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COMPREHENSIVE STUDY OF HIGH STRENGTH FIBER REINFORCED CONCRETE UNDER PULL OUT STRENGTH

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ABSTRACT

The present work deals with an experimental investigation and results obtained on the high strength steel fiber reinforced concrete. The effects of these fibers on workability, density, and on various strengths of high strength concrete (M60 grade concrete) are studied. Present paper emphasises on the Pullout strength of concrete. The fiber content varied from 0.5 to 5% by weight of cement at the interval of 0.5 %. Concrete cubes of 150x150x150 mm with 16mm tor bar embedded in concrete at the centre of the cube were casted. All the specimens are water cured and tested at the age of 7 and 28 days. Workability of wet mix is found to be reduced with increased fiber content. Super plasticizer is used to increase workability. Ductility and bond of concrete is found to increase in Steel Fiber Reinforced Concrete (SFRC) as observed from the results. New expressions for Pullout strength by regression analysis are proposed in relation with volume fraction of fibers ($\%V_f$) and bond strength. A significant improvement in the Pullout strengths is observed due to inclusion of steel fibers in the concrete. Maximum fiber content is found to be strength dependent.

Key Words: Crimped Steel Fiber, Volume Fraction of Fibers, Workability, Strength of Concrete, Ductility, Optimum Fiber Content.

I. INTRODUCTION

The term “High Strength Concrete” (HSC) is generally used for concrete having compressive strength higher than 42MPa (6000psi). The use of HSC in the construction industry has steadily increased over the past years, which leads to the design of smaller sections. This in turn reduces the dead weight, allowing longer spans and more usable area of buildings. Reduction in mass is also important for economical design of earthquake resistant structures. Such advantages often outweigh the higher production cost of high-strength concrete associated with careful selection of ingredients, mix proportioning, curing, and quality control.

HSC increases the post-peak portion of the stress–strain diagram, almost vanishes or descends steeply. The increase in concrete strength reduces its ductility. The higher the strength of concrete, the lower is its ductility. This inverse relation between strength and ductility is a serious drawback for the use of HSC and a compromise between these two characteristics of concrete can be obtained by adding discontinuous fibers. The concept of using fibers to improve the characteristics of construction materials is very old. Addition of fibers to concrete makes it more homogeneous and isotropic and transforms it from a brittle to a more ductile material. When concrete cracks, the randomly oriented fibers arrest a micro-cracking mechanism and limit crack propagation, thus improving strength, bond and ductility.

II. LITERATURE REVIEW

Giuseppe Campione [1] reported an analytical model which proposed that it is able to determine the flexural response of supported beams under four point bending tests. A simplified analytical model is presented that is able to calculate the load deflection curves and the maximum and ultimate deflections occurring in the case of shear or flexure failure.

Ghugal [2] studied effect of steel fibers on various strength of concrete. Author takes various percentages of steel fiber with four grades of mixes. For each mix cube, cylinder, beams and shear specimens are casted.

Thomas and Ramaswamy [3] described the experimental results of the strength properties of SFRC, namely cube and cylinder compressive strength, split tensile strength modulus of rupture, modulus of elasticity, Poisson’s ratio and strain corresponding to peak compressive stress. Empirical relationships were developed for various strength properties based on the regression analysis of the 60 tests data.

Balendran, Zhou, Nadeem and Leung [4] investigated the effectiveness of fiber inclusion in the improvement of mechanical performance of concrete with regard to concrete type and specimen size. Lightweight aggregate concrete and limestone aggregate concrete with and without steel fibers were used in the study. The compressive strength of the concrete mixes varied between 90 and 115 MPa and the fiber content was 1% by volume. The increase in spitting tensile strength, flexural strength and toughness index for lightweight concrete seems much higher than that of normal aggregate concrete.

Parviz and Ziad [5] investigated the flexural behavior of reinforced concrete beams containing steel fibers. They indicated that the ductility and the ultimate resistance are remarkably enhanced due to the addition of steel fibers. The design implication of fiber-reinforced concrete beams is also discussed along with the method for incorporating fiber effects in the flexural analysis of singly reinforced concrete beams.

Lambrechts, Nemegeer, Vanbrabant and Stang [6] investigated that steel fibers can replace stirrups as shear reinforcement in high strength concrete beams. Analysis of the results indicates that some favorable aspects concerning the use of steel fibers as shear reinforcement in high strength concrete beams.

Lok and Xiao [7] demonstrated that how the first crack flexural strength F_{cr} and the ultimate flexural strength F_{ult} can be derived from a constitutive stress- strain mode.
The model is described in a separate study for both strength F_{cr} and F_{ult} which are dependent on material and composite properties. Further studies are then conducted to derive a simplified form to assess the ultimate flexural strength of SFRC. Detailed comparisons with published data are presented to check the accuracy of both the analytical and simplified approaches.
Lok and Pei [8] proposed a constitutive model for SFRC, in with the tensile behavior incorporates a bilinear strain softening feature. Composite material properties (F_{cr},F_{ult}), fiber volume concentration ($\%V_f$), fiber aspect ratio (f/d) and fiber-concrete matrix bond stress (Td) are used to define the model.
Swamy and Al-Ta'an [9] described the influence of fiber reinforcement on the deformation characteristics and ultimate strength in flexure of concrete beams made with 20mm maximum size of aggregates and reinforced with bar reinforcement with specified minimum yield strength of 460 and 617N/mm^2 respectively. The fiber concrete was provided either over the whole depth of the beam or in the effective tension zone only surrounding the steel bars.

