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FLEXURAL STRESS BLOCK FOR HYBRID FIBRE REINFORCED CONCRETE MEMBERS

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ABSTRACT: There is increase in fiber use in concrete for the structural applications from last few decades. There is demand of providing cost effective technique with this innovative material while offering improved structural properties. In this paper the simple flexural stress block is converted for hybrid fiber reinforced concrete.By using the standard experimental study of HyFRC, from the same model we found fiber index for HyFRC. Which can be used for HyFRC member design. The flexural model takes into consideration the fiber orientation with respect to loading axis and fiber distribution at the cracked section. The model is Elastic and perfect plastic model for compression and elastic constant post peak response of HyFRC in tension is considered. Hence a simplified flexural stress block for HyFRC to find the flexural capacity is proposed. The standard experimental study of HyFRC has been done. This experimental study is used for finding the fiber index for the HyFRC. The standard test on HyFRC in compression and flexure are carried out. The tests are conducted using constant aspect ratio (75) and volume fraction (1.25% and 1.75%) by varying steel fiber content and polypropylene fiber content. The fiber index is related with fiber parameters (Aspect ratio, Volume fraction) and concrete compressive strength. The compression tests are conducted on cubes and flexural test on prismatic beams. The analytical results are cross checked with experimental results. A design chart is also proposed to find the fiber parameters during flexural design of HyFRC rectangular member.

Author keywords: Flexural model; Concrete; Steel fiber; Polypropylene fiber; volume fraction; fiber index; Stress block.

1. INTRODUCTION

The concrete becomes weak due to formation of internal micro cracks, these cracks are responsible for failure of plain concrete. The fibers helps to arrest cracks and prevent the breeding of the cracks. The fibers basically bridge the cracks and stop propagation of crack. To find the benefits of adding fibers into concrete leading to an extension of the possible areas of its application in structural and civil engineering. The main cause for adding fibers to concrete is to boost the post-cracking behavior of the concrete, i.e., to raise its energy absorption potential and apparent ductility, and to stop crack breeding. Also, it helps to maintain the concrete integrity.

With the help of hybridization we can solve the problem of workability in fiber reinforced concrete (T.S. Thandavamoorthy et al. 2013). With the help of hybridization we can also improve other properties of concrete by mixing particular types of fibers. Experimental results shows Steel-polypropylene fibre reinforced concrete showed increase in flexural strength when compared with steel fibre reinforced concrete. The maximum gain in flexural strength was achieved for 0.3% polypropylene fibre. Thereafter increase in fibre content has marginally reduced the flexural strength. Stress-Strain relationship showed that there was marginal increase in strain. Stress-Strain relationship shows that strain increases as the percentage of polypropylene fibre increases. As fibre volume increases failure strain also increases, which leads to more area under the curve, thus enhancing the toughness of concrete. (Parveen et al. 2013). The flexural model for SFR concrete given by Harvinder singh used in this paper. The proposed model considers an elastic perfect-plastic model for compression and an elastic constant post peak response of SFR concrete in tension (Singh et al. 2014). The objective of this research effort is to check the existing model and use similar model for HyFRC design, so that this material can be used for structural design purpose. In the analytical equation if we put the combined volume fraction of the fibers and aspect ratio of steel fiber then we can find residual tensile strength with the help of which we can find flexural moment carrying capacity of the member.

Steel fibers of 1% and polypropylene fibers 0.036% were added individually to the concrete mixture as mono fibers and then they were added together to form a hybrid fiber reinforced concrete. Mechanical properties such as compressive, split tensile and flexural strength were determined. The results show that hybrid fibers improve the compressive strength marginally as compared to mono fibers. Whereas, hybridization improves split tensile strength and flexural strength noticeably(B Vibhuti et al. 2013). After study the so many papers on hybrid fiber reinforced concrete mechanical properties I try to analyze their result with analytical expression given in this paper and found it considerable.

A bilinear model for compression and a drop-down model for tension in flexure (i.e., elastic up to first cracking, drop down at cracking, and then plastic response) have been pro-posed by Soranakom and Mobasher (2007). The RILEM TC 162-TDF (Vandewall et al. 2002) has recommended a slightly different stress block for concrete in the tensile zone of beams. However, the proposed method and analytical expressions of these models are difficult to use in the routine practice. Flexural models for SFR concrete have also been proposed by researchers (ACI 1993; Barros et al. 2005; Chalioris 2013; Lim et al.1987;van Zijl and Mbeweb 2013). They are more reliable on empirical formulas. Some of the researchers offers rectangular stress block in compression which is against the stress strain distribution of fiber reinforced concrete.Some of the researchers proposed a rectangular stress block in tension with justification that the fibers are effective throughout the cross section in tension zone. But they also ignore the post peak response of the fiber reinforced concrete in tension. To improve the analytical results and provide a model actually comply with the material behavior used in this paper. The actual stress blocks in compression and tension obtained from experimental results used in this model. The weightage is given to various parameters like (volume fraction, compressive strength of concrete, fiber aspect ratio) to find the residual tensile strength.

