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Comparative Study of The Steel and Polyester Fiber Reinforced Composite Under Impact Load

AbstractAbstract

Steel fibres which are not straight and non circular in shape are in use since the last decade as a result of innovations in the fiber technology. Flat corrugated steel fibres have been proven to be very effective at the interface in the cementitious composite during pull out. Such a performance of the fibers encourages in the development of a unique High Performance Fiber Reinforced Cementitious Composite (HPFRCC); well known as Engineered Cementitious Composite (ECC) to be used in challenging situations. ECC used in this experimental investigation is produced with 53 grade OPC, 300 micron passing silica sand, 1% dose of super plasticizer, w/c ratio of 0.35, cement: sand ratio of 1: 0.5, flat corrugated steel fibers of 12.5 mm length in 3% volume fraction and 0% and 30% fly ash replacement. Cylindrical specimens of 64 mm height and 150 mm diameter are used in drop weight hammer test. Number of blows to produce the first crack are recorded and effect of fly ash replacement on impact performance is critically examined. Impact performance of the steel fiber reinforced ECC is compared with the Recron fiber reinforced ECC and M20 concrete.

Keywords: ECC, Steel and Recron Fibers, Impact Load, Fly Ash, Drop Weight Test

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Introduction

Industrial flooring subjected to heavy machine vibration, cavitations and erosion damage in dams and other hydraulic facilities, ability of shotcrete to absorb energy, specialized cementitious coating for repair, fiber reinforced castable refractories, comparison of different matrices, military and blast applications etc. are some of the practical examples where impact test results help to access the performance of the material qualitatively.

Until now, the concrete and material industry has been lacking an acceptable impact test that demonstrates the relative brittleness, resilience, impact resistance and toughness of concrete and similar construction materials. Typically, owners and designers look at the compressive strength as an indicator of a material's ability to perform in an environment of repeated impact loads. This can be very misleading. A material with high compressive strength can be very brittle and may easily fail due to impact, whereas a more resilient material with much less compressive strength may perform better. A number of variables in concrete can cause changes in the impact resistance. The more notable ones are aggregate type and shape, admixtures and fiber reinforcement.

Because of the nature of the impact test and especially because of the variability and non homogeneous conditions of the concrete, data from the impact test may be noticeably scattered. If comparative test specimens have significantly different impact resistance, the test results will vary by orders of magnitude. Coefficient of variation and standard deviations will obviously aid in evaluating reported data. Recently, the variability in the test results has been reduced simply by applying a thin coating of petroleum jelly to the bottom of the test specimen. Another way is to use five samples, discarding the highest and the lowest readings and averaging the remaining three (V. S. Gopalaratnam & S. P. Shah, 1986; N. Lakshaman, P. Srinivasulu, K. Muthumani, B. Sivarama Sarma & N. Gopalakrishnan, 1991; K. Balasubramanian, B. H. Bharatkumar, S. Gopalakridshnam & V. N. Parameswaran, 1996).

A simple, portable and economical test which is known as drop weight test and which can be used to compare the relative merits of different matrices is selected here for evaluating the response of cementitious composites under impact loading. Actually speaking, the test also checks fatigue capacity because it repeatedly applies a load to the test specimen instead of failing it with one massive blow. The number of times a standard size mass must be dropped a standard distance before cracking the specimen and before causing it to induce first crack is recorded. Since toughness and strain capacity are really the ability to absorb energy and stretch, they are indirectly taken into account (S. Schrader, 1981).

Aim of Study

One of the most attractive resilient materials is the family of High Performance Fiber Reinforced Cementitious Composites (HPFRCC) known as Engineered Cementitious Composite (ECC) which represents a unique group of ultrahigh ductile material. ECC is a micromechanically optimized fiber reinforced cementitious composite without coarse aggregates (V. C. Li, 1993; V. C. Li & S. Wang, 2008)**.** The most affecting variable parameter i.e. aggregate is not present in this composite and hence results of impact test are more reliable in case of ECC compared to the concrete. Recron fiber which is polyester in nature has been used in ECC and detailed parametric study has been carried out (J. D. Rathod, S. C. Patodi &B. K. Parikh, 2008; J. D. Rathod & S. C. Patodi 2008; J. D. Rathod & S. C. Patodi, 2008; J. D. Rathod, S. C. Patodi, B. K. Parikh & K. H. Patel, 2007; J. D. Rathod, K. H. Patel & S. C. Patodi, 2007) to explore the extensive deformation capability of ECC in tension, shear, flexure, compression and impact. (Naaman, 2003) studied different cross-section shape of the fibers and concluded that the performance of any fiber reinforced composite depends upon fiber/matrix interface property which is largely influenced by effectiveness of bond between fibers and matrix. This can be enhanced by increasing length of fiber, modifying surface property of fiber, optimizing cross sectional shape of fiber and optimizing matrix properties.

