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A Review Report On Mechanical Properties Of Ferrocement With Cementitious Materials

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Abstract

Most developing countries are faced with problems of adject poverty, low standards of living, environmental degradation and housing shortage. Ferrocement technology has been established as environmentally friendly low cost technology. Ferrocement is a type of thin wall reinforced concrete construction where hydraulic cement is reinforced with layers of continuous and relatively small diameter mesh. This paper focuses on the materials, advantages, mechanical properties, practical design parameters, recommendations, research and development in ferrocement. The positive effects exerted by silica fume and fly ash on properties of Portland cement mortar have been emphasized.

Keywords: Ferrocement, wire mesh, Applications, mechanical properties, silica fume,fly ash.

1. INTRODUCTION

The world is witnessing a revolution in construction practices along with a new phase of development fuelled by the rapid economic growth and high rate of urbanization. Construction provides the direct means for the development, expansion, improvement and maintenance of urban settlements (Suresh, 2004).Construction provides the direct means for the development,expansion,improvement and maintenance of urban settlements(Abang, 1999)Thus, the construction industry must keep up with the advanced technology and systems to cope up with the modern trends and demands.

'Ferciment' or 'Ferro-cemento' or Ferrocement is the first invention of reinforced concrete (ACI 549R-97, Naaman2000) Ferro cement is thin cement based composite material. It has very wide applications due to its unique characteristics/mechanical properties, such as: environment friendly, sound technology; excellent tensile strength, improved toughness, water tightness, lightness, fire resistance, resistance to cracking and cost, time and material effective construction technology can not be matched by another thin construction material(Paul B.K and Pama.R.P 1978).Ferrocement model code (FMC) encourages the use of non metallic reinforcement and fibers.

The objective is to provide the trends and development outlook of ferrocement technology and to explore the effects of adding silica fume and fly ash with superplasticizer to ferrocement laminates.

2. THE HISTORY OF FERROCEMENT

"Ferro cement is a type of thin wall reinforced concrete construction where usually hydraulic cement is reinforced with layers of continuous and relatively small diameter mesh"

Joseph Aspdin introduced to the world Portland cement and patented it during 1824.Subsequent developments in material, higher burning temperature, continuous-process rotary kiln etc., drastically improved the material and reduced the cost. A spate of buildings erected from 1835 onwards was of concrete but the concept of reinforcing the material was hardly around this period (John E Morgan 1998).

To overcome the low tensile strength of concrete, attempts were made to reinforce it using bronze rods and strips. But the higher rate of thermal expansion of bronze caused cracking." A note on the history of reinforced concrete in buildings"by Hamilton.S.B. describes the early use of armatures of embedded iron in masonry and to reinforce brick work. Within a short period, use of reinforced concrete was put under use. Joseph Monier built large garden tubs (1849); Francois Coiquet (1852) cast concrete around an ion skeleton within timber shuttering; William Wilkinson a New castle builder took out a patent in 1854 for embedding in floors or beams of concrete a network of flat iron bars (John E Morgan 1998).

In the same period Joseph Louis Lambot an horticulturist living on his estate at Miraval near Bringnoles in Var experimented with plant pots, seats and tubs made of meshes and plastered with a sand and cement mortar replaced his rotting rowing boat. He called this material as 'Ferciment' in a patent, which he took in 1852.(Paul.B.Kand Pama.R.P,1978).Lambot's row boats still now available in Brignoles museum in France.

There was very little application of true ferro cement construction between 1888 &1942 when Pier Luigi Nervi began a series of experiments on ferrocement. He observed that reinforcing concrete with layers of wire mesh produced a material possessing the mechanical characteristics of an approximately homogeneous material capable of resisting high impact. After the Second World War Nervi demonstrated the utility of ferrocement as a boat building material.

In 1945,Nervi built the 165 ton Motor Yatch “Prune”on a supporting frame of 6.35mm diameter rods spaced 106mm apart with 4 layers of wire mesh on each side of rods with total thickness of 35mm.It weighed 5% less than a comparable wooden hull &cost 40% less at that time.

In 1947, Nervi built first terrestrial ferrocement structure was due to the corrugations of the wall &the roof which were 44.45mm thick.

