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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Mechanical Behaviour of Ferro-Fibro-Crete Pavements

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Abstract

Ferrocement and fiber reinforced concrete are very popular construction materials which have wide applications in the construction including pavements. Their individual technical merits against conventional concrete were often reported in the literature. However there are limited studies on application of ferro-fibro-crete combination in pavements. Ferro-fibro-crete is ferrocement with discrete fibers which is expected to have better crack resistance. Also the steel fibers increase the compressive and flexural strength thereby reduces the pavement thickness. Knowledge about behaviour of the material under impact loading is very important for pavement applications. In this regard this study aims at determining the compressive, flexural and impact strength of ferro-fibro-crete mixes. To accomplish this task, cubes, beams and cylinders were casted for different mixes namely; plain cement concrete, ferrocement (2 layer of wire mesh) with 0, 0.5, 0.75, 1 and 1.25 % of fibers by volume of the mix. The results showed that the mixes with higher fiber contents proved to be superior in compression, flexure and impact against plain cement as well as ferrocement.

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Keywords: Ferro-fibro-crete; ferrocement; compressiv strength; flexural strength; impact strength.

1. Introduction

India has the second largest road network (4689842 km) in the world after USA (6586610 km). Known the fact that the road infrastructure is a vital element of a country's economy, it becomes a crucial task for the government to maintain these roads. On the other hand, about 30 percent of the existing roads are not surfaced. The highways and expressways together constitute less than 2 percent of the total road network. India has least kilometer density per 100000 people among G-27 countries leading to traffic congestion. Around 15000 km of expressways has to be constructed additionally, in the next ten years to overcome the needs of fast-growing traffic. Hence, the pavement industry would consume enormous funds in the future years to come. Therefore, a light has to be thrown on different design and construction strategies which yield a durable and cheap pavement.

Though concrete roads have proved beneficial over bituminous roads, the choice between them still remains critical. The initial cost of bituminous roads being less than that of concrete roads, these roads often become an attractive option. However, concrete roads offer low maintenance requirements and in turn has a low overall cost

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compared to bituminous pavements. In this context, the concrete pavement has gained a lot of the recent research attention across the world.

Further, with the advent of ferro-cement, the concrete industry has overcome the inherent disadvantage of low tensile strength and low resistance to cracking (Dash 2007). Also, it is clear from the available literature that the thickness requirement would considerably reduce with the use of ferro-cement against conventional concrete. Past experiences showed that strength of ferro-cement increases with increase in the steel content. However practical applications of ferro-cement limit steel content, which in turn would limit the strength of ferro-cement.

Ferro-fibro-crete is an improvement of ferro-cement, in which ferro-cement is reinforced with discrete random fibers dispersed in cement sand matrix. Therefore the ferro-fibro combination helps in reducing the microcracks and has superior crack arrest properties. Even though some work has been reported on the mechanical performance of fiber reinforced concrete, and ferrocement separately, there is still lack of studies on ferro-fibro combination (Singh 1995). Also, impact behaviour of ferro-fibro-crete is not well investigated. Concrete pavements are subjected to impact loading in the form of million cycles of repeated axle loads during its service life. Hence it is important to study the impact characteristics along with the fatigue properties of the mixes. In this regard, this paper attempts to investigate the performance of ferro-fibro-crete under impact loadings. The tests conducted include workability, compressive strength, and flexural strength and impact strength tests.

2. Materials

The test specimens were casted using cement, coarse sand, water, steel fibers and wire mesh. Locally available materials were used in the present study. Physical and strength properties of the various materials were shown in the subsequent sections.

2.1. Cement

Ordinary Portland cement was used in the study. The cement was tested in accordance with IS 8112-1989. The physical properties of cement were presented in table 1.

Table 1. Properties of cement used in the study

S.No.	Property	Result
1	Initial setting time	70 minutes
2	Final setting time	225 minutes
3	Specific gravity	3.15
4	Consistency	28%
5	Fineness	335 m^2/kg
6	Compressive strength (28 days)	44.3 N/mm^2

2.2. Coarse sand

Locally available coarse sand was used. Sieve analysis was performed in accordance with IS: 383-1970. The gradation curve of sand is shown in fig 1. The fineness modulus of sand is found to be 2.76. Soundness of sand tested as per IS: 2386 (Part V) with sodium sulphate solution is found to 6%.

