Performance Evaluation Of Hybrid Fiber Reinforced Concrete Matrix

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ABSTRACT

In a Hybrid Fiber Reinforced Concrete (HFRC), two or more different types of fibers are rationally combined to produce a cementitious composite that derives benefits from each of the individual fibers and exhibits a synergistic response. The main aim of the present experimental investigation was to use different volume fractions of Recron 3S fibers (polyester fibers) and continuously crimped steel fibers to produce HFRC and thus to evaluate its performance under compression, tension, flexure, shear and impact types of loading. Based on I.S. Code method of mix design, proportion of different ingredients was obtained to get M20 grade concrete. Samples were prepared with and without fly ash and by varying the volume fraction of fibers from 0 to 1%. Total 12 different types of HFRC matrices were considered for performance evaluation. The improvement in mechanical properties of a matrix having volume fraction hybridization of 0.3% Recron and 0.7% of steel fibers was found to be the best.

Keywords – Fibrous concrete, Green HFRC, Mechanical properties, Recron and steel fibers.

1. INTRODUCTION

Research and development work in Fiber Reinforced Concrete (FRC) composites began in India in the early 1970s. Fiber reinforced concrete was developed to overcome the problems associated with cement based materials such as low tensile strength, poor fracture toughness and brittleness of cementitious composites. In the beginning, FRC was primarily used for pavements and industrial floors [1]. But currently, the FRC composite is being used for a wide variety of applications including bridges, tunnel and canal linings, hydraulic structures, pipes, explosion-resistant structures, safety vaults, cladding and roller compacted concrete [2]. The use of FRC in structural members such as beams, columns, connections, slabs and pre-stressed concrete structures is being investigated by a number of researchers at present in India and abroad.

Basically fibers can be divided into following two groups: (i) Fibers whose moduli is lower than the cement matrix such as cellulose, nylon, polypropylene and (ii) Fibers with higher moduli than the cement such as asbestos, glass, steel etc. Fibers having lower modulus of elasticity are expected to enhance strain performance whereas fibers having higher modulus of elasticity are expected to enhance the strength performance.

A Hybrid Fiber Reinforced Concrete (HFRC) is formed from a combination of different types of fibers, which differ in material properties, remain bonded together when added in concrete and retain their identities and properties. The hybridization of fibers provides improved specific or synergistic characteristics not obtainable by any of the original fiber acting alone. Three types of hybrid composites have been used by the researchers using the combinations of polypropylene-carbon, carbon-steel and steel-polypropylene fibers. Two types of steel fibers (continuously crimped and flattened ends with round shaft) and two types of polypropylene fibers (monofilament and fibrillated) have been tried.

Qian and Stroeven [3] studied the fracture properties of concrete reinforced with polypropylene fiber and three sizes of steel fibers with fiber content ranging from 0 to 0.95% by volume of concrete. Wu, Li and Wu [4] compared the mechanical properties of three different types of hybrid composite samples prepared by using the combinations of polypropylene- carbon, steel-carbon and polypropylene- steel fibers. Mechanical properties of hybrid composites produced by using carbon and aluminum whiskers in addition to polypropylene fibers were studied in detail by Mobasher and Li [5]. Banthia and Sappakittipakron [6] investigated three fiber hybrids with carbon and polypropylene micro fibers added to macro steel fibers and showed that steel macro fibers with highly deformed geometry produce better hybrids than those with a less deformed geometry. Also composites with a lower volume fraction of fiber reinforcement were seen as having a better prospect for hybridization than composites with a high volume fraction of fibers.

Steel fibers enhance strength of FRC under almost all types of loading but fail to demonstrate deformability [7]. On the other hand, non-metalic fibers such as Recron 3S (henceforth referred as Recron) fibers demonstrate superb deformation under different types of loading with moderate strength enhancement [8]. Therefore, the objective of the present study was to evaluate the mechanical properties of FRC having hybrid combinations of a metallic fiber (steel fiber) and a non-metallic fiber (Recron fiber). The total fiber volume fraction was kept up to 1% primarily from the point of view of providing good workability. With increase in fiber volume not only the workability is affected but also the cost of HFRC composite increases. For comparative evaluation of performance, 12 different types of mixes and 5 different types of specimens were prepared and tested under different types of loading.