In 1948 Nervi used ferrocement in first public structure, the Tutrin Exhibition building, the central hall of the building which spans 91.4m,was built of prefabricated elements connected by reinforced concrete arches at the top &bottom of the undulations.

In 1958, the first ferrocement structure a vaulted roof over shopping centre was built in Leningrad in Soviet Union.

In 1971 a ferrocement trowler named “Rosy in I”was built in HongKong.It had an overall length of 26m &is claimed to be the worlds most longest ferrocement fishing boat.

In 1972, the National Academy of Sciences of the United States of America set up an Adhoc Panel on the utilization of ferrocement in developing countries under the chairmanship of Prof.James P.Romualdi of Carnegie-Mellon University, U.S.A.The report of the panel was first published in early 1973.As a result of the report people became aware of this material and started using it.

In 1974, the American Concrete Institute formed committee 549 on ferrocement.ACI Committee 549 first codified the definition of ferrocement in 1980,which was subsequently revised in 1988,1993 and 1997(Naaman A.E ,2000)

In 1975, two ferrocement aqueducts were designed &built for rural irrigation in china.

In 1976,the International Ferrocement Information Centre(IFIC)was founded at Asian Institute of Technology,Bangkok,Thailand.The centre is financed by the United States Agency for International development, Government of New Zealand ,International Development Research Centre of Canada.

In 1978, an elevated metro station of 43.5mx1.6m in size with continuous ferrocement roofing was erected in Leningrad.

In 1979, RILEM (International Union of Testing &research Laboratories of materials &structures) established a Committee (48-FC) to evaluate testing methods for ferrocement.

In 1984, ferrocement was used in the construction of a shaking table of large scale earthquake simulation facility at the state university of NewYork at Buffalo.

The International Ferrocement Society (IFS) formed a Committee (IFS-10-01),the recommendations of which were published as “Ferrocement Model Code”(FMC) in January2001.The definition in the above model code reflects the advances in ferrocement and past experiences too.

3. CONSTITUENTS OF FERROCEMENT

3.1 Mortar Mix

The hydraulic cement mortar mix consists of Portland cement, fine aggregate, water and various admixtures as per the requirement. The materials should satisfy standards similar to those used for quality reinforced concrete construction, with particular attention paid to the type of application (IFS-10, 2001).Naaman (2000) proposed that the actual mix design should be optimized, whenever possible, with respect to the available local materials and environmental conditions.

3.2 Wire Mesh for Reinforcement

Steel wire meshes are considered the primary mesh reinforcement. This include the various types of the shape; square woven or welded meshes, chicken (hexagonal/aviary) wire mesh, expanded metal mesh lath etc.Except for expanded metal mesh, generally all the meshes are used galvanized.

3.3 Skeletal Steel

Skeletal steel used in ferrocement is in form of welded fabric as a grid of steel rods, strands of small diameters. Skeletal reinforcement is needed to form the shape of the structure to be built. Mesh layers are attached around. Skeletal steel is only used when the thickness of the ferrocement element allows.

4. DISTINCT CHARACTERISTICS OF FERROCEMENT VERSUS REINFORCED CONCRETE(Naaman 2000)

As stated in the definition, ferrocement is a type of reinforced concrete construction. While, such a definition implies many similarities between ferrocement and reinforced concrete, and there is a number of differentiating factors sufficiently important to explain the differences in their behavior

Compared to reinforced concrete, ferrocement is a thinner material.

- Has distributed reinforcement.
- Is reinforced in two directions.
- Has matrix made of fine mortar or paste instead of concrete which contains larger size aggregates.

5. FERROCEMENT CONSTRUCTION METHODS

Several methods of construction were identified during the early applications of ferrocement and described first in the ACI guide for the Design, Construction and Repair of ferrocement(ACI 549,1988).i)the skeletal armature method ii)the closed mold method iii)the integral mold method and iv)the open mold method. These were mostly suitable for the construction of a single structure. The layup technique for mortar application was proved to be cost effective in terms of labour.(Iorns M.E, 1977,1980).