III. MATERIALS, PROPORTIONING AND ADMIXTURES

1. Cement

Ordinary Portland Cement having 7days compressive strength of 45.20MPa and confirming to IS 12269 [10]

2. Aggregate

As a Fine Aggregate (FA) natural Sand from river is used confirming to IS 383-1970 [11]. As a Course Aggregate (CA) crushed black trap basalt rock of aggregate size 20mm down and 10mm down were used confirming to IS 383-1970 [11]. Various tests such as Specific Gravity, Water Absorption and Sieve Analysis have been conducted on CA and FA to know their quality and grading. The Fineness Modulus of CA is found to be 7.52 and of FA is 2.803 which are within the standard range.

3. Physical Properties of Steel Fibers

Novocon (Xorex) steel fibers conforming to ASTM A 820 type-I are used for experimental work. Fibers are high tensile steel cold drawn wire and specially engineered for use in concrete. Fibers are made available from NINA Concrete Industries and company, Mumbai.

Table1. Physical Properties of Steel Fibers

Sr.No.	Property	Value
1	Length of fiber	50.0 mm (Flat)
2.	Appearance	Bright in clean wire
3.	Average aspect ratio	50
4.	Deformation	Continuously deformed circular segment
5.	Fiber tensile strength	580.392 MPa
6.	Modulus of Elasticity	200 GPa
7.	Specific Gravity	7.80

Dosages fiber used: 0.5 % to 5.0% with the increment of 0.5% by weight of cement

4. Super Plasticizer

Sulphonated Naphthalene formaldehyde condensate CONPLAST SP-430 super plasticizer obtained from Fosroc Chemicals (India) Pvt. Ltd. was used. It conforms to IS: 9103-1999 [12] and has a specific gravity of 1.20.

5. Water

Potable water available in the laboratory is used for mixing and curing of concrete.

6. Mix Design of Concrete and Quantities of Concrete Ingredients

Mix design of M-60 grade is carried out using various methods and verified by IS method referring IS 10262-1982 [13], Entroy and Shaklok method as well as by testing concrete with various proportions on ingredients. The quantity of ingredient material and mix proportions as per design is as under. This proportions of the ingredients were authenticated by casting cubes and testing them at 7 and 28days age of concrete.

The M-60 grade of concrete having mix proportions 1: 0.75: 2.52(1.51+ 1.01) *i.e.* Cement: Fine aggregate: Coarse aggregate (20mm and 10mm) with w/c ratio of 0.3 was used throughout the experimental investigation. Following Moulds and Specimens were prepared for the testing purpose.

Table 2. Quality of Material per cubic meter of Concrete

Material	Proportion by weight	Weight in Kg/m^3
Cement	1.0	430
F.A.	0.72	309.6
CA I (20mm) (60%)	1.51	649.3
CA II (10mm) (40%)	1.01	434.3
Water/Cement ratio	0.3	129

IV. RESEARCH METHODOLOGY

To study the effect of fibers on interfacial bond strength between the matrix and the reinforcing bar (rebar) was performed. The bond strength test was carried out on cubes of 150mm size with 16mm diameter of steel bar of length 500mm was embedded in each test specimen on to a depth of 150mm at the centre. The bar is pulled out with the help of Universal Testing Machine.

The pull-out tests were performed at a specimen age of 7 and 28days. All the specimens were tested up to failure of bar matrix interfacial bond. All the specimens failed with vertical crack along the embedded length of bar with cracking sound.

The bond strength and the pullout energy (maximum work done during de-bonding of bar and the matrix) have been calculated from the test data and are presented in the TABLE 3 the bond strength was calculated by dividing the applied load, by the surface area of the embedded length the bar over the nominal diameter of bar. The pullout work was calculated for the slip at peak load.

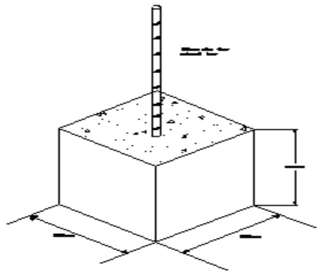

Fig. 1: Cube with 16mm diameter of tor steel rod embedded at center.