2. PREPARATION OF SPECIMENS

For the preparation of specimens, 53 grade Ordinary Portland Cement (OPC), locally available Zone-I sand having specific gravity as 2.62 and fineness modulus of 3.05, crushed angular coarse aggregate of 20 mm maximum size having specific gravity as 2.65 and fineness modulus of 6.9 and potable tap water were used. Trial mixes were prepared using I. S. Code method of mix design [9] to achieve a target strength corresponding to M20 strength at 28 days. Finally a mix proportion of 1: 1.445: 2.836: 0.471 (ratio by weight of cement: sand: coarse aggregate: water) was found appropriate to produce M20 concrete.

For preparing HFRC samples, Recron and steel fibers having properties as reported in Table 1 were used with fiber fraction up to 1% by volume of concrete. Six different proportions of Recron and steel fibers were tried for casting the different types of specimens with their designation as follows: 0: 0 (RS00), 1: 0 (RS10), 0: 1 (RS01), 0.5: 0.5 (RS55), 0.3: 0.7 (RS37), and 0.7: 0.3 (RS73) where R and S indicate percentage volume fraction of Recron and steel fibers respectively. For comparison purposes, another similar set of six mixes was prepared by using Pozzolona Portland Cement (PPC) instead of Ordinary Portland Cement (OPC). Such samples were distinguished from earlier samples by just writing P before RS where P stands for Pozzolona cement (containing 28% fly ash). In case of preparation of mix for the fibrous composite, to achieve the desired workability, a chemical admixture BASF Rheo-build 817 RL was used keeping the dose as 0.8% by weight of cement.

Table 1 Properties of Fibers Used

Property	**Recron Fiber**	**Steel Fiber**
Material	Polyester	Low Carbon Steel
Shape	Straight	Continuously Crimped
Cross section	Substantial Triangular	Round
Diameter	30 µm (Eq. Dia.)	0.45 mm
Length	12.5 mm	25 mm
Tensile Strength	1000 MPa	1079 MPa
Specific Gravity	1.36	7.60
Modulus of Elasticity	17250 (N/mm^2)	207300 (N/mm^2)
Pictorial View		

A concrete mixer of 100 liter capacity was used to mix the ingredients of concrete. To begin with coarse aggregates, sand and cement were allowed to mix for about two minutes. 80% of water was then added and allowed to mix for about two minutes. Remaining 20% of water and chemical admixture were then added. After mixing for about one minute, fibers were added manually and allowed to disperse throughout the mass gradually and ingredients were then allowed to mix thoroughly for two more minutes. A typical RS37 mix is shown in **Fig. 1**. Workability of the fresh HFRC mix was then checked by using a flow table. After measuring the workability the fibrous concrete mix was manually placed in respective moulds. From each mix, 3 cubes of 150 x150 x 150 mm size, 5 cylinders of 150 x 300 mm size (3 for split test and 2 for preparing 6 disc specimens), 3 beams of 100 x 100 x 500 mm size and 3 L-Type specimens were cast.

Fig. 1 RS37 HFRC Matrix

After casting and finishing the surface, the specimens were kept in mould for 24 hours at room temperature with top surface covered by gunny bags. After removing the specimens from the moulds, they were numbered. The specimens were then put into curing tank for 28 days at room temperature. Before testing the samples white wash was applied over them to clearly see the development of cracks during the testing of specimens.

3. TESTS CONDUCTED AND RESULTS

3.1 Compressive Strength Test

Compressive strength of concrete is the most useful and important property of concrete. Many other properties of concrete such as durability, resistance to shrinkage, Young's modulus, imperviousness etc. are dependent on the compressive strength of concrete. The purpose of the compression test is to determine the crushing strength of hardened concrete.

