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Investigations on Selected Mechanical Properties of Ferrocement and Polymer Impregnated Ferrocement

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The mechanical strength properties of ferrocement were investigated with reference to uniaxial tension, compression and flexure from deflection, cracking and ultimate strength. The effects of impregnation of polymer and that of incorporation of fly-ash in ferrocement on the mechanical properties were also studied. The data were further analysed in relation to specific surface and re-inforcement factor. The failure modes of impregnated and unimpregnated ferrocement are also discussed.

Ferrocement is a highly versatile form of reinforced morter, developed in 1940's (Nervi, 1956) in which a number of wire mesh reinforcement layers are closely arranged and filled with rich cement mortar. Essentially, it is a form of reinforced concrete exhibiting behaviour different from the conventional reinforced concrete in performance, strength and potential applications that it must be classed as a completely separate material. Thin panels of ferrocement can be designed to levels of strain or deformation with complete structural integrity and water tightness, far beyond limits that render conventional concrete inapplicable. Ease of fabrication makes it possible to form compound shapes with simple techniques with inexpensive materials and if necessary, unskilled labour. Potential applications of ferrocement are for fishing boats, cargo boats, tugs, barges, water tanks, food storage facilities, food processing equipment, low cost roofing and host of other applications. Of late, this material is attracting the special attention of structural engineers and researchers all over the world because of wide ranging applications and potentialities of modified conventional ferrocement.

The marked improvements in the mechanical properties of cementitious materials through the addition of binding or reinforcing materials have stimulated considerable development effort in recent years in several countries. Earlier works attempted to improve the mechanical properties of cement concrete have resulted in a new series of composites called polymer concrete composites which are highly durable and strong. Three major types of such composites that have been obtained by incorporation of polymers are polymer impregnated concrete (PIC), Polymer cement concrete (PCC) and polymer bound concrete (PC). The technological advancements and applications in this field have been reported in the successive international conferences on polymers in concrete held in U.K. 1975, U.S.A. 1978 and Japan 1981. Prompted by the success of polymer concrete composites, investigations have been extended on the improvements of the mechanical properties of ferrocement by incorporating polymers. Relatively little work has been done in this area especially in India(Velpari, *et al.* 1981; Subrahmanyam, *et al.* 1981a, 1981b).

The basic parameters which characterise ferrocement are:

The specific surface of reinforcement, the volume fraction of ferrocement and the surface cover of mortar over the reinforcement.

The parameters concerning the monomer, the model of impregnation, the percentage weight of monomer incorporated and the curing characteristics exert additional influence on the behaviour of ferrocement. The experimental works conducted in this area are very limited and had been mainly confined to tension and flexure of certain selected monomers and other constituent materials.

The aim of the present investigation is to study the behaviour of ferrocement plain (F.P.), ferrocement with flyash (F.F.A.) and polymer impregnated ferrocement (P.I.F.) in uniaxial tension, compression and flexure. The mechanical properties are investigated to gain better understanding of the composites with reference to (1) the influence of percentage reinforcement and specific surface of reinforcement on first crack and ultimate strength (2) the influence of styrene-polyester co-polymer on factors mentioned under (1) and (3) the influence of fly-ash.

Materials and Methods

The following materials were used in the preparation of tensile, compression and flexural test specimens.

Cement	Pozzolana cement
Sand	River-bed sand sieved through sieve no. 8 (Tyler series)

Reinforcement	Galvanised mild steel hexagonal wire mesh 12 mm x 20 SWG
Cement, sand and water ratio by weight	1.0:1.5:0.5
Resin system	100 parts of styrene monomer mixed with 10 parts of general purpose polyester, 2 parts methyl ethyl ketone peroxide in toluene catalyst and 2 parts cobalt naphthanate accelerator (by weight)

