The Future of Ferrocement in the Boat Building Industry

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1. BACKGROUND

The increasing cost and shortage of timber for boat construction have become serious issues that affect the fishing boat building industry around the world. As a consequence, some new designs, materials and development have been proposed to overcome these issues. The boat building industry has progressed from using traditional materials and methods to less conventional wood construction techniques (plywood or wood laminates) or optional materials such as glass reinforced plastic (GRP), steel, aluminum and ferrocement. Generally, although there have been numerous attempts to expand the development of various construction methods with varying degrees of success, timber remains the preferred boat building material.

One of the materials proposed for the future of the boat building industry is ferrocement. It can be defined as a composite material that consists of a matrix made from hydraulic cement mortar and a number of layers of continuous steel mesh reinforcement distributed throughout the matrix (National Academy, 1973). Like other boat construction materials, ferrocement has feasible characteristics, namely, the specific surface area of reinforcement, the volume fraction of the reinforcement, the surface cover of the mortar over the reinforcement and the relatively high quality of the mortar.

Ferrocement behaves like reinforced concrete in terms of its loading characteristics with the difference in crack development due to the dispersion of the reinforcement in fine form through the mortar. Therefore, this makes the ferrocement a special material for boat building. When there are cracks, a wide distribution of fine cracks will occur with a combination of the high alkalinity of the cement rich mortar, preventing corrosion in the reinforcing steel mesh. Ferrocement is considered a low cost material with low level skills required for the hull construction and lower maintenance cost while providing high resistance to rot and corrosion.

Ferrocement is a flexible and durable material for boat construction. Thus, it is easy to repair and possesses excellent features that help to produce a well-founded fishing boat. Generally, ferrocement is suitable for moderate to heavy displacement designs with well-rounded sections, and needs moderate supervision in all aspects of the construction. Although ferrocement has been accepted as a suitable boat building material, it is still not widely used. There are three main reasons for this.

Firstly, poor and unskilful construction can lead to an unimpressive physical appearance. Secondly, initial claims of a higher strength and low construction cost have not been fully proven, and thirdly, the labour intensive requirement for construction leads to a higher production cost. Nevertheless, the use of ferrocement has been expanded in recent times with improved construction techniques to compensate for the high labour cost.

2. HISTORY OF FERROCEMENT

In 1848, Joseph-Louis Lambot, an inventor, built the first ferrocement boat when there were doubts on the use of reinforced concrete. It was built right after the development of portland cement, where Lambot successfully built two rowboats in Miraval, southern France. The thin walls of the 12-feet long and about 4-feet wide boat were reinforced with grid and wire netting. In order to build the boat, a lot of time and effort was needed to arrange thousands of mesh wires that were made from rods used in standard reinforced concrete. In 1887, a small boat company, the Zeemeuw in Holland had introduced a new method where mortar is applied to the steel mesh. In the earlier development, the Dutch had successfully built 50 to 60-ton reinforced mortar barges for carrying ashes and waste on canals.

During the First World War, reinforced concrete for boatbuilding became popular as an alternative material due to the shortage of steel plates. Among the countries that were involved in the war, the governments of the United States (US) and the United Kingdom (UK) had appointed shipbuilders to build concrete boats and barges, and continued to do so during the Second World War. A similar situation occurred in the US where the shortage of steel resulted in the need to use reinforced concrete as a boat building material. However, the problem was that the thick hull skin that was developed to contain the large diameter of the steel rods can make the boats less practical and economical to operate compared to wooden or steel boats. The Italian navy, on the other hand, had accepted ferrocement as a boatbuilding material and a number of boats were built during the same war.

In the Second World War, an Italian engineer-architect, Pier Luigi Nervi, resurrected the original ferrocement concept from other forms of reinforced concrete. He designed the reinforcing concrete with layers of wire mesh and produced a 'new' material that had similar mechanical characteristics and were capable of resisting high impact.

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The thin slabs of reinforced concrete had proven flexible, elastic and extremely strong. When the war ended, Nervi led the way into the modern era on the use of ferrocement in the boatbuilding process. His first attempt in building a 165-ton motor sailer, which was named *Irene*, had a ferrocement hull with a thickness of 1.4 inches, weighed 5% less than using a wood hull and had cost 40% less. The *Irene* proved to be completely seaworthy when it survived two serious accidents that required simple re-plastering work and had proven to be less costly for the maintenance of the hull.

