydrates (CSH). This CSH is very dense and even after the first few hours, significant increases in compressive and flexural strength are observed.

Study into Strength Characteristics of Silica Fume Concrete

To test the strength theory of silica fume concrete, the author undertook a theoretical and experimental study of silica fume concrete as his final year project at Southampton University.[4] In brief the study was undertaken as follows:

A theoretical analysis was undertaken to predict the compressive and tensile strengths, modulus of elasticity and rupture of a number of mortar mixes. The theory was derived in parallel with an experimental investigation of the same mixes. These mixes were:

- An OPC control.
- A 5% Silica fume (SiO_2) partial replacement mix (where the partial replacement is 5% of the cement content).
- A 10% SiO_2 partial replacement mix.
- A 15% SiO_2 partial replacement mix.

With these mixes a number of test pieces were cast for subsequent destructive testing. Each batch of test pieces consisted:

- 1 wire mesh reinforced panel (for uniform load test).
- 6 cubes (for compressive loading at various times over the period of 30 days).

- 1 cylinder (for modulus of elasticity test).
- 1 beam (for modulus of rupture test)
- 2 'waisted' specimens (for direct tensile test).

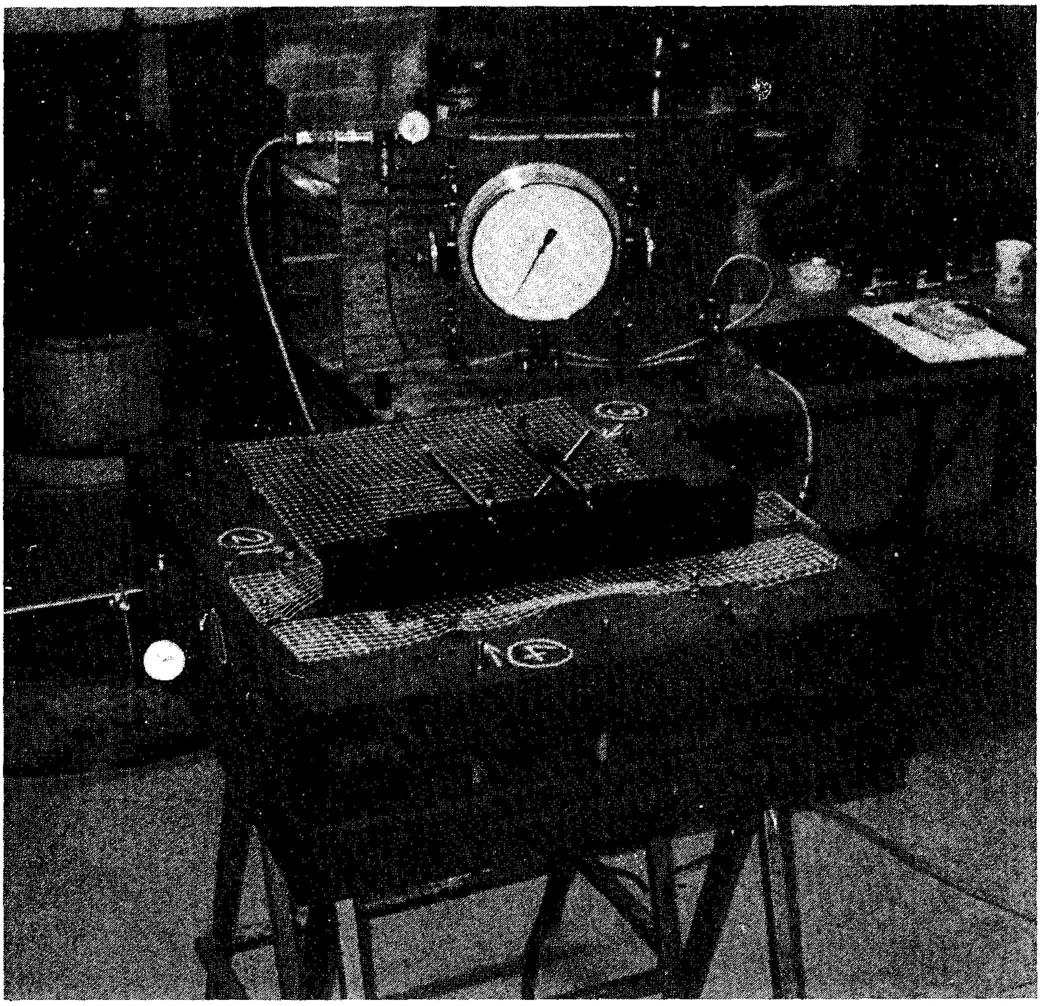

FIG. 3—PANEL TESTING RIG AND PRESSURE METER

The equipment used to test the reinforced flat panel is shown at (FIG. 3). It essentially relies upon a steel framework retaining the panel in place whilst a rubber bag is inflated below it to provide a uniformly distributed load over the lower face of the panel. Deflection of the panel is measured at a number of points on the upper face at increasing loads until the panel ultimately fails. (FIG. 4) is a graph of panel centre point deflection plotted against applied load for the early stages of panel loading.

