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Behavior of High Strength Reinforced Cement Concrete with Polypropylene and Steel Fibres

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Abstract. The robustness, hardness, and longevity of high strength conventional concrete have long been sought after qualities. Fibre reinforced concrete (FRC) was created to address shortcomings. The purpose of fibres used is to control cracking and to enhance tensile strength, flexural strength, toughness, impact strength, and failure mode by enhancing post-cracking ductility. To study the influence of specimen size on the flexural behavior of high strengthreinforced cement concrete of 60 MPa with hybrid fibres . The current work aimed to investigate the size effect of high strength, polypropylene and steel fibre reinforced RC beams under flexure loading more realistically in addition to that how specimen size affects the flexural behaviour of 60 MPa high strength hybrid fibre reinforced cement concrete. Correspondingly three cubes of size 150 mm x150 mm x 150 mm and the cylinders of size 100 mm diameter, 200 mm height are also cast. Three RC beams of size 150 mm x 200 mm x 1000 mm (1A), 150 mm x 300 mm x 1500 mm (2A) and 150 mm x 400 mm x 2000 mm (3A) are cast. Three hybrid fibre reinforced concrete beams (HFRC) of size 150 mm x 200 mm x 1000 mm (1B), 150 mmx 300 mm x 1500 mm(2B) and 150 mm x 400 mm x 2000 mm(3B) are cast. All beams are provided with HYSD longitudinal reinforcement of 0.52% of the cross section at 0% and 1% fibres were added. Tests Such as Compressive strength test ,Split tensile strength test and Flexural strength test was conducted .

1 Introduction

The flexural responses of high strength reinforced concrete beams with steel and polypropylene fibres in specimens of varying sizes are the subject of this investigation. Compared to regular concrete, high strength concrete has been found to have less ductility, which can lead to brittle failure. Fibres are therefore added to the concrete to increase ductility and alter the manner of brittle collapse.

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1.1 Size Impact

According to the traditional strength of materials hypothesis, two beams constructed of the same material will fail at the same load. However, in practice, a larger beam will fail at a lower stress than a smaller beam due to the size effect. We call this phenomena the size effect. Two things may be causing the size impact. Statistical, resulting from the unpredictability of material strength; energetic, arising from the release of energy when a sizable fracture containing damaged material appears before the maximum load is attained.

1.2 Ductility of High Strength Concrete

The ability of an element to behave inelastically and absorb energy is measured by its ductility[6]. strong strength concrete's (HSC) strong compressive strength acts against the concrete's ductility. One way to improve the compressive strength of HSC without compromising its ductility is to use discrete fibres as reinforcement. The equally dispersed fibres inside the high-strength fiber-reinforced concrete (HFRC) intersect, block, and even stop the formation of cracks when the composite bears service loads and fractures. In this sense, the fibre insertion helps to increase the HSC's ductility and strength

1.3 Fibres Purpose in Concrete

Depending on the fiber's shape and intended use, typical concrete can include fibre additions ranging from 1% to 2% by volume. When fibres are added to concrete, the weak matrix becomes much stronger and takes on characteristics of a composite material that are very different from those of regular concrete. Through the improvement of the matrix's overall cracking resistance and the bridging of even smaller cracks formed after the application of load on the member, the randomly oriented fibres help control the propagation of micro-cracks present in the matrix and prevent them from widening into major cracks.

1.3.1 Fibres Made of Steel

Elevated yield strength Steel fibres are a type of cutting-edge material that is frequently utilized for concrete reinforcement in building projects (Fig. 1.1). Concrete's physical qualities may be significantly improved by adding a certain amount of steel fibre, which can also significantly boost the material's durability, fatigue resistance, impact resistance, fracture resistance, and bending resistance. Steel fibres are often exceedingly ductile and especially well suited for constructions that must have the following properties: i) Resistance to impact; ii) Blast, shock loads, and high fatigue iii) Concrete shrinkage control iv) Extremely high flexural, shear, and tensile strength v) Resistance to erosion, abrasion, and splitting/spalling vi) Excellent resilience to seismic dangers and heat/temperature fluctuations.

Fig. 1.1 Pictorial Representation of Steel Fibres

1.3.2 Polypropylene Fibres

Researchers have focused much of their attention on polypropylene fibres among the polymer fibres because of its exceptional toughness in concrete reinforced with this type of fibre, as seen in Fig. 1.2, and its inexpensive cost. Polypropylene fiber's primary impact on concrete is to lessen shrinkage cracking. The softening branch of the load-displacement curves is improved by the bridge effect of the polypropylene fibers at the crack tip [5]. It is anticipated that polypropylene fibres will improve the ductility and toughness of concrete rather than its compressive strength. Concrete can be strengthened by adding polypropylene fibres to: i) prevent moisture- and heat-induced cracks; ii) increase mix cohesiveness. Concrete's ability to be pumped over long distances, its resilience to freezing and thawing, its impact resistance, and its capacity to increase resistance.