In 1942, Nervi had proposed to use ferrocement in making fishing boats. In the construction process, he had discovered that the mesh mortar is best used when increasing the number of mesh layers coated in mortar. His first attempt involved a 3/8 inch^2 mesh made of wires measuring between 0.02 inch and 0.06 inch in diameter. In order to yield the required thickness and strength, suitably sized reinforcing bars between the mesh layers had to be used.

Although ferrocement had proven to be a reliable and economic boat building material, it only began to be widely accepted in the early 1960s in the UK, New Zealand and Australia. In 1965, an American owned ferrocement yacht built in New Zealand, named *Awahnee*, went sailing around the world without a serious accident despite encountering 70-knot gales, colliding with an iceberg and being bumped by a steel hulled yacht. Since then, there has been a steady growth in the number of ferrocement boats being built.

In 1973, a 72-foot prestressed ferrocement boat, named *Helsal*, had succeeded in the Sydney to Hobart ocean sailing classic competition. In September 1974, Nervi, an amateur boat builder, launched *New Freedom*, a twin-master ferrocement yacht, which is believed to be the largest ocean racing yacht ever built in Great Britain since the war ended.

Nervi was celebrated as the founder of ferrocement in architectural history when he successfully prefabricated structural elements as forms for the cast-in-place concrete. His famous postwar structure is the Turin Exhibition Hall with a very large dome for the sports palace in Rome. Nervi's work on the application of ferrocement to commercial and residential buildings had overshadowed his ferrocement boat building interest.

3. ADVANTAGES AND DISADVANTAGES

Ferrocement is a unique material that can be flexibly applied in the marine related construction industry. There are several advantages and disadvantages in the use of ferrocement. The nature of ferrocement and its construction methodology can easily meet the safety and practical marine design and construction requirements.

One of the advantages of ferrocement is its low cost. In third world countries, ferrocement is almost as economically competitive as steel, wood or GRP construction, because steel and GRP are costly and wood has become scarce (J.P. Hartog, 1988). Based on the notes of the Stewart Marine Design Pty Ltd, the material cost of ferrocement is about 30% to 50% less compared to steel. In addition, construction material such as sand, cement and water can usually be obtained locally, and the cost of the reinforcing material (steel rods, mesh, pipe, chicken wire or expanded metal) can be maintained at a minimum (J.P. Hartog, 1988). It is also a form of green construction as it requires locally available resources and is regarded as a green material.

However, this notation of low cost can only be validated where the second advantage of low level of skills required can be demonstrated (Riley, R.O.N. and Turner, J.M.M., 1995). In the notes of Stewart Marine Design Pty Ltd, the setting up and fixing of the steel mesh in ferrocement construction does not require a high level of skill. A simple practice and basic instructions are able to ensure that workers can perform the work. Nevertheless, in industrialised countries, where the difference between the cost of skilled and unskilled labour is diminutive, both the advantages are imperceptible and can be discarded (Riley, R.O.N. and Turner, J.M.M., 1995).

Ferrocement can be shaped into any form (J.P. Hartog, 1988). The nature of ferrocement enables the formation of both simple and curved shapes. It is more versatile compared to reinforced cement concrete (RCC) because the construction of RCC is casted in sections and requires extensive and very solid formwork to support the weight of the concrete. On the other hand, ferrocement is formed into sections less than 25mm thick and can be assembled over a light framework (J.P. Hartog, 1988).

Ferrocement properties such as high resistance to corrosion and more durability compared to wood and steel are the criteria that are preferred in marine application. This material also has a high load carrying capacity, high strength and is able to withstand shock. It is also rot-proof and vermin-proof, impervious to worms and borers, and watertight (J.P. Hartog, 1988). However, these properties can be achieved only for a well designed and constructed ferrocement product. A well built ferrocement hull can reduce future maintenance work, hence reducing maintenance and repair cost (Riley, R.O.N. and Turner, J.M.M., 1995).

Stewart Marine Design Pty Ltd noted that a well designed and built ferrocement boat has demonstrated to have an extremely long economic life. Ferrocement can be made to last for many years although this depends on many factors such as mortar composition, corrosion of reinforcement, permeability and construction methodology (A. Masood and M. Arif, 2002).

