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Regression Anaylsis for the Experimental Study on the Pullout Strength of Steel Fiber Self-Compacting Concrete

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ABSTRACT

This article describes experimental research of the interfacial adhesion of triple blended steel fibre self-compacting concrete (TBSFSCC) and it varies depending on the percentage of steel fibre. In self-compacting concrete, mineral admixtures such as condensed silica fume and flyash are utilised as supplementary cementitious materials (SCMs).the percentage of replacement of cement by condensed silica fume at 10 where as flyash at 20 respectively, to meet the SCC criteria stipulated by ACI. The embedment length of a steel bar with a diameter of 12mm was chosen to be 100mm in all of the standard specimens. Fe-415 steel rod is used in this research. The pull-out test in the universal testing machine is used to evaluate the bond strength of this triple blended Self-Compacting Concrete (TBSCC). Ordinary steel fibres are then added to the concrete volume at various percentages, such as 0.2, 0.4, 0.6, and 0.8. The bond strength, slip, and the method of failure of each rebar were all noted in the test results. The comparison of these results clearly shows that the percentage of steel fibre contributes to the TBSCC bond strength, and conclusions are generated.

KEYWORDS: Self-Compacting Concrete, Triple Blended, Condensed silica fume, flyash, Steel fibers, Pull-Out strength, Slip of rebar.

INTRODUCTION

The concept of Self-Compacting Concrete will be utilized in places where concrete compaction is not feasible. Okamura and Ouchi [1], later Ozawa, and Nan-Su [2,3] designed SCC in Japan, and authors have shown very impressive outcomes in this type of concrete. One of the most common causes of concrete structural element failure is rebar slip. It could be due to corrosion of the embedded steel rebar or a lack of concrete-to-rebar bond strength. The bond between concrete and steel bar affects the behaviour of concrete structural elements such as beams and columns. Resistance to tangential shear formed between the concrete and rebar in it is known as bond strength. The density of the concrete (concrete grade) and the type of rebar used to evaluate extent of the bond strength. When fibres are employed in this concrete grade, it becomes stiffer and denser. The bond strength of the concrete composite is improved the quality of this, and this is depending on the percentage of fibre, as well as its geometrical and physical characteristics. Several studies have already evaluated the bond behaviour and manner of failure using various types of fibres in normal vibrated concrete (NVC). The present study is unique in that it investigates the behaviour of this bond strength for triple blended Self-Compacting Concrete with varied percentages of steel fibre and the best aspect ratio. The relationship between 12mm HYSD (high yield strength deformed) rebar and concrete in structural components will influences the strength of lap splices in beams, columns, and other elements of structural concrete. Pull-Test is the most common test used to determine bond strength and the mechanism of failure, and it is mostly dependent on the diameter, embedding length, and the grade of concrete and steel. The specimen's failure mode is usually either pull-out or splitting.

LITERATURE REVIEW

Ehsani et al. (8) (1995) tested the bond strength of a concrete composite containing hooked glass fibre reinforced plastic (HGFRP), and the findings were compared to the same concrete without the glass fibres. The outcomes are promising. Benmokrane et al. (5)(1996) investigated the bond strength and load distribution of glass fibre reinforced polymer (GFRP) composites in concrete. Ioan Pop et al(12) (2013) investigated the bond strength of SCC and compared the results to those of vibrated cement concrete (VCC), concluding that SCC had a stronger bond.. Laboratory experiments on the binding strength of NCC and SCC were conducted by Nipun Verma and Anil Kumar Misra(13)(2015). According to their findings, SCC formed the greater bond to the reinforcing bars than NCC, and the relationship between bond strength and compressive strength in NCC is more consistent than in SCC. A.Mohammed et al (7)(2016) adopted near-surface mounted fibre reinforced polymer (NSMRF) techniques for reinforcing reinforced concrete elements, which has proven to be a very successful technology, "The performance of NSM carbon FRP strengthening approach employing single-lap shear tests with new high-strength self-compacting cementatious adhesive (IHSSC-CA) under high temperatures"(7).