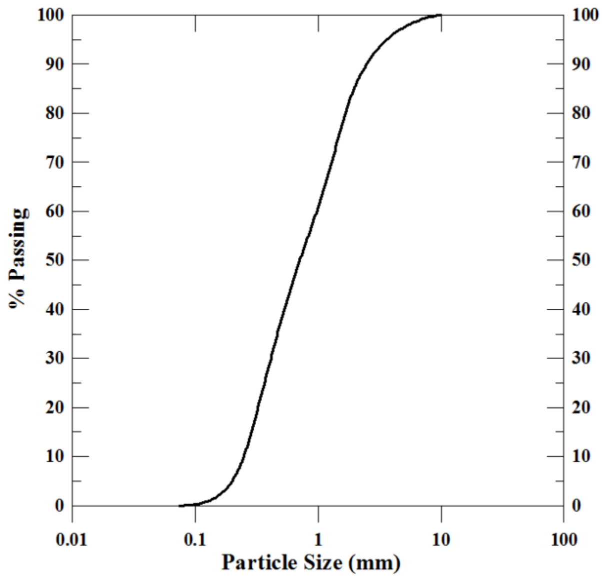

Fig. 1. Gradation Curve of Coarse Sand

2.3. Fibers used in the study

Steel fibers used in the study were procured from the National Council of Building Materials, New Delhi. The hooked shape fibers obtained from mild steel wires having a diameter of 0.82 mm and length 38 mm (aspect ratio 44) were used. The fibers were randomly oriented in the cement-sand mortar at different proportions (0.5, 0.75, 1 and 1.25 % of total volume of the mix). Various properties of steel fibers are presented in table 2.

Table 2. Properties of steel fibers

S. No.	Property	Value
1	Type	M.S. Black annealed wire
2	Shape	Hooked
3	Gauge	22 SWG
4	Young's modulus	2.16 x 105 N/mm2
5	Unit weight	78.6 KN/cubic m.

2.4. Wire Mesh

The mesh used in the study was rectangular woven wire mesh 10 x 10 mm of 0.82 mm diameter galvanised iron wires. As wires are simply woven, they do not have joints at the junctions. Also, a certain amount of waviness of the wires was observed.

3. Mix Details of Ferro-Fibro-Crete

The mix of ferro-fibro-crete was designed as per specifications for ferrocement (ACI-549, 1988). The cement-sand ratio has been selected as 1:2 having 0, 0.5, 0.75, 1 and 1.25% of fibers by volume of mortar with diameter 0.82 mm having aspect ratio 44 and 2 layers of 22 SWG wire mesh having a diameter of 0.82 mm embedded in the cement-sand mortar and water-cement ratio adopted was 0.4.

4. Tests conducted

Various tests are conducted on the plain cement concrete, ferrocement and ferro-fibro-crete combination to know different properties like compressive strength, flexural strength and impact behaviour of the respective mixes. The test methods and results are discussed in the subsequent sections.

4.1. Compressive strength

For determination of compressive strength of PCC and ferro- fibro-crete, cubes of 150 mm X 150 mm X 150 mm were prepared. The mixing was done by hand. Cement, coarse sand and fibers were mixed thoroughly. Water was then added and whole mass was mixed until the mix becomes uniform. Before placing the concrete, interior surface of the moulds and base plate were oiled. The moulds were filled with concrete in layers and are tamped by a tamping rod. The vibration was done with the help of vibration table.

The moulds were placed in moist air of at least 90% relative humidity and at a temperature of (270 C ± 20 C) for 24 hours. Then the specimens are removed from moulds and placed in clean fresh water at a temperature of (270 C ± 20 C) for 28 days. For testing, no cushioning material was placed between specimen and plates of the machine. The load was applied axially without shock at the rate of approximately 14X10 N/m/minute till the specimen was crushed. The compressive strength test results are shown in Table 3. When a plain concrete member is subjected to compression, the failure of the member takes place, generally in its vertical plane along the diagonal. The vertical crack occurs due to lateral tensile strains. A flow in the concrete, which is in the form of a micro crack along the vertical axis of the member will take place on the application of axial compressive load and propagate further due to lateral tensile strains. If the concrete contains steel fibers, the crack propagation gets effectively arrested by the fibers oriented at right angles to the axis of loading. The lateral tensile strains are resisted by the fibers and hence the compressive strength of the member is increased. The cracks get distributed on the surface and the width of the cracks was much less as compared to plain concrete specimens. The mode of failure changed from brittle to ductile with the inclusion of fibers. From the test results, it is evident that the inclusion of fibers and wire mesh layers increases the compressive strength.

