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ORIGINAL ARTICLE

Ductility Performance of Concrete with Dramix Steel Micro-reinforcement

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ABSTRACT

This paper presents a study on the ductility performance of dramix steel fibre reinforced concrete (SFRC). A total of 30 concrete specimens were tested to study the effect of micro-reinforcement on the strength and ductility of fibre reinforced concrete. The fibre content dosage V_f ranged from 0.0 to 2.0%. Addition of 2.0% by volume of hooked-end steel fibres increases the modulus of rupture, energy ductility and deflection ductility by about 58.78%, 59.0% and 46.0% respectively, when compared to the plain concrete. Empirical expressions for predicting the strength property of steel fibre reinforced concrete (SFRC) are proposed based on regression analysis.

Key words: Compressive strength; Ductility; Modulus of rupture; Steel fibre; Steel fibre reinforced concrete.

Introduction

Concrete is a relatively brittle material. Addition of fibres to concrete transforms it from a brittle to a more ductile material (Committee, 1989; Committee, 1982; Naaman, 1985; Surendra, 1987). The function of short-cut fibres as secondary reinforcement in concrete is mainly to inhibit crack initiation and propagation (Ramakrishnan, 2000). The basic purpose of using fibres is to control cracks at different size levels, in different zones of concrete (cement paste or interface zone between paste and aggregate), at different curing ages and at different loading stages. Information available pertaining to the ductility properties of steel fibre reinforced concrete is found to be limited. Hence an attempt has been made to study the ductility performance of steel fibre reinforced concrete. A total of 30 specimens were cast and tested to determine the impact of steel fibres on the strength and ductility of fibre reinforced concrete (FRC).

Experimental programme

This study is part of a research program on evaluating the performance of hybrid fibre reinforced concrete beams. In this paper, strength and ductility properties of steel fibre reinforced concrete are assessed and the applicability of empirical expressions for predicting the above properties is explored.

Materials and methods

The cement used in the concrete mix was Portland Pozzolana Cement (PPC), which confirms to (IS: 1489 :1991). The sand used was local natural sand with specific gravity of 2.54. The coarse aggregate was crushed granite with a maximum size of 20 mm and specific gravity of 2.67 which confirms to (IS: 383-1970). Two types of fibre, Polyolefin and steel fibres were used in this study. Properties of steel fibres are shown in Table 1.

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Table 1: Properties of Steel Fibres

Fibre Properties	Fibre details
Length (mm)	30
Shape	Hooked at ends
Size/Diameter (mm)	0.5 mm
Aspect Ratio	60
Density (kg/m^3)	7850
Young's Modulus (GPa)	210

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, M_{20} grade of concrete was used. The mix design for the above grade of concrete was done using ACI method. (ACI Committee: 2111.1-91, 1994) The designed mix proportion 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.

Test Specimens

150 mm cubes were used for determining the compressive strength of steel 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. (IS: 516, 1959).

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: Strength and Ductility properties of hybrid fibre reinforced concrete

Sl.No.	Fibre Content, V_f, (%)	Compressive strength (Mpa)	Modulus of Rupture (Mpa)	Energy Ductility	Deflection Ductility
1	0	26.65	7.06	1.00	1.00
2	0.5	27.96	7.16	1.25	1.18
3	1.0	28.18	10.18	1.38	1.27
4	1.5	31.10	10.52	1.42	1.35
5	2.0	30.74	11.21	1.59	1.46

Compressive strength

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

$$f_{cs} = f_{ck} + 2.272\ V_f \quad \text{Mpa} \tag{1}$$

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.

