

Experimental Investigation On Performance of Fibrous Ferrocement

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ABSTRACT: This paper deals with the study of impact resistance and flexural performance of reinforced ferrocement specimens with layers of welded mesh and varying percentages of steel fibers. The main objective of this work is to study the effects on specimens casted by using single and double layers of welded mesh and varying percentages of steel fibers 0.5%, 1 %, 1.5%, 2%. Mainly concentrated on energy absorption properties and flexural performance of ferrocement specimens. The size of impact test specimens is 500x500x25mm and the flexural test specimens is 700x300x25mm. Flexural specimens were tested under two point loading system in UTM machine and impact specimens were tested by conducting a low velocity impact test. The results indicated that impact energy increases with increase in steel fibers and flexural strength increases with increase in number of mesh layers and percentage of steel fibers (0.5%-2%).

KEYWORDS: Ferrocement, Welded mesh, Steel fibers, Energy absorption, Specimens, Flexural strength, Impact load.

I. INTRODUCTION

Among all the construction materials, concrete is the one single material used in huge quantity next to water in terms of utilization in the world. The main difference between ferrocement and reinforced concrete is ferrocement is a thin composite made of cement matrix reinforced with closely spaced small diameter wire meshes instead of larger diameter rods and large size aggregates. The thickness of ferrocement generally ranges from 25 - 50 mm. The latest ACI Code and the recently published 'Ferrocement Model Code' (FMC) encourages the use of non - metallic reinforcement and fibers. Ferrocement is an environment friendly / sound technology and possesses excellent unique mechanical properties such as good tensile strength, improved toughness, water tightness, fire resistance, resistance to cracking and cost, time and material effective construction technology. Ferrocement application originally started with boat building and presently it has got very wide applications in agricultural, water supply, sanitation, housing, repair and rehabilitation of structures etc .

Structural components, especially airport pavements and industrial floor overlays are subjected to severe impact loads and very high stress rates occur due to dynamic loads as a large amount of energy is transmitted to the structure in a short duration of time. For such applications involving high level of impact loads, Min, KH, Yang, JM, Yoo, DY and Yoon, YS, 2011 [2] investigated that fiber reinforced ferrocement (FRF) elements (produced with weld mesh, hydraulic cement mortar and discontinuous fibers) have an increased tensile strength, ductility, toughness, impact energy absorption capacity and durability are recommended.

Concrete fiber composite is the most promising and cost-effective material used in the construction. Many researchers have shown that the addition of small closely spaced and uniformly dispersed fiber to concrete transforms the brittle cement composite into a more isotropic and ductile material called Fiber Reinforced Concrete (FRC). FRC can be used in the preparation of various precast building units such as cladding sheets, window frames, roofing units,

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floor tiles, manhole covers and advanced applications in highway pavements, air field, machine foundations, industrial floorings, bridge deck overlays, sewer pipes, earthquake-resistant structures and explosive-resistant structures.

The fibrous ferrocement, which is a combination of fiber reinforced concrete and ferrocement. The fibers may be of steel, carbon, glass, polypropylene, GI etc. In this project two end hooked steel fibers were used. Fibrous ferrocement can be employed with assurance where high impacts, vibrations, wear and tear are expected. The fibrous cement is becoming a promising material for bridge overlays and industrial floorings where high impacts, high vibrations and high wear and tear are expected.

II. BACKGROUND

In the investigation of **Al-Hadithi and Al-Nu'man (2008)**[1] conducted low-velocity tests on square slabs of dimensions 500 X 500 X 50 mm subjected to repeated impact blows by falling mass (steel ball) of weight 12.753 N (1.3 kg) dropped from three heights 2.4 m, 1.2 m and 0.83 m at 91 days age; and found that the impact resistance represented by number of blows until failure decreases with the increase in falling mass height; and they obtained that this might be due to an increase in strike force with an increase in the falling mass height, and that means an increase in the absorbed energy by concrete slab body in each strike, and that leads to distribution of the total impact energy on the fewer number of blows until failure.

In another study, **Mahmood and Majeed (2009)** experimented on using various layers of steel wire mesh (with diameter 0.65 mm and grid size of 12.5 mm X 12.5 mm, and ultimate tensile strength of 500 MPa) with sand-cement ratio of 2:1 and water-cement ratio of 0.45, and studied the flexural strength of folded and flat Ferro cement specimens; in flat specimens, the single layer did not contribute in increasing the strength of the specimen since it is located at mid depth, close to the neutral *Sakthivel, et al. CRL Letters Vol. 5(1) 2014* axis of the section, but with two layers, the behavior of the specimens has significantly improved in terms of initial stiffness, ductility and energy absorption (area under the load deflection curve).