To measure the compressive strength, 3 cubes of size 150 mm were prepared (three specimens from each matrix) and tested under Compression Testing Machine of 2000 kN capacity under load control, as shown in the **Fig. 2**. The crack pattern at maximum load for cube having 1% Recron fiber volume (Cube RS10) is depicted in **Fig. 2**. The average test results of the there cube specimens for compressive strength of 12 different HFRC matrices are presented in Table 2.

Fig. 2 RS10 Cube under Compression

3.2 Split Tensile Strength Test

Direct tension test of concrete is seldom made because of difficulties in mounting the specimens and uncertainties as to the secondary stresses induced by the holding devices. An indirect test for tensile strength of concrete developed originally in Brazil has been standardized by ASTM and is in general use. Accordingly, 3 specimens of cylindrical shape of diameter 150 mm and length 300 mm were tested under a Compression Testing Machine of 2000 kN capacity under a compressive load across the diameter along its length till the cylinder splits (**Fig. 3**). The tension develops in a direction at right angles to the line of action of the applied load. The magnitude of the tensile strength was worked out with the help of 2P/ (π L D) where P is the ultimate load, D is diameter in mm and L is the length of specimen in mm. Results of split tensile strength are presented in the Table 2. The crack pattern observed for a no fiber content cylinder (RS00 mix) is depicted in the **Fig. 4**.

Fig. 3 Split Tensile Strength Test

Fig. 4 View of Failed Cylinder RS00

3.3 Flexural Strength Test

The steel moulds of size 100 mm x 100 mm x 500 mm were used for casting the beam specimens. The simply supported beams were loaded at 1/3rd points as shown in **Fig. 5** keeping the span as 450 mm and were tested on a Universal Testing Machine of 200 kN capacity. Load-displacement readings were automatically recorded in a user defined file name on computer through a data acquisition system attached to a load sensor having a least count of 0.01 kN and a displacement sensor having a least count of 0.01 mm. The system also has facility to display online load displacement graph on screen and to generate a report based on the data acquired during the testing of the sample including X-Y plot.

Flexural strengths based on the ultimate load are reported here in Table 2 for 12 different matrices. A photo of broken beam having designation as RS10 is depicted here in **Fig. 6**. Also, load- deflection graphs for Beam RS00 and RS37 are compared in **Fig. 7**.

Fig. 5 Beam Testing for Flexural Strength

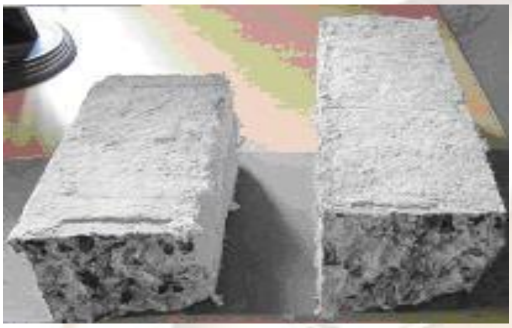

Fig. 6 View of Failed Beam RS10

As per ASTM C1018, a measure of toughness (I5) is derived from the analysis of load-deflection curve. It is defined as the ratio of area of load deflection graph up to 3 times the deflection at first crack and area of load deflection graph corresponding to first crack. Based on the load-deflection graph, apparent toughness indices (I5) were calculated for all the beam specimens. Average value for each mix is reported here in Table 2.

3.4 Shear Strength Test

For the preparation of the specimens, the usual cube mould of size 150 x 150 x 150 mm was used with a wooden block of size 150 x 90 x 60 mm. This wooden block was inserted at one corner of cube mould and the final shape of the specimen thus appears after de-molding is of inverted L-shape. The setup suggested by Bairagi and Modhera [10] was used for such specimens. The loading arrangement for the L-Shaped specimen is shown in **Fig. 8**. For testing the specimen, the intended plane for shear failure is so designed that the part of the compressive load P does job of keeping the specimen vertically standing under the force.