Preparation of specimens

The dimensions of the specimens shown in Fig. 1 are as follows:

a) Uniaxial tension 300 mm x 50 mm x 12 mm
b) Uniaxial compression 300 mm x 100 mm x 38 mm
c) Flexure 500 mm x 100 mm x 25 mm

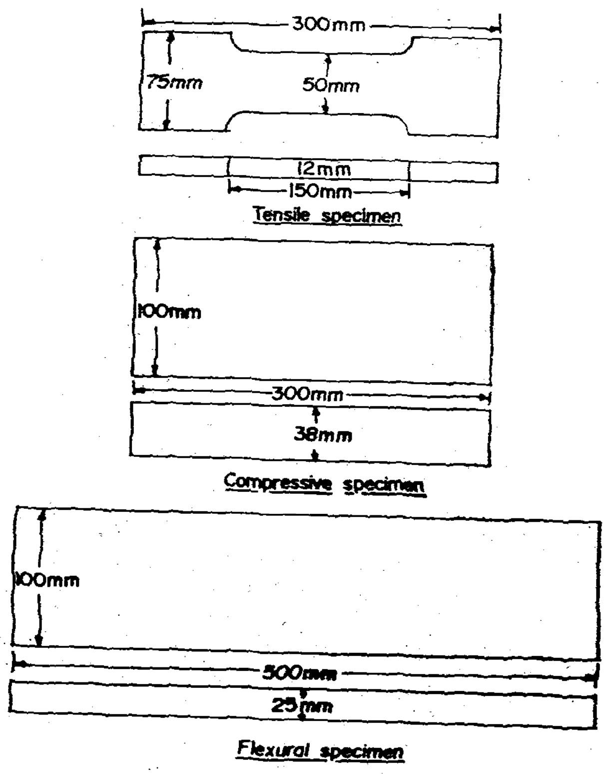

Fig. 1. Dimensions of test specimens

The entire quantity of river sand required for the experiment was washed in successive changes of tap water and dried in sunlight. The material that passes through sieve no. 8 was used for specimens preparation. Wooden moulds were fabricated and G.I. wire mesh cut as per the size for each type of test. Four specimens were cast for each series, the variable in all the specimens is the number of layers of the galvanised hexagonal wire mesh. (0, 2, 4 and 6 layers). The series covered in this studies are (1) ferrocement plain (2) ferrocement with 12.5% fly-ash with respect to cement and (3) plain ferrocement impregnated with styrene-polyester copolymer.

The specimens were cast in the wooden moulds and kept on a vibrating screen for a minute to achieve proper compaction and a void-free specimen. The specimens were cast so as to give a 3 mm mortar cover over the outermost mesh. The specimens were demoulded after 24 h and immersed in water for 28 days prior to testing them.

The polymer impregnation process started with the drying of the ferrocement specimens at 150°C till all the moisture was removed. The specimens were cooled to room temperature and were subjected to vacuum in a chamber tc remove all the air present in the voids of the ferrocement. The styrene-polyester copolymer resin system was then allowed into the chamber and was subjected to nitrogen pressure of 7 kg cm^{-2} for 16 h. The specimens were then removed from the chamber and kept for polymerisation at a temperature of 60°C for 90 h.

Testing of specimens

Tensile, flexural and compressive tests were conducted in a universal testing machine having a capacity of 40 t (UTM, VEB: 40 t, G.D.R.) on three composites: F.P., F.F.A. and P.I.F. Four specimens were tested in each series and the average value of the four was reported in the test results. Direct pull-out tests were carried out to determine the first crack and ultimate strength of the tensile specimens. The elongation was measured for a gauge length of 150 mm in the 4 t capacity range. Third-point loading on a span of 400mm was used to determine the deflection of the flexural specimens. A sensitive dial gauge of least count of 0.01 mm was used for measuring deformation over a gauge length of 300 mm for the compression test.

