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SHEAR BEHAVIOR OF FIBROUS REINFORCED CONCRETE WIDE BEAMS

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Abstract: When a reinforced concrete beam does not have enough shear strength and / or little amount of secondary rebar are reinforced, the "shear failure" is possible. Such type of failure is not acceptable in civil engineering due it does not indicate any prior notice before the complete failure of the intended structural member. One of the most popular solutions to overcome such shortcoming is the addition of steel fibers due to the ability for enhancing mechanical properties and ductility. Wide beams are such beams that have high width if compared with its thickness, such structural members are frequent in many reinforced concrete building systems and may also face "shear failure" during its service life. The current study investigates the structural behavior of the Steel Fiber Reinforced Concrete Wide Beams by proposing an experimental program comprising casting and testing of twenty beams specimen. The effective shear spans to depth ratio ratios were 2.5 and 3.5, respectively. Two nominal strength levels 30 MPa "Normal strength concrete" and 60 MPa "High strength concrete are also included. The types of steel fibers used are the "End Hocked" as well as the "Staggered" in 0.5% and 1.5% volume fractions for each one. The results showed that the addition of steel fibers enhances the consequent mechanical properties and the relevant structural behavior of wide beams to a serious concern. Furthermore, the addition of steel fibers modified the shear failure mode to "flexural". The first cracking load increased in "Normal strength" from 21.95% to 73.73% by adding "End Hocked" and from 12.19% to 45.45% by adding "Staggered" while such range reported 15.95% to 45.76% for "End Hocked" and 7.25% to 28.81% for "Staggered" in "High strength". Additionally, the ultimate load increased in "Normal strength" from 19.75% to 65.98% by adding "End Hocked" and from 10.52% to 43.81% by adding "Staggered" while such range reported 13.5% to43.57 % for "End Hocked" and 7.25% 29.29to % for "Staggered" in "High strength" ..

Keywords: *Wide Beam, Steel Fiber, Shear Strength*

1. Introduction

Wide beams or thick slabs are defined by their great width, which is at least twice their depth [1] [2]. Wide beams are frequently used in one-way R.C. joist floors for structural and architectural reasons [3]. They are widely utilized as cost-effective transfer elements in situations where the total structural depth must be minimized. When wide beams are used, the time savings associated with the ease of formwork and reinforcement placement can greatly improve the entire project's cost effectiveness [4]. Additionally, wide beams are advantageous for reducing reinforcement congestion in the column strip of a flat slab system and for tightening control over deflection and cracking requirements, in addition to providing adequate punching shear strength for this system without the use of drop panels or increasing slab thickness. Shear effects play a significant role in the failure of these sorts of beams and in determining their ultimate capacity; also, their shear behavior is somewhat different from that of regular beams due to the smaller depth to width ratio of these

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types of beams. As a result, the majority of study on this subject has focused on the shear capacity of wide beams by determining the effective width utilized to compute concrete shear strength and the role of stirrups in improving overall shear strength in multiple published studies [1] [5] [4] [6] [7]. Occasionally, it is necessary to increase the ultimate shear capacity and improve the cracking behavior of R.C. beams in order for them to be adequate for carrying additional loads not considered in their design, for increased safety, or to address a lack of quality control [8]. Steel plates may be used to reinforce structural components or to replace damaged members by attaching the plates to the surface of beams using adhesive materials or bolts [9] [10]. The glue establishes a shear connection between the concrete and the plates, causing them to behave as composite members [11]. This type of reinforcement is popular because it is readily available, inexpensive, isotropic, easy to deal with, has a high ductility, and high fatigue strength [12]. Numerous studies investigated the benefit of employing steel plates in enhancing the shear behavior of standard beams using a variety of connection strategies. Numerous studies have demonstrated that when this sort of strengthening is applied, significant improvements can be produced [13] [14].

2. Experimental Program

All the tested beams within this experimental program are of center to center span of 1200 mm. The beams were simply support over one span of 1100 mm center to center between two supports and a 50 mm overhang. The section dimensions are of total height of 110mm and width of 220mm. all the beams were reinforced by 4 φ 8mm longitudinal bottom bars as a main reinforcement and 2 φ 5mm top reinforcement. In addition, three φ 6mm stirrups were spaced @ 50mm from each end of beam as shown in Figure (1). The specimen designation includes four digits; the first represented either by "N" which means the "normal strength" concrete while the symbol "H" means the "high strength" concrete. The second digit represented by a number refers to "effective shear span to effective depth ratio". The third digit represented by either "H" which refers to hocked end steel fiber or "S" refers to staggered steel fiber. The fourth digit represented by a number refers to the volume fraction of steel fibers within the intended specimen. Figure (1) shows the specimen details and Table (1) shows the specimens map.

