Effect of Steel and Polypropylene Fibre on the Tension Stiffening of Ultra High Performance Concrete

Lijina Thomas, J. S. Jithin

Abstract: Tension stiffening is one of the important properties of concrete that reduces the strain in steel and leads to reduction in width and spacing of cracks in reinforced flexural members. The tensile strength of concrete between cracks in a reinforced concrete member represents the tension stiffening effect. Several attempts have been made in the past to improve the tension stiffening effect of conventional concrete by adding short discrete fibre in the matrix, but a few studies have been conducted to find out the tension stiffening effect of steel fibre and polypropylene fibre on the cracking behaviour of ultra high performance concrete. So this study investigates the effect of metallic fibre (crimped steel) and non metallic fibre (polypropylene fibre) on tension stiffening characteristics and the cracking behaviour of ultra high performance concrete. The variables included in this study are volume fractions of crimped steel fibre (0.25, 0.5%, 0.75% and 1%) and polypropylene fibre (0.1, 0.15 and 0.2) The optimum content of steel fibre and polypropylene fibre and their effect on the tension stiffening and cracking behaviour is finding out by studying the load deformation behaviour, crack width, crack spacing and crack pattern of the prismatic tension specimen subjected to uniaxial tension.

Index Terms: Load deformation behaviour, Tension stiffening bond factor and Ultra high performance concrete

I. INTRODUCTION

Although concrete is the most universally used material in building there are still some limitations to its use, such as tensile strength and brittleness. Ultra high performance concrete is a type of concrete (UHPC), may able to overcome these concerns. The concept of UHPC was first developed by Richard and Cheyrezy and was produced in the early 1990s at Bouygues laboratory in France [1, 2]. UHPC consists of a combination of Portland cement, fine silica sand, silica fume, quartz flour, high-range water reducer and discontinuous internal steel or organic fibers. Depending on the application, different combination of these materials may be used [3, 4].Addition of fibres improves the engineering properties of concrete like ductility, post crack resistance, energy absorption capacity etc.Thus addition of fibres in cement concrete matrix bridges these cracks and restrains them from further opening.UHPC offers more than 150MPa compressive strength and greater than 5Mpa post cracking tensile strength [1, 5].Compressive strength and modulus of elasticity of UHPC was 3 to 4 times greater than normal strength concrete according to Mohamadreza S. studies [2]. Hannawi K. (2016) investigates the effect of adding different type of fibres(steel, mineral and synthetic fibers) on the microstructure and the mechanical behaviour of UHPC. Results show that the fibre has a relatively slight influence on the compressive strength and elastic modulus of concrete except for steel fibre which improves the strength because of its intrinsic rigidity.Among the steel fibre crimped and twisted fibres gives better performance. The addition of steel fibres generally contributes towards the improvement of an energy- absorbing mechanism whereas the non-metallic fibre such as polypropylene fibre plays a vital role in delaying the formation of micro cracks [6]. Because of its weakness in tension, concrete is reinforced by steel bars which can carry tensile forces across the cracks after tensile failure of concrete. With tensile reinforcement, concrete can transfer tensile stresses across cracks as the result of bond action between concrete and reinforcement. Consequently, concrete can still carry a part of tensile force even if cracks are induced into RC element and tensile stress carried by RC element as a whole becomes superior to that carried by only bare steel bars at the same deformation. This phenomenon is called tension stiffening effect. Due to tension stiffening effect of concrete, the free elongation of steel under tension is prevented. This led to reduction in crack width and improves the serviceability of the structure [8, 11]. Tension stiffening would prevent free elongation of steel under tension and hence reduces the crack width in concrete. Finer cracks would prevent the entry of moisture and CO into the cracks and thus prevents corrosion and carbonation in concrete. There are many studies in UHPC with micro and macro steel fibres of different type and aspect ratio. The tension stiffening effect can be used as post-cracking stress-stain response of the reinforced concrete. Several attempts have been conducted to find out the tension stiffening effect of conventional and other concrete by adding short discrete fibres in the matrix. But only few studies have been conducted to find out the tension stiffening effect of ultra high performance fibre reinforced concrete. The effect of adding steel fibres (crimped steel fibre) and polypropylene fibre on the cracking behaviour of UHPC was investigated in this study. The main aim of this study is to investigate the effect of metallic (crimped steel fibre) and non-metallic (polypropylene fibre) on the tension stiffening characteristics and the cracking behaviour of Ultra High Performance Concrete (UHPC).

II. EXPERIMENTAL PROGRAM

The experimental work consisted of casting and testing reinforced concrete prismatic tension members with dimensions of 60 x 60 mm x 600mm and it was axially reinforced with a 10mm diameter high yield strength deformed steel bar with a reinforcement ratio of 2.18%. The reinforcement bar was extended 200mm on either side for proper gripping in the testing equipment as shown in figure 1.

