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Ferrocement—Past and Present

By Gajanan M. Sabnis

Synopsis: This is an introductory paper to the symposium and should be considered in conjunction with papers by Batson et al., and Romualdi presented in this volume. An attempt is made to review briefly the historical background and to create the stage for the symposium that ferrocement is a useful engineering material rather than a boat-building material.

Keywords: boats; construction materials; ferrocement; history; reinforced concrete; reinforcing materials; welded wire fabric; wire cloth.

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INTRODUCTION

ACI Committee 549 on Ferrocement was formed in 1974 and was charged with the mission to study and report on the engineering properties, construction practices and practical applications of ferrocement and similar materials and to develop standards and safeguards for ferrocement construction. The first activity of this committee was to prepare a state-of-the-art report and to review the literature on the subject by holding a symposium that would feature developments around the world. The present symposium reveals the success of the Committee's efforts.

Although ferrocement has been used as a construction material for several decades for various applications in many countries, establishment of the above ACI Committee 549 indicates the recent interest in this country in the use of ferrocement as a structural material. The major use of this material has previously been in the developing countries, where the advantage was taken of a large but unskilled labor force, and where excellent properties of ferrocement and successful field applications were observed with relatively little theoretical basis. As the material technology developed, so did the interest of engineers who began to view this material as a potentially significant material of construction. It is the hope this writer and the committee that such developments will continue and allow engineers to exploit ferrocement though their ingenuity in new structural applications.

This paper provides a brief historical review and discusses the current status of ferrocement. The papers in this symposium will present considerably more information in terms of the many properties and the applications of ferrocement in countries around the world. The last paper will be devoted to the research needs and potential applications of ferrocement.

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HISTORICAL BACKGROUND

Ferrocement is a form of reinforcement concrete in the sense of the grouping the terms 'reinforced' and 'concrete'. It differs, however, from reinforced concrete by the manner in which the reinforcement is distributed in the matrix. The general arrangement of closely spaced continuous reinforcement converts the matrix into a composite material unlike conventional reinforced concrete. Because of the closer spacing (of the order of 1 to 2 in. (25 to 50 mm)) and the small size of the reinforcing, the materials are used efficiently in thin sections. The nature of the reinforcement is such that hardly any formwork is required to form complicated shapes. Many of the characteristics of ferrocement are the result of the experience in field and not from theoretical analysis, since no skilled or trained labor was needed. It has been most widely used in the developing countries of Asia.

The use of ferrocement, if considered in the very broad sense of the term, goes back many centuries. One can consider it as reinforcement impregnated with mortar because of the high percentage of reinforcement, strongly influences the mechanical properties. The use of bamboo and mud (concrete) in constructing huts has been common for centuries in villages of India and other Asian countries.

The Europe, although others had attempted using reinforcement in concrete in the early part of the 19th century, credit for using ferrocement should go to J. L. Lambot in France, who constructed a concrete rowing boat in which the reinforcing was the form of interlocking wires and thin bars. His patent was issued in 1847 and it states a fairly accurate description of ferrocement (1):

> "My invention shows a new product which helps to replace timber where it is endangered by wetness as in wood flooring, water containers, plant pots etc. The new substance consists of a <u>metal net</u> of wire or sticks which are connected or formed like a <u>flexible woven mat</u>. I give this net a form which looks in the best possible way, similar to article I want to create. Then I put in hydraulic cement or similar bitumin tar or mix, to fill up the joints."

The underlined words in the above extract from his patent clearly indicates that ferrocement is even older material than the conventional reinforced concrete. Probably the use of words like water containers plant pot suggested the use of the material in boat-building, which remained the major application of ferrocement for a long time. In the First World War, large scale use of ferrocement was in the building ships using a combination of lightweight reinforced concrete with

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ferrocement, due to the shortage of steel plates for shipbuilding.

In the early 1940's, Nervi in Italy applied ferrocement for roofs of buildings and warehouses. Since then ferrocement has been used in the construction of domes and roofs of stadiums, opera houses, restaurants, etc. in Europe. It is worth mentioning that in spite of Nervi's demonstration of successful use of the material, no systematic investigation was carried out till much later.

It was not until the 1960's, that ferrocement began to be used in the developed countries such as Australia, the United Kingdom and New Zealand. However, it still remained largely a boat building material. But, because of the universal availability of the basic component materials of ferrocements and the low skill needed for construction of structural forms developing countries became more concerned with its use as a general purpose structural material. This resulted in its use (in applications such as) low cost housing, food storage silos, and irrigation troughs.

