STEEL FIBRES VERSUS STIRRUPS AS SHEAR REINFORCEMENT FOR ULTRA-HIGH PERFORMANCE CONCRETE BEAMS – AN EXPERIMENTAL INVESTIGATION

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Abstract

The shear strength and shear failure behavior of steel fibre-reinforced ultra-high performance concrete beams is investigated. Longitudinally reinforced ultra-high performance concrete beams with steel fibres and others with stirrups as shear reinforcement are tested to failure. The concrete strength of the tested beams ranged from 130 to 140 MPa. The extension of the existing design equations to such high concrete strengths is doubtful. Moreover, the effect of adding steel fiber on the shear behavior adds another dimension to the problem. In this research the feasibility of using steel fibers instead of traditional shear reinforcement is investigated. The minimum web reinforcement recommended by several codes of practice is intended to maintain adequate strength and ductility after the formation of diagonal cracking and to contain widening of the diagonal cracking. However, the expressions for estimating the minimum shear reinforcement in the codes of practice are based on the experimental data base observed on testing of normal strength concrete beams. Furthermore, no guidelines are available on using steel fibers as a possible alternative to the minimum amount of stirrups required by the various codes. The behavior of the tested beams is assessed based on the results of crack patterns, load at first cracking, ultimate shear capacity, and failure modes. The test results indicate that the fibers have significant influence on the shear resistance and provide results equivalent to beams with stirrups as shear reinforcement.

Keywords: Shear Failure, Steel Fibres, Ultra-High Performance, Concrete Beams, Stirrups Reinforcement

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1. Introduction

Due to the high compressive strength and ductility of steel fibre reinforced ultra-high performance concrete (UHPC) more slender structural elements can be designed. Such applications lead to saving of dead weight, a reduction in sub-structure costs and minimize construction duration. The reduction in the size of the super- and sub-structure can lead to lower consumption of material and yield many tangible and sustainable benefits such as lower transport costs, ease of handling and lower consumptions of natural resources and energy [1]. One of the important design aspects of fibre reinforced concrete beams is that of shear for ultra-high performance concrete beam. In general, concrete is considered as a brittle material with a low tensile strength and shear capacity. The shear failure of reinforced concrete beam is a common concern for structural engineers as it often occurs with little or no notice. The addition of steel fibres to a concrete mixture enhances the shear and toughness of concrete member. It is well established from many previous studies that the addition of steel fibres in concrete significantly increases its shear strength. It is difficult, however, to accurately predict the increase in shear strength as the interaction between the steal fibres and the concrete matrix is complex [2]. Most Design codes provide requirements for minimum shear reinforcement for concrete beam strength up to 69 MPa. The use of ultra-high strength concrete and fibre raised some doubts on the validity of the equations given for minimum shear reinforcement, since these equations were based on tests of beams made of normal strength concrete and stirrups. Most of the expressions given in codes for minimum shear reinforcement are empirical in nature and not based on well-established, accepted criteria. Therefore, the requirements are revised frequently whenever additional new data become available. It is generally agreed that reinforced beams should have adequate shear reinforcement to prevent sudden and brittle failure after formation of the diagonal crack, and also to keep crack width at an acceptable level. However, there is no established quantitative criteria for reserve strength required beyond cracking strength and limits for the crack width. The minimum shear reinforcement is also required to provide somewhat ductile behavior prior to failure [3].

2. Research Significance

Required shear reinforcement in the codes aims to provide adequate reserve capacity and reasonable ductility beyond diagonal cracking and to minimize crack width. The equations given for minimum shear reinforcement are based on previous experimental data from beams of normal strength concrete without steel fibres. Limited test data is available for high-strength and ultra-high performance concrete with steel fibres [4].

In this paper, the feasibility of using steel fibres as a practical shear reinforcement and as a replacement for ordinary stirrups is investigated. The shear behaviour of beams with steel fibres are compared of those with stirrups in terms of crack patterns, failure loads and ductility.