6.MECHANICAL PROPERTIES

6.1 Benefits of using cementitious materials in ferrocement as partial replacement for cement.

In many countries around the world, silica fume and fly ash are used for producing active pozzolanic admixtures. These pozzolanic admixtures are used for reducing the Portland cement content in mortar and concrete production.(Cook DJ,1985, Ruiz,1965).The positive effects exerted by such pozzolanic admixtures on properties of Portland cement mortar and concrete have been emphasized in many studies(Babu KG, Rao GSN ,2000).In addition to a strength gain, it was shown that such admixtures could improve the surface resistance of the Portland cement mortar and concrete (George J, xuz, Danie F,1995)

The benefits of using either fly ash or silica fume in concrete in partial replacement for Portland cement are fairly well established. However both materials have certain short falls. Silica fume, while imparting significant contributions to concrete strength and chemical resistance can create increases in water demand placing difficulties and plastic shrinkage problems in concrete and present handling difficulties in the raw state if not properly used. Deficiencies associated with the use of fly ash in concrete depend on the nature of fly ash being considered.

The combination of silica fume and fly ash in a ternary cement system (i.e. Portland cement being the third component) should result in a number of synergistic effects, some of which are obvious as follows (M.D.A.Thomas,1999).

- Silica fume compensates for low early strength of concrete with low fly ash.
- Fly ash increases long term strength development of silica fume concrete.
- Fly ash offsets increased water demand of silica fume.

- Very high resistance to chloride ion penetration can be obtained with ternary blends.
- The relative low cost of fly ash offsets the increased cost of silica fume.

6.2 Tensile Strength

In tension, the load carrying capacity is essentially independent of specimen thickness because the matrix cracks before failure and does not contribute directly to composite strength (ACI 549R, 1997).The tensile strength of ferrocement is directly

Proportional to the number of layers of the wire mesh (Naaman, 2000). The mesh orientation at 45^{o} results in the lowest volume fraction of the wire mesh in the loading direction, thus, exhibiting poorest performance (Arif et al.,1999;Hossain and Inoue,2000)

The tensile strength at first cracking in ferrocement is directly proportional to the specific surface of reinforcement (Swamy and Shaheeen, 1990; Somayaji and Naaman, 1985; Arif et al., 1999; Naaman, 2000).The tensile strength of ferrocement depends on the mesh orientation and whether the applied loading is uniaxial or biaxial because of the change in volume fraction in the loading direction (Arif et al., 1999; Abdullah and Mansur, 2001).

6.3 Compressive strength

The properties of mortar mix like compressive strength, water absorption are very important to consider during the design of thin ferrocement structural elements. The studies have been conducted to investigate the characteristics of mortar mix to use in ferrocement elements (Arif MP, Kaushik SK, 1996). In general, the compressive strength of ferrocement is considered as that of the mortar mix (ACI 549R, 1997; IFS-

10, 2001) ACI 549 recommends sand cement ratio (S/C)1.5-2.5 and water cement ratio (W/C) 0.35-0.5, for the use in ferrocement.

The compressive strength of cement paste containing silica fume decreases as the silica fume content increases at low water cementitious materials ratios of 0.25,but plain cement paste exhibited highest strength and greater strength development after 28days(Akkan MS, Mazlum F.A,1992). In the case of ternary use of Plain cement (PC),fly ash(FA) and silica fume(SF)the compressive strength also gradually decreased with the replacement ratio but the rate of reduction was much less compared to the case in the binary use of PC and FA(Mehmet Gesoglu et al.,2009).The corrosion resistance of the ternary blend mortar of OPC, Rice husk ash (RHA) and FA is consistently higher than that of mortar containing single pozzolana(Chindaprasirt.P,Rukzon. S, 2008) The concrete containing FA had generally lower compressive strength. However, binary (PC+SF and PC+S) and ternary (PC+S+SF) blends of SF and slag(S) provided comparably higher compressive strengths (Mehmet Gesoglu, Erdogan ozbay, 2007).