Fig. 1.2 Pictorial representation of Polypropylene Fibres

1.4.1 Composite Fibres

Concrete using hybrid fibre reinforcement (HFRC) demonstrates various fracture behaviour and strain hardening. Two or more different types of fibres are properly blended to take use of their distinct qualities in hybrid fibre reinforced composites. Toughness is provided by large macro fibres, which span the large fissures. Prior to or immediately after cracking, microcracks enhance the reaction. As seen in Figs. 1.3 and 1.4, a hybrid composite with the appropriate volume ratio of high and low modulus fibres should demonstrate simultaneous improvements in ultimate strength, strain capacity, and fracture width properties[1]. The following factors affect fiber-reinforced concrete) Aspect ratio, also known as l/d ratio ii) The volume percentage, Critical length (iii); fibre type (size, shape, strength, and modulus).

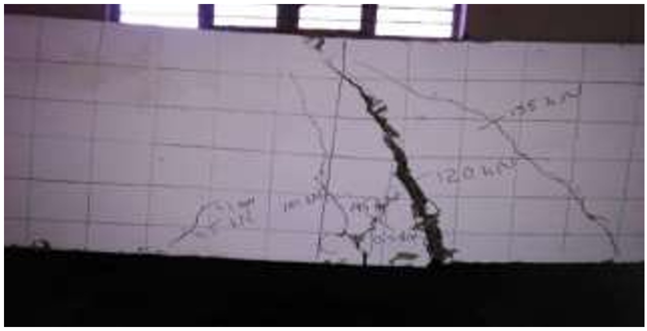

Fig. 1.3 Failure Pattern of Concrete with out Hybrid Fibres

Fig. 1.4 Failure Pattern of Concrete with Hybrid Fibres

2 Literature Review

2.1 A Review of Polypropylene Fibres influence in concrete Kakooei Saeid et al. (2011)

The authors made an effort to investigate how polypropylene fibres affected the electrical resistivity, permeability, and compressive strength of reinforced concrete buildings. Numerous studies on concrete have revealed that paste cracks occur when the rate at which water evaporates accelerates more than the rate at which the concrete emulsion rises to the surface. When the tension exceeds the strength of the concrete, tensile stress is created during the strengthening process and the concrete cracks. In order to reduce stress fractures, an experiment involving the addition of polypropylene fibres to siliceous aggregate concrete has been carried out. This is because the PP fibres function as bridging agents at the fractured area, therefore enhancing the mechanical characteristics of concrete, and PP fibre volume ratios of 1-2 kg/m3 have been proven to significantly boost compressive strength based on testing results. Comparing concrete samples with fibre ratios of 1 and 1.5 kg/m3 to those without PP fibres, the electrical resistivity of the former showed greater values.

2.2 Research on the strength prediction of polypropylene fibre reinforced concrete was done in 2011 by Rana A and Abbas M.

The concrete used is M30 strength reinforced with polypropylene fibres measuring 12 mm in length and 0.016 mm in diameter. Adding polypropylene fibres to cement has been done in several ratios: 0.4%, 0.8%, 1.0%, and 1.5%. 100 x 100 x 100 mm cubes and 100 x 100 x 500 mm prisms have been manufactured. The increases in flexural strength and compressive strength at a dose of 1.5% and 85%, respectively, of polypropylene fibres are seen. About 11.18% is the average ratio of flexural strength to compressive strength. Therefore, it has been determined that a 1.5% dose of polypropylene fibres is suitable for enhancing both compressive and flexural strength.

2.3 An experiment of the addition of polypropylene fibres to reinforced cement concrete was conducted by Roohollah B (2012).

Polypropylene fibres are mixed into M50 strength concrete at a weight percentage of 0.15 to 0.35 percent. Two polypropylene fibre lengths, measuring 6 mm and 12 mm, were used. The specimen with the largest gain in flexural strength, measured in relation to the control specimen, was the one with 12 mm polypropylene fibres added in a percentage of 0.35%. As a consequence, polypropylene fibres with a length of 12 mm and a cement weight of 0.35% demonstrated good splitting, tensile, and compressive strengths.

2.4 A Review of steel fibres influence in concrete Namaan (2003)

To determine the optimum kind of steel fibre to utilize in concrete, experimental research was done on a variety of steel fibre sizes and forms, including smooth surface, etched, round, round with buttons, crimped, and twisted. According to experimental findings, twisting steel fibres significantly increases their binding strength with concrete, making them appropriate for structural applications including blast and seismic resistance structures.