Sakthivel and Jagannathan (2012a) [4] conducted low velocity impact tests on cementitious slabs reinforced with 1-3 layers of steel mesh (two types, PVC-coated and galvanized steel weld mesh) using 9.81 N (1 kg) steel mass from a height of 0.3 m on to the slab of size 250 mm X 250mm X 15 mm (thickness). They have used sand-cement ratio of 2:1 and water-cement ratio of 0.43 for casting the specimens. No effective impact strength was obtained for the slabs with 1 and 2 layer mesh, when compared to layers. Also, the energy absorption of cementitious slabs with galvanized steel weld mesh reinforcement performed better than PVC-coated steel mesh.

III. OBJECTIVE OF EXPERIMENTAL STUDY

The main objective of this experimental work is to study the behaviour of ferrocement specimens under flexural and impact loading in which welded square mesh and steel fibers has been used as reinforcement. The various parameters considered in this study are as follows:

- To compare the compressive, flexural and impact strengths of fibrous ferrocement (using steel fibers) specimens with plain ferrocement (without steel fibers) specimens.
- To increase the stiffness and resistance to cracking than the conventional ferrocement
- To increase the flexural strength and energy absorption capacity for ferrocement composites by incorporating double hooked steel fibers.

IV. EXPERIMENTAL RESULTS

4.1 MATERIALS USED:- Portland Pozzolana cement, Fine Aggregate, Water, Super Plasticizer (CONPLAST SP430), Welded wire mesh, Double end hooked Steel fibers.

Cement: The Portland cement used in this study is characterized in the laboratory with the following physical properties as mentioned in table 1.

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Fine Aggregate: The Fine aggregate conforming to Zone-2 according to IS 383 was used. The fine aggregate used was obtained from a nearby river source. The sand obtained was sieved as per IS sieves (i.e. 2.36, 1.18, 0.6, 0.3, and 0.15mm).

Water: Potable water was used in the experimental work for both mixing and curing.

Table 1 Test results on cement



Fig 1 Hooked end steel fibers

Tests performed	Results
Fineness test	3%
Initial setting time	155 min
Final setting time	355min
Compressive Strength (28 days)	19 MPa
Specific gravity	2.74

Welded mesh : The welded mesh is of square opening of size 3.81 cm x 3.81 cm was used. Ibrahim H.M[7] investigated that the mesh is used as the primary reinforcing material and it increases the stiffness and flexural strength of the specimen. Mesh properties are shown in table 2 given below.

Double hook end Steel fibers: The fibers (shown in fig 1) used are hooked end steel fiber imported from local market. Generally Steel fibers used for reinforcing concrete are defined as short discrete length of steel having an aspect ratio from 20 to 100 with any of the cross sections and that are sufficiently small to be randomly dispersed in welded mesh opening in the a hardened concrete. In the present investigation Steel fibers of aspect ratio of 50 were used. The properties of steel fibers are shown in table 3 given below. A steel fiber when added to cementitious matrix substantially increase the static and dynamic properties and changes an inherently brittle material with low tensile strength and impact resistance into a strong composite with superior crack resistance, improved ductility & post cracking behaviour. It acts as a crack arrestor for propagation of micro crack to macro crack.

Table 2 Properties of Welded Mesh

Properties	Results
Tensile Strength (N/mm ²)	512.36
Yield Stress (N/mm ²)	406.51
Elongation (%)	7.12
Weld Shear (N/mm ²)	250
Density (g/cm ³)	7.82
Thickness (mm)	2.83mm

Table 3 Properties of Steel Fibers

Properties	Results
Length (mm)	30mm
Diameter(mm)	0.6mm
Aspect ratio	50
Specific gravity	7.8-8.2
Tensile strength	1100 MPa
Young's modulus	203 GPa

MIX PROPORTION: ACI 549 recommends sand-cement ratio (S/C) 1.5 - 2.5 and water - cement ratio (W/C) 0.35-0.50, for the use in ferrocement. For the present investigation, average values of the above recommendations i.e. S/C ratio 2.0 and W/C ratio 0.45 were chosen and adopted along with steel fibers at a ratio of 0.5% – 2.0% of the volume of

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the specimen .To impart additional workability ,a super plasticizer (CONPLAST SP 430) by 1% by weight of cement was used. The dry mix is incorporated with steel fibers as shown in fig 2(a) and thoroughly mixed. Calculated amount of water is added to the dry cement fibrous mortar at particular interval while mixing shown in fig 2(b), to attain proper consistency of wet mortar.