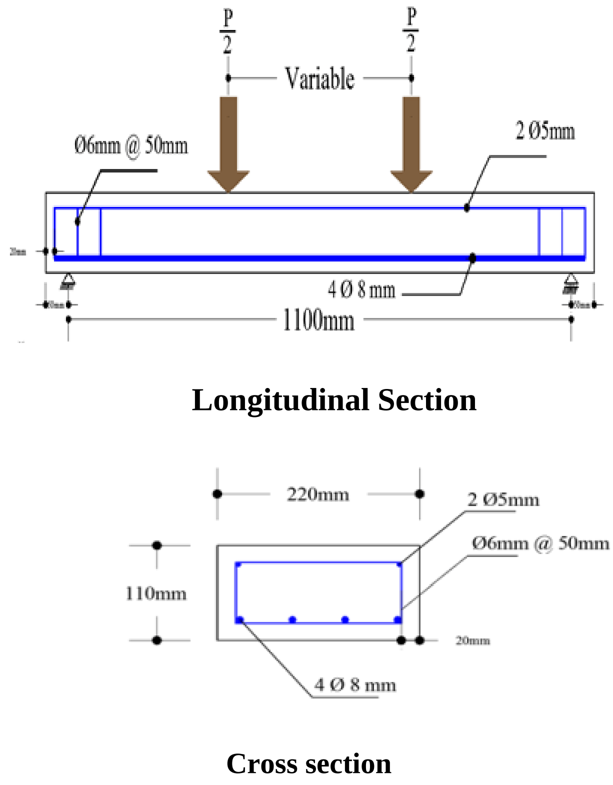


Figure 1. Specimen details of the current study

Table 1. Specimens map for the present study

f'c	a/d	Specimen Designation	Steel Fiber Ratio	Steel Fiber Configuration
30 MPa	2.5	N2.5R	/	/
		N2.5H 0.5	0.5	
		N2.5H 1.5	1.5	
		N2.5S 0.5	0.5	
		N2.5S 1.5	1.5	
	3.5	N3.5R	/	/
		N3.5H 0.5	0.5	
		N3.5H 1.5	1.5	
		N3.5S 0.5	0.5	
		N3.5S 1.5	1.5	
60 MPa	2.5	H2.5R	/	/
		H2.5H 0.5	0.5	
		H2.5H 1.5	1.5	
		H2.5S 0.5	0.5	
		H2.5S 1.5	1.5	
	3.5	H3.5R	/	/
		H3.5H 0.5	0.5	
		H3.5H 1.5	1.5	
		H3.5S 0.5	0.5	
		H3.5S 1.5	1.5	

3. Mix Proportions

Within the current study, the mix design was taken from [15]. Table (2) lists the final mix proportioned that used in casting the specimens.

Table 2. Properties of Concrete Mix

strength concrete(MPa)	30	60
Water(Liter)	150	155
Cement kg/m3	400	550
Superplasticizers (Liter)	0	10
Sand kg/m3	600	700
Gravel kg/m^3	1200	1000

4. Reinforcing Bars

The deformed bars that used throughout the present study are of 5mm, 6mm and 8mm in diameter. The reinforcing steel testing results of such bars are listed in Table (3) while Figure (2) shows the testing machine of that tests.

Table 3. Ultimate Load test results for group-one

Nominal diameter mm	Actual diameter mm	Weight (kg/m)	Yield stress MPa	Yield strain mm/mm	Ultimate strength MPa	Ultimate strain mm/mm
5	4.93	0.211	430	0.0020	531	0.161
6	5.92	0.216	435	0.0022	535	0.164
8	7.89	0.288	440	0.0023	539	0.167

*Implemented at the College of Engineering, Mustansiriyah University

Figure 2. Reinforcing bar testing

5. Hardened mechanical properties results

Table (4) shows test results of mechanical properties for hardened concrete. These properties are concrete compressive strength t (f'cu) use three cubic, splitting tensile strength (ft) and modulus of rupture (fr). Each value presented in this table represents the average value of three specimens.