2.5 Dum Lien, Dong Joo and Gum Sung (2012) studied the size effect on flexural behaviour of ultra high performance hybrid reinforced concrete.

Concrete of 150 MPa UHP – HFRC with two types of steel fibres blend in percentages of 1% T-fibres,0.5% SS fibre and 1% T – fibre, 1% SS – fibres had been used. Experiment had been conducted on beams of size 50 x 50 x 150 mm^3, 100 x 100 x 300 mm and 150 x 150 x 450 mm. Typical deflection hardening flexural behaviour, average equivalent bending stress v/s normalized deflection curve for UHP – HFRC for various specimen sizes has been studied. From experimental results it has been found that, normalized deflection capacity between the small and large sized specimen is 1.92 for UHP – HFRC WITH 1.5% steel fibre and 1.44 for UHP – HFRC with 2% steel fibre. Hence UHP – HFRC with higher tensile capacity produces smaller reductions in (a) Flexural strength (b) Normalised deflections (c) Normalised toughness as size of specimen increased.

3 Experimental Program:

3.1 Design of Test Specifications

3.1.1 Materials for Casting

The materials employed in this investigation include cement, sand, coarse aggregates, water, high yield strength deformed bars (HYSD), steel, and polypropylene fibres.

Cement: The cement used is regular Portland cement (53 Grade), having a specific gravity of 2.93. The initial and final setting times for the cement are 105 minutes and 535 minutes, respectively. Ordinary Portland cement of 53 grade is used, according to IS 8112-1989 [8].

Fine Aggregate: Good quality river sand, passing through a 4.75 mm filter with a specific gravity of 2.8, is employed. Sand that is readily accessible locally and meets IS 383-1979 specifications.

Coarse Aggregate: Crushed stone aggregates of 12.5 mm down size with a specific gravity of 2.75, according to IS 383-1970.

Water: Potable water is utilised in the experiments.

HYSD bars: High yield strength. Deformed bars are utilised for both flexural and shear reinforcement. Tensile tests are performed on two bars of each diameter, and the average yield strength is presented in Table 3.1. Steel bars have a modulus of elasticity of 2 × 105 MPa.

Table 3.1 Tensile Strength of Bars

Diameter of reinforcement (mm)	**le strength(MPa)**
6	483
10	528

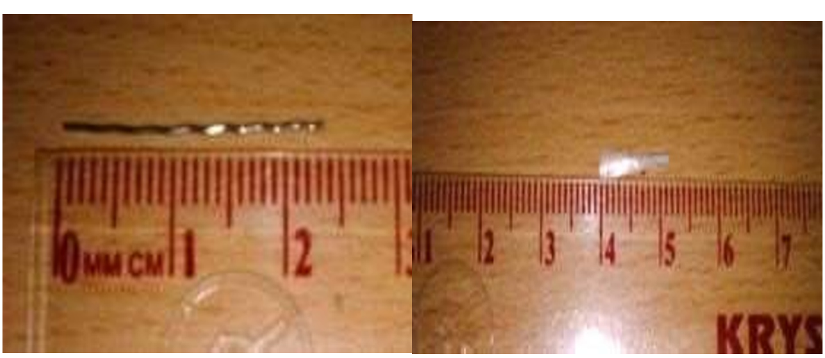

Fig. 3.1 Pictorial Representation of Length of a) Polypropylene fibres b) Steel Fibres

Fibrillated polypropylene fibres have gained popularity for usage in concrete, mostly to improve cracking resistance and hardness of plain concrete [8].Fibrillated polypropylene fibres of 12.5 mm length provide good results in increasing compressive strength, as demonstrated in Figure 3.1(a) [13]. The parameters of polypropylene fibres employed in the present experiments are presented in Table 3.2.

Table 3.2. Properties of Polypropylene Fibres

Fibres	**Geometry**	**Average iameter (mm)**	**Length (mm)**	**Tensile trength (MPa)**	**Density kg/m^3**
Polypropylene	Fibrillated	1000 µm	12.5 mm	375	910

Table 3.3 Properties of Steel Fibres

Fibres	**Geometry**	**Average Diameter (mm)**	**Length(mm)**	**Tensile Strength MPa**	**Density kg/m^3**
Steel	Twisted	0.2	25 mm	2300	7850

Concrete mix design refers to the process of selecting appropriate concrete materials and establishing their relative proportions with the goal of generating a concrete with the needed strength, durability, and workability as efficiently as feasible. The proportioning of concrete materials is determined by the performance requirements of concrete in two states: pliable and hardened. Plastic concrete that is not workable cannot be properly laid or compacted.