Towards the failure stage of the panel and hence at the point where the mortar starts to crack in tension (upper face) and crush in compression (lower face), the deflections of all four panels and the ultimate load at failure of the panel all tend towards the same values (not represented on FIG. 4). This goes to prove that ferrocement relies for the vast majority of its strength on the amount and type of reinforcement used and only to a very small extent on the strength of the mortar. This is a very important finding which corroborates the comment made by TURNER in reference 1. It also adds to the theory that if it were possible to create a

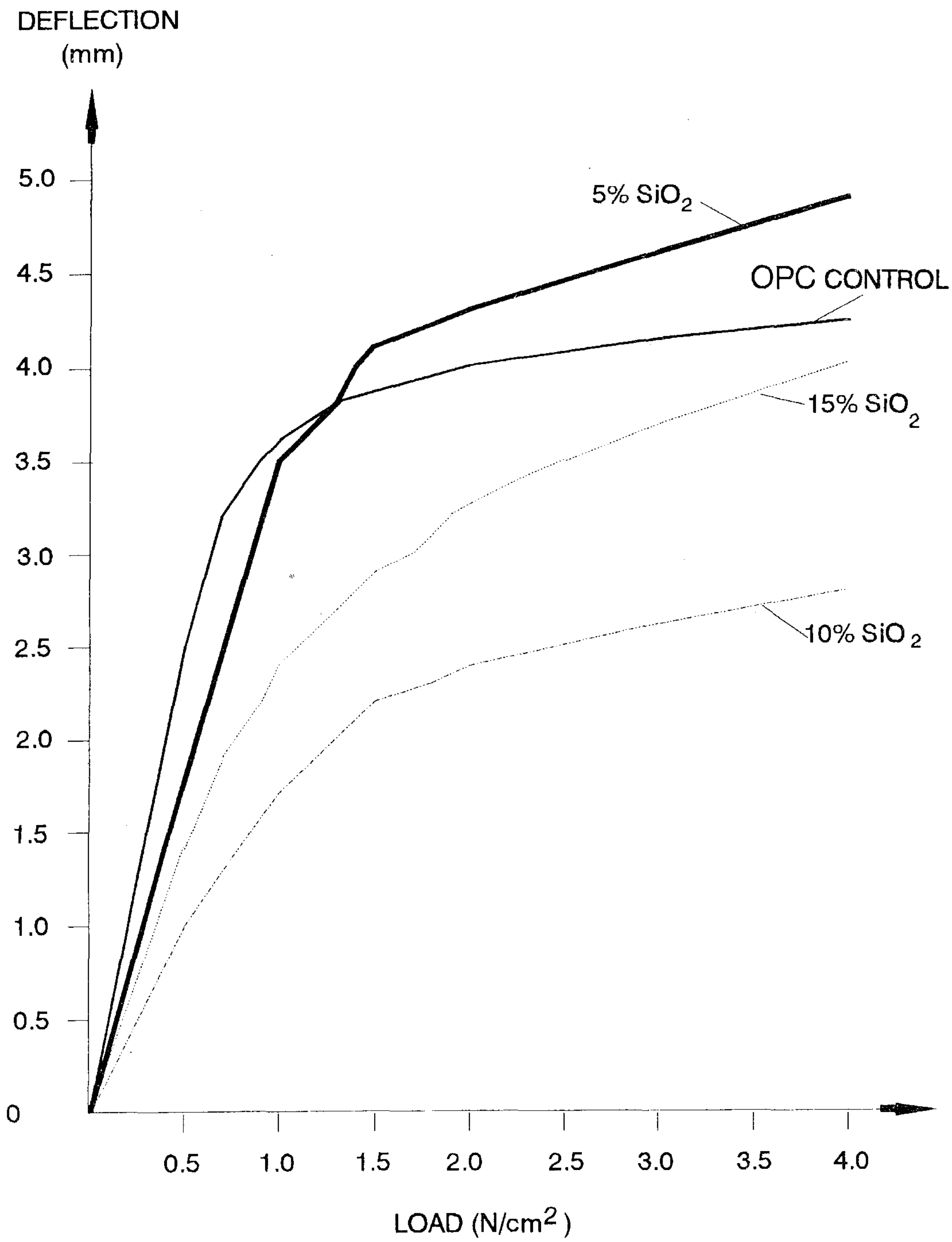

FIG. 4—LOAD VS DEFLECTION FOR SiO_2 CONCRETE PANELS

