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Evaluation of Workability and Cracking Pattern in Flexure of Steel Fibre Reinforced Concrete (SFRC)

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Abstract—*Concrete is a quassi-brittle material. The major failures that occur in plain concrete structures are sudden, leading to fatal accidents. Today 71,000 km of highways and expressways are in bitumen and only 40% of this conformed to quality standards. On the other hand concrete roads have a much higher average life cycle and also help save 15% in fuel consumption. Concrete composite roads are environment friendly and have a 50% longer life cycle and thus form a solution for today's need. There has been tremendous research in the field of performance characteristics of concrete. Many attempts have been previously made towards making concrete composite, more homogeneous and ductile material in order to decrease the problem of visible cracks. Using Fibres in concrete has significantly reduced the problem of sudden failure. It also works towards enhancing flexure strength in concrete composite. In this paper, workability characteristics and cracking patterns formed in different proportions of SFRC beam samples with varying proportion of Steel Fibre content have been analyzed.*

Keywords: *concrete, SFRC, Steel fibre, workability, cracking, flexure in concrete.*

1. INTRODUCTION

Concrete is a versatile material which can be cast into any desirable shape and structural form. It has conveniently stood the test of time by showing exuberant durability and strength characteristics. Though there is no doubt in its strength properties, micro cracking and low tensile strength are some of its shortcomings which are eventually faced by all concrete forms.

Micro cracking: Shrinkage and external loading causes stress concentration at the aggregate-paste interface due to difference in ttheir elastic modulus resulting in propagation of micro cracks continuing upto stress to strength ratio of 0.7-0.9,after which cracks open through the mortar forming continuous crack patterns.

Low tensile strength of concrete:

IS 456:2000[11] establishes that tensile strength of ordinary concrete varies from 7-10% of its compressive strength. Even a v small flaw leads to failure of concrete specimen in tension. Therefore its necessary to arrest these cracks by providing a reinforcement which can take tensile stresses that come over concrete structure. Material used as reinforcement should be such that it should have high modulus of elasticity, same thermal modulus of expansion and contraction as concrete so that no extra stresses are induced, should be cheap and abundant. Steel is the most apt material fulfilling all the above requirements and hence has been in use as structural reinforcement in concrete. Cheaper materials like bamboo, glass etc have also been tried as a reinforcing material but with little success.

Though reinforcing concrete with steel bars takes the tensile loads adequately, it still fails to capture the cracks developed in concrete structure. Adding steel fibres to concrete helps reduce this problem significantly and also rectifies the static and dynamic properties towards improvement. Such a composite is generally known as Steel Fibre Reinforced concrete (SFRC).

B.L. KARIHALOO, 1995[1] characterized micro cracks being responsible for variation in brittle behavior from linear elastic fracture mechanics (LEFM).He highlighted that concrete materials show prior strain hardening before attaining ultimate tensile capacity which is similar to behaviour of high strength metallic materials. In early times cracks were modelled based on wide sections of beams. The local definition of curvature for crack modelling by using block sections was defined first by Gelfi and Giurani(1982) [3][10].In fictitious model developed by (Hillerborg et al.,1976) [2][8],the flexural strength capacity of concrete section decreases exponentially with increasing crack width. This means that the concrete is capable of bearing flexural stresses only till first macro crack develops within its cross section. Once the crack propagates, the concrete failure is majorly brittle. This may thus lead to instantaneous failures of structures not giving any time to repair the crack or the structural component. Hsu et. Al [4][5]in his research proved that micro cracks form on the surface of coarse Aggregate particles existing even in zero load condition. On commencement of loading these cracks propagate along the Aggregate boundaries forming macro cracks.

2. NATIONAL AND INTERNATIONAL ADVANCEMENTS

In recent years many attempts have been made to quantify the microstructure of concrete in order to provide a significant solution to crack initiation and propagation. In their research, (Bache and Vinding; darter 1990) [3] proved that accumulation of damage in concrete is not linear.

The first structural use of steel fibres was done to make parking garage in London's Heathrow Airport[6]. The composition was 3% by weight of steel Fibre (0.645 mm dia, 2.54 cm long),forming the first attempt to install crack free concrete slab.