The mix proportioning was done in compliance with ACI 211-4R_08. The average strength of concrete is M60. The total binder cement is 440 kg/m3, the fine aggregate is 836 kg/m3, and the coarse aggregate is 1039 kg/m3. The water cement ratio is 0.3. Steel fibres and polypropylene fibres (Hybrid fibres) are added in the proportions (75:25) at a rate of 1% by volume of concrete, as illustrated in Table 3.5 [20]. The overall mixing time is five minutes. Concrete was compacted into three layers using a needle vibrator. Samples are cast to the desired size and left for 24 hours before demoulding. The specimens, with and without fibres, are then cured for 28 days. Table 3.4 shows the mix proportions for M60 concrete

Table 3.4 Mix Proportion of Concrete

Description	**Cement**	**Fine aggregate**	**Coarse aggregate**	**w/c**
Mix proportions	1	1.9	2.36	0.3
Quantities kg/m^3	440	876.4	1094.5	132

Table 3.5 Fibre Mix Combinations

Type of fibres	Fibre Mix Proportion by Volume (%) Total Volume Fraction, $V_f = 1.0\%$
Steel fibres	75
Fibrillated PP fibres	25

3.1.1 Geometrical Properties of Test Specimens

The experimental work involved casting six rectangular RC beams with the geometric parameters reported in Table 3.6. Three cubes measuring 150 mm x 150 mm x 150 mm, as well as cylinders measuring 100 mm in diameter and 200 mm in height, are cast. Three RC beams measuring 150 mm x 200 mm x 1000 mm (1A), 150 mm x 300 mm x 1500 mm (2A), and 150 mm x 400 mm x 2000 mm (3A) are cast. Three hybrid fibre reinforced concrete (HFRC) beams measuring 150 mm x 200 mm x 1000 mm (1B), 150 mm x 300 mm x 1500 mm (2B), and 150 mm x 400 mm x 2000 mm (3B) are cast. All beams have HYSD longitudinal reinforcement. that is 0.52% of the cross section. All of the beams are intended to fail in flexure.

Table 3.6 Test Series of Specimens According to Different Size and Geometry

Beams	Dimension (breadth x depth x length) mm	l/d	% of fibres	$\%p_t$	Stirrups
1A	150 x 200 x 1000	5	0%	0.52	6 mm Ø @ 100 mm c/c
1B	150 x 200 x 1000	5	1%	0.52	6 mm Ø @ 100 mm c/c
2A	150 x 300 x 1500	5	0%	0.52	6 mm Ø @ 100 mm c/c
2B	150 x 300 x 1500	5	1%	0.52	6 mm Ø @ 100 mm c/c
3A	150 x 400 x 2000	5	0%	0.52	6 mm Ø @ 100 mm c/c
3B	150 x 400 x 2000	5	1%	0.52	6 mm Ø @ 100 mm c/c

Six beams have been cast with a consistent l/d ratio, as shown in Table 6. RC beam 1A and HFRC beam 1B are equipped with two 10 mm longitudinal reinforcements at the bottom, two 10 mm hanger bars, and 6 mm shear stirrups at 150 mm c/c, as indicated in Figure 3.2. RC beam 2A and HFRC beam 2B are equipped with three 10 mm longitudinal reinforcements at the bottom, two 10 mm hanger bars, and six mm shear stirrups at 150 mm c/c, as illustrated in Fig. 3.3. RC beam 3A and HFRC beam 3B are equipped with four 10 mm longitudinal reinforcement at the bottom, two 10 mm hanger bars, and 6 mm shear stirrups with 100 mm c/c are given, as indicated in Fig. 3.4.