The inverted L- Shaped specimens were tested on UTM of 200 kN capacity. Similar to beam bending test, load- displacement data was automatically recorded in a file with online display of plot of graph. A view of failed L-Type PRS73 specimen is shown in **Fig. 9**. Load- displacement curves for RS00 and RS37 specimens are shown in **Fig. 10**.

The shear strength has been calculated by first finding the maximum applied force in the shear plane and then dividing it by the area of the plane (60 mm x 150 mm). The average test results of the three specimens are presented here in Table 2.

Fig. 8 L-Type Specimen under Shear

Fig. 9 View of Failed PRS73 L-Type Sample

3.5 Impact Test

Impact strength is characterized by a large amount of external energy suddenly being applied to a structure or to a structural element. The "repeated impact", drop weight test yields the number of blows necessary to cause prescribed levels of distress in the test specimen. This is the simplest and realistic test method of all which can be used to compare the relative merits of different matrices and therefore, it was selected here for evaluating the response of cementitious composites under impact loading.

For the preparation of samples for impact test, cylindrical moulds of 150 mm diameter and 300 mm length were used. The specimens after 28 days curing were cut using concrete cutter into 64 mm size specimens. These disc specimens were then kept in the test setup as shown in the **Fig. 11** which was locally fabricated as per the ASTM standard.

The hammer of weight 4.54 kg was dropped through a height of 457 mm on the steel ball consecutively and number of blows required to cause the first visible crack on top of disc were recorded. The test was continued further by counting the number of blows exerted on the specimen before it fails to exhibit rebound, i.e. becomes a composition of separate parts rather than a solid body. The fracture surface of disk RS10 specimens having 1% Recron fibers is shown in **Fig. 12.** A bar chart shown in **Fig. 13** compares the number of blows required for the first crack and final failure of the specimen prepared from 12 different matrices.

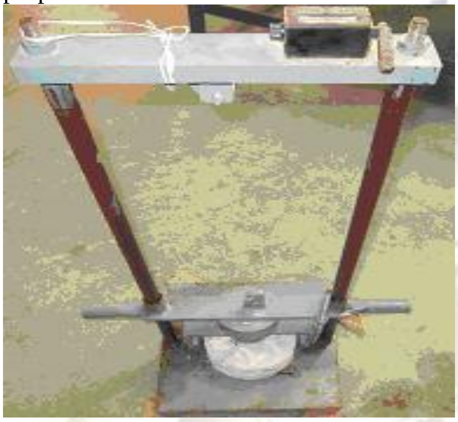

Fig. 11 Setup for Impact Test on Disc

Fig. 12 View of Failed RS10 Disc Sample

Table 2 Test Results of HFRC Specimens

Sr. No.	Fibrous Mix Designation	Compressive Stress N/ mm^2	Tensile Stress N/ mm^2	Flexural Stress N/ mm^2	Toughness Index I_5	Shear Stress N/ mm^2
1	RS00	28.44	3.68	4.67	--	3.57
2	RS10	28.89	3.96	4.69	2.36	4.61
3	RS01	35.56	5.66	5.09	2.87	5.63
4	RS55	32.00	4.81	4.98	2.78	5.06
5	RS37	34.67	6.22	5.79	3.13	5.91
6	RS73	30.22	4.24	4.70	2.50	4.84
7	PRS00	28.00	3.54	4.60	--	3.36
8	PRS10	28.44	3.82	4.65	2.22	4.48
9	PRS01	35.11	5.52	4.78	2.80	5.08
10	PRS55	31.11	4.53	4.66	2.68	4.65
11	PRS37	33.78	5.94	5.06	2.92	5.76
12	PRS73	29.33	4.10	4.55	2.42	3.80