3. Experimental Program

In order to investigate the feasibility of using steel fibres as a practical shear reinforcement, an extensive experimental program of twenty three third scale reinforced concrete beams has been performed. All tested beams were of rectangular cross section, 150 mm wide and 250 mm deep with the same total length of 2000 mm, as shown in Fig (1). They were simply support at span of 1800 mm apart. The parameters investigated are the shear reinforcement type and ratio. The shear span-to-effective depth (a/d) ratio was kept at 3 for all tested beams [5&6]. In this paper, the results of only 12 beams will be presented. All beams are reinforced with 2 ø 32 longitudinal bars (Fig. 1). In all specimens, the ends of the longitudinal bars were bent to provide better development of the bars beyond the support [7].The beams are divided into 3 groups. Group no. 1 contained 4 beams with different stirrups ratio as shown in Fig. 1(a). Group no.2 and 3 (Fig. 1(b)) contained steel fibres as shear reinforcement. The fibre volume ratio for these groups were 0.50, 1.00, 1.50 and 2.00 %. The data for the tested beams are summarized in Table 1.

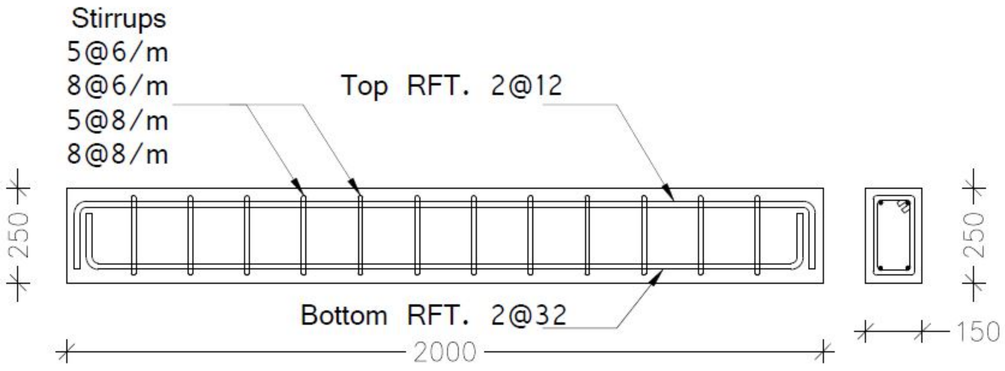


Fig 1-a: Dimensions and reinforcements of test specimens for Group no.1

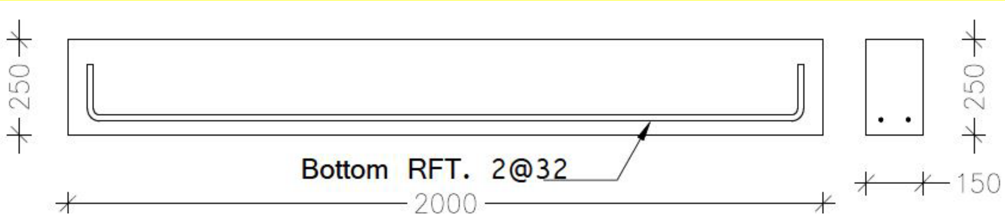


Fig 1-b: Dimensions and reinforcements of test specimens for Group no.2 and 3

Fig 1-c: Steel Fibre Photo

4. Materials

Concrete mix for compressive strength concrete 130 and 140 MPa were used in this test according to previous researches [8]. Table 1 shows the proportions of test specimens. As well as the required concrete characteristic strength. The concrete mix used in the tested specimens consisted of cement, silica fume, quartz powder, sand, dolomite, and water. Cement, silica fume and quartz powder were added and dry mixed together first and after that half the amount of mixing water was added gradually to the fines and mixed for two minutes. The superplasticizer was added to the remaining water then added to the mix. Mixing continues for three to four minutes till a homogenous paste is achieved. Fine aggregate was added gradually to the mix followed by the coarse aggregate and mixing continues for 5 to 6 minutes. In case of using the steel fiber, the fibers was added to the concrete mixer after the water and admixtures and mixed for at least 5 minutes to ensure even distribution in the concrete. Steam curing for three days was used for all beams.