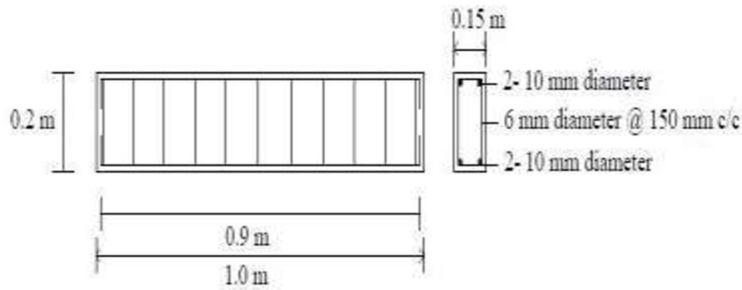

Fig. 3.2 Longitudinal and Transverse Cross Section of Beams for 1A and 1B

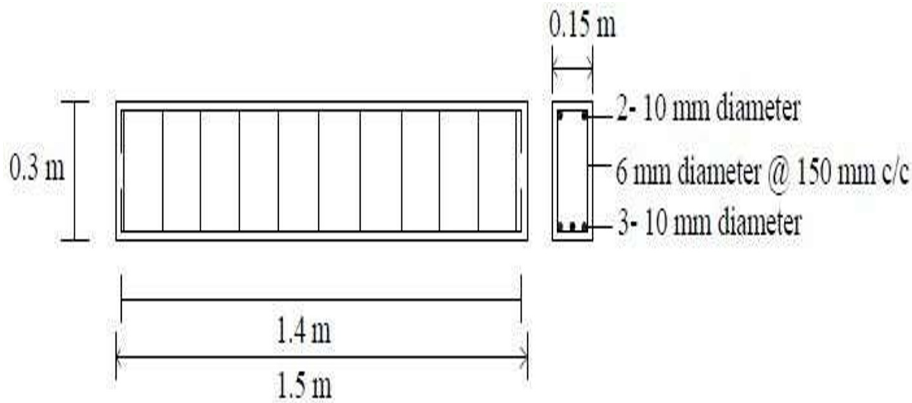

Fig. 3.3 Longitudinal and Transverse Cross Section of Beams for 2A and 2B

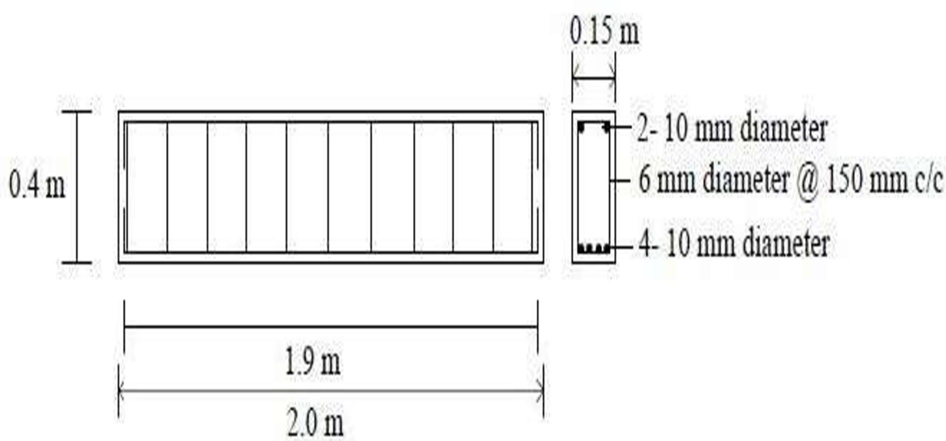

Fig. 3.4 Longitudinal and Transverse Cross Section of Beams for 3A and 3B

3.1 Experimental Setup

In the Structural Engineering Laboratory, the beams are tested with a 500 kN servo-controlled actuator fitted to the loading frame. Figure 3.6 shows the three-point loading setup used for beam testing. Figure 3.5 depicts a shear force and bending moment diagram for the specified loading setup. The load is transferred through a load cell in the middle of the beam. The beam is supported by roller bearings. The specimen is put over the two steel rollers, leaving a 50-mm bearing distance from the beam's ends. A linear variable displacement transducer (LVDT) with a minimum count of 0.001 mm is positioned below the beam centre. The crack widths were measured using crack measuring tools with a minimum count of 0.02 mm.

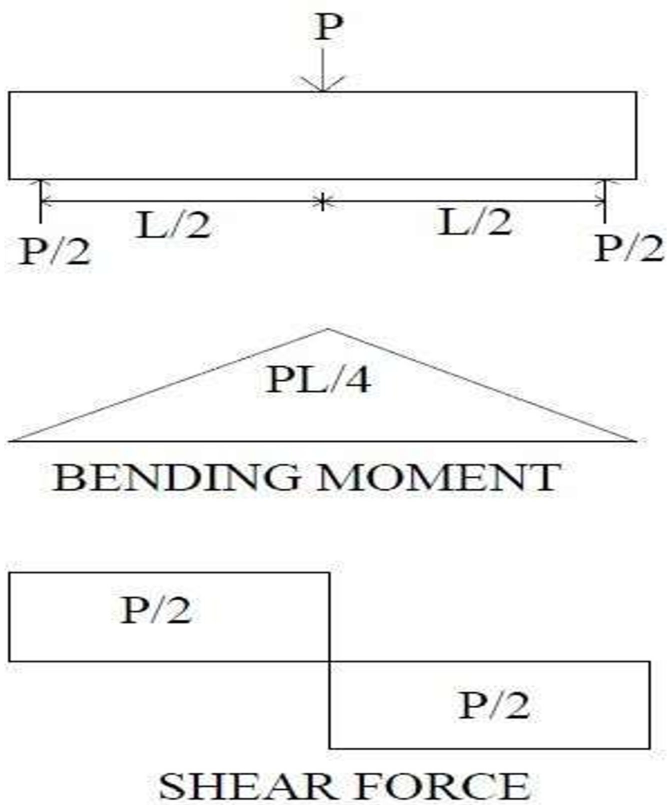

Fig. 3.5 Shear Force and Bending Moment Diagrams for Three Point Loading

Fig. 3.6 Test Set up for Beams

4 Test Results and Discussions

4.1 Compressive Strength

As illustrated in Fig. 4.1, cubes measuring 150 mm x 150 mm x 150 mm are evaluated in a servo controlled compression testing equipment with a capacity of 3000 kN. The obtained compressive strengths are given in Table 4.1 and Figure 4.2. The compressive strength of the hybrid fibre reinforced concrete cube rose by 15.22% when compared to the control concrete cube. [10].