Piotr Dybet(9) (2016) researched the relevance of the rebar-concrete bond, which is the primary cause of failure. A model for the relationship between bond and slip was also provided, which is mostly dependent on the type of rebar used in the concrete. The bond and slip correlations for High performance self-compacting concrete and High performance concrete were reported individually. Ahmed M. Diab et al(4)(2017) conducted experiments to compare the bond strength of regular vibrated concrete with self-compacting concrete. The authors also noted the role of polypropylene fibres in improving the slant shear bond strength in SCC. The surface adhesive qualities of self-compacting concrete with varying scattering gravel diameters (5–10 mm, 10–20 mm, and 5–20 mm) were studied by Jinrui Zhang et al (6) (2017). The failure characteristics of the bond interface" were observed through their analysis of the specimens after splitting and slant shear tests were performed. Yiyan Lu et al.(10) (2018) conducted a pull-test on steel fibre self-compacting concrete infill in a steel tube column and discovered that the inclusion of steel fibres greatly increased the bond strength. It was discovered during the experiment that the binding strength initially reduced and then grew, and authors also provided projected bond strength formulae. Nelly Majain (11)(2020) conducted an experiment on the pull test of 12mm, 16mm, and 20mm bars embedded in a 200mm cube with steel fibres. Adnan Al-Sibahy et al (14)(2020) investigated bond strength degradation caused by corrosion of steel bars implanted in the SCC, as well as variations in bond strength behaviour. Giacomo Torelli et al (15)(2020) looked at cement low weight concrete that may be simply layered into forms. Fresh casting can result in a better interlayer bond. The authors also came to the conclusion that wet casting of elements is a significant step forward in the development of light-weight, low-energy layered concrete.

MATERIAL USED

The grade concrete is designed according to IS-10262-2015[16] specifications for M40 for this experimentation. The fineness modulus of crushed granite coarse aggregate (12mm passing) was 6.8. As fine aggregate, river sand is employed (passing through 4.75mm). As per IS-383[17], it confirms to Zone-II. The Fine aggregate has a modulus of fineness of 2.8.The ratio of fine aggregate to the total aggregate of the concrete is arranged according to Nan Su's[3] simple mix design approach, and it fulfills the ACI [18] self-consolidating concrete criteria. The ratio has been adjusted at 0.64 after so many trials of the experiment. Because of rheological parameters that depend on the physical properties of the aggregates used, such as mineral, chemical admixtures, and the size of the coarse aggregate implemented, this ratio varies from mix to mix. Table 1 shows the proportions of the mix design.

Table 1. M40 Grade of SCC Mix Proportions

CEMENT	Fine Aggregate	Coarse Aggregate	Water to cementatious ratio
1.0	2.34	1.39	0.45

Mineral admixtures

Flyash (F-type), which is obtained from the Vijayawada thermal power plant, is the primary supplemental supplementary cementitious materials (SCMs) employed in this study. Suppliers provide another additive, micro silica. Table 3 lists the mineral admixtures' physical and chemical compositions. The percentages of flyash and micro silica used to substitute 53 grade Ordinary Portland Cement (OPC) according to IS 10269-2019[19] have been 20 and 10%, respectively.

Chemical admixtures

M/S.BASF India Limited provides Glenium B 233 as a superplasticizer (SP), which is a PCE-based chemical, and Glenium-2 as a viscosity modifying agent (VMA). The amount of these chemicals to employ is determined by the quantity of steel fiber in the concrete mix. Combinations of 1 percent SP and 0.15 percent VMA have been used in this experiment.

Steel fibers: The aspect ratio of the triple blended self-compacting concrete is limited to 40 since beyond this aspect ratio the flowability properties of the concrete are impacted.

The rheological characteristics were investigated according to ACI guidelines, and the typical results are provided in table 2 for 0.8% of steel fibre in the SCC Mix with an aspect ratio of 40.

Table 2.The rheological parameters of Typical Fiber Reinforced SCC.

Name of the test	Units	Experimental value*	Acceptance Value
Flow ability (Slump flow)	mm	680	650-800
Passing ability (V-Funnel test)	seconds	11	6-12
L-Box (Segregation resistance)	ratio	0.82	0.80-1.00

EXPERIMENTAL WORK

For evaluating the basic compressive strength of the SCC required number of standard cubes of size 150mm specimens size were casted for 5 different mixes, as shown in table 4, and 5 cubes were separately cast with 12mm diameter ribbed Fe-415 inserted in the fresh concrete, such that embedded length is 90mm, which is constant for all mixes. Figure 1 shows standard cubes with embedded length. Table 5 shows the compressive strength and bond strength of these mixes, and also the specimen's mode of failure.