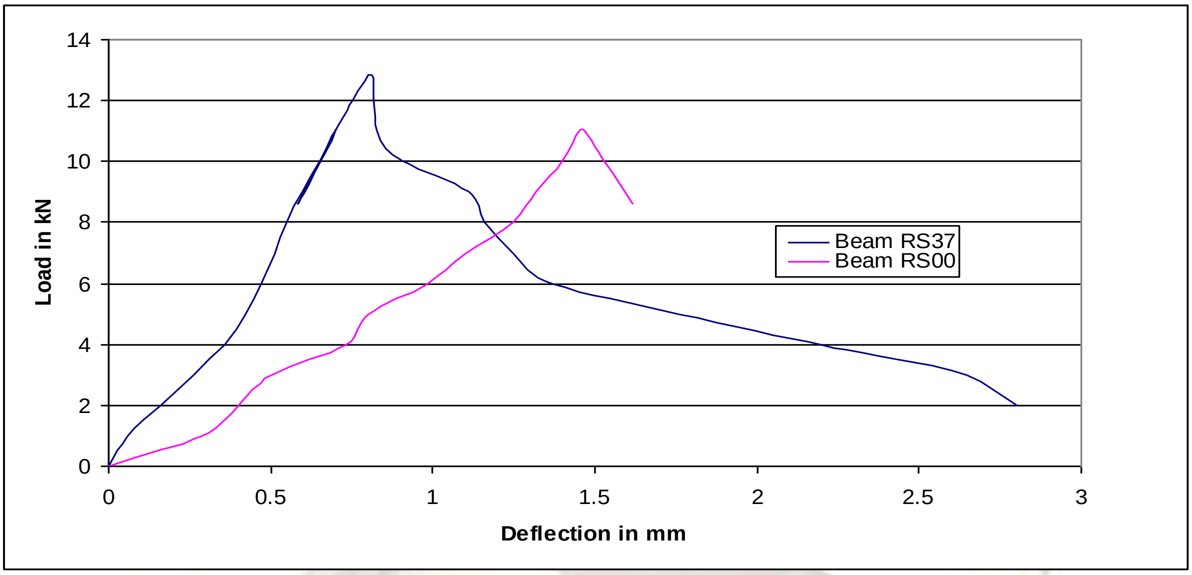

Fig. 7 Load Deflection Graphs for Beams with and without Fibers

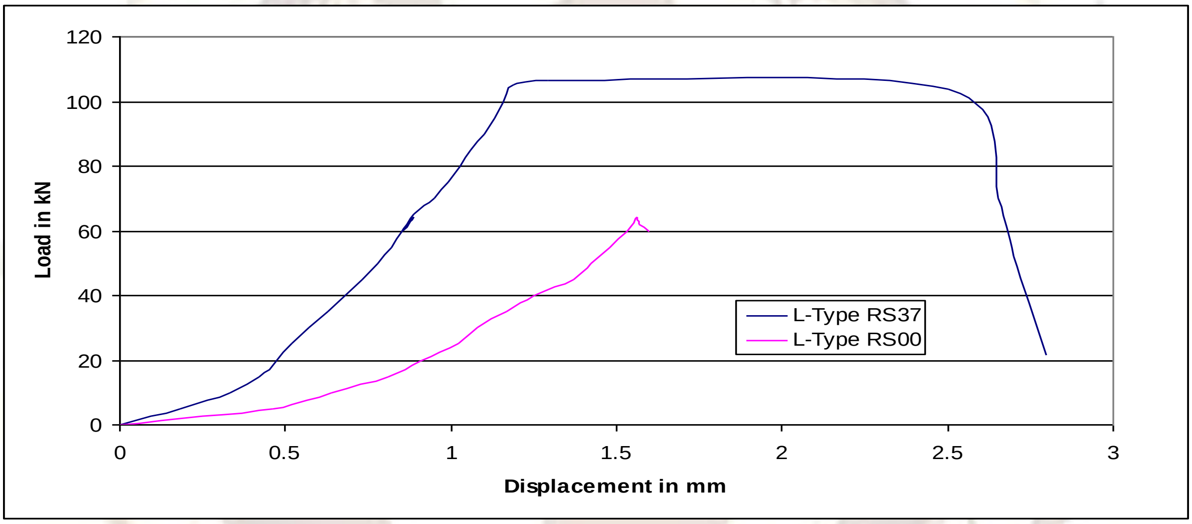

Fig. 10 Load Displacement Graphs for L-Type Specimens with and without Fibers

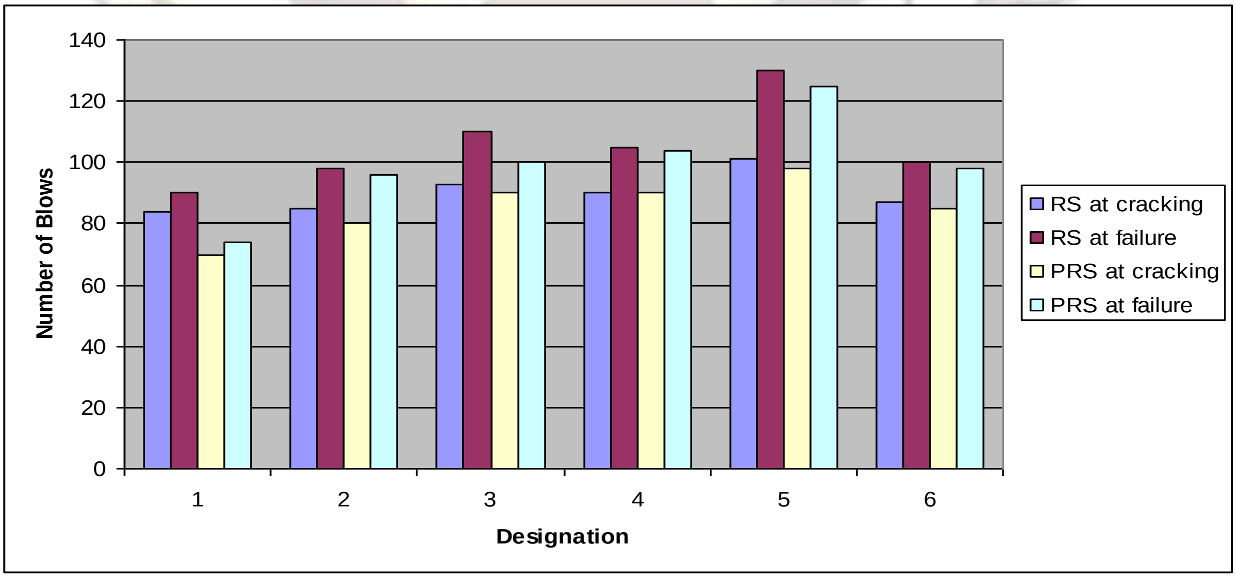

Fig. 13 Results of Testing of Disc Specimens

4. DISCUSSION OF RESULTS

- The compressive strength of all the fibrous matrices under investigation was found to increase with inclusion of fibers in the plain concrete. However, specimens having 1 % volume fraction of Recron fiber (RS10) indicated the marginal increase of 1.58% whereas specimens having 1% volume fraction of steel fibers (RS01) indicated the maximum increase to the tune of 25.04% compared to the plain concrete. RS37 specimens (having 0.3% of Recron fibers and 0.7% of steel fibers) followed closely with increase in compressive strength by 21.91%.
- The split tensile strength of all the fibrous composite matrices was significantly higher than that of plain concrete. A maximum increase of 69.02% of split tensile strength was indicated by RS37 matrix whereas RS01 samples indicated an increase of 53.80%. This is because in fibrous matrix when it cracks, the presence of fibers causes the load to be transferred from the cementitious composite to the fibers at the crack interface, thereby increasing the tensile load carrying capacity of the fibrous matrix.
- Flexural stress of RS37 sample was found to increase by 23.98% compared to RS00 sample. In case of RS01 matrix the comparative increase was 8.99%. Also, RS37 matrix indicated the highest toughness index (I5) of 3.13 while RS01 indicated the value of toughness index as 2.87. These apparent toughness indices were based on the cross head deflection at the loading point. Due to comparative nature of of the present study, the absolute values of the toughness may not be of much importance. Further, RS00 beam specimen indicated a sudden (brittle) failure whereas RS37 specimen indicated a ductile behavior as can be seen from the **Fig. 7**. Similar strain softening behavior was indicated by all other fibrous matrices also. By bridging across the macro cracks, the fibers obviously affect the post peak load response of concrete.