Results and Discussion

Tensile test

Very little information exists on the stress-strain response of ferrocement in direct tension although its crack spacing characteristics were studied (Shah & Sreenivasan, 1973; Huq & Pama, 1978; Naaman, 1979; Pama *et al.*, 1979). The need for evaluation of the influencing variables is felt for a better understanding of the fundamental behaviour of ferrocement and in view of the increased use of this material in several structural applications. Typical stress-strain curves in tension of F.P., F.F.A. and P.I.F. are shown

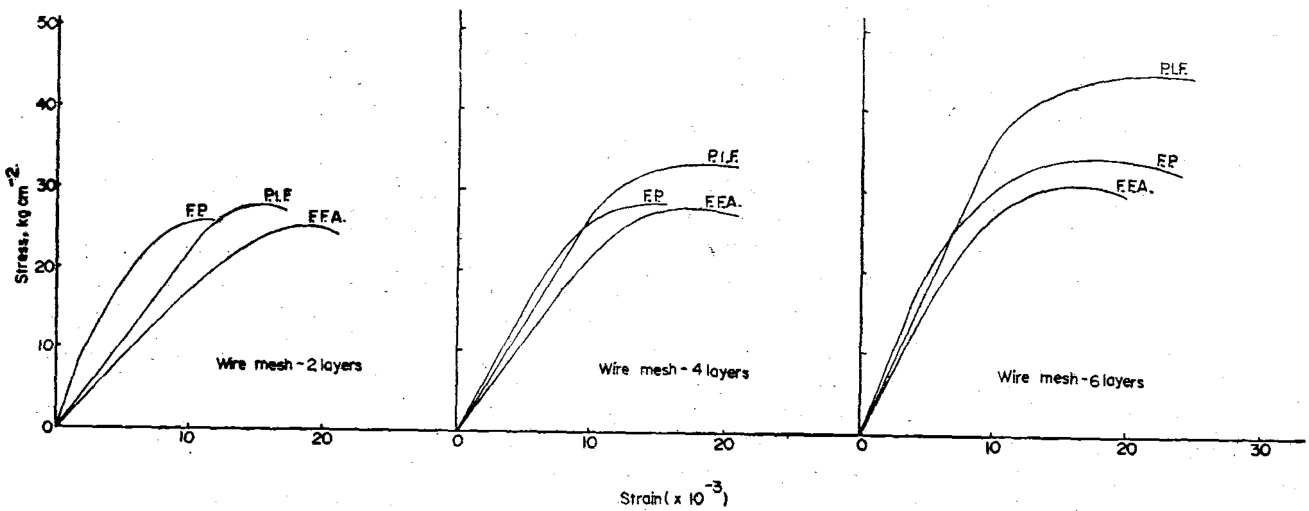

Fig. 2. Comparison of the stress-strain curve in uniaxial tension of F.P., F.F.A. and P.I.F.

in Fig. 2. They were derived from the experimentally observed load elongation values. The graphs show three stages which are characterised by the elastic stages, the crack formation stage and the crack widening stage. The important variables that affect these stages are the specific surface and the total volume fraction of the reinforcement (proportional to the number of layers of wire mesh) and the resultant effect of the polymer impregnation on them. In all these cases the stress-strain curve is linear up to the first crack as in the case of a homogeneous material. The deviation from the linearity occurred at a further increase of load which is also dependent upon the reinforcement factor of the composite.

Cracking behaviour

Elastic stage

Investigations on cracking behaviour of P.I.F. is very limited (Subrahamanyam *et al.*, 1981; Velpari *et al.* 1981) Fig. 3 illustrates the effect of polymer impregnation and fly-ash incorporation in ferrocement on the first crack tensile stress. The stress at first crack is considerably higher in the case of P.I.F. than F.F.A. and F.P. A similar trend in the first crack behaviour can be seen as the reinforcement factor is varied from 0.013 to 0.039. The resultant enhancement in strength was approximately three times in P.I.F. compared with F.P. and nearly four times with F.F.A.

