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Bending behavior of ferrocement plates in sodium and magnesium sulfates solutions

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ABSTRACT

To explore the potential uses of ferrocement as a construction material, the flexural performance of ferrocement plates under normal and aggressive environments is investigated. A series of thin mortar plate specimens were cast with varying number of mesh layers, and immersed in sodium and magnesium sulfate solutions, and tap water for a period of one year. The parameters investigated included (a) mesh wire spacing; (b) number of mesh layers (two and four); and (c) curing environment (tap water, sodium, and magnesium sulfate solutions). The test results indicated that, after one year of storage in sulfate solutions, the specimens reinforced with two layers of steel meshes, showed a significant increase in flexural strength accompanied with a noticeable decrease in ductility for specimens reinforced with medium and larger wire spacings, whereas most of the specimens reinforced with four layers showed some decrease in flexural strength and ductility compared to the specimens stored in tap water. All the plates tested showed no visible signs of significant deterioration, and exhibited typical flexural response with a varying number of fine hairline cracks occurring on the tension side of the plates.

1. Introduction

Ferrocement is a type of thin reinforced concrete construction where usually a hydraulic cement mortar is reinforced with layers of continuous and relatively small diameter wire meshes. The mesh may be made of metallic or polymeric materials. The fineness of the mortar matrix and its composition should be compatible with the mesh it is meant to encapsulate. Compared with the conventional reinforced concrete, ferrocement is reinforced in two directions and tends to have homogeneous-isotropic properties in two directions, high tensile strength, high modulus of rupture and high bond of the wire mesh with the matrix [1–4].

Ferrocement has been successfully used in new structures, for repair and rehabilitation of existing structures and in marine environments. Ferrocement construction activities have been increasing in both developed and developing regions of the world [3–6]. In China alone the tonnage of ferrocement vessels had reached about four million by 1989 [5]. The typical applications of ferrocement construction include water tanks, boats, roofs, silos, pipes, floating marine structures and low cost housing.

Durability of ferrocement can be defined as the resistance to deterioration of properties when subjected to various loading and environmental exposures. Although the measures required to insure durability in reinforced concrete also apply to ferrocement, it is relatively easy for liquids or corrosive agents to pass through a thin mortar cover and reach the ferrocement mesh. Being a thin reinforced concrete product, ferrocement has a larger surface area of mesh reinforcement that makes it prone to deterioration due to its exposure to harmful chemicals that may be found in some ground waters and soil. Ferrocement structures can satisfy design strength and serviceability criteria for many years but this depends on many factors such as mortar composition, corrosion of reinforcement, permeability and construction practice.

Several researchers have investigated the durability and performance of ferrocement structures. Vickridge and Ranjbar [7] investigated the effect of sodium chloride solution on the flexural performance of ferrocement. The results indicated that specimens with low water to cement ratio (w/c) exhibited less corrosion damage than those made with high w/c ratio. Ramesht [8] evaluated the effects of corrosion on the properties and flexural behavior of ferrocement by testing two series of specimens. It was concluded that the presence of sodium chloride and temperature increases the brittleness of mortar, reduces the number of cracks, and increases the crack width. Xiong et al. [9] studied the fatigue behavior of ferrocement in a corrosive environment. They reported insignificant effect on the moment capacity and fatigue life of welded-mesh ferrocement by up to 7 months of simultaneous action of load and accelerated marine environment; however, severe steel corrosion occurred after 18 months, and it resulted in a large loss of fatigue life and stiffness. Masood et al. [10] found that the addition of fly ash in different environments affects the load-carrying capacity under flexure for ferrocement panel with both woven and hexagonal wire fabric. Killoh et al. [11] concluded from their studies that chloride induced corrosion of steel can be effectively improved by the use of mineral admixtures in concrete such as

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fly ash, blast furnace slag and silica fume. Tori and Kawamura [12] have suggested that mineral admixtures such as fly ash, blast furnace slag, and silica fume help the formation of finer and discontinuous pore structures as a consequence of pozzolanic reaction.

Despite the literature reviewed above, systematic studies to determine the bending behavior of ferrocement plates under severe environment are still very limited. One of the best ways to insure good durability is to have a fully compacted matrix with low permeability and low porosity [3,13]. Limiting the water to cement ratio in the range of 0.35–0.45 seems to provide good protection [3]. ACI Committee 549 [1,2] recommends the use of ASTM Type II and Type V cements for exposure in marine environments. The addition of chromium trioxide to the mortar matrix is generally recommended to provide additional protection to the mesh reinforcement that is galvanized as well as to the case where a combination of galvanized and non galvanized steel meshes are in contact. For severe exposure conditions, the application of special protective coatings of the exposed surface of ferrocement is recommended [3].