4.2. Flexural strength

For determining the flexural strength of PCC and ferro-fibro-crete the beams of 100 mm X 100 mm X 500 mm were prepared. The moulds were placed in moist air of at least 90% relative humidity and at a temperature of (270 C ± 20 C) for 24 hours. Then the specimens are removed from moulds and placed in clean fresh water at a temperature of (270 C ± 20 C) for 28 days. After 28 days curing, the specimens were tested in flexure on a 150 KN transverse testing machine. Loads were applied by means of a third point loading arrangement at a constant rate of 1.8 KN/min. The distance between the centres of two rollers was kept as 400 mm. If the fracture occurred within the one-third of the beam the flexural strength was calculated on the basis of ordinary elastic theory using equation 1.

$$S_F = \frac{PL}{BD^2} \tag{1}$$

When A is greater than 133 mm
SF = Flexural strength of the specimen
D = Depth of the specimen (100 mm)
L = Span of the specimen (400 mm)
P = Maximum load in Newton applied to the specimen
A = Distance between the line of fracture and the nearest support, measured on the centreline of the tensile side of the specimen in mm.
If however, fracture occurred outside the load points i.e. less than 133 mm but greater than 110 mm, then the flexural strength was computed using the equation 2.

$$S_F = \frac{3PA}{BD^2} \quad (2)$$

The flexural strength results are shown in table 3. In case of ferro-fibro-crete ultimate flexural strength is increased due to the existence of crack arrest mechanism of the closely spaced fibers and layers of wire mesh. After the concrete matrix cracks, the fibers and layers of wire mesh continue to take higher load provided the interfacial bond is good. Thus the ultimate flexural strength is increased with the inclusion of fibers and the wire mesh

Table 3. Compressive and flexural strength test results

S. No.	Specimens	Compressive Strength (N/mm2)	Flexural Strength (N/mm2)
1	Plain	25.40	5.86
2	0% fiber and 2 layers of wire mesh	32.51	6.38
3	0.75% fiber and 2 layers of wire mesh	43.03	21.2

4.3. Impact strength

Impact energy is a measure of the work done to fracture a test specimen. When the striker impacts the specimen, the specimen will absorb energy until it yields. At this point, the specimen will begin to undergo plastic deformation. The test specimen continues to absorb energy and work hardens at the plastic zone. When the specimen can absorb no more energy, fracture occurs. For determination of Impact energy of PCC, Ferrocement and Ferro-fibro-crete, beams of 500 mm X 150 mm X 150 mm were prepared. For each mix, five beams and five cylinders were cast in all cases. The steel fibers were added in four concentrations of 0.5, 0.75, 1 and 1.25% by weight keeping percentage of wire mesh constant. For comparison, plain concrete beams were also casted.

The beams are tested for impact energy. The impact energy of the beams was determined in terms of the number of blows required from an impacting mass of cause complete fracture of the specimens. The same impacting mass was dropped repeatedly through the same drop-height until complete failure of the test specimen occurred. The mass used in the present investigation is 10.88 Kg and the drop height is 10 cm. The number of blows was then multiplied by the energy per blow to give the total impact energy to cause complete failure. The results are shown in fig 2.