lightweight mortar which still maintained a degree of strength and impact resistance whilst retaining water resistant properties, then the overall performance of the ferrocement would not suffer but benefits could be gained with respect to weight reduction. This then, is where the other tests on the remaining concrete specimens took on a new importance.

The compression testing on the six concrete cubes was undertaken at 1, 3, 7, 14, 21 and 28 days after mortar casting. Although concrete continues to harden beyond this time, the 28 day test is used as a guide to the final strength of all mixes

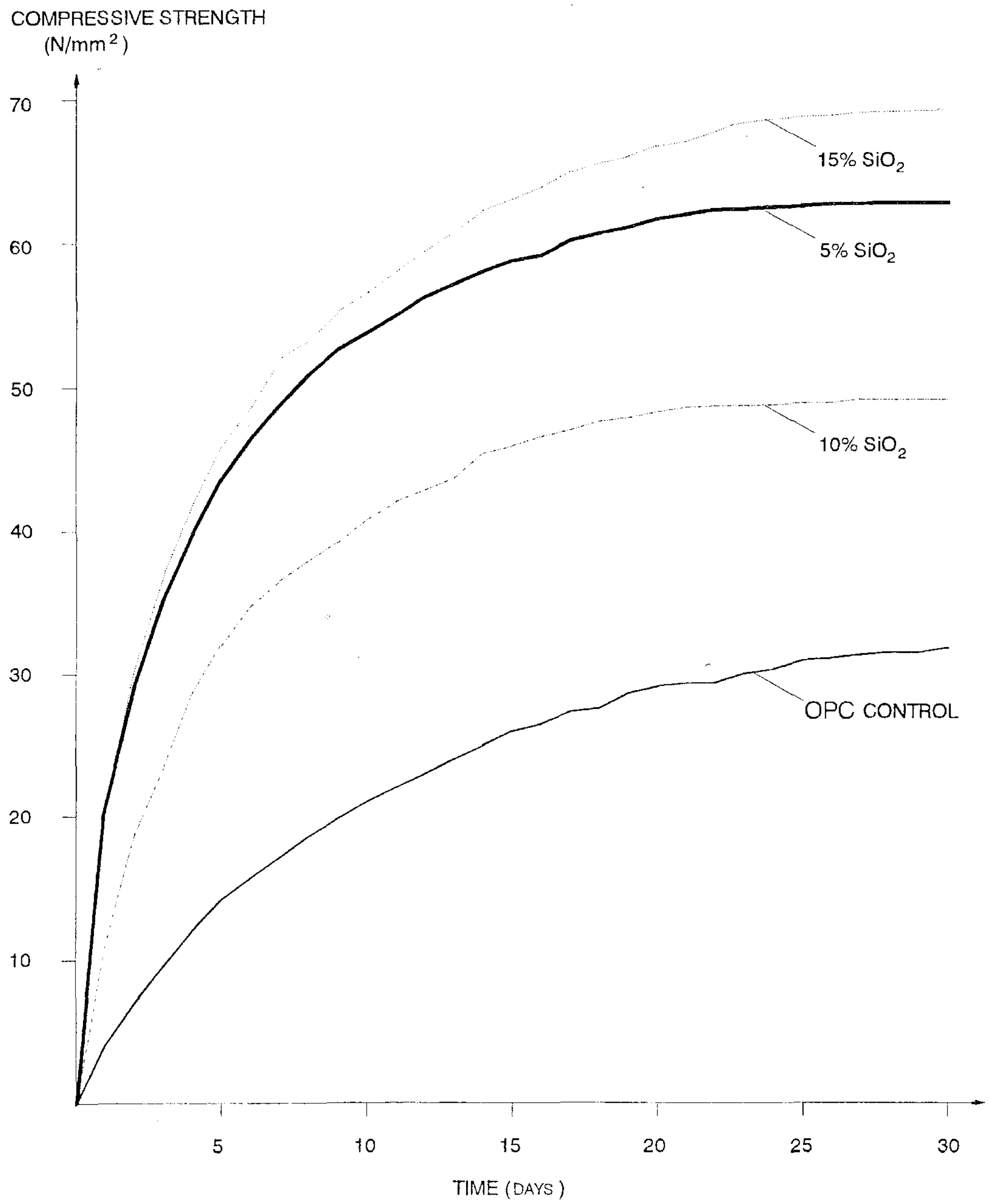

FIG. 5—STRENGTH COMPARISON FOR SiO_2 CONCRETES

subject to laboratory analysis. The comparison of compressive strengths of the four mix designs is shown at (FIG. 5).