The present study investigates the effect of normal and aggressive environments containing harmful chemicals on the flexural behavior of ferrocement plates reinforced with metallic meshes encapsulated with high strength cementitious matrix. The findings of this investigation can serve as motivation for further durability studies in this area, and for extending the application range of ferrocement within the construction industry for various types of environmental exposure.

2. Experimental program

The present investigation focuses on preparing ferrocement thin plates using local materials and testing them under center point bending to check the flexural behavior. These plate specimens were immersed in either tap water (as a control), a magnesium sulfate solution ($MgSO_4$), or a sodium sulfate solution (Na_2SO_4). A total of 54 specimens of size 300 × 75 × 12.5 mm with two and four layers of square wire mesh were prepared. The main parameters investigated in this study included: mesh opening size, number of mesh layers, and curing environment. Three replicate specimens were tested for each parameter set. Comparative effects of the aggressive solutions on the specimens were studied periodically by visual, photographic, and microscopic observations. At the end of the exposure period, the flexural strength and toughness of the specimens were evaluated. Load–deflection curves (including the points of first cracking and ultimate load) and energy absorption to failure were recorded. The crack pattern and failure mechanism were also studied.

2.1. Steel wire mesh

Woven galvanized steel square mesh with a wire diameter of 0.63 mm and three different wire spacings of 3.15 mm, 6.3 mm, and 12 mm were used. The mesh was tested in the laboratory following the guide for the design, construction, and repair of ferrocement reported by ACI Committee 549 [2]. The following properties were determined; equivalent yield strength = 250 MPa; ultimate strength = 350 MPa; ultimate elongation = 12%; elastic modulus = 200 GPa; density = 7.8 g/cc.

2.2. Mortar mix

The mortar mix was specially designed to achieve a high compressive strength and high workability following the guidelines of ACI committee 549 [1,2]. The mix proportions were 1:1:0.5:0.02 by weight of ordinary Portland cement, silica sand, water and superplasticizer, respectively. The mix designed had a 28-day compressive and tensile strengths of about 60 MPa, and 5 MPa, respectively.

2.3. Specimen preparation and casting

The specimens were poured in vertical molds made from plexiglass to insure a planar and smooth surface, with a cover of about 2–3 mm. Other layers, when present were distributed at best in between. Plexiglass spacers of small size were placed at the ends of the specimens to maintain approximately the same spacing between the mesh layers. Specimens were removed from their molds 24 h after casting, cured in water for 28 days, then immersed in one of the sulfate solutions and tap water until load testing.

2.4. Environmental exposure conditions

To evaluate the resistance of ferrocement specimens to sulfate attack, after 28 days moist curing, the specimens were submerged in either 5% magnesium sulfate solution, 5% sodium sulfate solution or tap water for a period of 1 year. The solutions were changed on monthly basis in order to minimize variations in the concentrations of sulfates due to the exposure to the atmosphere.

2.5. Specimen load testing and examination

The specimens were tested under center point bending with a constant span using a universal testing machine. A computer was used to record the load signal from the load cell and the deflection at mid span from an LVDT. The first crack load, ultimate load, and the corresponding deflections were observed. General micro level examination of the specimens were conducted at final stages, after testing, using a microscope to identify the degree of mesh deterioration in the plate specimens.

3. Results and discussion

The progressive deterioration of the specimens submerged in sulfate solutions and tap water was monitored by observing the visual changes in the ferrocement plates and relative flexural strength determinations with respect to strengths of control specimens stored in tap water. Typical results showing the effects of sulfate solutions on the flexural behavior of the specimens tested are presented in Figs. 1–6. The curves shown in these figures represent the average values obtained from the testing of three plate replicas. The maximum scattering in the data, measured in terms of coefficient of variation (COV) was less than 1%. The scattering in the test results for each replicate set was small and can be ignored when making comparisons among the series.

A comparison of first crack strength and ultimate strength for the plates stored in sulfate solutions and tap water is given in Table 1. Relative ultimate strength and energy absorption to failure as fractions of the control specimen values stored in tap water are shown in Figs. 7 and 8. The energy absorption values listed in Table 1, were determined by calculating the area enclosed by the complete stress–deflection curve.

3.1. Flexural behavior of ferrocement plates stored in tap water

The load–deflection behavior of the ferrocement plates stored in tap water is shown in Figs. 1–6. It is similar to that reported in the literature [3,4], and can be used as a basis of comparisons with the behavior of the specimens stored in sulfate solutions. After one year of storage in tap water, it was observed that the flexural strength of the section increases with increasing the number of