Present investigation reports the study of impact resistance of corrugated steel fiber reinforced ECC under drop weight hammer test. The test method presented here appears to be a good indicator, not only of impact, but also of other important properties which are often neglected simply because their tests are relatively difficult and requires sophisticated equipment which can be expensive. Results of steel fiber reinforced ECC are compared here with the results of the previous study conducted on Recron fiber reinforced ECC and M20 concrete to evaluate the qualitative performance between them under impact.

PREPARATION OF SAMPLES AND TEST SET UP

Generally, one cylinder of 150 mm diameter and 300 mm height as shown in **Fig. 1(a)** is casted and three specimens of 64 mm height are cut from it. This method of sampling is well suited to concrete or synthetic fiber reinforced cementitious composites which can be cut easily. Flat steel fibers are difficult to cut by the available concrete cutting machine. If very powerful cutting machine is used, it is observed that concrete is locally damaged at the location where steel fibers are cut due to heavy pressure. Such samples do not give correct picture of impact value. Therefore, it is decided to have directly mould of 64 mm height instead of 300 mm as shown in **Fig. 1 (b)**. Test set up for impact test is locally fabricated as per the ASTM standard as shown in the **Fig. 1 (c)**. The hammer of weight 4.54 kg is dropped through a height of 457 mm on a steel ball held firmly in the center of the specimen and number of blows required to cause the first visible crack on the top surface are recorded.

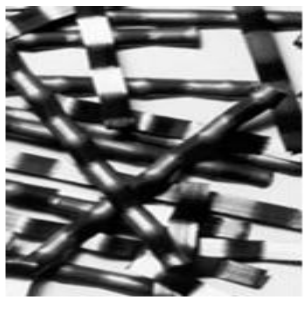
Five specimens are prepared of ECC with cement: sand ratio of 1:0.5, 3% steel fiber volume fraction, 0.35 w/c ratio, and variable dose of super plasticizer. Specimens are tested after 28 days of normal water curing. Xorex type corrugated flat steel fibers of 12.5 mm length, complying ASTM A820, having, tensile strength of 825 MPa, specific gravity of 7.6 and width of 2.36 mm are used. Impact strength of Steel fiber reinforced ECC is compared with 4% Recron fiber reinforced ECC (J. D. Rathod, D. A. Gandhi & S. C. Patodi, 2007) and M20 concrete (J. D. Rathod & P.V. Darji, 2006).

(a) Mould of 300 mm ht. (b) Mould of 64 mm ht.

(c) Test set up

Fig. 1 Cylindrical Moulds and Test Set Up for Impact Test

Recron fibers supplied by the Reliance Industries Ltd. have specific gravity as 1.36 and tensile strength as 1000 N/mm^2. Recron fiber has triangular shape of cross section for which equivalent diameter is considered as 30 μm. Pictorial view of the steel and Recron fibers is shown in **Fig. 2.**