Table1: Properties of test specimens

Group	Shear Reinfor-cement Type	Beam No.	Mix Design	Com. Strength MPa	Stirrups	Fiber Cont. (%)
Group No.1	Stirrups	SR1	M1	140	(5ø6/m')	0
		SR2	M1	140	(8ø6/m')	0
		SR3	M1	140	(5ø8/m')	0
		SR4	M1	140	(8ø8/m')	0
Group No.2	Steel Fiber	MFA1	M2	130	Without	0.5
		MFA2	M2	130	Without	1
		MFA3	M2	130	Without	1.5
		MFA4	M2	130	Without	2
Group No.3	Steel Fiber	MFB1	M1	140	Without	0.5
		MFB2	M1	140	Without	1
		MFB3	M1	140	Without	1.5
		MFB4	M1	140	Without	2

5. Instrumentation and test procedure

The test beams were mounted on the testing frame and were adjusted on the supports one is a roller and another is a hinge. Each support had two side plates with a special lateral bracing system in order to control the verticality of the tested beam during testing. All the test beams are subjected to two points loading, as shown in Fig. 2. One hydraulic jacks of 500 KN capacity supported in the testing frame were used to apply the required load on the beam. It was loaded in the center of as built steel two points loading. The applied loads were measured using load cell of 500 KN maximum capacity. The loading was applied successive increments. Beam deflections, strain gauge readings and crack observations were recorded after each load increment until failure of the specimen.

Thirteen electrical resistance strain gages were attached to the bars of the specimens with stirrups for Group no. 1 as shown in Fig. 2. The schematic diagram of experimental setup and the locations of linear displacement transducers (LVDT) are shown in Fig. 2. One LVDT was attached to each face of the beam near the shear-critical region to measure surface displacement and crack movement during the test [9]. Another LVDT was attached to the bottom surface at the midspan of the test beam to measure the midspan deflection of the beam.

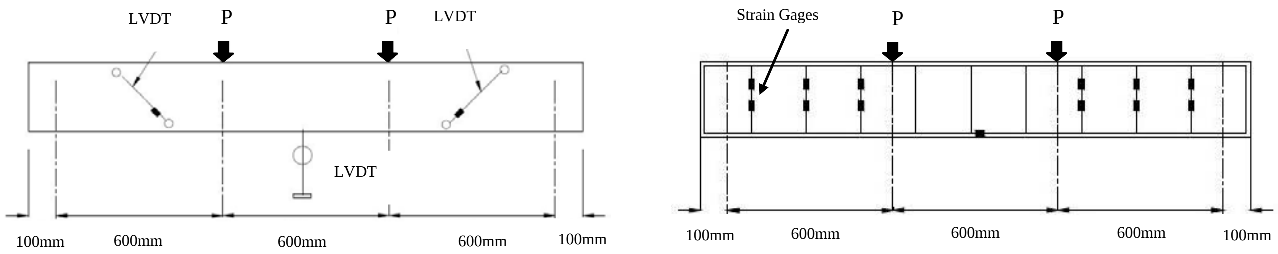


Fig 2: Test setup and instrumentation

Fig 3: Crack pattern

6. Test Results and Discussion

6.1 Crack Pattern

The crack pattern observed at the failure stage of beams are shown in Fig. 3.The loads at first crack are given in Table 2. In Figure 4 the cracking loads of the test specimens are compared. Figure 4 shows an increase in the cracking load with increasing steel fibre contents. At fibre contents of 1, 1.5 and 2 % the cracking load is comparable with the one of the beams containing stirrups. As the load increased, some of these cracks were gradually inclined toward the loading points. All beams failed after significant diagonal cracks had developed. The location of the significant diagonal crack was between the loading and supporting points. The beams with stirrups and steel fibre had the same crack pattern as shown in Fig. 3. As the point loads increased, more diagonal cracks, mostly of the web-shear types originating at mid-depth. A drop in the applied load was recorded when new diagonal cracks developed. The formation of new additional cracks ceased with the formation of the dominant diagonal cracks joining the loading point and support points.