The results from laboratory studies on the compressive strength of mortar containing silica fume and flyash reveal that compressive strength ranging between 89.42MPa and 49.43MPa depend upon the mix ratio, water binder ratio, replacement level and dosage of superplastisizer.The mortar 1:2, water binder ratio 0.35 with 5%silica fume,20%fly ash and 0.2% to 0.6% superplastisizer could be considered as suitable mortar for casting of thin ferrocement laminates.(Sasiekalaa.k et al.,2012).

6.4 Bending (Flexure)

Bending reflects the combined influence of parameters controlling both tensile and compression properties, such as mortar compressive strength, mesh type, mesh properties and mesh orientation.

The ferrocement with the mesh layers even bundled at the centre of the cross section behaves similar to that of the plane mortar under bending. Thus in ferrocement bending elements, as in reinforced concrete, the most efficient layer of mesh is that closest to the extreme fiber or face of the element (Paramasivam.P and Ravindarajah.S.R, 1998).The specific surface of reinforcement does not have as strong an influence on the cracking behavior in bending as in tension. The average crack width in ferrocement bending elements is primarily a function of the tensile strain in the extreme layer of mesh and transverse wire spacing (Naaman, 2001).

The size of the mesh openings should be within 6-25mm (FMC 2001).The meshes to be used as reinforcement in ferrocement should have other unique characteristics, such as easy to install, light weight, adaptability to the curves and contours of any structural shape.(Paul B.K and Pama.R.P ,1978)The compressive strength of mortar does not seem to have much influence on the bending resistance of ferrocement beams. Everything else being equal, an 80% increase in mortar compressive strength led to an average increase of only 11% in bending strength(Montesinos.G.P and Naaman.A.E 2004)

Square welded wire meshes perform better in bending than the other meshes. This is due to the transverse wires in welded meshes provide a better anchorage for bond zone, thereby strengthening the matrix through biaxial confinement. hexagonal mesh has the poorest performance among the wire meshes (Arif.M,Akhtar.S,Masood.A,Basi.Fand Garg.M 2001).In ferrocement crack width at working load remain very small compared to that of reinforced concrete, thereby leading towards to good impermeability,stiffness,and durability (Onet.T,Magureanu.C and Vescan.V ,1992).

The results from experimental study on flexural behavior of ferrocement reinforced with chicken mesh reveal that based on load carrying capacity,deflection and crack width, the partial replacement of cement by 5% silica fume and 20% fly ash with volume fraction 2.823% and 3.770% can successfully produce mixes of adequate early strength and increased long strength development coupled with excellent flow characteristics.(Sasiekalaa.k et al.,2012).

6.5 Impact Resistance

Resistance to impact is often measured by the amount of energy absorbed during the impact loading.(Alwis et al.,2001)conducted experimental programme to study the behaviour of steel ferrocement concrete sandwich plates under lateral impact.(Alwis and paramasivam,2001)investigated the impact response of ferrocement.(Achyutha et al.,1988)have determined the impact resistance of ferrocement slabs by measuring the dimensions of indendation.

The results from impact tests indicated that both the duration and amplitude of the square pulse influence the dynamic amplification. The dynamic amplification ranges from 0.7 to 1.7 hp to 60% of estimate static load and 1.2 to 4 beyond (Arif et al., 1998) A linear relationship was observed between compressive strain and deflection after localized damage. The energy expended in impact damage could be assigned to localized damage, crack opening compressive failure of mortar and bending of reinforcement. (Kobayashi et al., 1992).

The experimental results on impact strength indicated that Ferrocement laminate with addition of fly ash and silica fume to the matrix distribute the stresses over large area resulting increase in energy absorption capacity due to impact. It can be very effective in preventing the spalling of the mortar cover at failure and can lead to comparable results in terms of impact strength.

7 RECOMMENTATIONS OF FERROCEMENT

7.1 Residential Buildings

One logical solution to the housing problem is the adoption of prefabrication for the construction of houses. The prefabricated housing system and the Systems Design approach include the manufacture of components of a building such as roof, wall, door and window frames, lintel and sunshades etc.in the small scale industrial sector enabling the assembly of the units on the site, within a short period of time. Ferrocement roof and wall elements could be factory mass produced in prefabricated form, a process best suited to the demands of urban area.Alternatively,it could be fabricated in –situ in rural areas.