- The ultimate single shear strength of all the fibrous concrete was also significantly higher that that of no fiber concrete as can be seen from the experimental results presented in Table 2. The maximum increase in shear strength was indicated by RS37 L-Type of specimens, the increase being 65.55% relative to plain concrete. RS01 and RS 55 L-Type of specimens also gave an encouraging performance in shear. The shear strengths of these matrices were 57.70% and 41.74% higher relative to that of plain concrete. A comparison of performance of RS37 and RS00 samples is made in **Fig. 10** where one can clearly see that RS00 L-Type of specimen indicates a sudden failure whereas RS37 specimen indicates a prolonged failure due to the presence of fibers at the shearing plane. The horizontal straight line in curve of RS37 specimen shows displacement (sliding) of the projected portion of inverted L-Type of specimen at the shearing plane due to shearing load.
- The average of 6 disc specimens (prepared by cutting two cylinders) was considered as per ASTM standard for evaluating the relative performance of different matrices. The numbers of blows required for final failure by OPC specimens were 90, 98, 110, 105, 130 and 100 respectively by RS00, RS10, RS01, RS55, RS37 and RS73 disc specimens whereas numbers of blows required for final failure by PPC specimens were 74, 96, 100, 104, 125 and 98 respectively by PRS00, PRS10, PRS01, PRS55, PRS37 and PRS73 disc specimens. The increase in impact strength of RS37 was noticed as 44.44% and that of RS 01 was found as 22.22% compared to RS00 disc specimens. Thus, RS37 disk specimens show the maximum impact resistance