At this stage, the rate of increase in the widths of the existing cracks decreased significantly and all subsequent deformation of the beam was mainly associated with the growth of the major diagonal web-shear cracks. At the peak load, a major diagonal crack formed and the beams failed in diagonal shear. After the peak load, the diagonal crack opened considerable and the load decreased as recorded in the previous researches [10].

6.2 Failure Loads

The failure loads are given in Table 2. In Fig. 5 the failure loads of the specimens are compared. From Fig. 5 it can be concluded that the steel fibres are effective in increasing the shear strength of the specimens. Increasing the steel fibres from 0.5% to 2% resulted in an increase in the failure load by 50-70%. By using steel fibres failure loads comparable to those of stirrups can be achieved. Increasing the concrete compressive strength from 130 to 140 MPa leads to a significant increase in the failure loads by 10-30 % as shown in Table 2.

Table 2: Cracking and Failure loads of test specimens

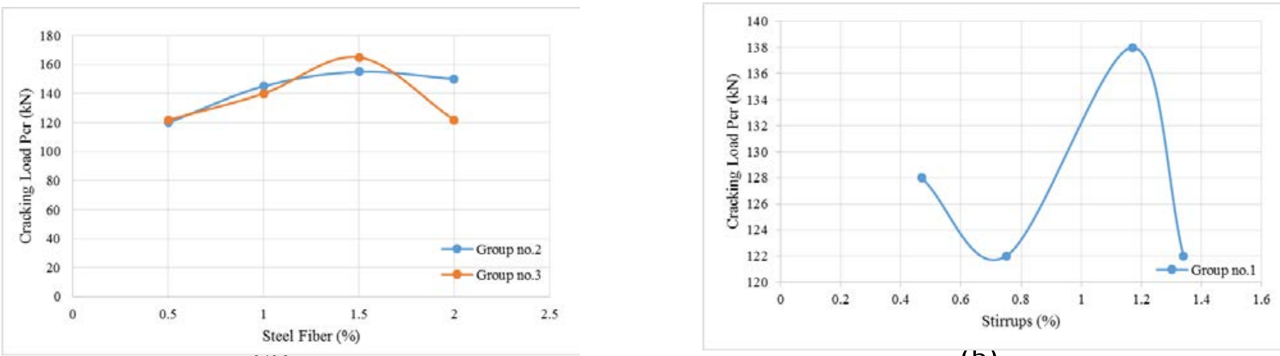
Specimen	*Pcr* (kN)	*Pu* (kN)	*Pu/Pcr*
SR1	128	260	2.03
SR2	122	320	2.62
SR3	138	343	2.49
SR4	122	346	2.84
MFA1	120	176	1.47
MFA2	145	235	1.62
MFA3	155	281	1.81
MFA4	150	302	2.01
MFB1	122	230	1.89
MFB2	140	308	2.20
MFB3	165	310	1.88
MFB4	122	350	2.87

6.3 Load-Deflection Curves

The load-deflection curves for the steel fibres specimens are shown in Figure 6. It can be concluded that the stiffness of the beams are not significantly affected by the steel fibre ratio. In Fig. 7 the deflections of beams with stirrups are compared with those with steel fibres. The type of shear reinforcement (steel fibres or stirrups) does not have a significant effect on the deflection behaviour of the tested beams. Changing the concrete compressive strength from 130 MPa to 140 MPa seems not to significantly change the stiffness of the beams no. MFB3 and MFB4 as shown in Fig. 8.