A tri-linear model for the tensile zone is also proposed by (T. Soetens et al. 2014). Similar to the other models the analytical calculations are difficult to perform in routine design work. So in this paper we have made an effort to provide an existing model (singh 2014) for SFR concrete to HyFRC which is simple to use. Design chart also proposed to find the flexural strength with the help of analytical equations. I found the behavior of HyFRC similar to SFR concrete in terms of stress strain behavior for tension and compression from past studies and from my experimental studies.

At last we have proposed the model with analytical equations with some validations from past research's and found the considerable results from analytical expressions.

2. FLEXURAL STRESS BLOCK MODEL

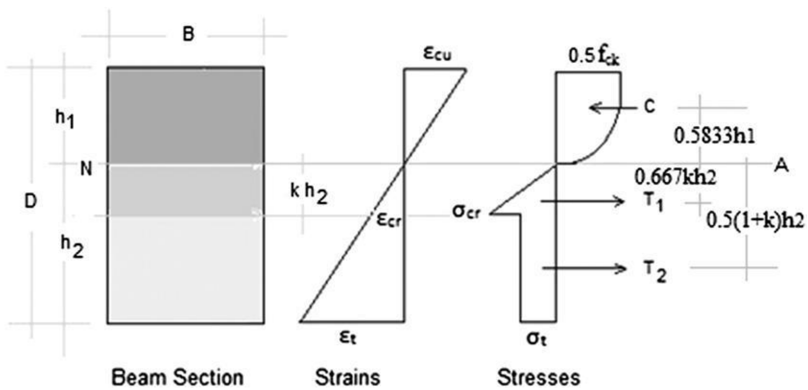

Fig. 1. Schematic diagram of SFR concrete section in flexure; stress and strain profile (Singh 2014)

At a section flexural capacity or ultimate moment carrying (M_u) of the section can be determined from equation below (Singh 2014).

$$\frac{M_u}{f_{ck}BD^2} = \left[0.24\left(\frac{2.38\beta}{1+2.38\beta}\right)^2 + 0.5\beta\left(\frac{1}{1+2.38\beta}\right)^2\right] \quad (1)$$

The constant $\beta = \left(\frac{\sigma_t}{f_{ck}}\right)$ = it is the fraction of tensile to compressive strength of hybrid fiber reinforced concrete.

Here

$$\frac{M_u}{f_{ck}BD^2} = R$$

$$R(1+2.38\beta)^2 = 1.36\beta^2 + 0.5\beta$$

$$R(1+5.67\beta^2+4.76\beta) = 1.36\beta^2 + 0.5\beta$$

$$R + 5.67R\beta^2 + 4.76R\beta = 1.36\beta^2 + 0.5\beta$$

$$(5.67R - 1.36)\beta^2 + (4.76R - 0.5)\beta + R = 0 \quad (2)$$

By putting the experimental value of the R we can solve above quadratic equation to find the Fiber index (β) of hybrid fiber reinforced concrete.

The expression for tensile stress in fibers given by (Singh 2014)

$$\sigma_t = 0.3V_f\frac{l}{d}\sqrt{f_{ck}} \quad (3)$$

3. EXPERIMENTAL TEST RESULTS

3.1 Compression Test Results

The cubes of volume fraction (1.25% and 1.75%) were test in compression. This volume fraction contains various volume fractions of steel and polypropylene fibers.

Table 1 Average value of stress in (MPa)

Set Type	Combined Volume(V_F) with PPF variation	Sample one Load (kN)	Sample two Load (kN)	Sample three Load (kN)	Average load (kN)	Compressive strength (MPa)
Set-0	0%	600	640	624	621.33	27.61
Set-1 (1.50%SF&0.25%PPF)	1.75% (0.15%)	794	815	839	816	36.26
Set-2 (1%SF&0.25%PPF)	1.25% (0.20%)	766	785	760	770	34.22
Set-3 (1.25%SF&0.50%PPF)	1.75% (0.30%)	656	664	675	665	29.55
Set-4 (0.75%SF&0.50%PPF)	1.25 % (0.40%)	556	546	575	559	24.84

