MARINE APPLICATIONS OF FERROCEMENT

by

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ABSTRACT

Ferrocement has been accepted as a suitable building material for marine structures. However, its potentials have not been fully utilized. The reasons are manifold. This study identifies and analyzes the problem areas, the possible solutions and the improvement of ferrocement marine technology.

INTRODUCTION

Ferrocement is a type of thin-wall reinforced concrete commonly constructed of hydraulic cement mortar, reinforced with closely spaced layers of continuous and relatively small diameter mesh. The mesh may be metallic or made of other suitable materials [1]. Ferrocement is considered to be an extension of reinforced concrete technology [2]. It is the uniform distribution of the reinforcement in the resulting composite and its different material performance, strength behavior and potential applications which creates a distinction from conventional reinforced concrete, that it must be classified as a separate material.

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Ferrocement possesses a degree of toughness, ductility, durability, stregth and crack resistance that is considerably greater than that found in other forms of concrete construction [3]. These properties are achieved in structures with a thickness that is generally less than 25 mm, a dimension that is nearly unthinkable in other forms of concrete construction, and a clear improvement over conventional reinforced concrete. Surprisingly, good performance can be achieved in ferrocement with almost primitive field conditions and it does not necessarily require highly skilled practitioners. One can call it a high technology material, yet its production in terms of required labor skills and lack of sophistication of its constituent parts could be viewed as low technology.

The vast literature shows that ferrocement is a versatile construction material and that it has already attained worldwide popularity in almost all kinds of applications: housing, sanitation, agriculture, fisheries, water resources, and water transportation both in freshwater and sea water environment [4,5].

In its present state of development, ferrocement find its widest utilization in boat-building. Boats with legth ranging from 5-30 m have been used for transport, for leisure, and for fishing in various countries [6]. Although these are mostly indigenous human-powered workboats, there are also many deep water vessels now in operation. Other possible marine applications [4,9] include buoys [7], breakwaters [8], dry docks, submarine structures, floating and submerged oil reservoirs, offshore tanker terminals, floating bridges, barges, pontoons, floating molds, and floating shelters for floodprone areas.

PROPERTIES OF FERROCEMENT

Ferrocement possesses high elasticity, tensile strength, flexibility, ductility, impermeability, impact resistance and crack resistance, which are attained by proper control of matrix and reinforcement parameters.

The uniform distribution and high surface area to volume ratio (specific surface) of its reinforcement results in better crack arrest mechanism, i.e., the propagation of cracks are arrested resulting in high tensile strength of the material [4]. Test results [10] show that the use of an expansive admixture in ferrocement is extremely effective in increasing crack strength. Crack widths in service remain very small and invisible to the naked eye, thus making ferrocement suitable for marine applications.

The impact resistance of ferrocement is considered to be reasonably higher than that of ordinary reinforced concrete because of its high energy absorption capacity. Experimental results [4] show that the properties of mesh reinforcement and skeletal steel have significant influence on the impact resistance capacity of ferrocement. Impact strength strongly depends on the specific surface of the reinforcement [11,12].

As regards its resistance to sea water, it has been found that it can withstand the corrosive effect of sea water if proper quality control in selecting the constituent materials, water-cement ratio, and proper choice of construction methods are used.

ADVANTAGES OF FERROCEMENT

Ferrocement is a high quality structural material. Its simple, cheap, and commonly available constituents; its superior mechanical properties -- high elasticity, tensile strength, flexibility, ductility, impact resistance and crack resistance -- make it suitable for boatbuilding. When properly made, ferrocement boats have proved to be durable with excellent fire resistance, good thermal insulation, low maintenance costs, and easy repair methods [13]. It can be fabricated into almost any shape to meet the needs of the users, with minimum of skilled labor.

There is no difference in hydrodynamic requirements between steel and concrete [ferrocement] ship construction [14]. With respect to requirements such as resistance, seakeeping behavior and maneuvering properties, the hull shape is in both cases the same. The material choice will have an effect on hydrodynamic requirements, only when the choice of concrete results in a shape fundamentally different from that of steel, as in production platforms.

Ferrocement construction is cheap. The cost effectiveness of ferrocement arises from low unit cost of materials; manufacturing savings in aggregate; low capital investment; savings in general handling and transport, and savings in erection costs resulting from thinner and lighter section [15]. The attribute that has made ferrocement attractive specially in developing countries is its lack of capital intensive production and its dependence on hand labor [3].