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The variable includes the volume fraction of crimped steel fibres (0.25%, 0.5%, 0.75% & 1%) and volume fraction of polypropylene fibres (0.1%, 0.15% & 0.2%).

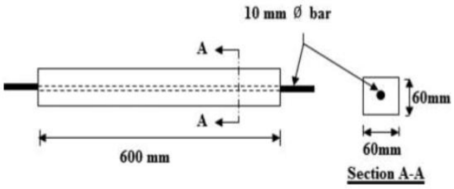

Fig 1. Specimen details

A. *Material Used*

Ordinary portland cement (53 grade) conforming to IS: 12269-1987 (reaffirmed 2004) [13], 75% of fine aggregate passing through 600µm and retained on 300µm, 25% of fine aggregate passing through 300µm and retained on 150µmconforming to [383- 1970 (Reaffirmed 2002) [14],IS 2386 (Part III) - 1983 (Reaffirmed 2002)[15]], silica fume, glass powder and superplasticizer were used for the investigation. The mix proportion for UHPC is selected from the optimum mix obtained from the trial mixes conducted in previous study [12]. The cube compressive strength and prismatic specimen (60mm x 60mm x 600mm) for uniaxial tension test is to be casted and cured in water. The details of tested specimens and variables are given in table 3

Fig 2. Steel fibres

Fig 3.Polypropylene fibres

TABLE I. PROPERTIES OF FIBRES

Type of fibre	Crimped steel fibre	polypropylene fibre
Length, mm	30	12
Diameter, mm	0.5	0.8
Aspect ratio	60	15

TABLE II. DETAILS OF SPECIMENS AND VARIABLES

Specimen designation	Volume fraction of fibres %		No. of Specimens
	Steel	Polypropylene	
C	0	0	3
$S_0P_{0.10}$	0	0.10	3
$S_0P_{0.15}$	0	0.15	3
$S_0P_{0.20}$	0	0.20	3
$S_{0.25}P_0$	0.25	0	3
$S_{0.50}P_0$	0.50	0	3
$S_{0.75}P_0$	0.75	0	3
S_1P_0	1	0	3

B. *Testing of Specimens*

The specimens of each steel fibre reinforced UHPC mixes and polypropylene fibre reinforced UHPC mixes were tested under uniaxial tension in a Universal Testing Machine (UTM) with a capacity of 1000 kN.The axial elongation of the specimen was monitored by a Linear Variable Differential Transducer (LVDT). The location of each crack is to be marked on the specimen immediately after its appearance during the test. The crack spacing was measured along the centreline of the front face of specimen. Crack widths were measured along the specimen at regular intervals using a crack detection microscope. The load-control condition and contained until yielding occurred. One longitudinal reinforcement bar was also tested under the same loading condition to obtain the response of the bare bar. For each mix, three specimens were cast and test. The average values of three results are to be taken as the final value. Figure 4 shows the test setup.

Fig. 4. Casting of prismatic specimen

Fig 5. Test setup

III. RESULTS AND DISCUSSIONS

A. *Load Deformation Behaviour*

The axial load-deformation behaviour of the specimen was obtained by plotting the axial load against member strain. The load deformationbehaviour ofall the specimens was linear up to first crack load. All the specimens showed a higher initial stiffness compared to bare steel bar. Figure 5 & 6 shows the axial load-deformation behaviour of different steel fibre and polypropylene fibre reinforced UHPC specimens. All the fibre reinforced specimens showed a higher stiffness compared to normal UHPC and bare steel bar. Also there was a considerable increase in the stiffness with increase in fibre content. Maximum stiffness was observed in that specimen with steel fibre content of 0.75% and polypropylene fibre content of 0.15%. Specimen with steel fibre content of 0.75% exhibited the maximum first crack load and yield load. The specimen with 0.75% steel fibre content to have higher number of smaller cracks than to have smaller number of wider cracks compared to other steel fibre reinforced UHPC mixes. Similarly among the polypropylene fibre reinforced UHPC mixes 0.15% polypropylene fibre content mixes have higher number of smaller cracks. It may be due to the ability of UHPFRC to carrying tensile stresses at the cracks and the between cracks.

