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DURABILITY OF FERROCEMENT

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ABSTRACT: During the opening of the second day of the International Symposium on Ferrocement FERRO 10 held between 12-17 October 2012 in Cuba, the president of the organizing committee, engineer, Hugo Wainshtok Rivas, presented dozens of examples of the durability of this technology after decades of application. In Cuba, in the 1990s the widespread use of ferrocement was truncated. However, many works prior to this stage are still preserved in good condition. Such is the case of Baconao Park in Santiago de Cuba. This paper will present the ferrocement advantages over conventional reinforced concrete concerning the durability wih focus over the materials used: cementitious matrix and steel mesh.
KEYWORDS: durability, corossion, carbonatation, cover thickness

INTRODUCTION TO FERROCEMENT

Ferrocement as the name implies is a material made from steel and cement. A working definition of ferrocement is "a thin shell of highly reinforced Portland cement mortar" that was invented by Louis Lambout in 1848 but introduced for the civil buildings by Per Luigi Nervi in 1943.[1] At the beginning it was used only for boat construction. Basically it's a reinforced concrete with small diameter steel mesh with a nominal cover of 2mm to 5mm [Figure 1]. Being flexible the meshes are fixed on steel rods and then a cement matrix is applied just like in Figure 2 (a, b). The formwork is not necessary in all the cases or is used only on one side of the element and this represents one big advantage of ferrocement.

Figure 1. Ferro cement detail

Figure 2. Applying the mortar (a), (b)

MATERIALS USED

A ferrocement shall range from 1cm to 10cm in thickness, and the reinforcement consists of layers of steel mesh. The resulting shell or panel of mesh is impregnated with a very rich (high ratio of cement to sand) portland cement mortar. The high quality cement matrix has a ratio of 1:2 to 1:2.5 cement: sand, the maximum dimension for the course is 8mm and the water/cement ratio is 0,40…0,45. For optimum performance, steel should be rust-treated, (galvanized) or stainless steel and like a general requirement is the flexibility. Shapes with tight curves need more flexible meshes. Chicken wire, the cheapest and easiest to use, is adequate for the structural requirements of most boats in developing countries and for all uses on land. It is not the most recommended mesh for high-performance structures, such as deep-water marine hulls.

CONSTRUCTIONS DURABILITY

Concrete durability has been defined by the American Concrete Institute as its resistance to weathering action, chemical attack, abrasion and other degradation processes. Different concretes require different degrees of durability depending on the exposure environment and properties desired.

The design service life of most buildings is often 30 years, although buildings often last 50 to 100 years or longer. Most concrete and masonry buildings are demolished due to obsolescence rather *than deterioration. A concrete shell can be left in place if a building use or function changes or when a building interior is renovated. Concrete, as a structural material and as the building exterior skin, has the ability to withstand nature's normal deteriorating mechanisms as well as natural disasters.*

A durable material helps the environment by conserving resources and reducing wastes and the environmental impacts of repair and replacement. Construction and demolition waste contribute to solid waste going to landfills. The production of new building materials depletes natural resources and can produce air and water pollution. The use of a durable concrete increase the cost of the material with 10-20%, but does not increase the cost of the whole structure for more than 1%. However, the costs of restoration work for a non-durable concrete can reach up to 125 times the original cost of the structure when the deterioration is so advanced. [2]

CONSTRUCTIONS DURABILITY

During the opening of the second day of the International Symposium on Ferrocement FERRO 10 held between 12-17 October 2012 in Cuba, the president of the organizing committee, engineer, Hugo Wainshtok Rivas, presented dozens of examples of the durability of this technology after decades of application.

In 1982 Baconao Park in Santiago de Cuba was opened with more than 100 large pieces by sculptor Dagoberto Moreno. At present all are kept in good condition.