The economy of ferrocement construction compared with steel, wood or glass fiber reinforced plastic, depends greatly on the product being built, but ferrocement is almost always competitive. According to UNIDO [16], where unskilled low-cost labor is available and can be trained and as long as standard type of construction is adhered to, the efficiency of labor will improve considerably, resulting in a reduced unit cost. Under these conditions, ferrocement compares more than favorably with other materials used in boat-building, such as timber, steel aluminum or fiberglass all of which have higher unit material cost and greater inputs of skilled labor.

However, the development of new materials, and construction equipment and techniques [3] converted ferrocement from a material associated with extensive hand labor to an advanced material for highly industrialized countries. These have put ferrocement on a cost competitive edge with fiberglass or steel for marine use. Some examples are the adoption of special three-dimensional mesh to minimize time and labor in laying up several layers of wire mesh; the use of power-driven fasteners to hold the mesh in place; and the refining of guniting means for encapsulating the mesh.

Iorns [17] claims that a one-of-kind builder could obtain a structurally sound hull with a minimum of labor at less than one-fourth the cost of fiberglass (GRP) hull of the same dimensions. Furthermore, the ferrocement hull is superior to GRP as it is fireproof, less likely to rip open in a collision, easier to maintain and repair, and durable. The same principles and same procedures which apply to one-of-kind building, also apply to series building but efficient commercial production requires more sophisticated equipment and methods.

A new type of ferrocement, produced by shotcrete lamination in conjunction in precast concrete bulkheads, enables the construction of ships, pontoons, wharves and floating structures of any size to be built at much lower cost than if fabricated from welded steel [18,19]. The use of floating ferrocement molds for boat hulls and floating plywood form for pontoons enables low stress launching before full strength is attained.

Laminated concrete made an important breakthrough in 1970 when it won a contract to construct a 24.4 m x 7.3 m x 1.5 m pontoon to house a marine fuelling station in San Francisco Bay with a bid that was less than half the lowest quotation for the same pontoon in steel. In 1981, a concrete bid for the construction of a 30.5 m x 14.6 m floating dry dock in the Republic of Vanuatu was only one-sixth the price quoted by an Australian company specializing in steel construction [18].

Cost comparisons become even more significant when considering ship hulls with compound curvatures. A 12-m hull of ferrocement costs a mere US$700.00 while comparable fiberglass and steel canal boat hulls (in England) sell at US$6,500.00 and US$6,000.00 respectively. A complete 55 ft. (16.76 m) steel boat in the U.S. is now being offered at US$110,000.00 while a similar ferrocement structure is priced at a mere US$36,900.00 (actual production costs barely exceeds US$16,000.00) [18].

It is estimated that the average unit cost of ferrocement hulls is about 5.5 cents/kg while welded steel plate costs US$1.98/kg for flat work and over US$3.00 for hulls with compound curvature. When in a ferrocement floating mold, the use of shotcrete laminating techniques can result in a very substantial saving in construction costs compared to steel, wood, fiberglass or conventional ferrocement [18].

PROBLEMS OF MARINE APPLICATIONS

Ferrocement like any other construction material, has strong and weak points. The success stories of countless vessels which went into operation and are still in operation attest that these weak points could be overcome and that well-built ferrocement vessels give satisfactory service performance. It is important that the material be applied to boat types and boat sizes where its characteristics are best utilized [20]. At its present state of development, ferrocement has proved most suitable for boats longer than 33 ft (10 m) [4]. The criteria in Japan for ferrocement vessels stipulate that ferrocement may be used for boats not longer than 30 m (98 ft) [10].

In England, Windboats Marine Ltd. has built 521 Seacreate-hulled crafts in 22 countries (over 4 continents) and there has never been a single failure of Seacreate-hulled crafts. In fact, in April 1986 eight Seacrete-hulled crafts were under construction at Windboats Marine Ltd. [21].

Compared with wood and fiber reinforced plastic, ferrocement is a relatively heavy material. Even in larger sizes, ferrocement will be heavier than a wooden boat but this is of little disadvantage at moderate speeds. Iorns [22] found that boats over around 55 ft (17 m) are lighter than steel and he speculates it could possibly progress in very large vessels.

Another problem of ferrocement is its public image. The well-finished ferrocement hulls are mistaken for fiberglass molding while the poor ones are recognized as ferrocement. This indicates that people perceive ferrocement as a low quality and sloppy construction material. Perhaps, this is the reason why operators do not mention ferrocment in their publicity, although their crafts have been certified for passenger service by national agencies [23]. There is, therefore a need for a change of image and of public opinion. In the face of these biases, there is a need to educate the potential customers on the advantages of ferrocement [24], and to emphasize the importance of correct marketing techniques to all people involved in the product.