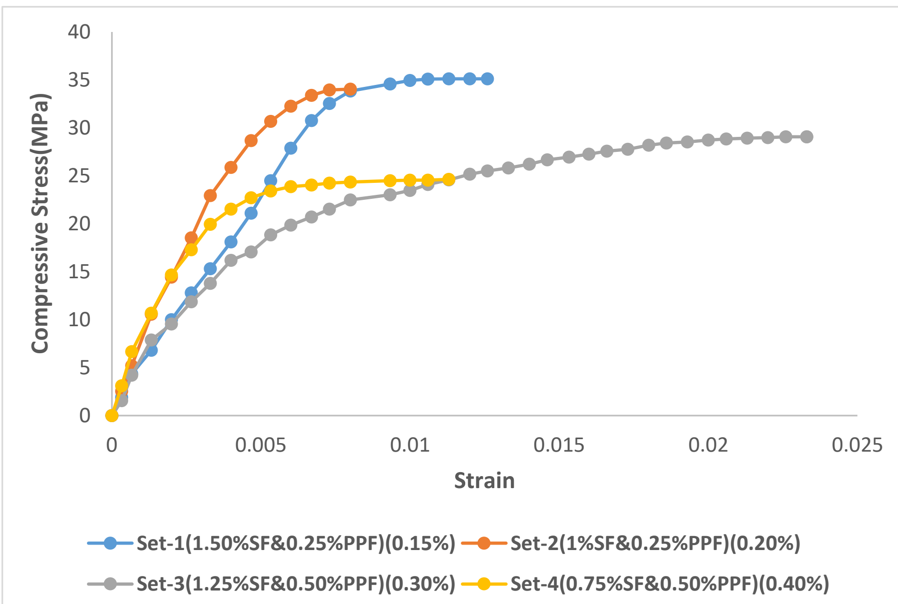

Fig 2 Stress Strain curves for various sets of hybrid fiber reinforced concrete.

3.2 Flexural Test Results

The flexural test Results for the 500X100X100 mm prismatic beam section are shown in tabular form for various sets of HyFRC.

Table 2 Ultimate load for hybrid fiber reinforced concrete for various sets.

Set Type	Combined volume fraction (with PPF Volume content to combined)	Sample1 Load (kN)	Sample 2 Load(kN)	Sample 3 Load(kN)
Set-0 (Conventional)	0%	4.5	5	5
Set-1(1.50%SF&0.25%PPF)	1.75% (0.15%)	15	14.7	15
Set-2(1%SF&0.25%PPF)	1.25% (0.20%)	11	10.5	10.5
Set-3(1.25%SF&0.50%PPF)	1.75% (0.30%)	14.5	14.2	14.5
Set-4(0.75%SF&0.50%PPF)	1.25% (0.40%)	7.5	7.3	7.5

4. DETERMINATION OF RESIDUAL TENSILE STRENGTH

Using Equation (2) which is having a relation of moment and fiber index. In that equation the experimental value of moment from flexure test is substituted to obtain the value of experimental fiber index.
From the literature (Singh 2014) it is reported fiber index β value is

$$\beta = \frac{\alpha V_f \frac{l}{d}}{\sqrt{f_{ck}}}$$

From the above expression we will find the constantα. The calculations are shown in tabular form.

Table 3 - Calculation of fiber index using three point loading flexure test

Set Type	Volume Fraction (V_F) percentage (with PPF content to overall (V_F))	Aspect ratio (l/d)	Fiber index (β) $\beta = \frac{\alpha V_f \frac{l}{d}}{\sqrt{f_{ck}}}$	Ultimate Load (P) kN	Moment at Centre (M=PL/4) kN-m	Fiber index Experimental value β	Constant (α)
Set -1	1.75% (SF1.5%& PPF 0.25%) (0.15%)	75	0.217964α	15	1.725	0.11820	0.5422
				14.7	1.6905	0.11528	0.5288
				15	1.725	0.11820	0.5422
Set -2	1.25% (SF 1%& PPF0.25%) (0.20%)	75	0.16023α	11	1.265	0.08389	0.5234
				10.5	1.2075	0.082496	0.5148
				10.5	1.2075	0.082496	0.5148
Set -3	1.75% (SF1.25% & PPF 0.50%) (0.30%)	75	0.24144α	14	1.61	0.14035	0.5813
				14.2	1.63	0.14261	0.5906
				14.5	1.66	0.14602	0.6047
Set -4	1.25% (SF 0.75% &PPF 0.50%) (0.40%)	75	0.188065α	7.5	0.8625	0.080920	0.4327
				7.3	0.8395	0.07841	0.4354
				7.5	0.8625	0.080920	0.4327
Avg. value							0.5204

From the above calculations we found the average value of constant α as 0.5204. By using this constant we proposed a design chat to find the value of fiber index and corresponding to which we can find moment coefficient and vice-versa.