The same applies to the pools. In 1984 it was designed and built the first pool of ferrocement in Cuba, in Villa Loma, Jibacoa beach, now Mayabeque province. It has 25 x 12.5 m and its deepest part is of 1.80m deep, with a thickness of 25 mm in the walls formed with prefabricated panels. The total cost was nearly seven times lower than a concrete one of equal size.

Similarly, the specialist shows examples of homes that were built with ferrocement roofs and are still in good conditions all over the world. Another examples of durable ferocement buildings are Nervi's contructions build in the years 1950-1980 that are still used (Figure 3).

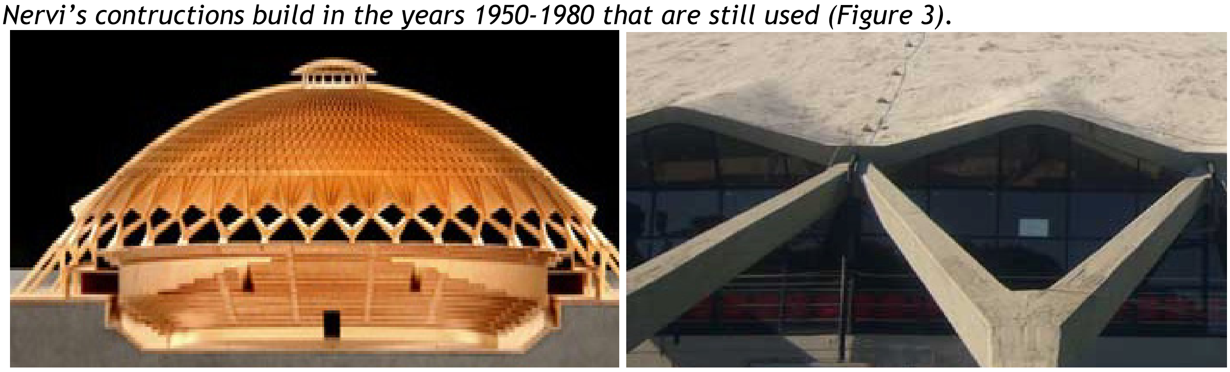

Figure 3. a) Pallazetto dello Sport Roma, Section, b) Pallazetto dello Sport Roma, Detail

His interest in ferrocement made him test all it's limits and he built boats for comercial use. Figure 4 shows the original project of Nervi's Studio in 1972 and in Figure 5 the picture of boat Giuseppa still in good condition, now on shore sitting in front of Civil Engineering Department, Rome Tor Vergata.

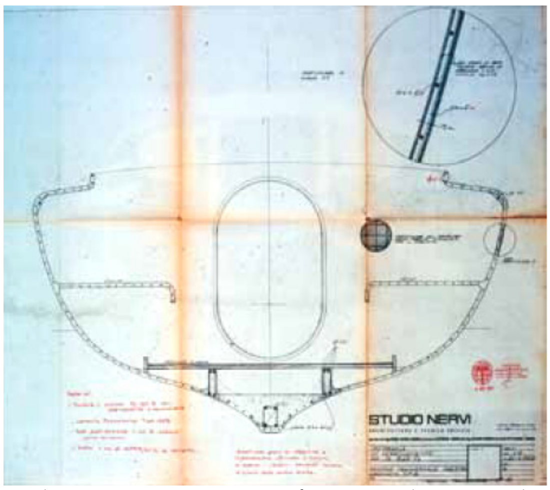

Figure 4. Ferrocemet boat section. Nervi Studio, 1972

When it comes to concrete durability, engineers should not rely only on specifying a minimum compressive strength, maximum water-cement ratio, minimum cementitious content and air entrainment. There are better ways to quantify durability. Low permeability and shrinkage are two performance characteristics of concrete that can prolong the service life of a structure that is subjected to severe exposure conditions. For durability provisions, the ACI 318 Building Code generally relies on the w/c to reduce the permeability of water or chemical salts into the concrete that impacts its durability and service life. However, along with the w/c ratio, the code requires a concomitant specified strength level, recognizing that it is difficult to accurately verify the w/c and that the specified strength (which can be more reliably tested).