Sample preparation: For impact and flexural tests, the specimens were cast using steel moulds as shown in fig 2(c). The moulds were coated with oil/grease for easy demoulding. The required size of welded mesh was first cut according to the mould sizes for impact and flexural tests. Fibrous mortar was prepared by mixing required percentages of steel fibers ranging from 0.5% -2% into the cement mortar. During the preparation of specimen, a layer of mortar of 11mm thick was cast at first as shown in fig 2(c) following the placement of one layer of mesh above it and then second layer of mortar was placed over the mesh as shown in fig 2(f). For some specimens two welded meshes were used. The two welded meshes were binded using a binding wire at regular intervals. After 24 hours of casting the specimens were demoulded and transferred to curing tank for 28 days. After 28 days of curing, they were taken out of water and were tested for their respective strengths.



Fig. 2 Casting of specimens(a) Mixing of dry cement mortar uniformly with the addition of fibers (b) Addition of calculated amount of water to the dry mix (c) Laying of first layer of fibrous mortar in steel mould of thickness 11mm (d) Placing of welded mesh over the 1st fibrous mortar in the steel mould (e) Laying of second layer of fibrous mortar over the welded mesh of thickness 11mm (f) Finishing and smoothing of the top layer with help of trowel and screen board

Impact test procedure: Low-velocity impact test procedure is adopted as per ACI (544). Specially made apparatus shown in the fig 3 given below. A 3.84kg steel ball was released from a height of 1m repeatedly, through a pulley arrangement which would come in contact with the surface of the cement composite which were placed in simply supported condition see fig 3. The number of blows received on appearance of initial and final cracks(at the bottom of the specimen)were counted precisely and noted down, and accordingly initial and ultimate impact energy absorption is calculated in Joules and tabulated in table (5&6). While conducting the impact study, vigorous monitoring of the experimental works has been done, and the initial and final crack formation were carefully studied .Even though the decision to stop the impact blows at ultimate failure has been mainly based on some change in the sound pattern, indicating that ultimate failure has taken place. The schematic setup of impact test experiment with specimen is shown in fig 3 given below.

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Fig 3 Impact test apparatus with pulley and steel ball arrangement

Grabowski, J[9] said that the energy absorption value is obtained by: $E = N \times (w \times h)$ joules. Where, E is Energy (absorbed by the specimen on impact) in Joules, w is weight (of steel mass) in Newton, h is height (from where steel mass is dropped on the specimen) in meter, N is number of blows (on impact specimen).

Flexural test: Flexural strength specimens were tested under two point loading over an effective span of 500mm. A detail of the test specimen set up with loaded specimen is shown in fig 4. In order to test the specimen, the centre of the line of the specimen and the roller supports were marked and ferrocement specimen was seated on the bottom rollers. Loading was applied through a hydraulic jacking arrangement to cause downward deflection as shown in the fig 4. The load was given through the jack in small increments, to measure the deflection dial gauge is arranged as shown in fig 4. The loading was continued till the ultimate failure of the specimens is reached shown in fig 4(d).

The modulus of rupture is the ultimate strength determined in a flexure test. The modulus of rupture for each sample was evaluated using the following equation.

$$R = \frac{PL}{bd^2}$$

Here, R= Modulus of Rupture, P= ultimate Load, L= length of specimen, b = width of specimen, d = depth of specimen.



(a)



(b)

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Fig. 4 (a) 28 days cured and dried specimen arranged for flexural test (two point load) (b) Applying load in small increments (c) loading of specimen to attain initial crack and corresponding dial gauge reading are measured at mid span (d) Loading continued till ultimate failure load situation has reached and corresponding dial gauge are measured at mid span for deflection

IV. RESULTS AND DISCUSSIONS

4.1 COMPRESSIVE STRENGTH OF CUBES: Compressive strength of fibrous mortar specimens was evaluated according to ASTM standard using Universal Testing Machine (UTM).

Table 4 Compressive strength of cubes

% of Steel fibers	0	0.5	1	1.5	2
Compressive Strength(MPa)	20.5	25.62	28.55	32.25	37

From the above results of table 4, it is clear that the compressive strength of cubes increased with the increase in percentage of steel fibers and the highest compressive strength of 37mpa was attained by adding 2%(of volume of specimens) of steel fibers .