Table 4. Tests results of mechanical properties for hardened concrete

Type of Steel Fiber	Amount of Steel Fibers %	F'_{cu} (MPa)	F_t (MPa)	f_r (MPa)
Normal Concrete				
Reference	/	32	3.15	3.7
End Hocked	0.5	35.5	3.8	4.3
End Hocked	1.5	41	4.8	5.6
Staggered	0.5	34.5	3.7	4.15
Staggered	1.5	39.5	4.6	5.45
High Strength Concrete				
Reference	/	64	4	5
End Hocked	0.5	68	5	6
End Hocked	1.5	74	6.5	7.2
Staggered	0.5	67	4.8	5.7
Staggered	1.5	72.3	6	6.8

6. Molds of Specimens

The tested specimens of the current study were casted using the molds shown in Figure (3). Such molds consisted of a bed and suitable moving sides that can be fastened accurately by suitable screws. The clear dimensions of the molds were (1200 mm x 220 mm x 110 mm).

7 .Casting Procedure

The wood forms were cleaned and oiled by a suitable car engine prior to casting, as shown in Figure (3).Then the selected reinforcement placed accurately before the concrete were added .After casting, all the specimens were vibrated by electrical tool till the entrapped air was expelled. By polishing the upper layer of the wooden block with a steel trowel, the top portion of the block of wood was leveled with the concrete surface. To avoid moisture loss, the slab was coated with polyethylene sheets. The specimen was demolded after 24 hours and covered by commercial clothing bags to maintain moisture until the time of testing.

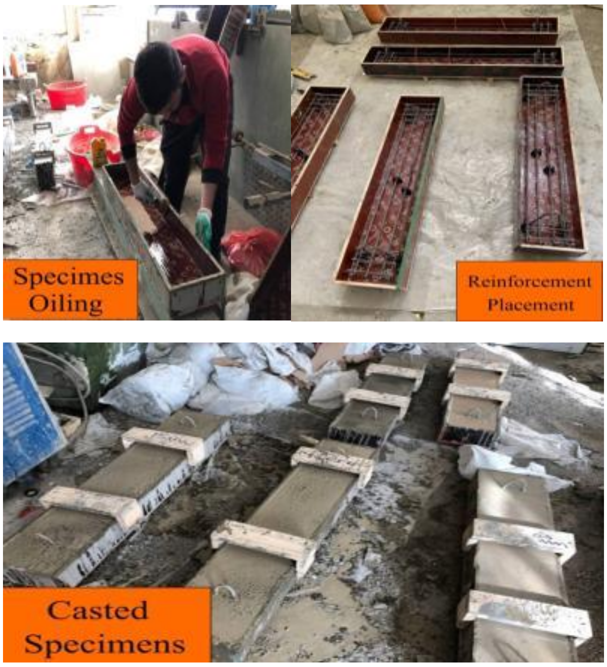


Figure 3. Casting procedure

8.Steel Fibers

There have been 2 types of steel fibers utilized, which are “end hocked” as well as “staggered or zigzagged” steel fibers. The steel fibers that used in the current experimental program were manufactured by the Turkish company “SPI Fiber force”. Table (5) lists the properties of such fibers. In addition, Figure (4) shows a photograph for such fibers.

Table 5. Steel fibers physical properties*

Property	**Specifications**	
	End Hocked	**Staggered**
Ultimate strength	“2000 MPa”	“1983 MPa”
Relative Density	“7860 kg/m^3„	7420 kg/m^3”

“Strain at proportion limit”	5650 x10-6	“5490 x10-6”
“Modulus of Elasticity”	“200x10^3 MPa”	“174x10^3 MPa”
“Average length”	“50mm”	“50mm”
“Nominal diameter”	“0.375 mm”	“0.375 mm”
“Aspect ratio (Lf/Df)”	“80	“80”
Poisson's ratio	“0.28”	“0.28”

*According to the manufacturer.