Table 4. Mixes used for the experimentation and their abbreviations

Mix	Abbreviation of the Mix
M0 SF	Mix with 0.0% of the steel fiber
M2 SF	Mix with 0.2 % of the steel fiber
M4 SF	Mix with 0.4 %of the steel fiber
M6 SF	Mix with 0.6 %of the steel fiber
M8 SF	Mix with 0.8 % of the steel fiber

Table 5 The 28 day compressive and bond strength values for the mixes

Mix	The compressive strength in MPa	The bond strength in kN/mm	Mode of failure
M0 SF	44.50	1.32	splitting
M2 SF	49.82	1.59	Pull-out
M4 SF	54.15	1.85	Pull-out
M6 SF	60.74	2.38	Pull-out
M8 SF	68.50	2.65	Pull-out

Fig 1 indicates the variation of the 28 day compressive strength of steel fiber SCC, and fig 2 shows the variation of bond strength for those mixes.The embedded length is 7.5 times the steel bar's diameter. All of the steel bars are 700mm long, allowing these to be easily tested in the Universal Testing Machine using the usual pull-out testing procedure. Fig 3 shows with12mm diameter steel bar with the embedded length is 90mm and fig 4 shows the experimental setup for evaluating the bond strength in a triple blended SCC cube.

The slip of the 12mm steel bar "δ" is calculated by

$$\delta = \delta_l - \delta_p$$

δ_1 is deflection reading in the dial gauge placed between the platens of the universal testing machine

δ_p is 700mm steel rod deformation, δ_p =PL/ AE

P is the applied load at the corresponding dial gauge reading,

L is gauge length of the steel rod (700mm)

A cross sectional area of the steel road (diameter is 12mm)

E_s Young's modulus of the steel; E=2.0 x 10^5 MPa

$$f_{cc} = 2.463(x) + 44 \text{------------------------} equation(1)$$

$$R^2 = 0.9525$$

Here "f_{cc}" is bond strength in MPa and x is percentage of steel fiber.

The percentage of the compressive strength is increased by 54 due to presence of 0.8 percentage the steel fibers.

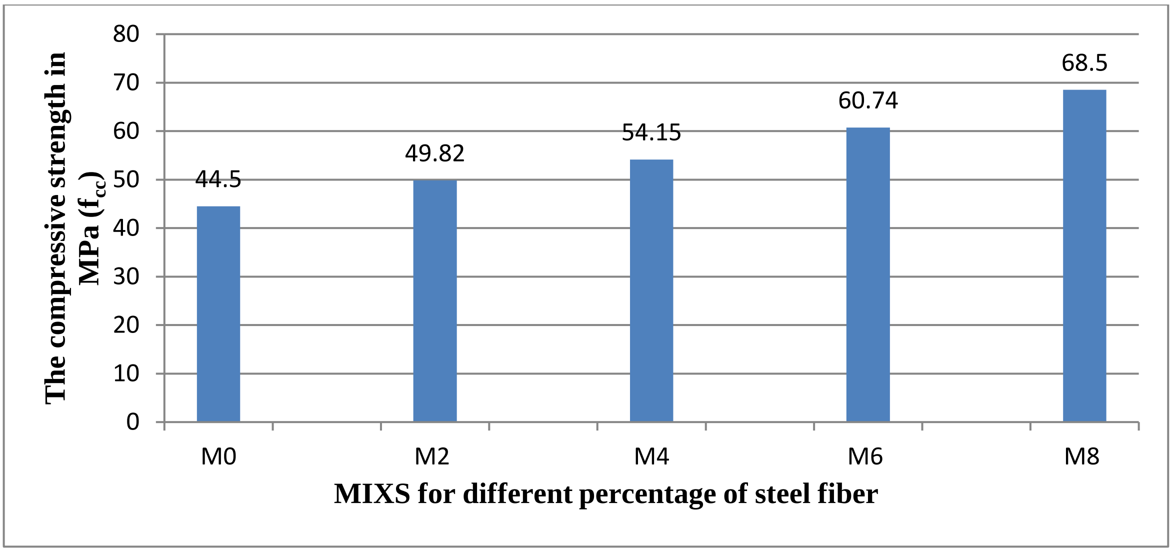

Fig 1. 28 day compressive strength for the mixes with different percentage of steel fibers

