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Experimental Investigation on Structural Fibrous Concrete with Polyolefin - Steel Hybrid Fibres

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Abstract
This paper presents the experimental results on the hybrid fibre reinforced concrete (HFRC) with hybrid fibres. A total of 30 concrete specimens were tested to study the effect of hybrid fibre reinforcement on the flexural performance of fibre reinforced concrete. The fibre content dosage V_f ranged from 0.0 to 2.0%. Steel and Polyolefin fibres were combined in different proportions and their impact on strength and ductility studied. Addition of 2.0% by volume of hybrid fibres increases the above study parameters appreciably, when compared to the plain concrete. Empirical expressions for predicting the strength property of hybrid fibre reinforced concrete (HFRC) is proposed based on regression analysis.

Keywords: *Compressive strength; Ductility; Hybrid fibre reinforced concrete; Modulus of rupture; Polyolefin fibre; Steel fibre.*

Introduction
Concrete is a relatively brittle material, addition of fibres to concrete makes it more homogeneous and isotropic and transforms it from a brittle to a more ductile material[1-3]. The basic purpose of using hybrid fibres is to control cracks at different size levels, in different zones of concrete (cement paste or interface zone between paste and aggregate) and at different loading stages. The large and strong fibres control large cracks. The small and soft fibres control crack initiation and propagation of small cracks[4-6]. This research work focuses on the polyolefin-steel hybrid fibres reinforced system. It has been shown recently that the hybrid composite can offer more attractive engineering properties because the presence of one fibre enables more efficient utilization of the potential properties of the other fibre[7]. However, the hybrid composites studied by previous researchers were focused on cement paste or mortar. Information available pertaining to the strength and ductility properties of hybrid fibre reinforced concrete is found to be limited. Hence an attempt has been made to study the strength and ductility properties of hybrid fibre reinforced concrete. A total of 30 specimens were cast and tested to determine the impact of hybrid fibres on the strength and ductility of fibre reinforced concrete (FRC).

Experimental Program: *Materials*
The cement used in the concrete mix was Portland Pozzolana Cement (PPC), which confirms to IS: 1489 (1991) [8]. The sand used was local natural sand with specific gravity of 2.54. The coarse aggregate was crushed granite with maximum size of 20 mm and specific gravity of 2.67 which confirms to IS: 383-1970[9]. Properties of steel and polyolefin fibres are shown in Table 1. The polyolefin fibres used were straight, while the steel fibres were with hooked ends.

Table 1 Properties of Fibre

Fibre Properties	Fibre details	
	Polyolefin	Steel
Length (mm)	48	30
Size/Diameter (mm)	1.22×0.732	0.5
Aspect Ratio	39.34	60
Density (kg/m^3)	920	7850
Specific Gravity	0.90-0.92	-
Young’s Modulus (GPa)	6	210
Tensile strength (MPa)	550	532

TABLE 2 CONCRETE MIX PROPORTIONS

Material	Quantity
Cement (kg/m^3)	400
Sand (kg/m^3)	745
Coarse aggregate (kg/m^3)	960
Water (kg/m^3)	200
Slump (mm)	100

In this study, M20 grade of concrete was used. The mix design for the above grade of concrete was done using ACI method[10]. The mix proportion adopted was 1: 1.82: 2.64: with a water-cement ratio of 0.50. Table 2 presents the control concrete mix proportions used in the testing program. For concrete with fibres, superplastizer was used in appropriate dosage to maintain a slump of about 100 mm.
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Test Specimens

150 mm cubes were used for determining the compressive strength of hybrid fibre reinforced concrete. 100 mm x 100 mm x 500 mm prisms were used for determine the modulus of rupture as well as the ductility.

Testing Procedure

150 mm cubes were tested in a standard manner in a 2000 kN capacity compression testing machine. The prisms were tested in a loading frame. The specimens were subjected to four-point bending. Deflection measurements were made using dial gauges of 0.01 mm accuracy. The above tests were conducted as per the relevant Indian Standard specifications[11].

Test results and Discussion

The principal test results are presented in Table 3. Each strength value presented is the average of three specimens. A total of 30 specimens were tested in this investigation.