In 1980, NCBM (National Council for Cement and Building) [7] undertook an experimental project in New Delhi on SFRC Pavements in collaboration with IAAI.A section of 400mm thick plain cement concrete pavement was placed over a 150mm thick WBM base as reference for Fibre reinforced pavement slab(300mm SFRC Pavement , Fibre volume 106 kg/m^3).NCBM reported that the SFRC slab with lesser thickness than PCC section showed no crack formation. It further recommended use of SFRC with reduced slab width up to 40% of recommended PCC.

The research done so far conveniently shows that there is a reduction in crack propagation rate on addition of steel Fibres.

Thus a need arises of finding efficient ways for arresting these cracks and giving substantial time to repair the existing facilities which will further reduce the restructuring expenditure and accidental damage losses. For this steel as a reinforcing material has been used for ages ,wherein steel takes all the tensile stresses and allows for ductile failure in otherwise brittle concrete structure. But due to its expensive characteristic, its generally not used in structures where the major component of expected stresses are compressive in nature. For such structures the problem of crack arresting can be efficiently tackled by using Fibre as a part of concrete mixes. The most versatile and widely accepted material for Fibres is mild steel due to its high ductility and comparatively easy manufactured availability.

Though many reference design codes are available, yet use of steel Fibres in developing nations like India has been limited in infrastructure projects. Thus there a need to investigate the properties of locally available steel Fibres so that their implementation can be done in Indian infrastructure development projects.

3. OBJECTIVES

In this paper, the variation of mix properties on variation of Fibre content has been analyzed. Further Post crack analysis of SFRC beams in flexure has also been performed by means of visual inspection technique.

4. MATERIALS AND METHODS

Materials used:

Cement: Ordinary Portland cement of Grade 53.

Type of cement	IS Code	Fineness m^2/kg (min)	Initial Setting time (min)	Final Setting time (max)	Soundness (Le Chatelier) (mm)
OPC 53	12269:1987	225	30	600	10

Table 1: showing properties of cement used in experimentation

Sand: Sand in Zone 2 having following gradation has been used.

Coarse Aggregates: of nominal size 10mm and 20mm have been used. The Gradation is specified below

Table 2: Shows gradation of all in aggregates used for experimentation.

IS Sieve Size (mm)	Cumulative % of Passing by Weight((M-40)					
	C.A		F.A	Combined All in aggregates Passing %	Spec. Limit for 20 mm Nominal size Aggregates	
	20 mm	10 mm				
	65%		35 %	100%	Lower	Upper
40	100	100	100	100	100	100
20	99	100	100	100	95	100
10	2	63	100	60	-	-
4.75	1	4	92	34	30	50
2.36	0	2	77	28	-	-
1.18	0	0	66	23	-	-
0.600	0	0	55	19	10	35
0.300	0	0	41	14	-	-
0.150	0	0	18	6	0	6
Coarse Aggregate	40%	60%	-	-	-	-

C.A= coarse aggregate, F.A=fine aggregate

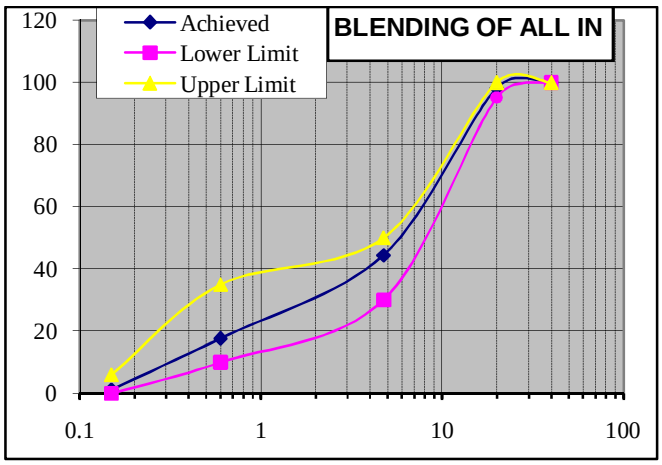

Fig. 1: Shows gradation in graphical form.

Steel Fibres: Three dimensional, made of mild steel with aspect ratio 60 and having hooks at ends have been used. The physical properties of these Fibres have been described below.

Table 3: Shows physical properties of steel fibres used in present study.