The public has been led to believe that ferrocement is cheap [21]. It has to be emphasized that a hull might cost 25% less than a similar hull in timber, steel or glass fiber, however the filling out, the engine and the equipment costs are the same irrespective of hull material.

Infrastructure is indispensable in any industrial production; it is necessary in order to produce cost-effective ferrocement elements. The steel industry after long years of development have produced steel-making facilities, foundries, rolling mills, welding techniques and others. A similar infrastructure is missing for ferrocement except where it is represented in the precasting and prestressing technology appropriate to reinforced concrete.

Another problem which causes considerable alarm to ferrocement marine users is the degradation of ferrocement in sea water environment and the engineers' perception of thin covers to steel [15]. Any conventional boat, by virtue of its marine environment, is liable to corrosion attack. The severity of this attack will depend on how well it has been designed and built, the material used and what happens to it when in and out of use. To combat corrosion needs an understanding of what it is and what it does. As a result intensive investigations are being undertaken to determine the suitability of ferrocement to offshore environment [10,25,26].

One of the primary roles of the mortar in ferrocement is to cover and protect the reinforcing steel from corrosion and other environmental effects. The mortar must have sufficient thickness, low permeability and must be void-free at the mortar steel interface. The cover of mortar to the mesh reinforcement of ferrocement is usually in the range of 1.5-4 mm. These demands a very high impermeability to provide protection to the reinforcement. Voids may be avoided by using "two-shot" plastering method, where the second shot is applied two weeks after curing the first shot [27].

The permeability of the mortar can be controlled by using sand free from pores and low water-cement ratio, but the extremely thin protective layers of mortar common in ferrocement sections, may not be sufficient to give protection in all cases especially in marine applications. Areas exposed to constant wetting and drying or areas sprayed to a significant degree by sea water are most susceptible to deterioration [28].

To minimize absorption, the exterior of ferrocement hull may be covered with an impermeable film of epoxy paint. However, epoxy paints have disadvantages: the coating is subject to abrasion, deterioration, porosity and others.

The use of galvanized wire mesh in ferrocement is one solution: it resists corrosion better than ordinary steel, when the reinforcement is exposed to the environment; it has better and longer resistance to aggressive environment than concrete reinforced with black steel; and it reduces the possibility of corrosion in the wire mesh. Furthermore, once corrosion is initiated in ferrocement, the zinc will corrode preferentially and will furnish cathodic proctection to the steel. Galvanized steel is anodic to black steel in concrete and furnishes galvanic protection to steel. Corrosion may be slower in starting with galvanized steel, because zinc is somewhat more tolerant to chlorides than in the alkaline concrete environment [28].

However, the use of galvanized mesh will generate hydrogen gas while the mortar is wet. It is recommended to add 200 parts per million of chromium trioxide to the mixing water to chemically inhibit the galvanic cell action [29].

Recommended Precautions Against Corrosion

- The ferrocement hull must have sufficient structural strength to resist stress cracking. Crack-prone areas such as square corners, opening, etc., should be specially reinforced. Areas which may suffer impact damage or abrasion should be protected.

- Mortar must be designed for maximum strength and watertightness though with enough workability to minimize voids. The watertight construction required in boat hull is obtained by keeping the water-cement ratio in the mortar below 0.4 by weight which means no more than 20 kg of water of each 50 kg bag of cement, and the use of avery fluid mortar to insure complete saturation of the mesh cage [29,30,31]. However, the mortar should not be too dry -- too grainy -- that it does not knit after passing through the mesh and rods.

- Workability requirements change with the various stages in the application of the mortar where the overriding consideration is to prevent voids. The first stage is to flood the mesh armature with a very fluid mortar to be sure all the mesh wires are coated and all the tiny crevices where wires touch are filled. Apply this mortar with a spray, brush or gloved hands if it is too thin to trowel conveniently. When the first has developed enough strength, the stiffer second stage mortar can be applied [29,31].
- Ensure adequate 3-4 mm mortar cover, ensure total penetration and employ good quality plasterers [30].
- Seal coat outside with epoxy [preferably coal tar] and inside where sea water, diesel oil and grease come in contact [32].
- Below waterline fittings must have sacrificial zincs attached, and replaced as needed. Above waterline fittings must be made of stainless steel, galvanized iron or non-ferrous metals.
- Grouting around keel, stem and stern, deck edge, toe rail and all intersections of internal structures such as frames, floors and engine beds with the hull shell, should be undertaken before fitting out or painting.
- Avoid contact of dissimilar metals.