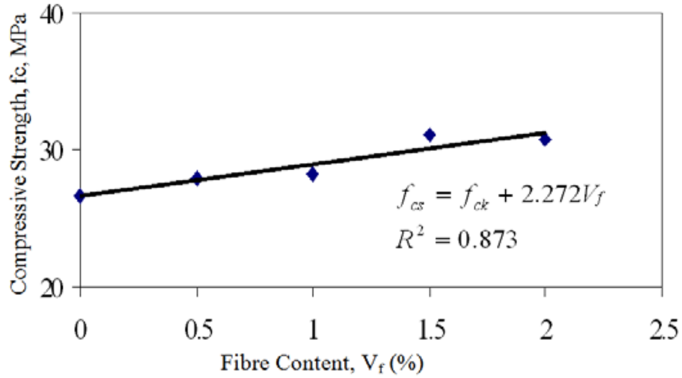

Fig. 1: Relation between fibre content and compressive strength of concrete

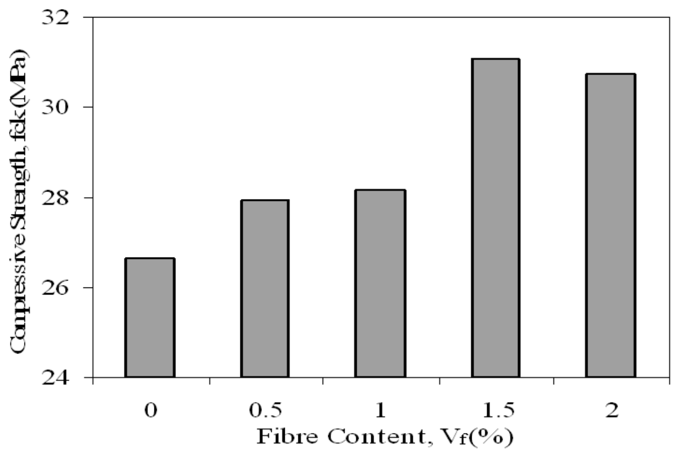

Fig. 2: Compressive strength for concrete with and without Fibres

Modulus of rupture

Fig. 3 presents the variation of the modulus of rupture f_r as a function of the compressive strength *Ö*f_{ck} of plain concrete. A regression analysis of the test results provided the following equation.

$$f_{rs} = 1.707\ \text{Ö}f_{ck}\ \text{Mpa} \tag{2}$$

This equation yield values higher than those obtained by IS: 456-2000[10] of *0.7Ö*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 49% with 1.5% fibre content and 58.78% 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 equations.

$$f_{rs} = f_r + 2.088\ V_f \quad \text{Mpa} \tag{3}$$

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

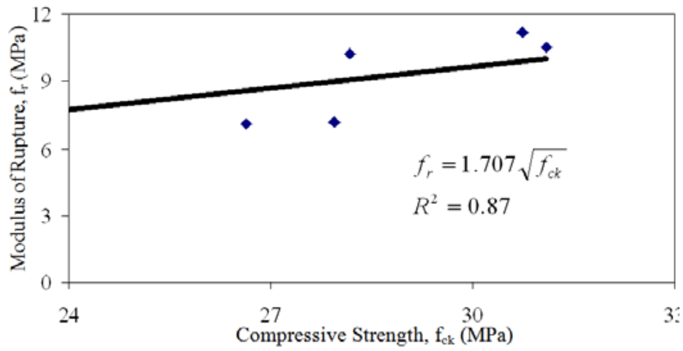

Fig. 3: Relationship between modulus of rupture and compressive strength of concrete