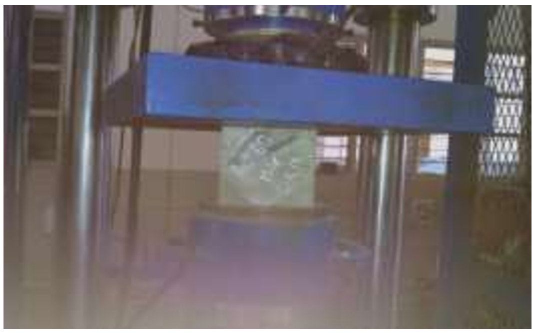

Fig. 4.1 Compression test on cube

Table 4.1 Compressive Strength of Concrete

Mix	Specimens	Compressive Strength (MPa)	Average Compressive strength (MPa)
M60	1A	70.35	67.10
	2A	66.65	
	3A	64.32	
I60 with Hybrid fibres	1B	83.11	79.15
	2B	75.43	
	3B	78.92	

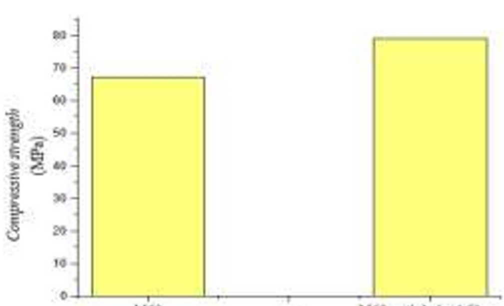

Fig. 4.2 Compressive Strength of Concrete

4.2 Split Tensile Strength

Cylinders of 100 mm diameter and 200 mm height are tested in a hydraulic compression testing equipment with a capacity of 2000 kN. The split tensile strengths achieved are given in Table 4.2 and Figure 4.3. The split tensile strength of hybrid fibre reinforced concrete cylinders increased by 27.43% as compared to the control concrete cylinder [12].

Table 4.2 Split Tensile Strength of Concrete

Mix	**Specimens**	**Split Tensile Strength MPa**	**Average Split Tensile strength MPa**
M60	1A	5.84	5.58
	2A	4.99	
	3A	5.92	
I60 with Hybrid fibres	1B	7.80	7.69
	2B	8.11	
	3B	7.175	

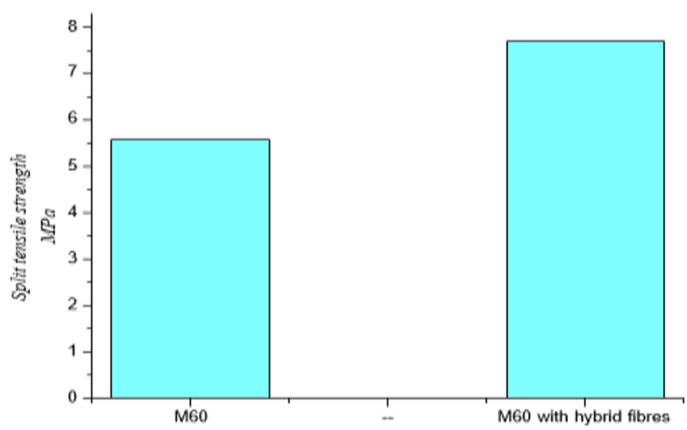

Fig. 4.3 Split Tensile Strength of Concrete

4.3 Flexural Behavior Of Rc Beams With And WithoutHybrid Fibres

Flexural strength is defined as resistance to transverse force. The control beams 1A, 2A, and 3A all failed at 77, 110, and 154 kN, respectively. The HFRC beams 1B, 2B, and 3B failed at 112, 144, and 179 kN, respectively. Table 4.3 shows the ultimate load enhancement ratio (λ), which compares the ultimate load of the HFRC beam to the RC beam. The results reveal that the insertion of hybrid fibres enhances the ultimate load capacity of HFRC beams by the ratio reported in Table 4.3. The average increase in ultimate load capacity across all three beam sizes is 1.30.