As can be seen, the SiO_2 mixes have far greater compressive strengths than the OPC mix. Observation of this graph suggests that the 10% SiO_2 was subject to quality control problems as it should have strength values between those of the 5 and 15% mixes. Nevertheless, the results show that the 5 and 15% mix designs have in excess of double the strength of the OPC control mix. Even the suspect 10% mix improves upon the OPC by around 50%. Subsequent to the author's own investigations, the Departments of Civil Engineering and Ship Science, University of Southampton, have repeated these experiments a number of times and though the author does not have the results, it has been confirmed that these findings are of the same order.

(FIG. 6) shows the results of the Modulus of Elasticity test as undertaken on the cylindrical specimens. It can be seen from this graph that, as in the compressive tests, the ultimate compressive loads on the SiO_2 mix designs are far in excess of that at which the OPC mix failed. Another important result of this test was also the strain values of the mixes prior to failure. It can be seen that the 5% mix had a strain at failure value 30% larger than the OPC whilst the 15% mix was some 65% larger. In the world of relatively large flexure values associated with ferrocement hulls, these values are quite significant.

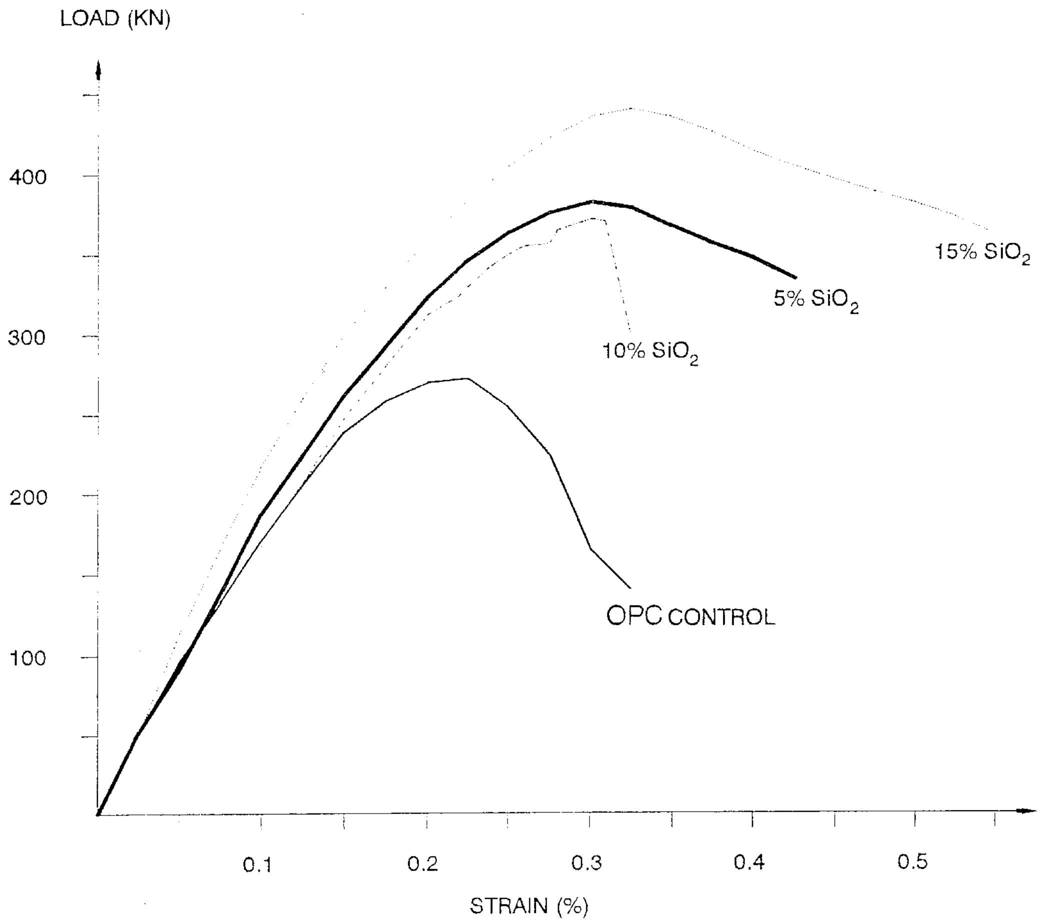

FIG. 6—LOAD VS STRAIN CURVES FOR SiO_2 CONCRETES

The tensile test figures show similar trends to those of the compressive tests. Using the tensile test pieces (waisted section) the values for maximum load prior to failure are shown in table I.

TABLE I—*Tensile Test Results of 'Waisted' Specimens*

Mix Design	OPC Control	5% SiO_2	10% SiO_2	15% SiO_2
Maximum Ultimate Tensile Strength (N/mm^2)	2.72	5.5	4.5	3.73

With respect to ferrocement, the tensile strength of the mortar is not of serious consideration as in a similar manner to GRP, the ferrocement obtains virtually all of its tensile strength from the reinforcing mesh alone.

The findings outlined in this article are represented in their most simplistic form based on the more definitive account at reference 4. The results as represented here have been fully verified by the repeat experiments undertaken at Southampton University and they do convey the significantly greater strengths that SiO_2 concretes and mortars have over standard OPC mix designs.

SiO_2 Mix Applications

As has already been discussed, the effective strength of a ferrocement hull is derived from the reinforcement used in its manufacture. As such, for any ferrocement boat design, the thickness of the hull will be determined by the naval architect and the classification societies who will specify the absolute minimum thickness of the hull, regardless of what type of mortar matrix is used. It would not therefore be at all sensible to propose a standard OPC mortar is replaced by a high strength SiO_2 mix-especially as the SiO_2 mix would actually be marginally denser and so would add to the overall mass of vessel. If, however, the high strength mortar had a large degree of the sand aggregate replaced with small polystyrene spheres, a structure would be created which would:

- Have the same strength as an OPC mix with or without reinforcement.