Corrosion in ferrocement hull can be prevented or their effects reduced by careful attention to detailed design. For a builder to discount the possibility of corrosion developing in his hull is obviously too great a risk to take.

FERROCEMENT MARINE STRUCTURES

It is in the field of boat-building that ferrocement finds intensive marine use although it has great potentials for floating cities, airports, wharves, pontoons, offshore terminals, smelters, oil tankers, barges, oil drilling platforms, and domes to contain oil seeps or spills [15]. Ferrocement has been used extensively for boats in Australia, Bangladesh [34], China [16, 35], France, Hongkong [36], India [20], Indonesia [37], Korea [38], Malaysia [39], New Zealand [47], Sri Lanka [20], Thailand, [20,40], U.K. [21], U.S.A [33] and in many other countries. The application of ferrocement marine technology to a developing country is most successful in China, where social acceptability results in large-scale ferrocement boat construction. The continued research and development work on ferrocement coupled with the fast pace of materials development technology certainly lead to increasing satisfaction and confidence in ferrocement as a boat-building material.

The service experience of MATY 1st, a pleasure yacht, proves that lightweight 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 [42]. The technology offers enough flexibility for it to be made labor-intensive depending upon the needs and conditions of a particular region.

Tests on a composite of cement/fer-a-lite/fiberglass produces a material that is lighter and stronger that if the same armature was plastered solely with cement. However, because of the extra expense and labor 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 [42].

Another recent variation of the traditional mesh reinforced ferrocement is the high tensile wire reinforced fibrous ferrocement [43], wherein the multi-layers of fine wire mesh are replaced with a single layer of coarse high tensile wire and wire fiber. All the strength of the reinforcement is concentrated at the outer layer and is therefore more effective than conventional ferrocement. It has been observed that construction costs would be of the order of 80% of current steel prices and that weight surcharge would be less than 25%. This surcharge is not for strength purposes but for increasing the ill-defined property of piercing resistance. This type of construction may include large tankers using cellular construction, a totally unsinkable ship, which is virtually impractical to achieve in steel. A similar form of construction was employed for the 180 ft (55 m) long oil tanker for the Pertamina Oil Company in Indonesia [44].

Initial development of precast ferrocement panels suitable for the fabrication of ships and floating structures within the length range of 30-80 m has been carried out. It used sandwich type precast prestressed ferrocement panels, which will be accurately assembled, jointed and stressed together on site to form a complete hull. From the tests carried out, the panels showed satisfactory flexural behavior, efficient absorption of impact loads, and impermeability [13].

OBSERVATIONS -- PROSPECTS OF FERROCEMENT

Ferrocement is "everyone's" material [46] but the degree of construction sophistication employed may differ depending on one's financial capability. For example, on one extreme, people in developing countries build small water crafts using simple hand plastering methods and they are satisfied with the performance that meet their simple lifestyle. On the other hand, people in the industrialized countries build yachts that will serve as a home, constructed by mechanized techniques and equipped with modern appurtenances.

The prospects are bright. The creation of ACI Committee 549, their publication of ACI State-of-the Art Report in 1982, and their forthcoming "Design Guide for Ferrocement Construction", will pave the way to increased consideration of ferrocement as an alternative material in various applications. The advances of materials technology e.g. additives, superplasticizers, silica fumes, and others, allow the properties of mortar (workability, strengths durability) to be easily obtainable. New steel or polymeric meshes have become available. Three-dimensional meshes may replace several layers of plane mesh and saves labor-cost. The use of polymer mortar composites (resin mortar matrixed ferro composites, latex modified ferrocement, polymer impregnated ferrocement) and the use of epoxy or polymer surface coating [45] shows improved durability characteristics.

In recapitulation, it can be said that ferrocement is the most suitable, cost-effective material for marine applications: its material properties are excellent; its advantages outweigh that of steel; its weak points can be overcome; the technology is well-established, well-understood, rapidly improving; it is recognized by engineering societies and classification agencies; the experiences of well-built ferrocement marine structures are excellent; corrosion problems can be controlled, if not avoided.

In spite of the above arguments, steel remains to be the fashionable material for commercial marine applications. Established shipbuilders are firmly committed to steel and would not welcome a technology that makes their facilities obsolete [23]. It is in this area that needs a break -- a commitment by funding agencies so that a whole new set of infrastructure could be established. This, if realized could turn around the current pseudo-public image of ferrocement as a material for marine structures.

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