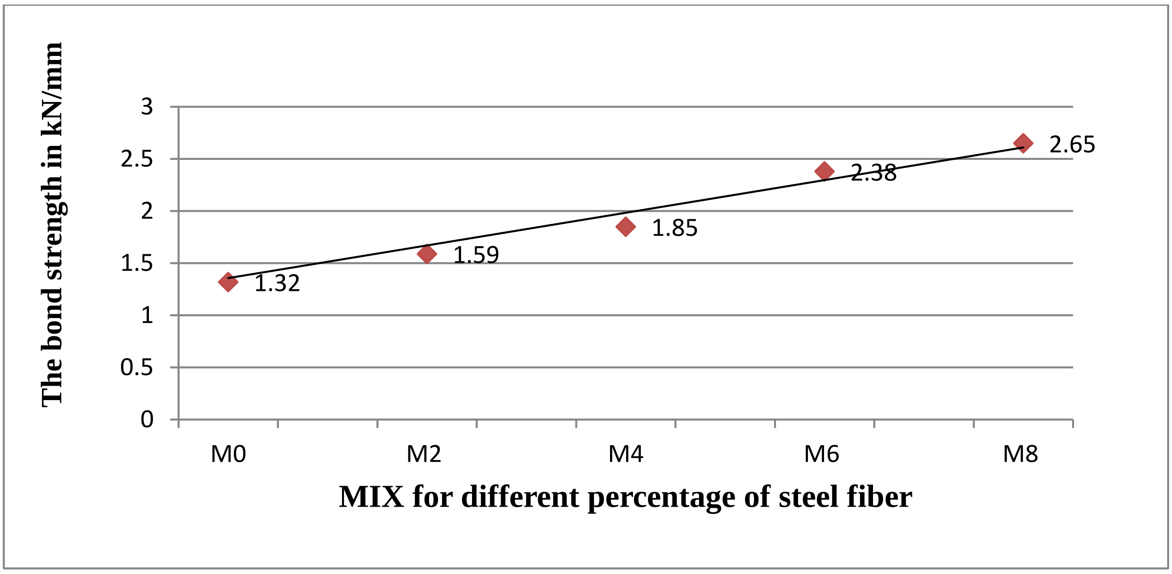

Fig 2. 28 day Bond strength for the mixes with different percentage of steel fibers

$$\tau = 0.1567(x) + 1.2 \text{---------------------} \textit{equation (2)}$$

$R^2 = 0.9719$

Here "**τ**" is bond strength in MPa and x is percentage of steel fiber.
In the above equations 1 and 2, R^2 value is within the acceptable limit (R^2>0.95).

The percentage of the bond strength is increased by more than 100 due to presence of 0.8 percentage the steel fibers.

<table>
<tr><td></td><td></td></tr>
<tr><td>Fig 3. Cubes with12mm diameter steel bar with the embedded length is 90mm</td><td>Fig 4. Experimental setup for finding the bond strength</td></tr>
</table>

THE BOND STRENGTH:
The average bond strength (τ) between the steel rebar to the concrete is given by the equation,

$$\tau = \frac{P}{\pi\, d\, l}$$

P -The pull strength on the steel rod,
d- Diameter of the steel rod (12mm),
L-Length of the embedment (90mm).

To reduce the bearing plate's influence, a soft plastic hollow tube was used to break the contact between the steel bar 12mm diameter and concrete along the deboned length. Splitting failure of the concrete and pull-out failure of the steel rod is the failure modes. Concrete has failed due to splitting in this experiment for the mix M0 SF, whereas all other mixes were failed due to pull-out. The bond strength-slip relationship generated for various steel percentages is shown in fig 5.