Table 4.3 Experimental Results

Designation of beams	**Ultimate load (kN)**	**Deflection Δ (mm)**	$r = \frac{HFRC\ BEAM}{Control\ beam}$
1A	77	3.682	1.45
1B	112	8.084	
2A	110	3.972	1.30
2B	144	5.723	
3A	154	2.606	1.16

4.4 LOAD Vs. DEFLECTION

4.4.1 Load Vs. Deflection Curves for Beams of 200 mm Depth

Figure 4.4 depicts the change of load vs deflection for RC beam 1A and HFRC beam 150 mm x 200 mm x 1000 mm. The maximum load bearing capacity of RC beam 1A is 77 kN, whereas that of HFRC beam 1B is 112 kN. The corresponding deflections are 3.682 mm and 6.145 mm, and the equivalent bending stress is 21.38 MPa and 31.11 MPa, respectively. The ultimate load bearing capability of HFRC beam 1B improved by 31.25% compared to RC beam 1A.

4.4.2 Load Vs. Deflection Curves for Beams of 300 mm Depth

Figure 4.5 depicts the change of load vs deflection for RC beam 2A and HFRC 2B beams of 150 mm x 300 mm x 1500 mm. The maximum load bearing capacity of RC beam 2A is 110 kN, while that of HFRC beam 2B is 144 kN. The corresponding deflections are 3.972 mm and 5.723 mm, and the equivalent bending stress is 19.64 MPa and 25.71 MPa. The ultimate load bearing capability of HFRC beam 2B and RC beam 2A is found to improve by 23.6%, respectively.

4.4.3 Load Vs. Deflection Curves for Beams of 400 mm Depth

Figure 4.5 depicts the change of load vs deflection for RC beam 2A and HFRC 2B beams of 150 mm x 300 mm x 1500 mm. The maximum load bearing capacity of RC beam 2A is 110 kN, while that of HFRC beam 2B is 144 kN. The corresponding deflections are 3.972 mm and 5.723 mm, and the equivalent bending stress is 19.64 MPa and 25.71 MPa.The ultimate load bearing capability of HFRC beam 2B and RC beam 2A is found to improve by 23.6%, respectively.

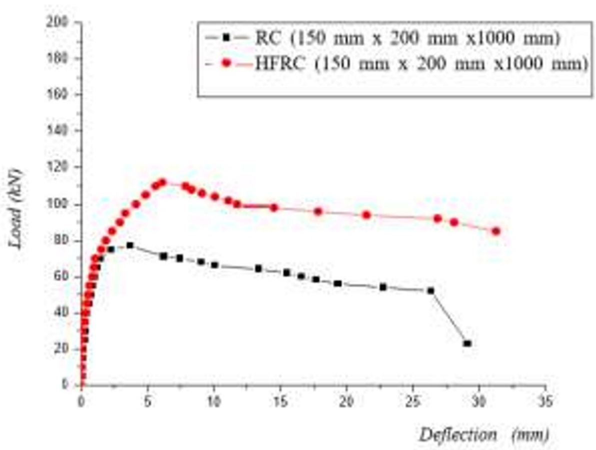

Fig. 4.4 Load Vs. Deflection for Control and HFRC Beams of size 150 mm x 200 mm x 1000 mm

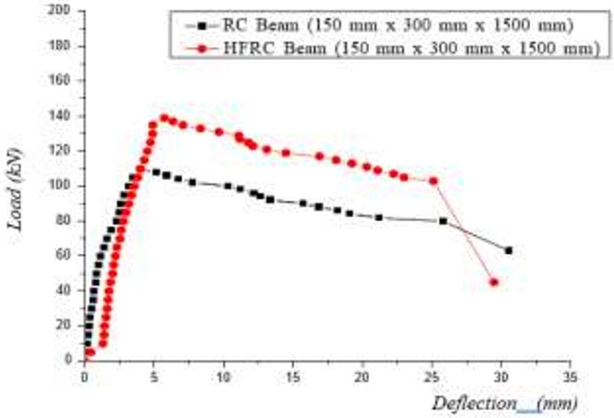

Fig. 4.5 Load Vs. Deflection for Control and HFRC Beams of size 150 mm x 300 mm x 1500 mm

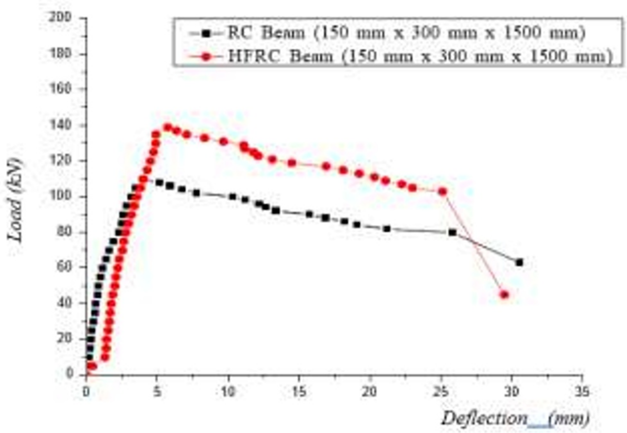

Fig. 4.5 Load Vs. Deflection for Control and HFRC Beams of size 150 mm x 300 mm x 1500 mm