Crack formation stage

The stress-strain curve deviates from linearity and a number of cracks are formed with increase in stress. At this stage of crack development, the transfer of stress from the reinforcement to matrix occurs and the very fine cracks formed increase in number. In this range visible cracks were formed. The number of visible

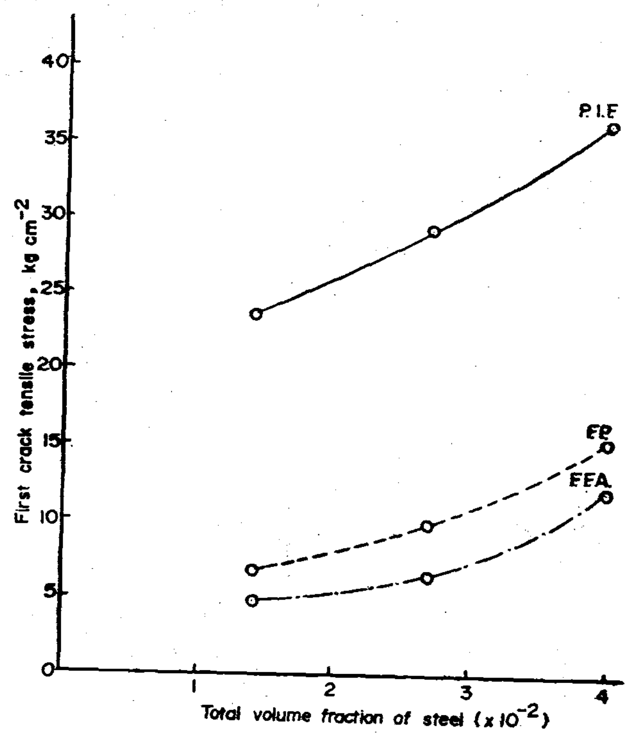

Fig. 3. Variation of first crack tensile stress of plain ferrocement (F.P) due to the incorporation of flyash (F.F.A) and polymer impregnation (P.I.F) with the reinforcement factor

crack formed did not show any correlation with polymer impregnation in the study as reported by Velpari *et al.* (1981) who observed a single fracture in polystyrene impregnated ferrocement. A trend observed with impregnated ferrocement is that the number of cracks increased with the reinforcement factor but the data are not sufficient to draw a specific conclusion on this.

Crack widening stage

There is no further increase in the number of cracks but the crack width increased with increasing strain on the reinforcement. An increase in strain in the reinforcement is mainly responsible for the increase in the width of cracks, which is further dependent upon the bond between the reinforcement and the matrix. An increased interface bond strength between the matrix and the wire mesh has already been reported in impregnated specimens (Velpari *et al.* 1981).

Flexural test

Though flexural strength properties of ferrocement have been the subject of investigation by many workers only few references are available on the flexural strength behaviour of polymer impregnated ferrocement (Velpari *et al.*, 1981; Subrahmanyam, 1981 c).

Typical load-deflection curves for F.P., F.F.A., P.I.F. are shown in Fig. 4. The load deflection curves are trilinear which are characterised by three ranges