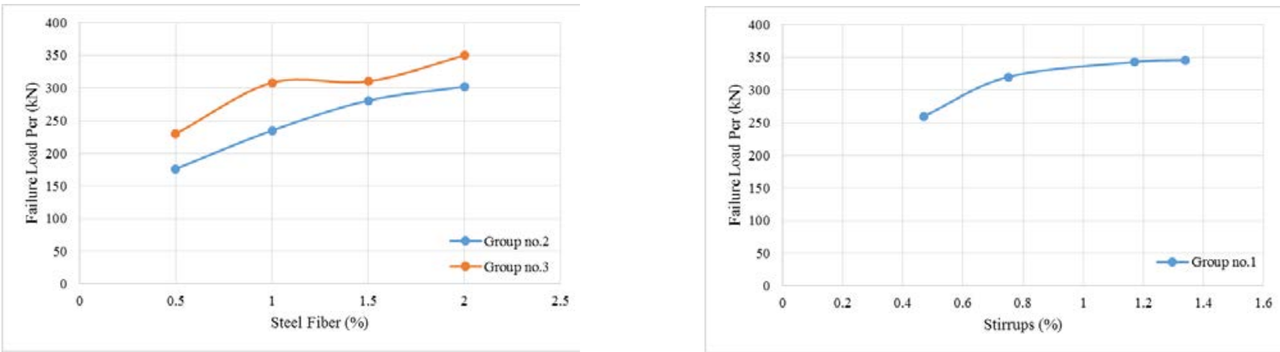
6.4 Strain Measurements

Figures 9 and 10 contain selected longitudinal steel strain measurements. Figure 9 shows that the steel strains are not significantly affected by the type of shear reinforcement (steel fibres or stirrups). The compressive strength of the concrete seems to have an impact on the steel strains as shown in Figure 10.



(a) (b)

Fig 4: Effect of shear reinforcement on the cracking load



(a) (b)

Fig 5: Effect of shear reinforcement on the Failure load

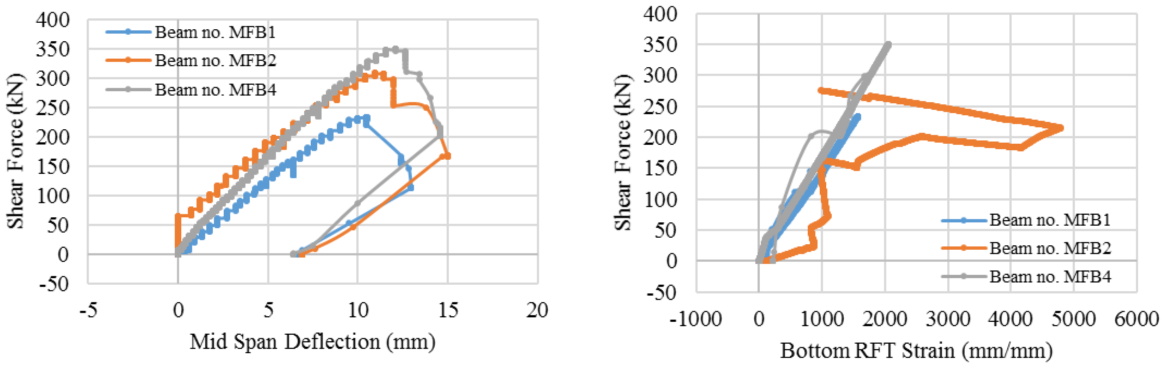


Fig 6: Shear force versus mid span deflection and bottom RFT strain for specimens with steel fibre (0.5, 1 and 2%)

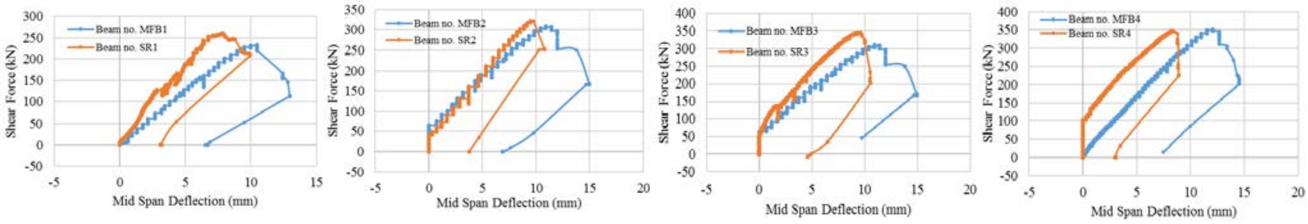


Fig 7: Shear force versus mid span deflection for specimens with stirrups and steel fibre