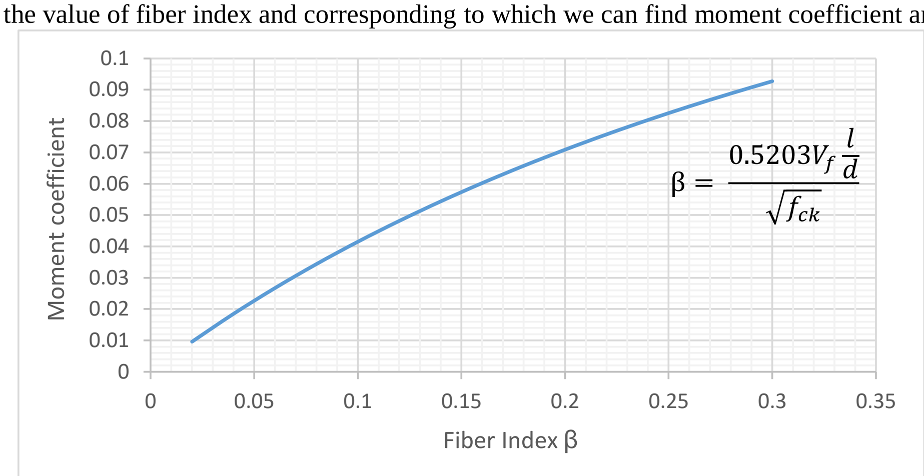

Fig 3 Design curve for HyFRC flexural Member

5. VALIDATION OF RESULTS

Konapure (June 2014) conducted experiment on HyFRC with volume fraction 1% (SF 0.70% and PPF 0.30%) on M25 grade concrete with specimen size 150X150X700mm. From the result the ultimate moment carrying capacity comes out is 2.98 K-Nm.
Using the data from his research
Analytical Value of Ultimate Moment Carrying Capacity
The fiber index value for HyFRC

$$\beta = \frac{\alpha V_f \frac{l}{d}}{\sqrt{f_{ck}}}$$

Putting values

$\frac{l}{d} = 71$

$V_f = 1\%$

$f_{ck} = 25$

$\alpha = 0.60$ From Table 5.4 for set-3.

We get value of $\beta = 0.06747$

Then from equation

$$(5.67R - 1.36)\beta^2 + (4.76R - 0.5)\beta + R = 0$$

By putting value of β

We get R = 0.02904

$\frac{M_u}{f_{ck} BD^2} = R = Moment\ coefficient$

From here putting the values of all parameters we get

$$M_u = 2.5\ KNm$$

6. NUMERICAL PROBLEM

A Beam Simply Supported over an effective span of 3m carries a super imposed load of 30kN at the Center. Design the beam using M20 concrete and Fe415 steel.

B = 250mm, D = 300mm.

Design the hybrid fiber reinforced section for same section of beam as above for hybrid fiber reinforced concrete l/d = 75 find the volume fraction.

Solution: Ultimate moment ($M_{ultimate}$) = 30*3/4 = 22.5kNm

Design of SFRC beam

$$\frac{M_u}{f_{ck} BD^2} = R = Moment\ coefficient = \frac{22.5 \times 10^6}{20 \times 250 \times 300^2} = 0.05$$

Putting Value in analytical equation and obtain fiber index Value

$$(5.67R - 1.36)\beta^2 + (4.76R - 0.5)\beta + R = 0$$

Solving we get

$$\beta = 0.125$$

And from equation

$$\beta = \frac{0.59 V_f \frac{l}{d}}{\sqrt{f_{ck}}}$$

We get

$$V_f = 1.26\%$$

0.30% of V_f = 0.3591%

Hence amount of Steel fiber required = 0.900×0.250×0.300×7850×3 = 15.91 kg

Amount of Polypropylene Fiber = 0.3591×0.250×0.300×0.91×10^3×3 = 0.735kg = 735gm

7. CONCLUSIONS

A flexural model has been suggested for the analysis of HyFRC concrete members. HyFRC can sustain large strain value before failure. Strain value increases as the fiber content increases. An analytical Model for calculating flexural strength of the HyFRC rectangular section is proposed. Simple mathematical equation for finding the flexural strength is presented which can be used easily by finding the value of fiber index from given moment or vice versa. The analytical model takes into account the effect of fiber parameter (Aspect ratio), Volume content and their random scattering in the mix. The experimental results are used to calibrate the analytical model. It was observed that polypropylene fiber content up to 0.30% gives good result but decrease in flexural and compressive strength was noted when the content was increased more than that.

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