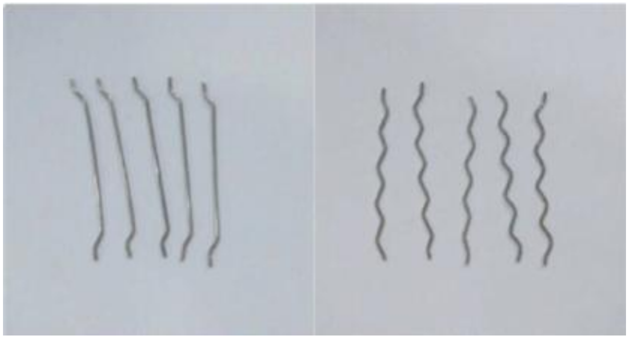


Figure 4. The steel fiber used in the present study

9. Test Process

The wide beam samples were tested by the detailed apparatus demonstrated in Figure (5). All samples were brushed and white colored by suitable paint prior the test demonstrate the resulted cracking paths. Two concentrated loads were applied through a steel loading plate over a thin rubber strip which is used to get a suitable support. Just at start of the experiment, the initial readings of the dial gauge and the strain gauge were taken. The load was imposed in smaller steps in each of the experiments and readings of deflection, strain and load were recorded in each increment. The load was gradually increased until failure.

Figure 5. The testing machine

10. Structural Shear Behavior of SFRCBs

10.1. Group One

10.1.1. Normal Strength Concrete – a/d= 2.5.

The specimens that were included within this group are N2.5R, N2.5S0.5, N2.5S1.5 N2.5H0.5 and N2.5H1.5, which are normal concrete beam with a/d=2.5 as a reference, 0.5% Staggered SFRCB, 1.5% Staggered SFRCB, 0.5% End hocked SFRCB and 1.5% End Hocked SFRCB respectively.

10.1.2. First Crack Load, Ultimate Strength and Yield Load

Table (6) and Figure (6) show a comparison between the proposed specimens within this group concerning 1st crack load, ultimate strength and yield load. It can be recognized that the first crack load increased by 13.64%, 45.45%, 22.73% and 73.73% for N2.5S0.5, N2.5S1.5, N2.5H0.5 and N2.5H1.5 respectively if compared with reference N2.5R. On the other hand, the relevant yield load increased by 4.35%, 34.78%, 16.96% and 50.87% for the same set of specimens as well as increase in ultimate load strength by 11.74%, 39.57%, 19.57% and 57.83%. It can be recognized that the rate of increase in first cracking, yielding and ultimate load in the SFRCBs is sorted according to the same arrangement of the basic mechanical properties when the End Hocked have also the excellency against staggered. It is argued that such behavior can be ascribed to the mechanical supremacy (between the different materials circumstances) which governed the consequent structural behavior of the built SFRCBs. However, the matter of how much each (first cracking, yielding and ultimate load) can be compatible with the inherent control mechanical properties is still an inviting field of research.

Table 6. Group one comparison with respect to 1st crack load, ultimate strength and yield load

Specimens Designation	First Cracking Load kN	Increase in first cracking Load%	Yielding Load in kN	Increase in yielding Load%	Ultimate Load in kN	Increase in Ultimate Load%
N2.5R	11	/	57.5 *	/	57.5 *	/
N2.5S 0.5	12.5	13.64	60	4.35	64.25	11.74
N2.5S 1.5	16	45.45	77.5	34.78	80.25	39.57
N2.5H 0.5	13.5	22.73	67.25	16.96	68.75	19.57
N2.5H 1.5	19	73.73	86.75	50.87	90.75	57.83

* At peak load

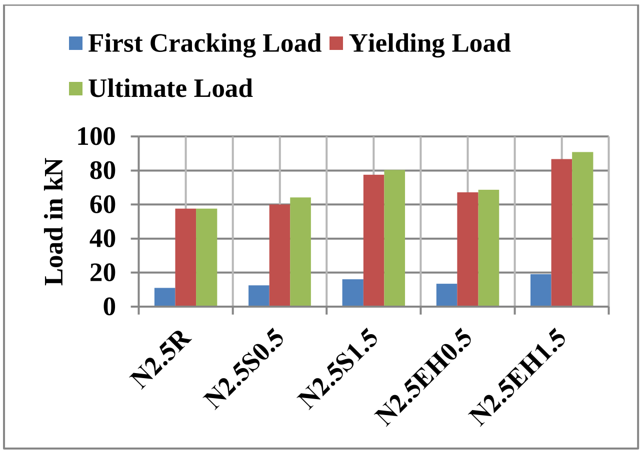


Figure 6. Levels of 1st crack load, ultimate strength and yield load of group one

