FERROCEMENT: PROGRESS REVIEW AND CRITICAL NEED FOR THE FUTURE

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Abstract: This paper comprises two main parts, namely: a brief summary of key advancements in the field of ferrocement over the past five decades, and an opinion as to the critical need for an active dedicated professional society to continue to spur future advancements, particularly the development and maintenance of a widely recognized building code for ferrocement. Progress over the past five decades covers topics such a better understanding of the key mechanical properties of ferrocement, their modeling and prediction; improved properties of component materials; improved construction methods; improved practices; and some daring applications.While progress has definitely been commendable, it is nevertheless hindered by the lack of a focused environment and continually fostered activities such as generally provided by a dedicated professional society that can address systematically and in details all issues related to ferrocement. These include the development of standards, guidelines and codes, cost-effective housing solutions, durability issues, etc...While it can be argued that such activities can be addressed by existing concrete societies such as *ACI*, RILEM, or a number of other institutes generally dealing with concrete, efficiency, sustained progress and leap advances seem only possible when a dedicated institution is involved. It is unfortunate that the lack of funding or endowed funding has been very detrimental to the full progress of ferrocement and its potential, and, as a result, has not served the branch of society that could most benefit from it, the public and more particularly its less fortunate component.

INTRODUCTION

Thin reinforced cement-based composites such as ferrocement and TRC (textile reinforced concrete) form a special category within the broader family of reinforced concrete. Such composites can provide slender, light-weight, durable solutions in many structural applications and are often cost competitive with respect to their methods of production and material/structural properties. Their applications cover both marine (boats, pontoons, docks) and terrestrial structures, as well as repair-rehabilitation for both types. Marine structures also cover floating structures such as floating houses on river banks or in areas prone to flooding. Terrestrial structures include mostly small containment structures (silos, water tanks, waste containment and treatment vessels), and structural and non-structural components for various types of construction (housing, school facilities, agricultural structures, and water channels). A limited number of larger size structures using ferrocement have been built and the trend is increasing but, unfortunately, it is constrained by legal construction issues. Indeed, while there is a building code for ferrocement developed by the International Ferrocement Society [1], it is limited by the fact that it is not yet adopted and sponsored by large worldwide organizations such as ACI (the American Concrete Institute), Fib, or Rilem.

SUMMARY-EVOLUTION OVER THE LAST FIVE DECADES

In a prior publication [2] the author had summarized key advancements in the field of ferrocement since its modern development in the1960's. At that time a shift took place whereas ferrocement, which was seen then as a marine material for amateur boat building evolved into a construction materials for terrestrial applications as well, particularly small scale agricultural structures. Below is a brief summary of some key issues discussed in [2].

1. **Evolution in Applications.** The most noticeable progress here relates to a significant shift from marine applications to terrestrial applications, particularly at first in small size agricultural structures such as grain silos, water tanks, and housing units. Today we can cite examples of large scale applications such as the roof of the Siger monument in Lampung, Indonesia [3], and under construction at time of this writing, the roof of the Stavros Niarchos Foundation Cultural Center in Athens, Greece [4].

2. **Evolution in Cement Matrix**. Here the most notable progress relates to changes in the composition and workability of the cement mortar matrix as modified by various additives or agents; its compressive strength which was commonly in the range of 20 to 30 MPa, can today exceed 200 MPa in the case of UHPC (ultra high performance concrete). Furthermore, with UHPC the fineness of the matrix and is flow-ability can be ideal in ferrocement mold-cast applications and for excellent surface finish.

3. **Evolution in Reinforcemen**t. Here progress has been quite impressive on several fronts. Initially the reinforcement consisted mostly of chicken wire mesh (also called hexagonal mesh or aviary mesh) made with relatively low strength steel wire; it evolved into stronger forms of square woven or welded meshes and more cost-effective ones such as expanded metal mesh. Today the choices are many and include the use of very high strength steel wires or stands in mat formats, 3D steel meshes (limited commercial availability), 2D or 3D textiles with non-metallic reinforcements, and hybrid combinations of both steel and polymeric reinforcements with the possible addition of discontinuous fibers.