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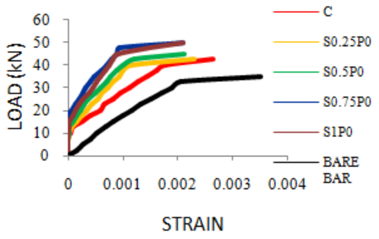

Fig 6. Load deformation behaviour of steel fibre reinforced UHPC

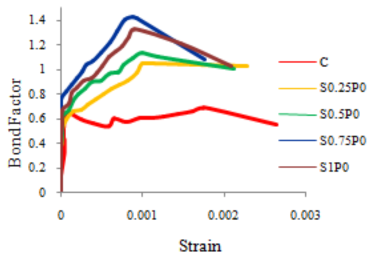

Fig 8. β of steel fibre reinforced UHPC

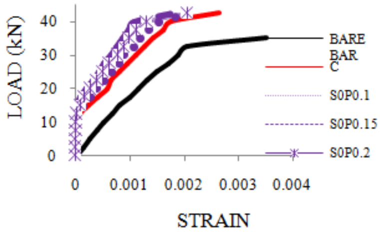

Fig 7. Load deformation behaviour of polypropylene fibre reinforced UHPC

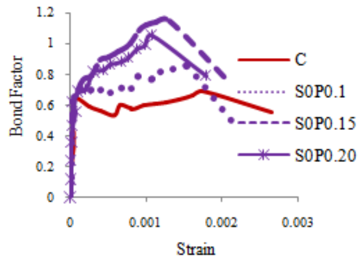

Fig 9. β of polypropylene fibre reinforced UHPC

TABLE 4.TEST RESULTS

Designation	First crack load (kN)	Yield load (kN)	Crack spacing (cm)	No. of cracks
C	17.5	40.69	9	6
$S_0P_{0.10}$	18	42.02	7.1	8
$S_0P_{0.15}$	21.4	42.33	4.94	9
$S_0P_{0.20}$	20.2	42.1	5.92	7
$S_{0.25}P_0$	19.2	41.87	5.38	8
$S_{0.50}P_0$	20	44.68	5.2	10
$S_{0.75}P_0$	23.2	49.8	4.59	12
S_1P_0	22	49.6	5.35	11

B. Tension stiffening bond factor (β)

The tension stiffening contribution of each mixture is represented by the tension stiffening bond factor, which is calculated by dividing Pcm with Pcr, where Pcm is average load carried by cracked concrete and is obtained by subtracting the bare steel response from the specimen responses, and Pcr is the load carried by concrete at first cracking [[11].

The above figure 8 & 9 shows the variation of tension stiffening bond factor of UHPC mix having different volume fractions of steel fibre and polypropylene fibre. An increase in the tension stiffening bond factor indicates an increase in the stiffness of the member. From the graph, all fibre reinforced specimens showed considerable tension stiffening effect compared to UHPC specimen. Also the bond factor increases with increase in the volume fraction of fibres up to optimum percentage variation of fibre content. The maximum tension stiffening bond factor was exhibited by the specimen with 0.75% steel fibre and 0.15% polypropylene fibre content. It may be due to the balling effect of fibres S_1P_0 and $S_0P_{0.2}$gives lesser bond factor values than $S_{0.75}P_0$ and $S_0P_{0.15.}$ The average tensile strength in concrete increases even after the first crack, which leads to enhanced values of bond factor.

C. Crack pattern, crack spacing and crack width

Fig 10. Crack pattern of steel fibre reinforced UHPC

Fig 11. Crack pattern of polypropylene fibre reinforced UHPC

Figure 10 & 11 shows the crack pattern of steel fibre and polypropylene fibre reinforced UHPC prismatic tension specimens subjected to uniaxial load. The first transverse crack appeared near the middle portion of the specimen.

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The first crack widened and additional cracks appeared as the load increased. On all sides of the specimen the development of cracks was not uniform. Also the longitudinal splitting cracks were appeared with transverse cracks. The number of transverse cracks increased and the spacing of cracks decreased with increasing fibre content. Maximum number of transverse cracks was obtained for UHPC specimen with 0.75% steel fibre and 0.15% polypropylene fibre content compared to other fibre reinforced UHPC specimens.

IV. CONCLUSION

The tension stiffening and cracking behaviour of UHPC and fibre reinforced mixes were studied in this work. An optimum steel fibre and polypropylene fibre volume fractions were found out based on the tension stiffening and cracking behaviour of specimens subjected to uniaxial tension test. Based on the results of this study, the following conclusions are made:

1) In steel fibre reinforced UHPC mix, the maximum tension stiffening and yield load is obtained for the mix with 0.75% steel fibre content, it may be due to good confinement effect of fibres and ability of UHPFRC to carrying tensile stresses at the cracks.
2) 0.75% steel fibre content increases the yield load, compressive strength and first crack load by 18%, 3% and 25% respectively than normal UHPC mix
3) In polypropylene fibre reinforced UHPC mix, the maximum tension stiffening and yield load is obtained for the mix with 0.15% polypropylene fibre content, it may be due to good confinement effect of fibres and ability of UHPFRC to carrying tensile stresses at the cracks.
4) 0.15% polypropylene fibre content increase the yield load, compressive strength and first crack load by 4%, 1% and 18% respectively than normal UHPC mix.

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