Nevertheless, the disadvantages of ferrocement include the requirement for specialist design expertise and skilful workers, heavy displacement, difficult and tedious operation in construction and critical atmospheric environmental effect during curing. Some of the related references stated that the construction of ferrocement is easy and flexible. In contrast, most of the ferrocement composition that affect the good properties required in marine applications depend on proper techniques to produce a good quality ferrocement product.

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It is essential for a professional and experienced designer to provide a comprehensive and precise design plan and documentation due to the many variables that can influence the intended finishing. In addition, skilled labourers are required especially for the plastering process. Stewart Marine Design Pty Ltd affirmed that the plastering of the boat is a job that requires some skill and expertise. Normally, only qualified workers are suitable for the work because they have some experience in applying concrete to a ferrocement boat structure.

It has been found that ferrocement contributed to a heavier displacement compared to a similarly sized boat built of steel as stated in the Stewart Marine Design Pty Ltd notes. One of the materials utilised in ferrocement is cement which has a mass of 1506kg/cu^3. By combining all the materials required to build a ferrocement boat, it will obtain a mass that is 20% to 40% heavier than steel. However, this problem can be overcome by producing a flexible design.

Ferrocement construction in marine application is very tedious and difficult. It requires thorough supervision during construction. For example, the result from the experiments carried out by Vickridge and Ranjbar has shown that ferrocement with a low water-to-cement (w/c) ratio exhibited less corrosion damage than those made with a high w/c ratio (A. Masood and M. Arif, 2002). Thus, meticulous and rigorous works are required especially during the plastering process in order to attain the intended structural properties. Some tasks such as drilling and fastening can be quite challenging due to the intense hardness of ferrocement. Hence, excellent detailed planning during the design process is crucial.

The curing process in ferrocement construction requires a critical atmospheric environment. Attentive supervision and strict control of the environmental conditions, such as temperature and humidity, is required. A good quality ferrocement product depends greatly on a proper curing process. The properties of the ferrocement may be degraded if the curing process is carried out differently.

4. APPLICATION AND CONSTRUCTION OF FERROCEMENT

Ferrocement is a widely-used construction material in many areas because of its advantages over conventional construction materials and its useful features. For instance, ferrocement is conveniently applied in the construction of buildings, ducts, tanks, containers, fire resistance structures, chemical-resistant treatments, waterproofing treatments and marine industry. In structural applications, ferrocement is a better material option for compound curved structures because it adds to the strength, stiffness and impact resistance of these structures. It also behaves like a composite where the concrete absorbs most of the compression and the steel frame absorbs the tensile and sheer stresses. On the other hand, for marine application, ferrocement is used mainly to construct the hull of boats, trawlers, barges or floating docks due to its resistance and non-corrosive nature in the marine atmosphere.

Construction of ferrocement is generally covered by the four main steps in Figure 1.

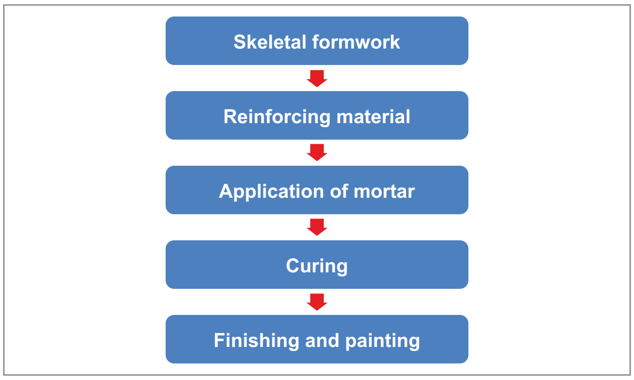

Figure 1: Ferrocement construction process

A skeletal framework acts as the basic mould for the mortar to form the final product. This form can either be removable or can be incorporated into the finished product. They should be strong enough to support themselves and the weight of the steel and concrete structure before the mortar is applied. Wooden frames are sometimes removable provided that the work is done with care. This removable frame can be reused for the construction of similar structures. There are three types of framework methods, namely, the wooden-frame, pipe-frame and webbed-frame methods. However, the most often used method is the webbed-frame or trussed-frame method. Instead of wood and pipe from the previous two methods, this frame uses reinforced steel bars and/or rods.