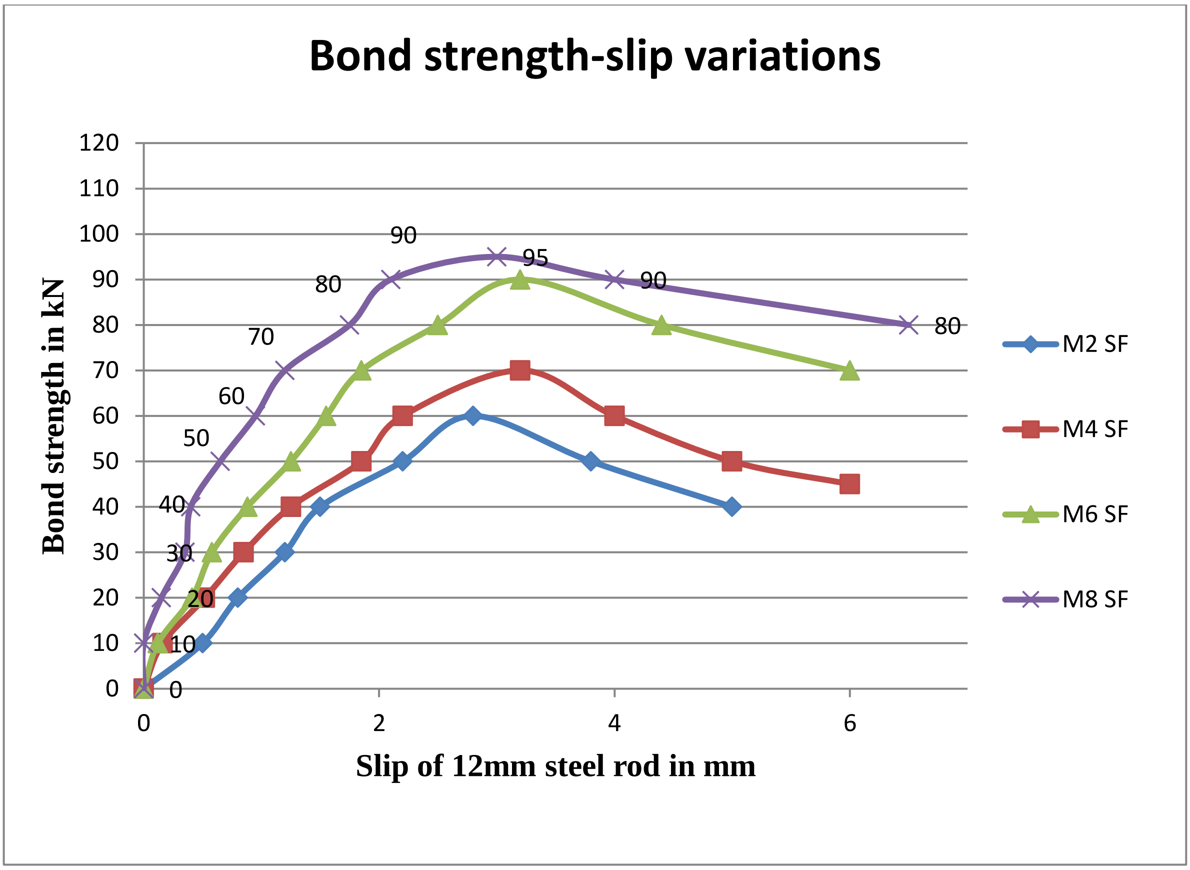

Fig 5. Variation of the bond strength and slip for different percentage of steel fibers in TBSCC.

CONCLUSIONS

The following conclusions have been drawn from the above experimental investigation of bond strength-slip of steel fiber triple blended self-compacting concrete (SFTBSCC):

1. The compressive and bond strengths of SCC specimens rise as the percentage of steel fibers increases due to fiber confinement around the concrete, which is modulated further by mineral admixtures.
2. The compressive strength is improved from 44.5Mpa to 68.50Mpa when the percentage of steel fiber is increased, while the bond strength (kN/mm^2) is increased from 1.32 to 2.65. It is evident that the steel fiber contributes more to the increase in bond strength than to the improvement in compressive strength.
3. The percentage of increase in bond strength of optimum percentage of steel fiber is 100 compared with no fibers SCC
4. Splitting is observed as the failure mode of the SCC without steel fiber. The mode of failure shifts to pull-out failure as the percentage of fiber content increases.
5. The concrete compressive strength and percentage of steel fiber, as well as the confining effect, define the specimen's mechanism of failure.
6. From 50kN to 90kN, the magnitude of the pull-out strength is increased in SCC from no fiber to 0.8 percentage of the steel fiber.

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