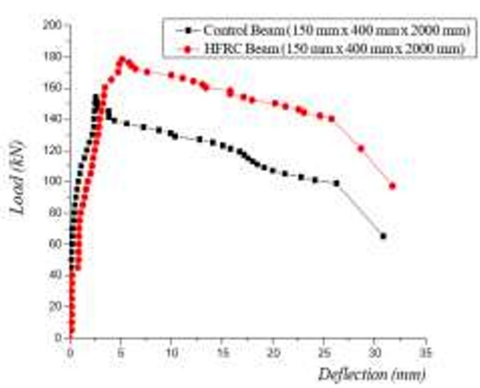

Fig. 4.6 Load Vs. Deflection for Control and HFRC Beams of size 150 mm x 400 mm x 2000 mm

4.4.4 Load Vs. Deflection for RC and HFRC Beams

Figures 4.7 and 4.8 illustrate the load-deflection relationship for RC beams 1A, 2A, and 3A, as well as HFRC beams 1B, 2B, and 3B with varied depths. The ultimate load of RC beam 3A increases by 50.0% and 27.27% when compared to RC beams 1A and 2A. The ultimate load of HFRC beam 3B exceeds that of HFRC beams 1B and 2B by 37.07% and 21.91%, respectively. As a result, when the depth of the beams is increased, the ultimate loads for HFRC beams do not rise much when compared to RC beams

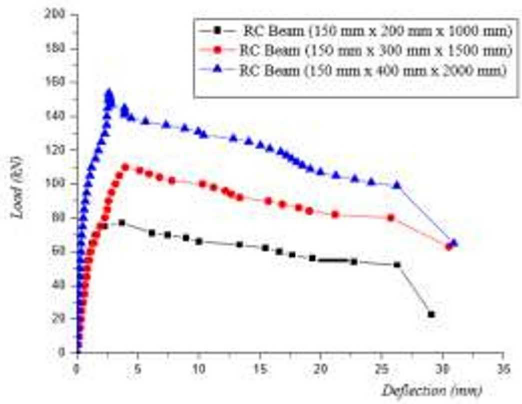

Fig. 4.7 Load Vs. Deflection for RC Beams

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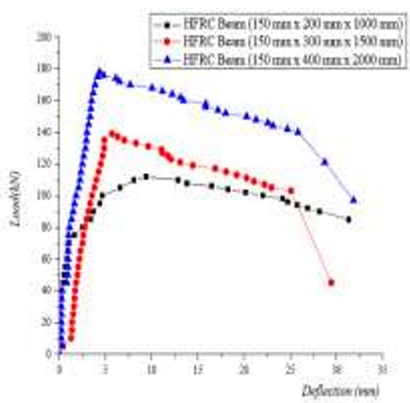

Fig. 4.8 Load Vs. Deflection for HFRC Beams

5 Conclusions

1. The experimental work at the Structural Engineering laboratory was designed and carried out in accordance with the current study's goals. The experimental results allow us to derive the following conclusions.
2. Adding hybrid fibres to M60 concrete boosts its compressive strength by 15.22% compared to normal concrete. As a result, the use of hybrid fibres reduces micro cracking and enhances the compressive strength of concrete.
3. Adding hybrid fibres to M60 concrete raises its split tensile strength by 27.43%. As a result, the inclusion of high modulus steel fibre enhances the tensile strength of concrete.
4. HFRC beams 1B, 2B, and 3B had higher ultimate loads than RC beams 1A, 2A, and 3A, by 31.5%, 23.6%, and 13.9%, respectively. Thus, HFRC beams have a higher ultimate load than RC beams.
5. RC beams 1A, 2A, and 3A have bending strengths of 21.38, 19.64, and 18.26 MPa, respectively. The bending strength of HFRC beams 1B, 2B, and 3B is 31.11 MPa, 25.71 MPa, and 23.55 MPa. As a result, as the specimen's size increases, its bending strength diminishes.
6. HFRC beams 1B, 2B, and 3B had higher ductility ratios than RC beams 1A, 2A, and 3A by 29.22%, 29.67%, and 39.4%, respectively. As a result, we may deduce that the ductility of the HFRC beam .
7. Crack pattern, Crack width and failure mode are different for RC beams and HFRC beams. Secondary cracks are very less in HFRC beams because fibres strongly arrest development of racks.

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