Table 3 Principal Test Results of Specimens

Type of Fibre			Compressive strength (MPa)	Modulus of Rupture (MPa)	Energy Ductility	Deflection Ductility
V_f (%)	Polyolefin	Steel				
0	0	0	26.65	7.06	1.00	1.00
0.5	30	70	27.86	9.60	1.46	1.39
1.0	30	70	28.98	11.50	1.51	1.48
1.5	30	70	31.16	11.04	1.67	1.59
2.0	30	70	30.34	12.18	1.98	1.83

Compressive strength

It is clear from Table 3, that addition of fibres has significant effect on the compressive strength. Based on the test results, the compressive strength of hybrid fibre reinforced concrete f_{ch} may be estimated in terms of the compressive strength of plain concrete f_{ck} and the fibre content V_f as follows

$$f_{ch} = f_{ck} + 2.277\, V_f \quad \text{MPa} \qquad (1)$$

The relation between fibre content on compressive strength of concrete is presented in Fig. 1. A graphical representation of compressive strength of concrete with and without fibres is presented in Fig. 2.

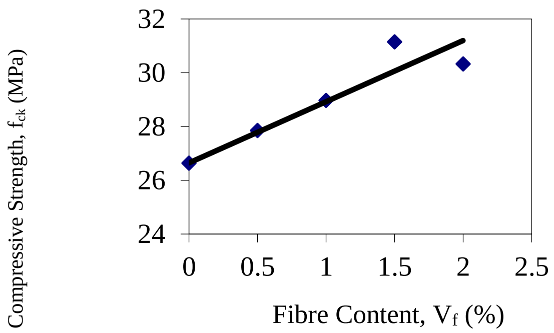

Fig. 1 Relation between Hybrid fibre content on compressive strength

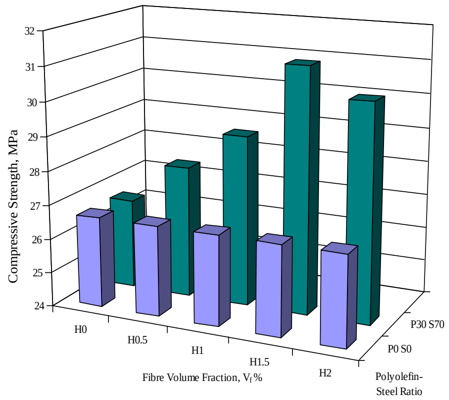

Fig 2 Compressive strength of concrete with and without Fibres Modulus of rupture

Fig. 3 present the variation of the modulus of rupture f_r as a function of the compressive strength $\sqrt{f_{ck}}$ of plain concrete. A regression analysis of the test results provided the following equation $f_{rh} = 1.916 \sqrt{f_{ck}}$ MPa (2)

These equations yield value higher than those obtained by IS: 456-2000[13] of $0.7 \sqrt{f_{ck}}$ for normal strength concrete.
It is evident from Table 3 that increasing the fibre content from 0.0 to 2.0% increases the modulus of rupture. The increase in modulus of rupture was found to be 56.37% with 1.5% fibre content and 72.52% with 2.0% fibre content when compared to the plain concrete. Fig. 4 shows the correlation between the modulus of rupture and various fibre contents. A regression analysis of the test results provided the following equation. $f_{rh} = f_r + 2.923\, V_f$ (3)

A graphical representation of modulus of rupture of concrete with and without fibres is presented in Fig. 5.

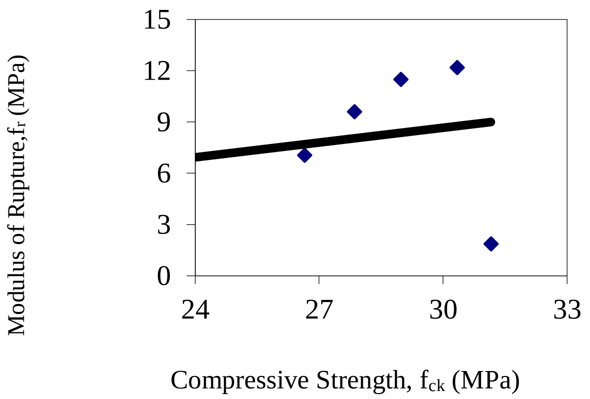

Fig. 3 Relationship between Modulus of Rupture and Compressive Strength

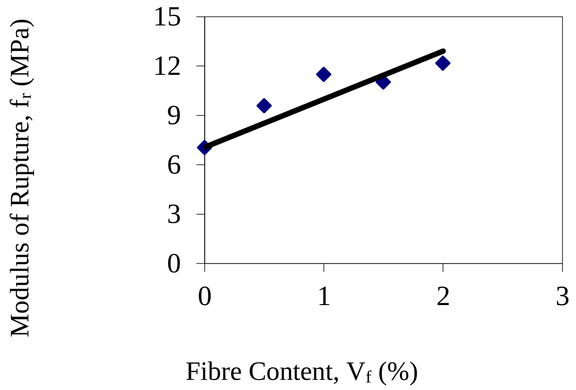

Fig. 4 Relationship between Modulus of Rupture of Hybrid Fibre Reinforced Concrete