It should be stated that strength should not be used as a surrogate test to assure durable concrete. It is true that a higher strength concrete will provide more resistance to cracking due to durability mechanisms and will generally have a lower w/c to beneficially impact permeability. However, it should be ensured that the composition of the mixture is also optimized to resist the relevant exposure conditions that impact concrete's durability. This means appropriate cementitious *materials for sulfate resistance, air void system for freezing and thawing and scaling resistance, adequate protection to prevent corrosion either from carbonation, chloride ingress or depth of cover, a low paste content to minimize drying shrinkage and thermal cracking, and the appropriate combination of aggregates and cementitious materials to minimize the potential for expansive cracking related to alkali silica reactions.*

Figure 5. Nervi's boat"La Giuseppa", in front of Dipartimento di Ingegneria Civile dell'Università di Roma Tor Vergata , 2011

There are three main types of fluids involved in concrete durability decisive: the water, carbon dioxide and the oxigen and they can move in different ways in the concrete but the overall transport depends primarily on the structure of hydratated cement. Durability of concrete depends on the ease with which fluids enter and move in the concrete also called permeability.

FERROCEMENT DURABILITY

Just like for reinforced concrete the ingredients, their proportioning, interactions between them, placing and curing practices, and the service environment determine the ultimate durability and life. An investigation was conducted on the condition of a 13 year old ferrocement structure which has been left abandoned at the National University of Singapore. Tests were performed to determine depth of carbonation, extend of chloride-ion penetration, state of embedded reinforcement and strength characteristics. The results were compared with those documented at the time of construction and the conclusion was that the structure still retains its desired strength.[3]

Mortar Cover of Reinforcement

For a normal reinforced concrete the iron cover is 25-30 mm and for a ferrocement section is 1,5mm and 5mm. This small concrete cover is achievable by using small size aggregates (0-4mm) in the micro concrete mix. The only problem is to keep this cover constant. For the test in Singapore on the abandoned ferrocement 100 random measurements were taken and the bottom layer varies from 1.5mm to 5mm, giving an average of 3mm. [3] This will affect mesh corrosion.

Condition of Embedded Reinforcing Steel

Ferrocement surfaces have wire mesh layers. This wire mesh prevents crack formation at the surface of the ferrocement and stops the further travel into the material. Ferrocement has a crack-arrest mechanism and is a denser material compared to concrete.

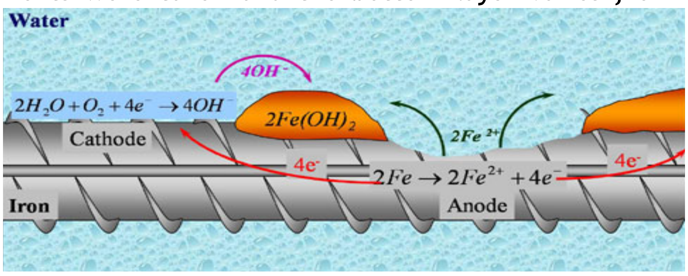

Figure 6. Corrosive reaction

The samples taken during the durability test showed clear signs of corrosion Figure 6 especially on the bottom layer of wire mesh because of a higher percentage of moisture and a relatively thin mortar cover.