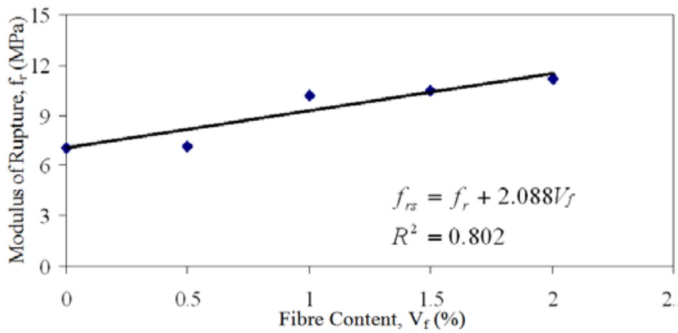

Fig. 4: Relationship between Modulus of rupture and Fibre Content of Concrete

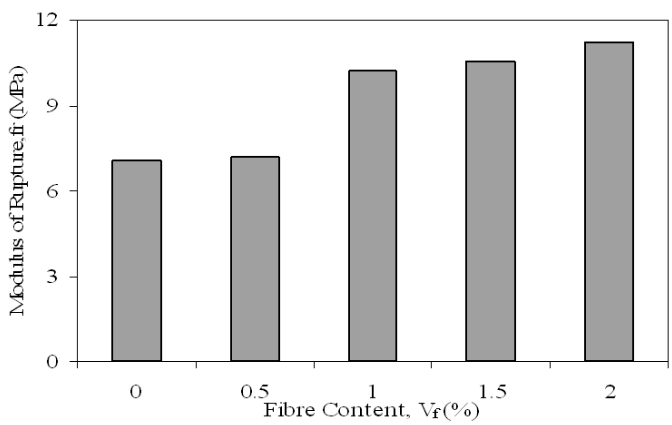

Fig. 5: Modulus of Rupture for Concrete with and without Fibres

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 (Eswari *et al.*, 2008).

The test results show that ductility increases with all fibre contents. The increase in energy ductility was found to be 42% with 1.5% fibre content and 59% 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 35% with 1.5% fibre content and 46% 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.

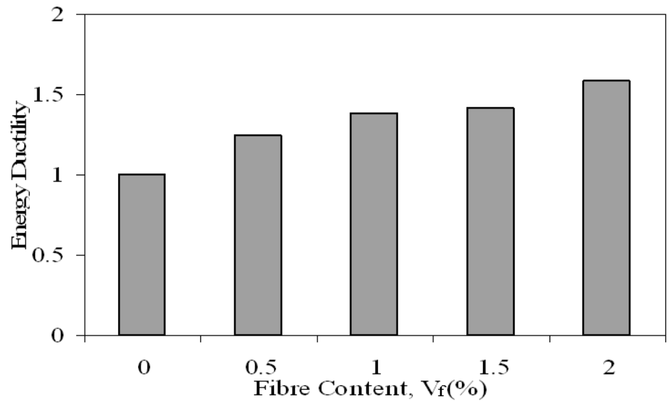

Fig. 6: Energy Ductility for Specimens with and without Fibres

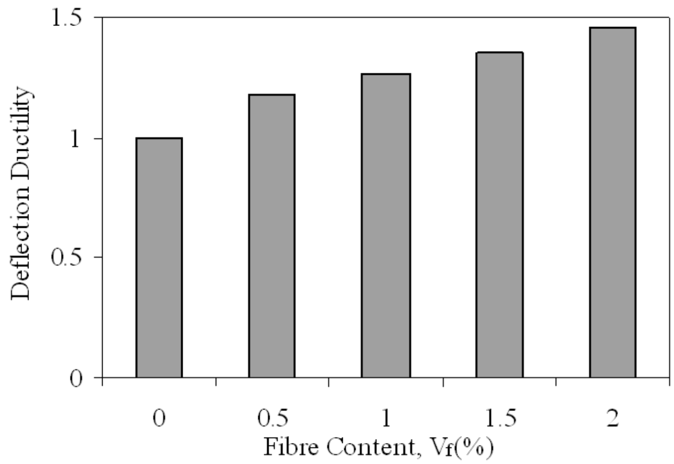

Fig. 7: Deflection Ductility for Specimens with and without Fibres

Conclusions

Based on the test results of this investigation, the following conclusions are drawn:

- Addition of fibres has marginal improvement on the compressive strength when compared to the plain concrete.
- SFRC beams exhibit enhanced strength in flexure. The values of modulus of rupture increased up to 58.78% compared to their plain concrete counterparts.
- SFRC beams provide ductility indices up to 1.59 compared to the plain concrete specimens.
- Empirical expressions that predict the influence of fibre contents on the strength and ductility properties of steel reinforced concrete are proposed. These expressions give a close estimate of the experimental results.

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Notations

f_{ck} - compressive strength of plain concrete, MPa
f_{cs} – compressive strength of steel fibre reinforced concrete, MPa
f_r – Modulus of rupture of plain concrete, MPa
f_{rs} - Modulus of rupture of steel fibre reinforced concrete, MPa
V_f – Fibre content, Percent

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