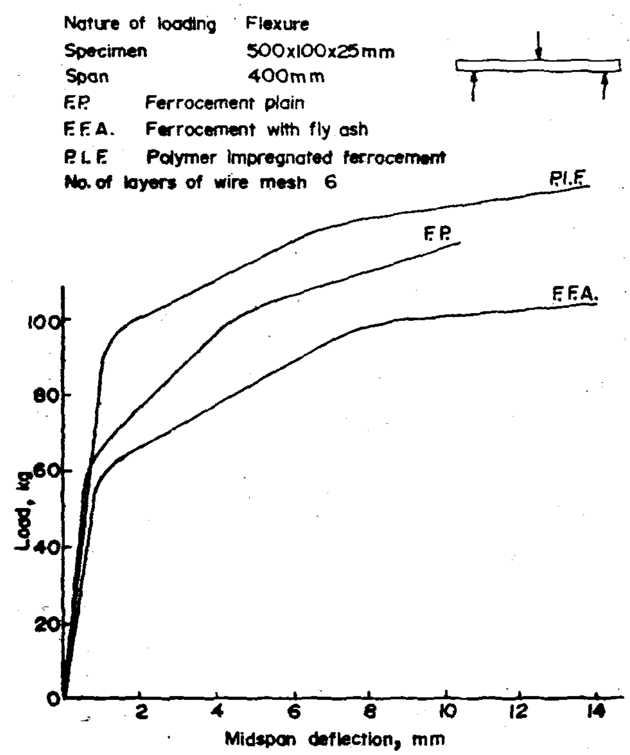

Fig. 4. Typical load deflection cruve-flexure

namely uncracked range, cracked range and yield range. The flexural tensile stress at first crack increased by polymer impregnation which can be observed from the change in slope. Similar results were also obtained when the reinforcement factor was varied. The formation of cracks in the vicinity of the mid-section was carefully observed when the load was applied. Transverse cracks were formed in this area irrespective of the fact whether the ferrocement is impregnated or not. However, in general, the number of such cracks increased with increase in the number of layers of the wire mesh. At the point of failure, the crack pattern shcwed distinct difference in F.P. and P.I.F. An analysis of the crack pattern shows that plain ferrocement failed in shear whereas the P.I.F. failed in flexure. A similar conclusion was arrived at by Janardanan & Lenschow (1981) while studying the flexural behaviour and strength of partially polymer impregnated concrete beams. The delamination which occurred in plain ferrocement has not been observed in P.I.F. which also resisted the crushing in the compression zone when the specimen failed.

Compression test

The strength of ferrocement in uniaxial compression was well documented (Bezukladov *et al.*, 1968; Rao *et al.*, 1969) but very little information is available on the compressive strength of polymer impregnated ferrocement.

Deformational behaviour of the polymer impregnated compression specimens as a function of reinforcement factor is shown in Fig. 5. It can be seen from the curves that the compressive strength is primarily dependent upon the strength of the mortar and only

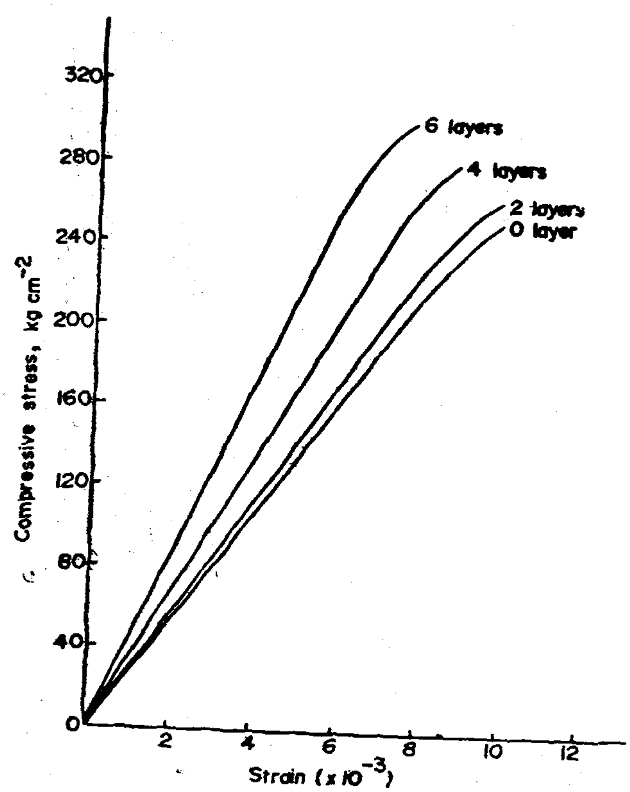

Fig. 5. Deformation behaviour of PIF in axial compression.

to a lesser extent on the reinforcement factor which results in a slight progressive increase in the compressive strength.

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