- Still retain water impermeability.
- Retain or improve its impact properties.
- Be considerably lighter.

This theory has not as yet been proven but the experimentation is continuing and the theoretical strength calculations on this structure do bear much promise. It may be that the concrete boat designer may soon have a material which can greatly reduce the largest problem faced in this field, that of excessive weight.

Implications for Small Craft

If enough interest is generated in the furtherment of this high strength/low mass mortar, then the research work can be intensified to produce accurate experimental data leading to full scale manufacturing trials. It is important also to further the work so that comparative studies can be undertaken with GRP, aluminium and steel equivalents with respect to:

- Craft weight.
- Strength.
- Impact and fatigue resistance.
- Cost of material and manufacture.

It is the belief of the author that the utilization of the very latest manufacturing techniques in combination with the latest material developments will provide ferrocement with the necessary armaments to take on alternative manufacturing techniques. The potential for this material is vast.

In terms of specific applications in the Royal Navy, ferrocement could provide hulls for small craft such as sailing dinghies, motor boats and ferry boats right up to motor launches, patrol boats and coastal training craft of around 20 m lbp. Even vessels in excess of 20 m are not beyond the capabilities of this material, however boats of this size are getting into the realms of reinforced concrete (but the design philosophies remain the same).

Conclusion

This article has endeavoured to scratch the surface of this wide and very varied subject. It has also attempted to introduce a number of different and probably new concepts to those who read the *Journal*. As a result, these concepts have been outlined here in very basic and spartan descriptions which have not gone far enough to do the material justice. It is to be hoped, however that the subject has been covered in great enough depth to show even the 'unbelievers' that there are a number of possibilities for this material.

It is fully understood that small boats in Royal Navy service are effectively bought off the shelf, direct from the designers/manufacturers; so there is little need for research and development work in manufacturing materials for such craft. However with a little forethought, all ideas and concepts which may provide an economical and reliable alternative to existing manufacturing methods are worth exploring. It is in this belief that the information within this article may have instilled in many the belief that many Royal Naval craft could be made from ferrocement. The research work will continue regardless, but an interested end user will do much to emphasise the importance of such work.

If it is at all necessary to have an incentive in embarking upon such a programme of research and development into ferrocement applications in Royal Navy vessels, it must come from the knowledge that should the theory become reality, alternative vessels for those in service at the current time could be produced for up to one quarter the cost of current equivalents.

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