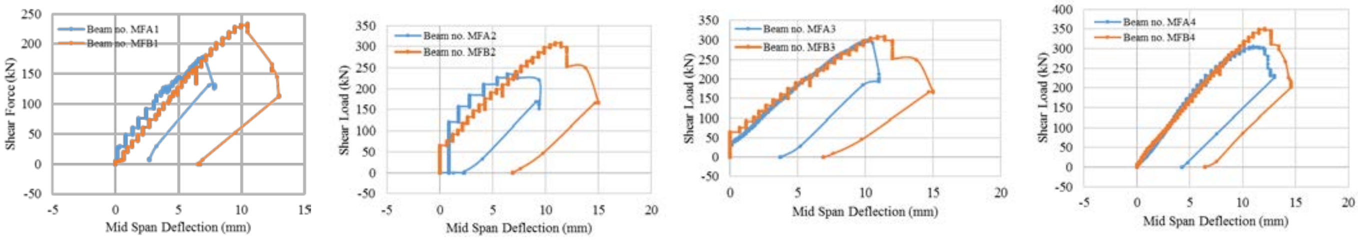


Fig 8: Shear force versus mid span deflection for specimens with steel fibre and different compressive strength

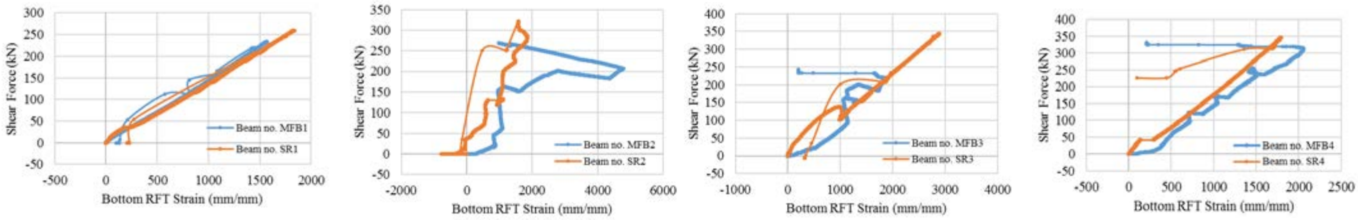


Fig 9: Shear force versus bottom RFT strain for specimens with stirrups and steel fibre

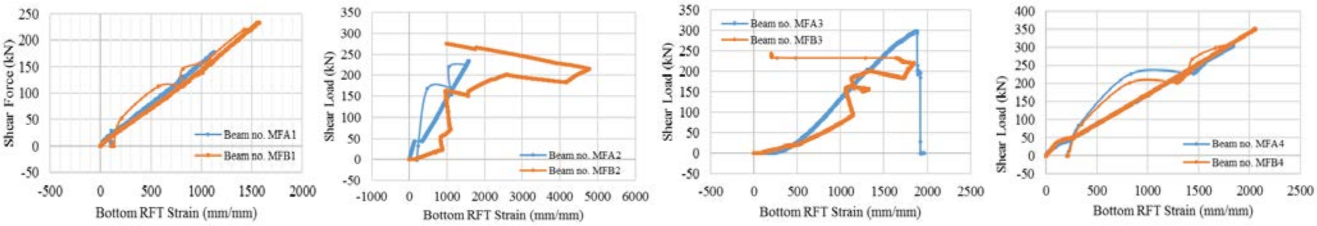


Fig 10: Shear force versus bottom RFT strain for specimens with steel fibre and different compressive strength

7. Conclusions

In this paper, the test results of 12 UHPC beams are presented. The effect of steel fibers on the shear behaviour of such beam are discussed and compared with similar beams with ordinary stirrups as shear reinforcement. Based on the test results, the following conclusion are drawn:

1. For UHPC beams steel fibers are an efficient and practical alternative for stirrups as shear reinforcement. Especially for low and medium stirrups reinforcement ratios, steel fibers are a a competitive solution.

2. Adding a steel fiber ratio of up to 2% did not negatively influence the workability of the mix.
3. Increasing the steel fiber ratio from 0.5% to 2% resulted in an increase in the shear capacity of the tested beams by 50- 70%.
4. Increasing the steel fiber ratio leads to an increase in the cracking load and ductility of the tested beams. This is more advantegous than in case of stirrups.
5. The shear type of shear reinforcement (steel fibers or stirrups) does not significantly affect the deflection behaviour of the tested beams.

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