In 1972 the National Academy of Sciences established the Ad Hoc panel to study the use of ferrocement in developing countries. The final NAS report (2) aroused interest in Ferrocement in the United States. This was followed by the American Concrete Institute (ACI) establishing the Committee 549 on Ferrocement in 1974 with the following mission:

> "To study and report on the engineering properties, construction practices, and practical applications of Ferrocement and similar materials; develop standards and safeguards for ferrocement construction."

In the last 4-5 years, considerable effort has been made by the many individuals and organizations around the world to develop ferrocement as a construction material. Another symposium planned by the International Ferrocement Information Center (IFIC) in Bangkok Thailand, later this year is another indication of interest of the professional community in the potential of this material.

DEFINITION OF FERROCEMENT

As the material "Ferrocement" was used for a long time in boat building and similar allied structures rather than in structural applications and a rigorous engineering definition of ferrocement was not essential. Within ACI Committee 549 and after considerable discussion on various definitions from many sources, it came up with a concise, accurate definition that may be acceptable to the engineering profession. Some of the definitions from various sources are presented.

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The definition according to the American Bureau of Shipping is:

> "A thin, highly reinforced shell of concrete in which the steel reinforcement is distributed widely throughout the concrete, so that the material under stress acts approximately as a homogenous material. The strength properties of the material are to be determined by testing a significant number of samples..."

Although at first glance, the above definition seems a pretty good one, it raises a number of questions about the words underlined that obviously may suggest different meanings to different people. BIGG (3) has discussed the various aspects of this definition and has suggested other ways to define it, including reference to ferrocement as a composite material. He points out how the available engineering concepts in composites of fiber reinforced concrete may be used to come up with a definition of ferrocement.

BEZUKLADOV (4) defined ferrocement in terms of the ratio of the surface area of reinforcement to the volume of the composite. In this manner, ferrocement was distinguished from conventional reinforced concrete by assigning arbitrarily a specific surface greater than 2 cm^2/cm^3 was considered reinforced concrete.

SHAH (5) defined ferrocement in a manner similar to Bezukladov, and called it a composite made with mortar and a fine diameter continuous mesh as reinforcement. The continuous mesh has higher bond due to its smaller size and a larger surface area per unit volume of mortar. According to him, this ratio may be as much as ten times that which is observed in conventional reinforced concrete. This results in failure of ferrocement in tension by the actual breaking of wire mesh and a much higher cracking strength in the matrix.

Certain characteristics of ferrocement as a composite may be summarized as follows:

a. Since the wire mesh (reinforcement) is much stronger in tension compared to the matrix (mortar), the role of the matrix is to properly hold the mesh in place, to give a proper protection and to transfer stresses by means of adequate bond.

b. Compression strength of this composite is generally a function of the matrix (mortar) compressive strength, while the tensile strength is a function of the mesh content and its properties.

c. It follows from (b) that the stress-strain relationship of ferrocement in tension may show either complete elastic behavior (up to fracture of reinforcement mesh) or some inelasticity depending upon the yielding properties of the mesh.

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d. Since the properties of this composite are very much a function of orientation of the reinforcement, the material is generally anisotropic and may be treated as such in theoretical analysis.

The above discussion indicates the variety of approaches that have been used in a structural definition of ferrocement. ACI Committee on Ferrocement defined it as a construction material as follows:

> "Ferrocement is a type of thin wall reinforced concrete construction, where usually a hydraulic cement is reinforced with layers of continuous and relatively small diameter mesh. Mesh may be made of metallic materials or other suitable materials."

ENGINEERING PROPERTIES

Traditionally, ferrocement has been viewed as a material for boat building rather than for building applications. Its use, however, has been extended to many types of structures in the eastern hemisphere. As such, little scientific information on its engineering properties was available. This is not to say that the intent here is to make a simple material used by unskilled labor more complex, but to throw light on its engineering properties in order to assist the profession in the design and use of ferrocement as a viable material for construction.

The main properties which have been studied include:

1. Tensile behavior (or alternatively, flexural strength)
2. Cracking behavior
3. Compressive strength
4. Impact strength
5. Fatigue strength

and 6. Water (or liquid) retaining capacity

Since ferrocement is basically composed of reinforcement and mortar one may be tempted to compare it with reinforced concrete. However, from the discussion of its definition, the material differences are clear. Structural properties also differ due to the fine dispersion of the reinforcement in ferrocement.