4. **Evolution in Mechanical Performance.** Bending resistance in ferrocement plates increased from about 3 MPa per 1% total volume of hexagonal steel wire mesh reinforcement to 24 MPa per 1% total volume of reinforcement consisting of very high strength steel mat. For these numbers the bending resistance is equal for positive or negative moment and for the X or Y directions. As a result the cost-performance ratio has also improved (decreased) significantly. In conventional ferrocement with conventional square steel wire mesh, a modulus of rupture of about 50 MPa can be achieved with 7% total reinforcement by volume. A recent investigation has shown that with an ultra-high performance cement matrix and very high strength steel strands in a mat format, a modulus of rupture close to 230 MPa can be achieved; the reinforcement consisted of 6.27% by volume of steel mat and 3.5% by volume of micro steel fibers [5]. Note for ferrocement composites with uniformly distributed reinforcement, the direct tensile strength can be assumed equal to about one third the bending resistance.

5. **Evolution in Equipment and Construction Methods.** Here the evolution has been modest and much less noticeable than in other areas. Most applications of ferrocement involve hand trowel-ling over reinforcement armature but the introduction of super-plasticizers and the use of small particles such as fly ash and fine sand allows ferrocement elements to be cast in molds (as in typical reinforced concrete) while guaranteeing penetration of the mesh system by the matrix. However, the most important piece of equipment needed for everyday ferrocement and for both contractors and the amateur builder is a mechanical mesh tying instrument; while rebar tying machines exist for reinforced concrete, they have not been tailored and optimized for use with wire meshes where the opening between wires is relatively very small. It is believed that the development of such instrument can cut the cost of labor in ferrocement structures by half. Since generally labor accounts for more than half of total cost, such an improvement will have an enormous impact on ferrocement competitiveness.

6. **Evolution in Guidelines and Code**. Here progress has been slow and the subject is in dire need of a serious effort. Committee 549 of the American Concrete Institute developed two widely used reports, one titled "State-of-the-Art Report on Ferrocement," initially in 1982 and a modified version in 1997 [**6**], and the other one titled "Guide for the Design, Construction and Repair of Ferrocement," initially in 1988 and a revised version in 1993 [**7**]. The need to develop a technical Code for ferrocement design was identified in the early 1970's by numerous researchers and practitioners, but little progress was made. Related history is given in the next Section.

Other progress areas related to modeling, technical and professional activities, education, people training, and the like are discussed in [2]. In the next section, what the writer considers to be at the moment the most important driver for the progress of ferrocement is expanded upon.

FERROCEMENT MODEL CODE AND CRITICAL NEEDS AND MISSION OF THE INTERNATIONAL FERROCEMENT SOCIETY

As mentioned in item 6 the above Section, the need for a building code for Ferrocement has been identified as early as the 1970's at the onset of modern development of ferrocement. Although some guidelines were developed, the development of a detailed building code for ferrocement carrying legal weight encountered enormous difficulties. For instance, from a reinforced concrete code viewpoint, how can a type of reinforced concrete (ferrocement) have almost zero cover to the reinforcement? It seems easy but then how to put it in a code in such a way that it cannot be "mistaken" or "mis-interpreted" or even "abused." Similarly, how can a ferrocement structure be only 10 mm thick while minimum requirements for fire rating in concrete slabs often leads to thicknesses exceeding about 100 mm. Legally appointed construction inspectors have difficulties with such issues and unless legally clear tend to dis-approve them. Reconciling reinforced concrete and ferrocement within the same code turned out to be a daunting task if carried out through the numerous committees leading to the reinforced concrete building code committee. So it was concluded that perhaps an entirely separate code focused on ferrocement and thin cement based composites with steel reinforcements should be developed.

In the late 1980's, a number of pioneers in the field ferrocement entertained the idea to form a society dedicated to ferrocement with the primary mission to develop a building code for ferrocement design, construction, and repair. And thus the International Ferrocement Society (IFS) was born. IFS was officially formed in 1991 and registered as an entity within the Asian Institute of Technology in Bangkok, Thailand. Ricardo Pama, then at AIT, became the first president of IFS, and Lilia Robles Austriaco, who was also involved with the International Ferrocement Information Center at AIT, became the first secretary. To develop a mission statement for IFS broad enough to cover all future expansions, the mission statement of the American Concrete Institute (ACI) can be first used as a model:

> *"..The American Concrete Institute is a leading authority and resource worldwide for the development and distribution of consensus-based standards, technical resources, educational programs, and proven expertise for individuals and organizations involved in concrete design, construction, and materials, who share a commitment to pursuing the best use of concrete."*

On a grand scale the above mission statement applies to thin reinforced cement composites such as ferrocement and textile reinforced concrete (TRC). To make it more specific, it is sufficient to simply replace the word "concrete" by ferrocement or TRC. In its present form IFS is not a trade association; such an association is typically founded and funded by businesses; it is industry and niche specific with the objective to interact to the mutual benefits of all its members. So far, IFS has acted mostly as a learned society for the benefits of all including the public at large, with particular attention to the less fortunate portion of that public. Since its inception in 1991, IFS has received very little funding from businesses; its funding was strictly from membership and publication activities such as the Journal of Ferrocement. IFS can be viewed as the result of an expression of love, faith, enthusiasm and commitment by a combination of researchers, academics, amateur builders, and businesses. Thus IFS is a leaned society with a mixed mission: on the one hand to be the repository of all resources and information related to ferrocement and make them available to the public, and on the other hand to help develop resources for ferrocement when they are missing and needed. The most urgent being to develop and maintain building codes, standards and guidelines for analysis, design, construction, repair and appropriate materials for ferrocement.

Although the starting activities and progress of IFS are modest it is useful to expand its potential mission to simulate that of the American Concrete Institute, that is:

> *"The mission of the International Ferrocement Society is to provide resources worldwide for the development and distribution of consensus-based standards, technical resources, educational programs, and proven expertise for individuals and organizations involved in ferrocement design, construction, and materials, who share a commitment to pursuing the best use of ferrocement."*

Note that the above mission statement could be similarly applied to textile reinforced concrete (TRC) should a related international society be sought for that material. During the mid-1990's, IFS organized several committees to help develop reports and recommendations for various activities; they included: the Ferrocement Model Code committee, the Education Committee, the Corrosion and Durability Committee, the Housing and Terrestrial Structures Committee, the Advanced Materials Committee, and the Seismic Applications Committee. These were considered subjects of most importance at the time and are still relevant to today's needs. The Ferrocement Model Code was first published by IFS in January 2001 [1]. History would likely conclude in the future that the onset of the third millennium was not kind to ferrocement. IFS encountered several difficulties; key board members who were working at AIT in Bangkok, retired. Shortly thereafter, AIT cut out funding and the physical facilities of the IFS and its right arm, the International Ferrocement Information Center (IFIC) were taken over for other activities. All physical documents, paper prints, reports, photos, and journal archives of IFS and IFIC were then stored in a room on the floor of the structural engineering laboratories at AIT awaiting further decision as to their future permanent housing. Then disaster struck in 2011 when Bangkok was flooded by torrential rains; all the above documents were flooded and stayed in water for many days. For all practical purposes they were destroyed and later, when attempt was made to remove all damaged materials, they were too damaged and simply discarded. Members of the Board of IFS decided then to recreate a repository of information related to ferrocement by collecting all hard copies documents available to them (personal library or other) and the membership, and digitize them. This activity is being carried out at the University of Manchester by Paul Nedwell while simultaneously a web site is being built where such information will be stored. Since 2011, the IFS society has been acting mostly virtually awaiting the completion of the web site in Manchester, and the establishment of a base at the University of Manchester in the UK. In the meantime, the most urgent need remains most critical: the Ferrocement Model Code, first published in 2001, needs to be updated and expanded. It is hoped that such activity will be given top priority by the society.

CONCLUDING REMARKS

None of the recognized advantages of ferrocement have changed since the onset of its modern development in the 1960's, while both its cost-performance and mechanical effectiveness have improved with the introduction of new materials and systems. It seems that the main deterrent to its progress remains the establishment of a widely accepted and updated building code for its design and construction. Amateur builders and self-help practitioners will continue to use ferrocement in small scale applications, but opportunities for all other applications are hindered by the absence of such a code. The objective of the proposal for an international technical society (such as IFS) will foster a related discussion at large among professionals that should lead to some tangible actions. On one hand, dedicated focus and independence will guarantee the production of a code document for ferrocement; on the other hand, to receive wide acceptance, the adoption of such code by a larger umbrella organization such as ACI or Rilem will be eventually necessary. This could be the only route to follow in the future to guarantee the worldwide adoption of a code.

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