The bond strength has been computed from the following expression:

$$f_p = \frac{P}{\pi D L_e} \qquad (1)$$

Where, f_p - Pullout Strength (N/mm^2)
P = load (N)
L_e = embedment length (mm) and
D = diameter of the rebar (mm)

III. RESULTS

Experimental results and results of regression analysis at 7 and 28 days are presented in TABLE 3. Expression for Pullout strength in terms of V_f (% fiber) at 7 and 28days from Fig. 2

for 7 days $f_p = -0.121\, V_f^{\,2} + 0.577\, V_f + 7.882$ (2)
for 28 days $f_p = -0.298 V_f^{\,2} + 1.581 V_f + 12.58$ (3)

Result of Bond or Pullout strength is obtained from Equation1. , and results are presented in TABLE 3. And percentage variation of strength is given in TABLE 4

Table 3: Pullout Strength by testing and Regression Analysis

Sr.No.	Fiber content V_f (%)	Pull out Strength in N/mm^2 using Eqn. 2 and 3			
		Experimental value	From Eq^n.2	Experimental value	From Eq^n.3
		7 Days		28 Days	
1	0.0	7.39	7.882	12.11	12.58
2	0.5	8.52	8.140	13.53	13.30
3	1.0	8.65	8.338	13.86	13.86
4	1.5	8.62	8.475	14.85	14.28
5	2.0	8.49	8.552	14.83	14.55
6	2.5	8.47	8.568	14.66	14.67
7	3.0	8.36	8.524	14.39	14.64
8	3.5	8.29	8.419	14.01	14.46
9	4.0	8.16	8.254	13.83	14.14
10	4.5	8.04	8.028	13.60	13.66
11	5.0	7.89	7.742	13.46	13.04

Table 4: Percentage Variation of Pullout strength

Sr.No.	Fiber content V_f (%)	Pull out Strength in N/mm^2 using Eqn. 23		% increase in Pull out Strength over control Concrete	
		7 Days	28 Days	7 Days	28 Days
1	0.0	7.39	12.11	0.00	0.00
2	0.5	8.52	13.53	15.29	11.72
3	1.0	8.65	13.86	17.00	14.45
4	1.5	8.62	14.85	16.64	22.62
5	2.0	8.49	14.83	14.88	22.46
6	2.5	8.47	14.66	14.61	21.05
7	3.0	8.36	14.39	13.21	18.82
8	3.5	8.29	14.01	12.27	15.68
9	4.0	8.16	13.83	10.41	14.20
10	4.5	8.04	13.60	8.79	12.30
11	5.0	7.89	13.46	6.76	11.14

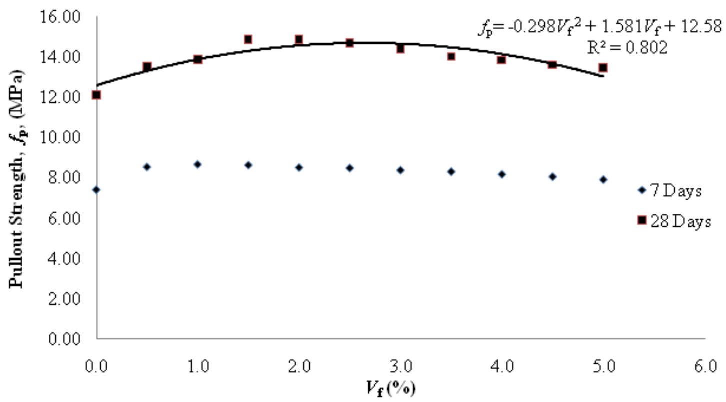

Fig. 2: Variation of Pullout Strength With Respect to Fiber Content

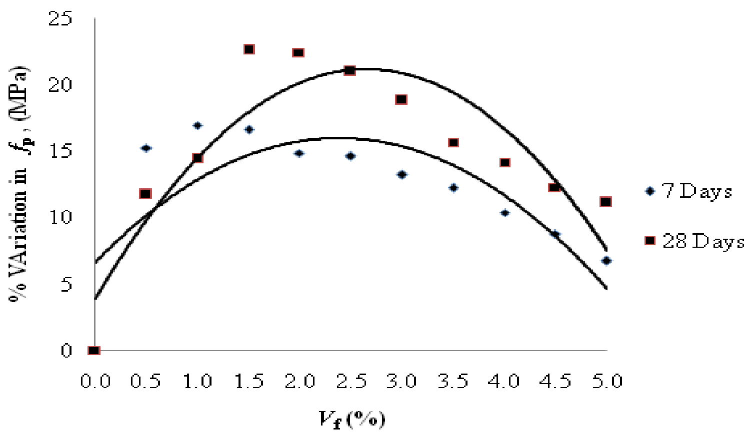

Fig.3: Percentage Variation in Pullout Strength on Prisms Over Controlled Concrete With Respect to Fiber Content (Vf %)

VI. CONCLUSION

1) The Optimum Fiber Content (V_f) was found 1.5% and the highest Pullout Strength 14.85N/mm^2 and percentage increase over plain concrete is 22.62%.

2) All the specimens failed with vertical crack along the embedded length of bar with cracking sound.
3) While testing plain cement concrete cube, spalling of concrete is observed. However, it is not observed in SFRC cubes due to randomly distributed fibers.
4) The vertical crack width of cracks is found to vary between 1.16mm and 2.48mm.
5) In general, the significant improvement in Pullout Strengths is observed with the inclusion of steel fibers in the plain concrete. However, maximum gain in strength of concrete is found to be depent upon the amount of fiber content.

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