10.1.3. Load - Deflection Relationship

Table (7) shows a comparison between the proposed specimens within this group with respect to the yield deflection, ultimate deflection, and ductility ratio for the proposed specimens within this group. It has been stated that load deflection curve of the reference beam is consisted of the linear elastic load till the first cracking while the second in begun after such limit till the shear brittle failure. For the SFRCBs, It can be noticed from the figure that load – deflection curves consists of three parts, the 1st part is linear elastic until the first crack load, the second portion began beyond the elastic stage until yielding tensile reinforcement steel, and final portion is the stage after yielding of tensile steel reinforcement when the residual strength was taken a fluctuated until the beam failure. However, the relevant yield deflection increased by 2.22%, 8.33%, 3.78% and 8.89% for N2.5S0.5%, N2.5S1.5%, N2.5H0.5% and N2.5H1.5% respectively if compared with N2.5R while the ultimate deflection increased by 31.22%, 40.22%, 37.89% and 45% for the same order of the defined specimens of this group. In addition, Figure (7) shows the load – mid span deflection curves for the N2.5R, N2.5S0.5, N2.5S1.5, N2.5H0.5 and N2.5H1.5, respectively. It can be reported from such figure that SFRCBs illustrated higher stiffness than the normal Reinforced Concrete (RC), while the ductility ratio levels were increased for SFRCBs specimens and report 1.28, 1.29, 1.33 and 1.33 respectively. It is noticed that the difference in flexural rigidity between the proposed specimens dictates the variation between them even in the early stages of load. However, the divergence is become more obvious after early stages and became so clear after the yielding.

Table 7. Group one comparison with respect to the yield deflection, ultimate deflection, and ductility ratio

Specimens Designation	Yield Deflection Δy (mm)	Increase in Δy %	Ultimate Deflection Δu (mm)	Ratio of Ductility	Increase in Δu %
N2.5R	9	/	9	1	/
N2.5S0.5	9.20	2.22	11.81	1.28	**31.22**
N2.5S1.5	9.75	8.33	12.62	1.29	**40.22**
N2.5H0.5	9.34	3.78	12.41	1.33	**37.89**
N2.5H1.5	9.80	8.89	13.05	1.33	**45**

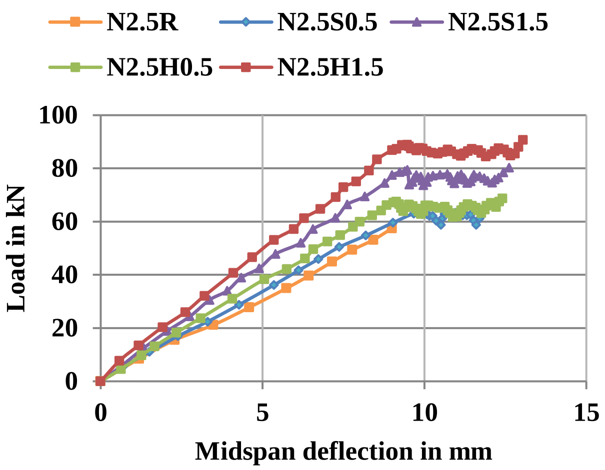


Figure 7. Group one curves of load deflection

10.1.4. Initial Stiffness

During the present study, the initial stiffness may be defined as the slope of the first part of the load-deflection curve. It is computed through the division of yield load (Py) to the yield deflection (Δy). The equation used are shown below:

$$\text{Initialstiffness} = \frac{P_y}{\Delta_y} \quad (1)$$

However, stiffness calculation is carried out according to Sullivan et al., (2004) [48].The stiffness results for all wide beams specimens are presented in Table (7) and Figure (7).

It is reported that the initial stiffness of the specimens increased by 1.72%, 24.41%, 12.68% and 38.50% for N2.5S0.5, N2.5S1.5, N2.5H0.5 and N2.5H1.5 respectively if compared with N2.5R specimen (normal concrete beam).

It can be recognized that the priority map between the SFRCBs specimens concerning the initial stiffness is relative to the modulus of elasticity (which is characterized the stiffness of any concrete element).In this way, it is believed that studying the degree of correlation between the modulus of elasticity of the SFC material and the consequent SFRCBs initial stiffness is very useful for understanding impact of the important steel fibers key elements like amount and type.