Material of Fibre	Mild Steel
Mechanism of Mechanical Anchorage	hooks at ends to provide optimal pullout resistance
Impact strength	High
impact strength	High
L/d ratio	60
Special Characteristic	Glued Fibres to avoid Balling

Experimentation

A mix of M40 grade (Designed as per IS 10262:2009), has been prepared with material properties as specified above. The Steel Fibres were added to the mix in small proportions during mixing to form homogeneously mixed concrete composite. Four design mixes were separately mixed, M1=Plain M40 mix, S1=M40 mix with 0.5 % Fibre content by volume.,S2=M40 mix with 1% Fibre content by volume,S3= M40 mix with 1.5% Fibre content by volume. The slump test was performed on this concrete to check the varying workability with increasing proportion of Fibre content by volume.

Thereafter 6 beams of each mix were cast .For each mix, three batches were prepared. The value of slump for each batch is recorded. The beams were tested under flexure in Four Point Flexure Testing Machine after 7 days of curing. Complete immersion in water was adopted as curing technique.

The crack arrest patterns formed after first crack load were observed and analyzed by means of visual inspection.

5. RESULTS AND ANALYSIS

(A) Workability

It was seen that workability of concrete reduced on increasing the Fibre content. As shown from following table, the value of slump decreased from 80 mm at no Fibre content to 10mm at 1.5 % Fibre content.

Table 4: Shows the value of slump obtained for various mixes as a measure of workability.

Specimen Name	M1	S1	S2	S3
Slump(mm) Batch 1	80	65	42	10
Batch 2	76	62	44	16
Batch 3	84	57	39	12
Average	80	61.33	41.66	12.67

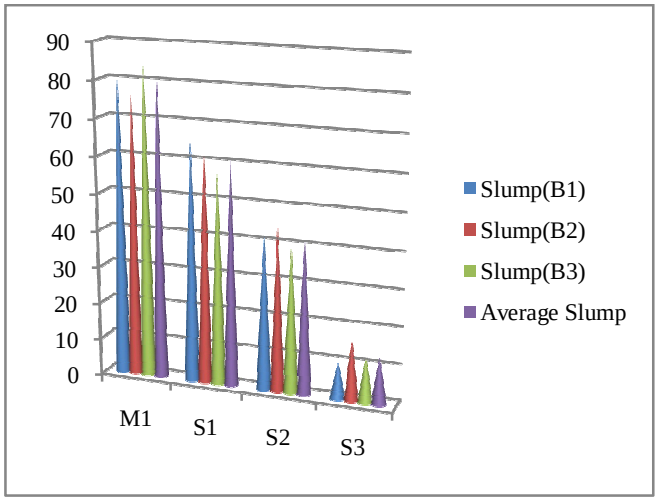

Fig. 2: Derives a comparison between values of slump (mm) obtained of all the mixes.

(B) Cracking Patterns in Bending

The beams tested on four point flexure testing machine is shown. Each sample was subjected to load corresponding to 3mm deflection to obtain comparable results. In M1, the beam breaks instantly clearly depicting brittle nature of concrete mix. In S1, the beam doesn't fall after first crack load, it sustains cracks up to certain load fraction before completely collapsing. This shows that beam has achieved a partial ductile behavior due to addition of fibres. The results show further improvement in crack arresting mechanism with increasing fibre content.

M1=Plain M40 Mix

Image 1: Shows cracked beam M1 after first crack loading.

Comment : No deflection is seen, Brittle Failure observed

S1=M40 mix with 0.5 % Fibre content by volume

Image 2: Shows cracked beam S1 after first crack loading up to 3mm deflection.

Comment : Partially Brittle Failure

S2=M40 mix with 1% Fibre content by volume

Image 3: Shows cracked beam S2 after first crack loading up to 3mm deflection.

Comment : Ductile strength comes into play, the sample doesn't fail abruptly, the cracks are more concise.

S3= M40 mix with 1.5% Fibre content by volume

Image 4: Shows cracked beam S3 after first crack loading up to 3mm deflection.

Comment: better ductile properties, lower cracking, better load energy absorption on reverse loading

6. CONCLUSION

From cracking patterns it's observed that increasing the Fibre content increases the crack arrest mechanism in concrete composite even after failure. The plain concrete samples showed completely brittle failure. The sample consisting of 0.5% Fibre content performed a bit better but still could not reach all the corners of concrete composite due to limited availability. This problem was solved better in 1% Fibre content samples.1.5% Fibre content samples formed excessively rich mix which though improved the crack arrest mechanism but was ultimately difficult to handle and is not recommended. Analysis of images 1,2&3 shows that though increasing the Fibre content in concrete clearly increases the crack arrest mechanism, but concrete with higher volume of Fibre content becomes difficult to work with due to reduced workability.

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