compared to the RS00 disk specimens. Actually speaking, this test also gives an idea about fatigue capacity because it repeatedly applies a load to the specimen instead of failing it with one massive blow. The bar chart depicted in Fig. 13 clearly indicates the relative performance of RS and PRS matrices at cracking and at final failure. In the **Fig. 13**, the designations 1, 2, 3, 4, 5 and 6 corresponds respectively to 00, 10, 01, 55, 37, and 73 volume fractions of Recron and steel fibers.
- All the PRS specimens (samples prepared from PPC) followed the same trend as indicated by RS specimens (samples prepared from OPC). However, the values of different stresses were found slightly less in case of PRS matrices compared to RS matrices. This is due to the reason that strength development at early ages is typically slower in green concrete (PPC) than that for conventional concrete (OPC), especially at higher level of replacement. At later ages, after proper curing, green concrete specimens are likely to give at least same performance, if not better compared to the specimens prepared from OPC.

5. CONCLUSIONS

Among the 12 different fibrous matrices considered in the present investigation, matrix having 1% volume fraction of steel fibers (RS01 specimens) indicated the maximum increase in compressive strength whereas matrix having 0.3% of Recron and 0.7% of steel fiber volume fraction (RS37 specimens) had the best performance in tensile stress, flexural stress and shear stress. The combined behavior of RS37 matrix was found more balanced in terms of strength and post- peak ductility. This matrix also indicated the best resistance against impact and the maximum toughness. Thus, the optimum fiber ratio of Recron and steel fibers for HFRC matrix was found to be 0.3: 0.7 for overall better performance and, therefore, offer potential advantages in improving concrete properties.

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