10.1.5. Mode of Failure Visual Observation

In fact, the mode of failure that observed by visual inspection is shear failure for N2.5R. in addition, the presence of steel fibers enabled the change to flexural mode of failure as shown in Figure (8). It is deduced that such change was happened due to the bridging role between the fragments of concrete and this matter has many prior indicators in the load – mid span and load –strain response.

Figure 8. Cracking pattern of group one

10.2. Group Two

10.2.1. Normal Strength Concrete – a/d = 3.5

The specimens that were included within this group are N3.5R, N2.5S0.5, N2.5S1.5 N2.5H0.5 and N2.5H1.5, which are normal concrete beam with a/d=3.5 as a reference, 0.5% Staggered SFRCB, 1.5% Staggered SFRCB, 0.5% End hocked SFRCB and 1.5% End Hocked SFRCB respectively.

10.2.2. First Crack Loading, Ultimate Strength and Yield Load

Table (8) and Figure (9) show a comparison between the proposed specimens within this group with respect to 1st crack load, ultimate strength and yield load. It can be recognized that the first crack load increased by 12.19%, 43.90%, 21.95% and 65.85% for N3.5S0.5, N3.5S1.5, N3.5H0.5 and N3.5H1.5 respectively if compared with reference N3.5R. On the other hand, the relevant yield load increased by 9.28%, 38.14%, 15.46% and 54.60% for the same set of specimens as well as increase in ultimate load strength by 10.52%, 43.81%, 23.71% and 65.98%. as in the previous group, the mechanical properties (in accordance to the resulted flexural rigidity) have drawn the priority of the increasing rate with respect to first cracking, yielding and ultimate load in the SFRCBs which reveals again the preeminence of the End Hocked against staggered steel fibers specimens. On the other hand, the levels of first cracking, yielding and ultimate load within this group are generally less than the last group due to the effect of a/d. Finally, it is argued that there is a need to propose the empirical equations to correlate the first cracking, yielding and ultimate load levels to the inherent a/d ratio taking reasonable incremental order in normal strength SFRCBs**.**

Table 8. Group two comparison with respect to 1st crack load, ultimate strength and yield load

Specimens Designation	First Cracking	Increase in first	Yielding Load in kN	Increase in yielding	Ultimate Load in kN	Increase in Ultimate
N3.5R	10.25	/	48.5*	/	48.5*	/
N3.5S0.5	11.50	12.19	53	9.28	53.6	10.52
N3.5S1.5	14.75	43.90	67	38.14	69.75	43.81
N3.5H0.5	12.50	21.95	56	15.46	60	23.71
N3.5H1.5	17	65.85	74.98	54.60	80.5	65.98

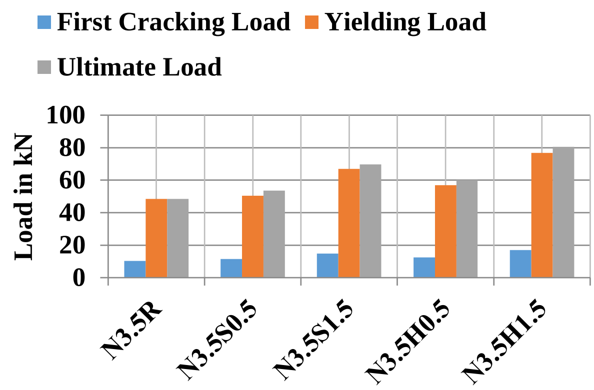


Figure 9. 1st crack load, ultimate strength and yield load levels of group two

10.2.3. Load - Deflection Relationship

Table (9) shows a comparison between the proposed specimens within this group with respect to the yield deflection, ultimate deflection, and ductility ratio for the proposed specimens within this group. As in last group, it has been stated that load deflection curve of the reference beam N3.5R comprised a linear elastic load region till the first cracking while the second region is started after that limit until failure. For the SFRCBs within the current group, it can be drawn from the figure that the load – deflection curves comprised three distinctive stages, the 1st stage represents the linear elastic until first crack load, the second stage started behind the elastic stage until yielding of tensile reinforcement steel, and final portion is the stage after yielding of tensile steel reinforcement when the fluctuated residual strength is also obvious as in the previous group until the beam failure. However, the relevant yield deflection increased by 4.75%, 12.5%, 16.5% and 15.75% for N3.5S0.5, N3.5S1.5, N3.5H0.5 and N3.5H1.5 respectively if compared with N3.5R while the ultimate deflection increased by 19.63%, 28.25%, 25.13% and 36.50% for the same order of the defined specimens of this group. In addition, Figure (10) illustrates the load – mid span deflection curves for N3.5R, N3.5S0.5, N3.5S1.5, N3.5H0.5 and N3.5H1.5, respectively. As in the previous group, the SFRCBs viewed more stiffness levels than the normal (RC) for the same a/d ratio. The ductility ratio levels were increased for SFRCBs specimens and report 1.26, 1.47, 1.50 and 1.62 respectively. It is reported that the yielding and ultimate deflection of this group is less than the corresponding in the previous group due to the effect of a/d. As observed at the first group, the early stages of load have also viewed the difference between the specimens according to the flexural rigidity while such variation is more obvious after yielding.