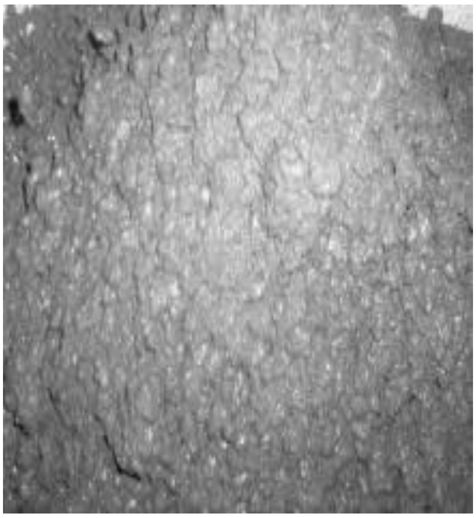


Xorex steel fibers

Recron 3S fibers

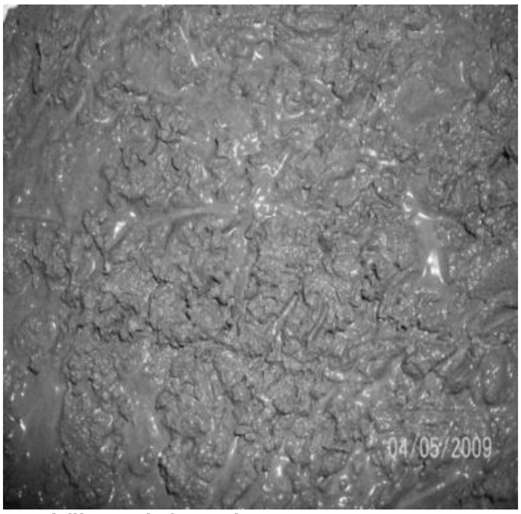
Fig. 2 Pictorial View of Fibers

Workability of M20 concrete and steel fiber reinforced ECC is found to be satisfactory with 0.5% dose of super plasticizer while Recron fiber reinforced ECC requires 2% dose of high performance concrete super plasticizer for satisfactory workability. Overview of fresh mix of all the matrices can be seen in **Fig. 3.**



Concrete

Recron fiber reinforced ECC



Steel fiber reinforced ECC

Fig. 3 Pictorial View of Fresh Mix

Results and Discussion

Percentage variability of the results from the average was observed to be less than 25% in case of Recron fiber reinforced ECC due to more uniform distribution of the fibers in the matrix and consequently homogeneous nature of the composite. Average number of blows required to cause the first visible crack on the surface of the specimens are indicated in the Table 1 for three different types of matrices. Results of steel fiber reinforced ECC with 30% fly ash and Recron fiber reinforced ECC with 30% fly ash are also included for comparison purpose.

Table-1

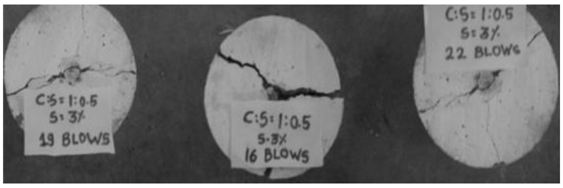
Impact Strength of Various Matrices.

Material	Average No. of Blows	Percentage Enhancement over M20 Concrete
M20 Concrete	17	----
Steel fiber reinforced ECC	19	+12
Steel fiber reinforced ECC with 30% Fly Ash	11	-54
Recron fiber reinforced ECC	297	+1647
Recron fiber reinforced ECC with 30% Fly Ash	201	+1082

Recron 3S fibers produced by Reliance industries Ltd. are of polyester type in which aster is a functional group, responsible for good bond with the cement. Its silicon coating helps in better dispersion in the matrix which is essential requirement in any fiber reinforced composite. Most of the synthetic fibers available are of the circular cross section. Whereas, Recron fibers are of substantial triangular in cross section due to which enhanced efficiency between fiber and the matrix at the interface is obtained. These fibers are of very small diameter as a result of which large number of fibers are distributed evenly in the matrix. There is an effective stress transfer mechanism from one plane to another by fiber bridging action. Substantial triangular shape of the cross section, polyester nature and very small diameter are the reasons behind success of this composite to perform excellent. 1647 percentage enhancement of impact strength over M20 concrete is found which is rare in any composite.

Failure pattern of impact specimens prepared from Recron fiber reinforced ECC and steel fiber reinforced ECC are shown in **Fig. 4**. Failure pattern of Recron fiber reinforced ECC shown in **Fig. 4 (a)** clearly reveal ultra high ductility of the composite by the extensive deformation in the centre of the specimen due to penetration of the hard steel ball. There is a perfect splitting crack and large deformability without disruption, disintegration or spalling of cementitious material. On the other hand the failure pattern of steel fiber reinforced ECC as shown in **Fig. 4 (b)** is very similar to that of concrete for being brittle in nature.

(a) Recron fiber reinforced ECC

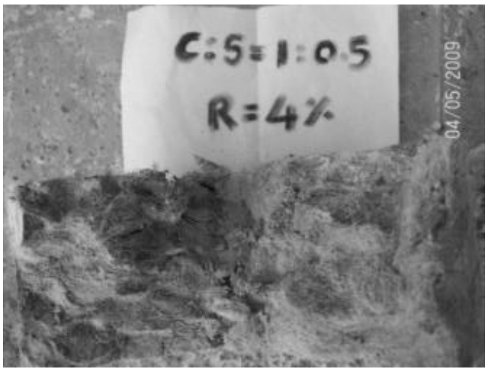


(b) Steel fiber reinforced ECC

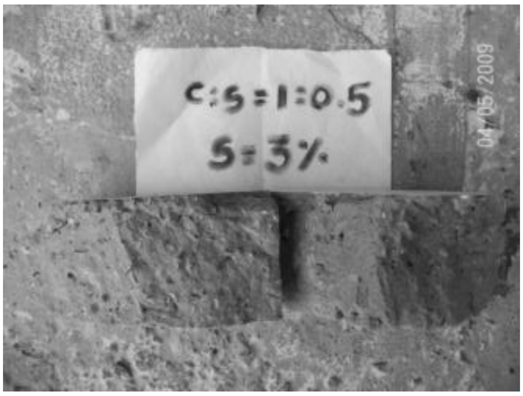
Fig. 4 Failure Patterns of Impact Specimens