7.2Watertanks

Precast or cast-in-situ water tanks of any capacity and any shape can be economically constructed with ferrocement because practically no shuttering is required for its construction. These water tanks are leak proof, durable and maintenance free and lead to up to 40 percent savings, compared to tanks built in steel, fiber concrete and masonry. It can also be effectively used for various water supply structures like casings for shallow wells, water tanks, sedimentation tanks, and slow sand filters and for sanitation facilities like septic tanks, service modules and sanitary bowls.

7.3 Biogas Holders

Ferrocement gas holders can be constructed to replace the mild steel gas holders for biogas plants. These gas holders are about 50percent cheaper than steel gas holders and have good functional properties.

7.4 Silos

Inadequate storage facilities for grain exist in villages in most developing countries. It has been reported that up to 25 percent of food grain is lost to birds, fungi, rodents and insects. Ferrocement silos to store upto 300KN of grain appear quite suitable and economical. Ferrocement is water tight and appropriate sealants it can be made airtight too.

7.5 Fishing Boats

Construction of ferrocement boats has been found attractive because it can be fabricated into any shape and traditional designs could be reproduced and often improved, besides being more durable and cheaper than wooden boats.

7.6 Ferrocement roofing channels

Ferrocement roofing channels have a uniform segmental profile; they are 2.5cm thick and 83cm wide maximum length of mechanically produced channels can be 6m.Longer spans for roofing can be built with intermediate supports.

7.7 Ferro-cement reservoirs

Ferrocement reservoirs are strong, durable and watertight. They can be built either with or without shutters. Reservoirs have been built up to 400kl in size and the 100kl ferrocement reservoir is becoming common.

8 RESEARCH AND DEVELOPMENT

Pierre Luigi Nervi conducted the first experimentation on ferrocement. Nervi established the properties of ferrocement as a construction material. From then on many researchers have undertaken and established the mechanical properties of ferrocement.

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The materials have also been used for many innovative applications and development structures in many countries worldwide.

Researchers on ferrocement on mechanical properties concentrated on cracking and deformation behavior in tension and in flexure; creep and fatigue behavior; impact and weathering tests; quality and efficiency of constituent materials; and improvement of behavior with modification including metallic and inorganic fiber reinforcement and polymer modification.

Recent studies include behavior and strength of rectangular beams in shear, punching shear strength of ferrocement slabs, and use to repair and strengthen reinforced concrete structures. New additives are being used to improve workability, flow ability, setting time, strength, bonding, high durability and high impermeability. Mortar compressive strengths of upto 100 Mpa can be readily achieved using superplasticizers and microsilica (silica fumes). Fibers or micro fibers can be added to the matrix to improve its intrinsic properties.

At the reinforcement level, while steel meshes remain the primary reinforcing material, other materials such as carbon fiber meshes and organic synthetic meshes offer many advantages. Recent studies include comparison of the mechanical properties of ferrocement elements under compression for square and chicken meshes.

Recent researchers are focus on high performance ferrocement using steel mesh and high strength mortar. Recently hybrid composites are being considered. These composites combine different fibers with various properties, as well as combining short fibers with different meshes. Using hybrid composites allow control of the composite properties for the desire end use and to achieve much wider composite performance.

9 CONCLUSION

In summary, most experts and users agree that ,in all respects, Ferrocement is an excellent construction material, for the past and the future, from self-help construction to advanced prefabrication. In thin concrete products, ferrocement plays the link between reinforced concrete and fiber reinforced concrete. However, in spite of very significant advances over the last three decades, which are in great part due to the existence and efforts of the International Ferrocement Information Center, the International Ferrocement Society, the American Concrete Institute and RILEM.Ferrocement is at a critical point of its development.

The history of ferrocement as a modern construction material is longer than that of reinforced concrete, prestressed concrete and steel. Its path for the future as laminated cementitious composite combining advanced cement based matrices, high performance reinforcing meshes and fibers, and new construction techniques promises to be as bright. It is hoped that engineers, architects and other professionals will increasingly discover the superb characteristics of ferrocement laminates and hybrid cementitious composites, and will expand their use worldwide for the benefit of the public.

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