Figure 2: Steel frame for ferrocement hull construction

The frame by itself would not be able to keep the mortar in shape. Thus, the next step in the construction process is to apply the reinforcing materials to hold it in place, add stiffness and impact resistance. The materials used can be steel rods, wires, reinforced mesh or any combination of these. The materials used for reinforcement need to be flexible. The tighter the curves of the structure, the more flexible the reinforcing materials have to be.

The application of mortar, which is made from a good grade of cement, well-graded sharp sand, clean water and, optionally, a small amount of additives, is conducted to achieve an earlier setting strength for plasticising.

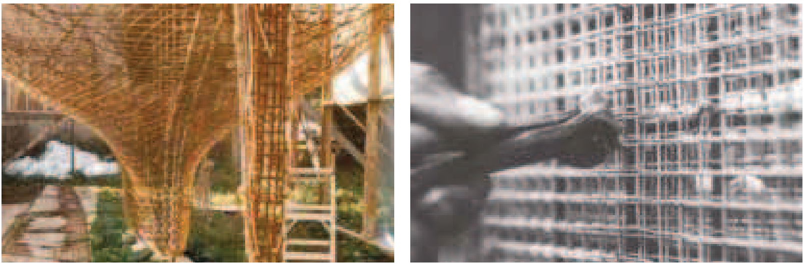

Figure 3: Reinforcing wires and mesh

The sand used in mortar should be dry, clean and sharp. When applying the mortar, one must ensure that the reinforcing steel is completely covered to avoid corrosion. The mortar applied should not exceed 2mm thick to avoid cracking. The chemical reaction between the cement and water in the mortar mix makes the mortar set. The hardening and strengthening of the mortar is rapid. It reaches near-maximum strength by the time curing is complete, usually up to 30 days, but this period can vary depending on the weather and environment. The mortar must keep the moisture out during application and curing.

Curing reduces shrinkage and increases strength and water tightness. There are two types of curing, which are wet curing and steam curing, but ultimately, both methods strive to provide a moist atmosphere during the curing process. At the end of this process, the final structure is rigid, solid and strong even if the walls are thin. The last step is the finishing and painting of the structure. In this process, the surface of structure is made to be as smooth as possible while painting is optional and mostly opted for its aesthetic value. Ferrocement construction, however, continues to offer unlimited flexibility for application on both water and land in places where labour costs are low. In the marine industry, there are possibilities that larger boats can be built using ferrocement.

5. SAFETY OF FERROCEMENT IN THE MARINE INDUSTRY

There are concerns whether ferrocement is safe to be used since it is a mixture of cement or sometimes fly ash. This is due to the heavy metal contamination in fly ash. This should not be an issue since the heavy metals in fly ash differ significantly both in terms of type and quantity. The vast majority of coal and fly ash are not significantly enriched in radioactive elements or in associated radioactivity compared to common soils or rocks. Limited measurements of dissolved uranium and iridium in water leachates of fly ash and in natural water from some ash disposal sites indicate that dissolved concentrations of these radioactive elements are within the safety limit for human health. It would take centuries of exposure to be effected by this level of radiation; given daily and prolonged exposure.

The skills for ferrocement construction can be quickly acquired, including traditional skills in developing countries, and the construction does not need heavy plant or machinery; however, it is labour-intensive. Threats of rust to the steel structures are possible if air voids are left in the original construction. The air voids can turn into pools of water as the cured material absorbs moisture. If the voids occur where there is untreated steel, the steel will rust and expand, thus causing the system to fail. The usage of liquid acrylic additives and other advances to the grout mixture can create a slower moisture absorption and also increase the bonding strength to tone down these failures. This should include steel treatment when doing restoration to get rid of the rusty parts in order to avoid further damage.

Highly polluted water can also create cracks on critical joints; while air pollution, with the presence of carbon dioxide with a 75% humidity, is also highly corrosive.

6. CONCLUSION

Ferrocement has a bright future in the marine industry as it has proven to have several acceptable qualities despite its weaknesses. Nowadays, it is more common to see the use of ferrocement in small boats and simple floating structures. If the safety of the material to the users as well as to the environment could be improved significantly and a simplification of the procedures could be introduced, its use can be expanded further. Hence, there is a pressing need to conduct a critical and in-depth study and further R&D on the potential use of ferrocement in the marine industry, specifically in the boat building sector. ■

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