Table 5 Impact test results of FFC using single layer mesh

Specimen id	% of steel fibers	N ₁	N ₂	Impact energy at first crack (joules)	Impact energy at failure (joules)
I-1	0	2	9	75.34	339
I-2	0.5	4	21	150	791.04
I-3	1	6	34	226.02	1280
I-4	1.5	10	45	376.7	1695.16
I-5	2	20	55	753.4	2071.87

* N1- Number of blows at first crack; N2- Number of blows at failure. (I-Impact test specimen)

Table 6 Impact test results of FFC using double layer mesh

Specimen id	% of steel fibers	N ₁	N ₂	Impact energy at first crack (joules)	Impact energy at failure (joules)
I-6	0	5	19	188.35	715.73
I-7	0.5	12	35	452.04	1318.46
I-8	1	15	48	565.05	1808.17
I-9	1.5	18	62	684	2335
I-10	2	26	83	979.43	3126.64

* N1- Number of blows at first crack; N2- Number of blows at failure. (I-Impact test specimen)

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Throughout the experiment the weight of the ball and height of fall is maintained as 3.84 Kg and 1m respectively. The first crack load is defined as the load which cause first crack of tested plates, and the ultimate load (Final load) is defined as the load which causes failure of the plates as shown in fig 5. The energy absorbed by the fibrous ferrocement specimens when impacted depends on the local energy absorbed both in contact zone and by the impactor. The impact energy increased with increase in % of steel fibers and also with the no. of welded meshes. Also it was found that the energy absorption capacity is maximum in I-10 and minimum in I-1 as shown in table 5&6.

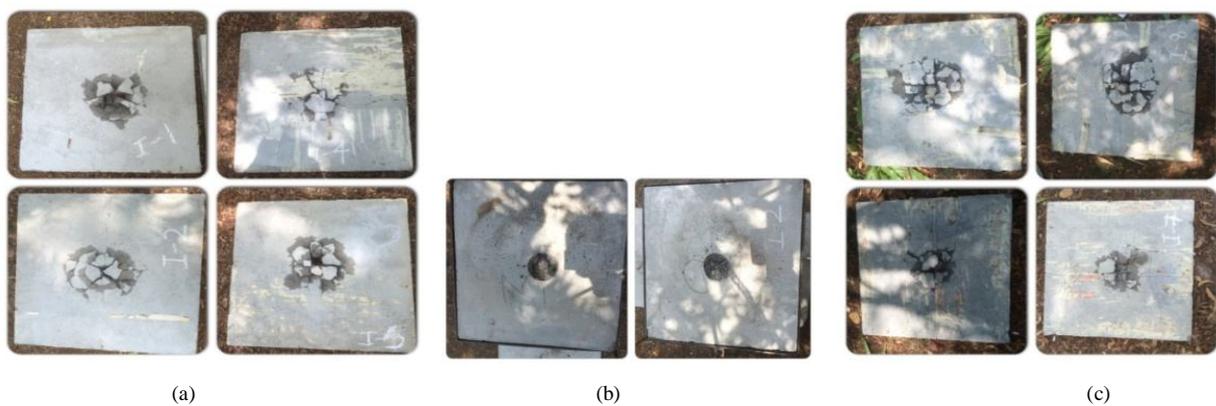


Fig. 5 (a) Crack pattern and its propagation from central portion to sides of the specimen for single layer mesh (bottom view) (b) Failure of specimen top layer completely (c) Crack pattern and its propagation from central portion to sides of the specimen for double layer mesh (bottom view)

4.2 Flexural strength: Flexural strength of fibrous ferrocement specimens of five different compositions was determined using UTM following ASTM standard methods. The results are shown in table 8. From the results, it is found that the modulus of rupture of fibrous ferrocement specimens with double welded meshes exhibited modulus of rupture as high as 29 MPa.

Table 7 Flexural strength test results of FFC using single layer mesh

Specimen id	Percentage of steel fibers	Flexural strength(MPa)
F-1	0	10.47
F-2	0.5	12.71
F-3	1	15.7
F-4	1.5	21.69
F-5	2	23.93

*(F- FLEXURAL TEST SPECIMEN)

Table 8 Flexural strength test results of FFC using double layer mesh

Specimen id	Percentage of steel fibers	Flexural strength(MPa)
F-6	0	11.96
F-7	0.5	14.9
F-8	1	18.7
F-9	1.5	24.68
F-10	2	29.17