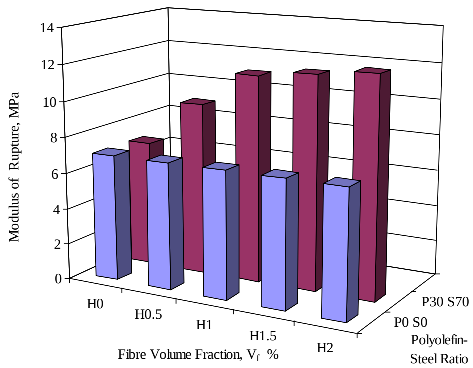

Fig 5 Modulus of Rupture of Concrete with and without Fibres

Ductility

It can be observed from the results reported in Table 3 that beams without fibres exhibit little ductility. It was noticed that once the maximum tensile stress was reached, the beams without micro-reinforcement failed suddenly. For beams with fibres the failure was not sudden. The randomly oriented fibres crossing the cracked section resisted the propagation of cracks and separation of the section. This caused an increase in the load-carrying capacity beyond the first cracking[12-14]. The test results show that ductility increases with all fibre contents. The increase in energy ductility was found to be 67% with 1.5% fibre content and 98% with 2.0% fibre content when compared to the plain concrete. The enhancement in energy ductility for specimens with and without fibres is shown in Fig. 6. The increase in deflection ductility was found to be 59% with 1.5% fibre content and 83% with 2.0% fibre content when compared to the plain concrete. The enhancement in deflection ductility for specimens with and without fibres is shown in Fig. 7.

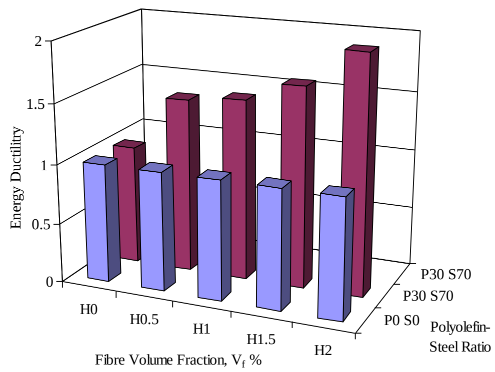

Fig. 6 Energy Ductility for Specimens with and without Fibres

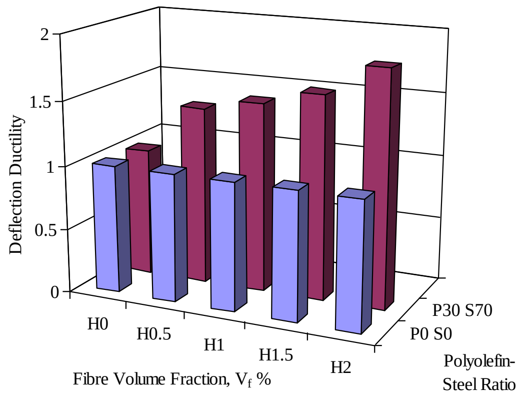

Fig. 7 Deflection Ductility for Specimens with and without Fibres

CONCLUSIONS

Based on the test results of this investigation, the following conclusions are drawn:
1. Addition of fibres has significant improvement on the compressive strength when compared to the plain concrete.
2. HFRC beams exhibit enhanced strength in flexure. The values of modulus of rupture increased up to 72.52% compared to their plain concrete counterparts.
3. HFRC beams provide ductility indices up to 1.98 compared to the plain concrete specimens.
4. Empirical expressions that predict the influence of fibre contents on the strength and ductility properties of hybrid fibre reinforced concrete is proposed. These expressions give a close estimate of the experimental results.

Notations

f_{ck} - compressive strength of plain concrete, MPa

f_{ch} - Compressive strength of hybrid fibre reinforced concrete, MPa

f_r – Modulus of rupture of plain concrete, MPa

f_{rh} - Modulus of rupture of hybrid fibre reinforced concrete, MPa

V_f – Fibre content, %

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