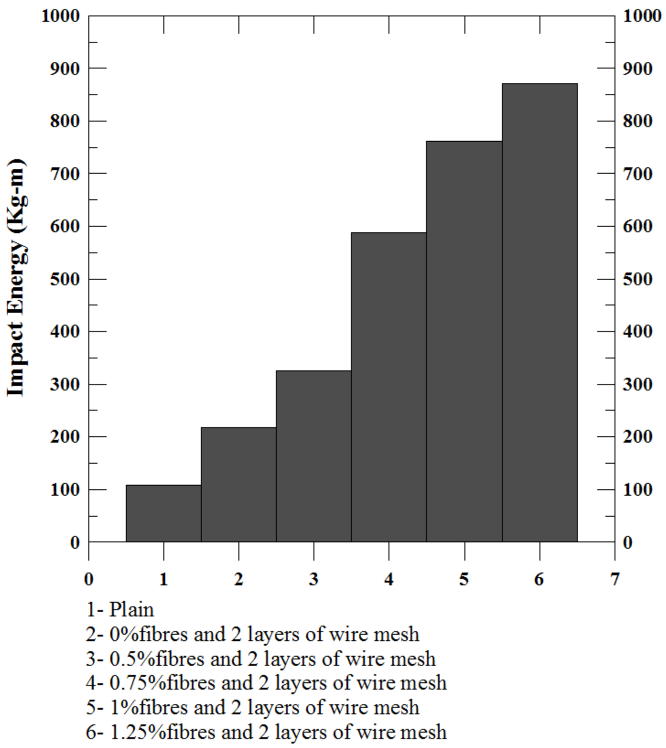

Fig. 3. Impact energies of different beam specimens

The cylinders are tested for impact energy. The impact energy of the cylinders was determined in terms of the number of blows required from an impacting mass of cause complete fracture of the specimens. The same impacting mass was dropped repeatedly through the same drop-height until complete failure of the test specimen occurred. The mass used in the present investigation is 5 Kg and the drop height is 54 cm. The number of blows was then multiplied by the energy per blow to give the total impact energy to cause complete failure. The results are presented in fig 3.

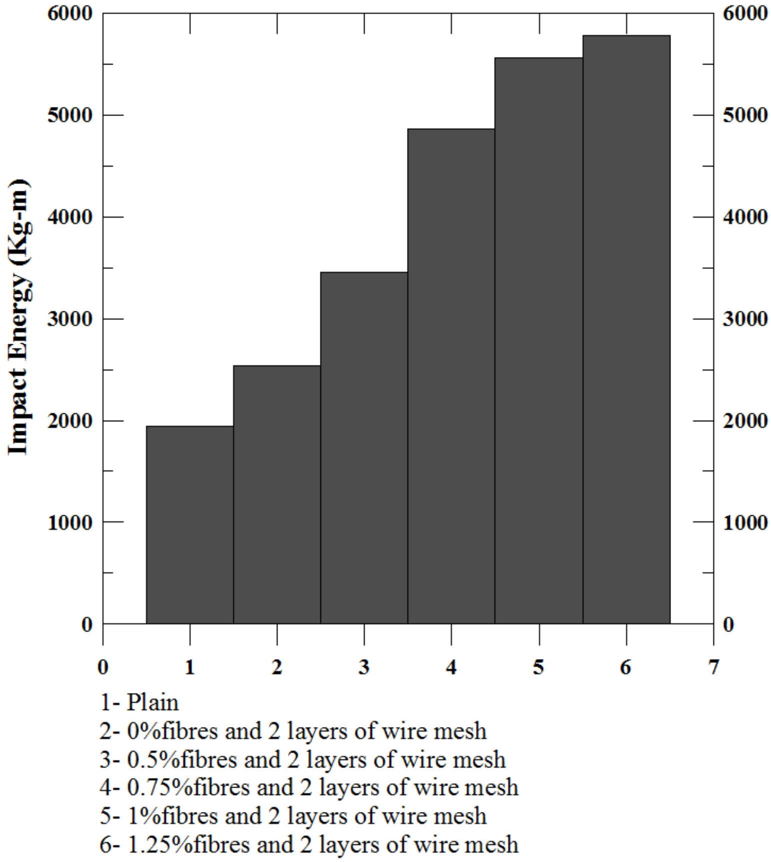

Fig. 3. Impact energies of different cylindrical specimens.

5. Conclusions

The present study was carried out to evaluate the impact characteristics of ferro-fibro-crete. Based on the results obtained the following conclusions have been drawn.

- The incorporation of steel fibers and layers of wire mesh result in an appreciable increase in compressive and flexural strength. The strengths are observed to be 1.69 and 3.62 times respectively of ferrocement and ferro-fibro-crete as compared to PCC.
- The incorporation of layers of wire mesh results in an appreciable increase in Impact energy. The impact energy of ferrocement with 2 layers of wire mesh was almost observed to be double that of plain concrete beams.
- After the addition of fibers to the ferrocement the specimens showed higher impact energies. By the addition of 0.5, 0.75, 1 and 1.25 % of fibers the increase in impact energy are 1.5, 2.75, 3.5 and 4 times compared to ferrocement beam specimens.
- The incorporation of layers of wire mesh results in an appreciable increase in Impact energy. The impact energy of ferrocement with 2 layers of wire mesh was almost observed to be 1.3 times that of plain concrete cylinders.
- After the addition of fibers to the ferrocement the specimens showed higher impact energies. By the addition of 0.5, 0.75, 1 and 1.25 % of fibers the increase in impact energy are 1.36, 1.9, 2.19 and 2.26 times compared to ferrocement cylinder specimens.

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