Less number of flat corrugated steel fibers are available in the matrix for a given volume fraction. Therefore, workability was satisfactory in the fresh state even in small size specimens. The less number of fibers in the matrix is the fundamental cause for not achieving the required deformable and energy absorption performance in ECC even with 3% steel fiber volume fraction in the specimens. Energy dissipation in the composite is mainly attributed to the compatible and connected fiber action. Fractured surface of impact specimens are shown in **Fig. 5** which indicates that more number of fibers are evenly distributed in Recron fiber reinforced ECC compared to steel fiber reinforced ECC. Good strength performance may be obtained under static load due its geometry, surface deformation and stiffness. However, impact performance of the steel fiber reinforced ECC is very poor. It is almost similar to the M20 concrete. 12 percent enhancement in the impact strength can be considered as negligible.

When cement is replaced by 30% fly ash in ECC, the impact strength is reduced in comparison to that of ECC without fly ash. Therefore, the use of fly ash tends to reduce energy absorption capability of ECC by making it brittle. Large volume fraction of steel fiber will be required to achieve the same impact strength as of Recron fiber reinforced ECC which is not the proper solution as far as economy of the composite is concern. Therefore, it is not worth to use the flat steel fiber in ECC for impact resistant application.



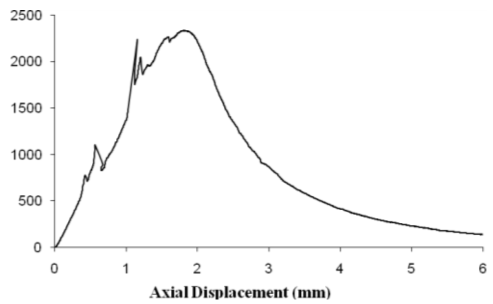
Recron fiber ECC



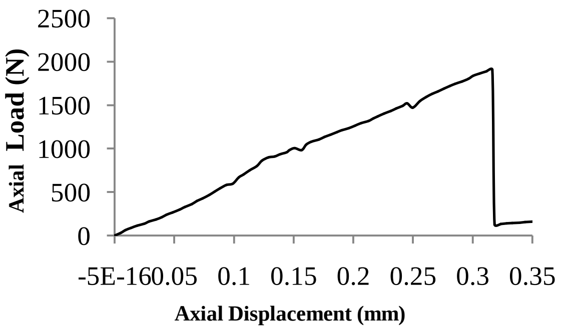
Steel fiber ECC

Fig. 5 Fractured Surfaces of Impact Specimens

Large difference of the impact strength value between the Recron fiber reinforced ECC and steel fiber reinforced ECC attributes to the performance of both the composites in axial tension. Recron fiber reinforced ECC undergoes extensive deformation with significant stain hardening performance indicating super ductile behavior in axial tension as shown in **Fig. 6 (a)**. Whereas, the steel fiber reinforced ECC fails suddenly after the formation of the first crack (**Fig. 6 (b)**) similar to the concrete indicating brittle nature. Therefore, there is not much difference in the impact strength between the steel fiber reinforced ECC and M20 concrete.



(a) Recron fiber reinforced ECC



(b) Steel fiber reinforced ECC

Fig. 6 Response of ECC in Axial Tension

Conclusion:

1. Drop weight test which yields the number of blows with approximately 30% variability from the average value in case of steel fiber reinforced ECC seems to be easier, reliable and economically viable test set up. More consistent results were obtained in case of Recron fiber reinforced ECC.
2. Even with 3% steel fiber volume fraction, there is a marginal increase in impact resistance. Hence, flat corrugated steel fibers may not be the right choice to enhance the impact performance of ECC.
3. The present comparative study reveals that the impact resistance of material depends upon the strain hardening performance of the material. Enhancement of impact strength of Recron fiber reinforced ECC over ordinary concrete and steel fiber reinforced ECC is due to its ultra high ductility.
4. 30% replacement of cement by fly ash in ECC reduces energy absorbing capacity of steel fiber reinforced ECC by making it brittle. Therefore, the use of green ECC is not recommended in such applications.

Suggestions :

It is suggested to use synthetic fibers instead of steel fibers in the cementitious composites without use of fly ash for impact kind of applications.

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