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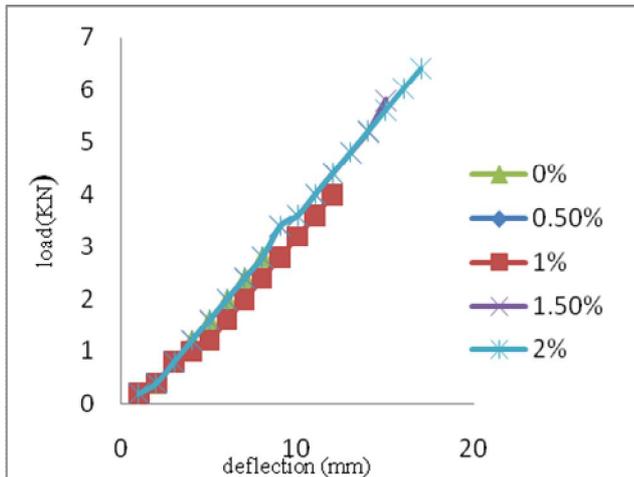


Fig 6 Graph showing Comparison of load Vs deflection of FFC for different percentages of steel fibers using single layer mesh

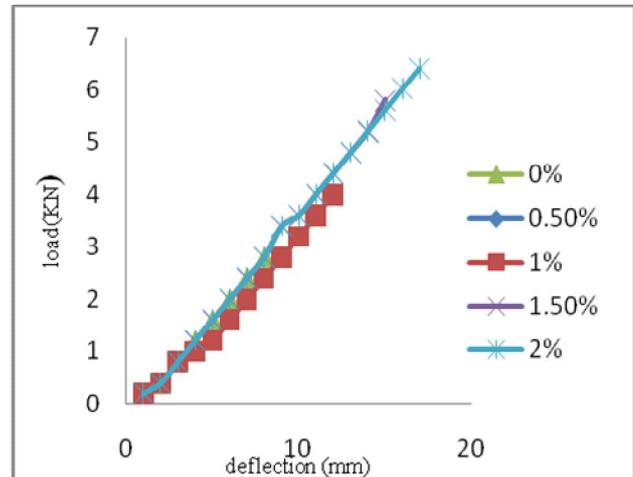


Fig 7 Graph showing Comparison of load Vs deflection of FFC for different percentages of steel fibers using double layer mesh

V.CONCLUSION

- Presence of steel fibers increases the flexural strength and decreases the central deflection tendency of specimens as compared to those without steel fibers due to increase in bond strength from fig 6 & 7.
- The percentage increase in compressive strength of FFC when compared to 0% fibers is (5%, 8%, 12%, 17%) for (0.5, 1, 1.5 & 2) percentages respectively from table 4. This increase in strength is attributed by transfer of stress from matrix to the fiber by inter lock between the fibers and the matrix.
- The occurrence of first crack was delayed & better crack distribution is attained in the ferrocement composites due to existence of fibers which led to the higher stiffness of specimen.
- There was a nominal amount of increase in impact energy absorption capacity of welded mesh reinforced specimen when the layers were increased from 1 to 2 layers. But, when small amount of steel fibers were added in small quantities (0.5% to 2%) the ultimate energy absorption of cementitious composites has increased from table 5 & 6, as the steel fibers role is to act as crack arrestors.
- In all the impact test specimens, the damage is found to be localized i.e., at the point of impact of load from fig 5, the failure is characterized by formation of cracks initially at the bottom surface of the specimen, propagating to the top surface and then widening further.
- It is predicted that the randomly-oriented fibers assist in controlling the propagation of micro-cracks present in the matrix, first by improving the overall cracking resistance of matrix and later by arresting across even smaller cracks formed after the application of load on the member, thereby preventing them to widen into major cracks.
- Welded mesh exhibited linear elastic behavior (i.e., with respect to load Vs deflection) up to the maximum load shown in fig 6 & 7. The welded mesh is responsible for increase in tensile and flexural strength.
- The flexural load at first crack and ultimate loads shall depend on number of reinforcing mesh layers used in specimens.
- From fig 6 & 7, it is noted that the specimens with single mesh with 2% of steel fibers showed 10mm deflection with 6.4kN load and that of the specimens with double layered wiremesh with 2% of steel fibers showed 16mm deflection with 7.8kN load.
- Incorporation of steel fibers in welded mesh reinforced ferrocement specimens have contributed significantly in improving the cracking behavior under flexure. On reaching the maximum load (under flexure), the specimens exhibit cracks that are possible to be easily identified by the naked eyes, then there is slow propagation i.e., progressive cracking behavior. And also the cracked specimen does not separate into various pieces and there is reduction in the crack – width from fig 5. The above behavior is clearly due to the contribution of fibers, which has helped to bridge the cracks that have developed and prevent breaking of specimens.

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- The overall results shows that the incorporation of steel fibers along with increment in number of mesh layers leads to increase in load carrying capacity and increase in deflection without failure..

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