The above properties are important in many structural applications. Although the first three properties are of general structural use, the rest having use in special applications. These properties will be dealt in detain in the next paper (6) in this symposium.

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IMPROVEMENT OF FERROCEMENT PROPERTIES

Attempts have been made recently to improve the properties of ferrocement. Notable improvement is reported by ATCHESON and ALEXANDER (7) in another symposium paper using fibers with ferrocement. Fibrous concrete has also been found to have good structural properties. Combining the two types of concrete, the above authors demonstrated that fibrous ferrocement performed equal, or better than either individually. The fibrous ferrocement produced by using large aperture steel mesh and fibers, thus removing the restriction on ferrocement to have closely spaced wire mesh.

Other possibilities of improving the properties of ferrocement exist such as using polymerization techniques, which have been demonstrated to improve properties of reinforced concrete. As the technology progresses toward more economic use of polymerization, it is hoped that research will encourage its application in ferrocement.

RECENT APPLICATIONS

There have been many applications of ferrocement all over the world, both in developing and developed countries. The particular aspect of using the reinforcing cage as the stiff formwork itself is an important advantage of ferrocement for use in complex structures. Where the cost of forming is sometimes prohibitive. Recent applications have been discussed in some of the papers in this symposium. The universality of the applications of this material is apparent from the contributions from countries around the world. In addition, recent use of ferrocement in North America has been demonstrated for prefabricated thin domes in Quebec, Canada (8). Naaman and Shah (9) also have pointed out some potential of this material in off-shore structures such as buoys, deep submersibles and vessels for transportation of liquid gases.

CONCLUDING REMARKS

This introductory paper presents briefly the past and the present status of ferrocement as a construction material. The next paper will present the detailed version of the properties of ferrocement, while the others include both analytical and experimental evaluations of the various properties. There are a number of application papers, as mentioned earlier, to give one the range of its uses as a potential material in structural applications. Finally, the last paper will take the reader into future of ferrocement to conclude the symposium.

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Survey of Mechanical Properties of Ferrocement as a Structural Material

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Synopsis: This is a summary of the mechanical properties of ferrocement as a structural material based on the state-of-the-art report being prepared by ACI Committee 549, Ferrocement. The mechanics of ferrocement is very complex because of the almost infinite variety of size, geometry, fabrication methods, orientation, yield and ultimate stress of the steel wire mesh reinforcement available. The specific surface area of the wire mesh appears to correlate well with the first crack strength and the spacing and number of cracks. The tensile, flexural and compressive strengths depend on the orientation of the mesh, technique of fabricating the mesh and its ultimate strength. It appears that the conventional methods of analysis for reinforced concrete can be used to calculate the flexural strength of ferrocement. Ferrocement has superior impact properties, but its fatigue strength may limit the otherwise high allowable stresses to which it could be subjected. A design approach based on allowable crack width for service loads seems to be practical.

Keywords: compressive strength; construction materials; cracking (fracturing); crack width and spacing; fatigue (materials); ferrocement; flexural strength; hydraulic cements; impact strength; mechanical properties; tensile strength; welded wire fabric; wire cloth.

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INTRODUCTION

One of the historical difficulties in considering ferrocement as a unique material has been the problem of defining it. There are, in essence, two problems. The very term ferrocement implies the combination of a ferrous product with cement. Yet there are certain characteristics of ferrocement that can be achieved with reinforcement other than steel mesh. The idea of ferrocement boats, for example, can be said to predate Lambot because the Chinese long ago used for a similar purpose burnt lime in combination with a reinforcement of bamboo rods. Also, the ancient and universal method of building huts or reinforced structures in countries like India by using reeds to reinforce dried mud (wattle and daub) is a form of ferrocement.

Thus, the ACI Committee 549, Ferrocement, concluded that a definition of ferrocement should not be limited to steel reinforcing even though it is recognized that most applications emphasize it.

Another difficulty has to do with the spacing or dispersion of the reinforcement. It is generally recognized that ferrocement utilizes "closely spaced" layers of mesh in which the opening or mesh spacing is "small." But how close and how small? In short, if one expands the distances between the individual wires, at what point does ferrocement become reinforced concrete?

In attempting to overcome these difficulties, the Committee has adopted the following definition:

> "Ferrocement is a type of thin wall reinforced concrete construction where usually a hydraulic cement is reinforced with layers of continuous

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