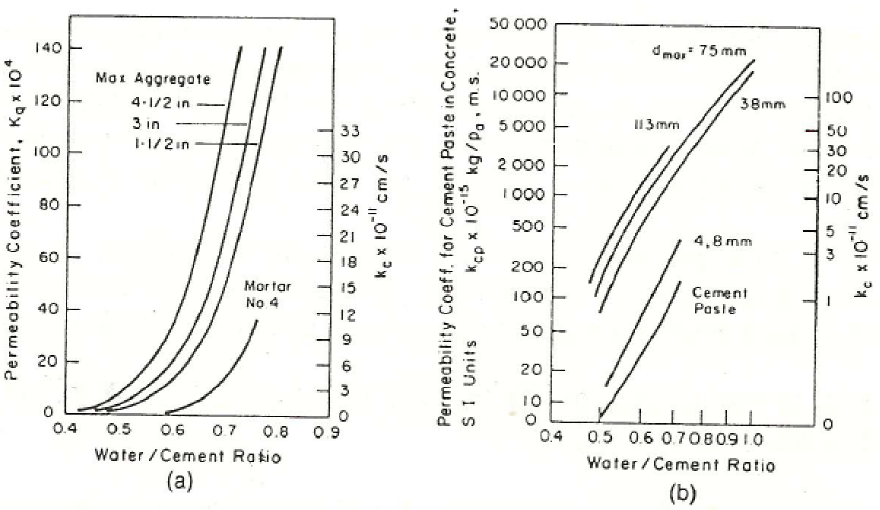

Figure 7. Influence of w/c ratio (a) and maximum aggregate size (b) on concrete permeability

Many aspects of concrete durability are improved by reducing the permeability of concrete. The ACI 318 Building Code addresses an exposure condition for "concrete intended to have a low permeability when exposed to water" by requiring a maximum w/c of 0.50. This recognizes that a lower water-cement ratio is important to control the permeability of concrete (Figure 7a).

The paste content (Figure 7b) influence also durability and two concrete mixtures of the same volume fractions w/c composition but with different paste content will have different performance because the higher paste content could be a higher heat of hydration, higher potential for cracking, lower -modulus of elasticity, higher creep and different resistance to durability to chemical elements depending on the composition of the cementitious material.

Depth of carbonation

Carbonation is the result of the dissolution of CO_2 in the concrete pore fluid and this reacts with calcium from calcium hydroxide and calcium silicate hydrate to form calcite ($CaCO_3$) Figure 8.

The carbonatation depth of a concrete subjected to 15 years of normal indoor exposure is approximately equal to 5mm so the non-acceptance of ferrocement in practice might be due to its relatively small depth of cover over wire meshes, which controls corrosion. [4] Iorns [5] inspected galvanized and ungalvanized mesh specimens with various thickness of cover exposed in the working cockpit (open to the weather and salty spray) periodically over ten years. The mortar had water: cement ratio of 0.4 and a sand/cement ratio of 2. He found that the rusting stopped when the cover reached approximately 1mm in thickness. He explained that the steel wire diameters in ferrocement were usually small therefore not enough pressure is exerted to cause spalling of high strength cover. He also pointed out that the corrosion product of reinforcement may plug the pores of mortar cover and retard further penetration of corrosion stimulants. [5]

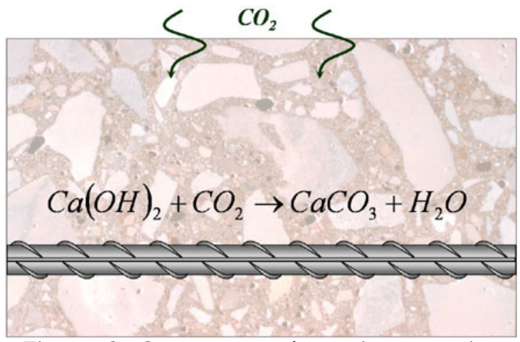

Figure 8. Concrete carbonation reaction

CONCLUSIONS

Ferrocement can be made to last for many years, but this depends upon several factors like mortar composition, quality of aggregates, water-cement ratio, degree of compaction, thickness of mortar cover over the reinforcement, curing and corrosion of reinforcement [6]. A building can show its durability only after 30years of existence and ferrocement buildings passed this test. If few design and technological rules are followed, a ferrocement element can resist all kinds of aggression factors. Suitable surface coating to prevent intrusion of moisture and air and regular inspection and maintenance are essential to enhance the long term durability of ferrocement structures. The use of galvanized steel alone is not enough as a protection against corrosion but a suitable cover is the best solution. Also a surface coating will offer the best protection for the mortar and the mesh.

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