Table 9. Group two comparison with respect to the yield deflection, ultimate deflection, and ductility ratio

Specimens Designation	Yield Deflection Δy (mm)	Decrease in Δy %	Ultimate Deflection Δu (mm)	Ratio of Ductility $\Delta u/\Delta y$	Δu % Increase
N3.5R	8	/	8	1	/
N3.5S0.5	7.62	4.75	9.57	1.26	**19.63**
N3.5S1.5	7	12.5	10.26	1.47	**28.25**
N3.5H0.5	6.68	16.5	10.01	1.50	**25.13**
N3.5H1.5	6.74	15.75	10.92	1.62	**36.50**

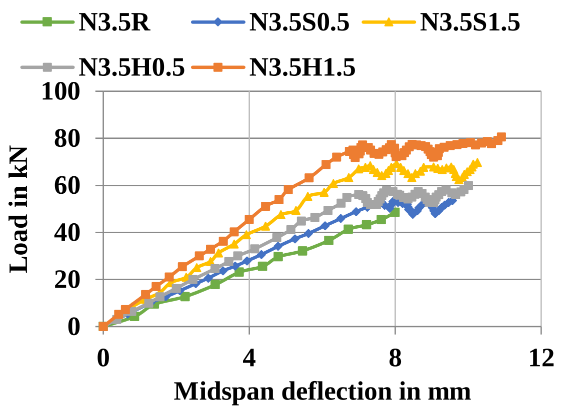


Figure 10. Group two curves of load deflection

10.2.4. Initial Stiffness

Views the variation in initial stiffness for the beam within this group.

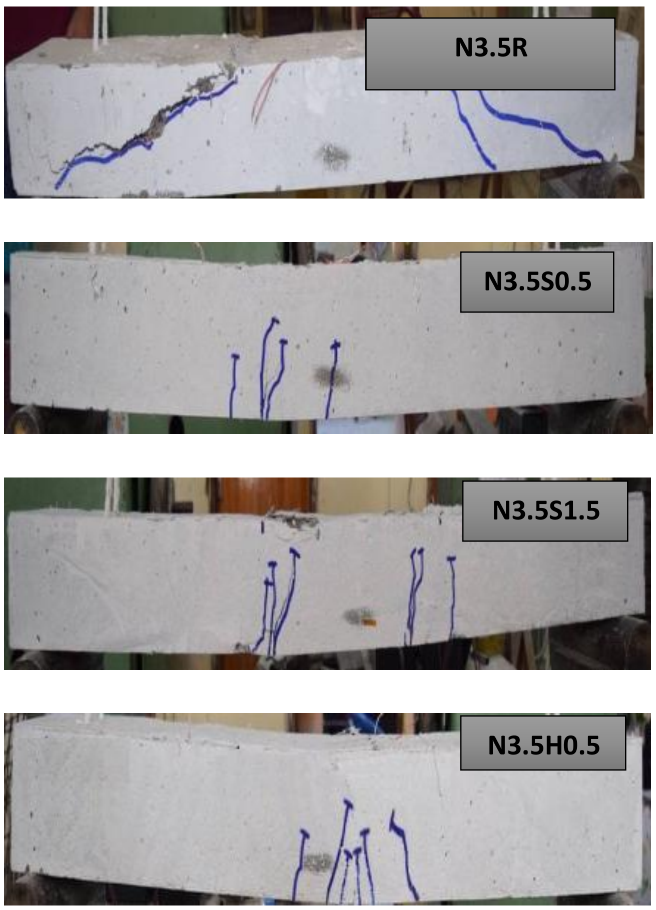
It is reported that the initial stiffness of the specimens increased by 14.85%, 57.92%, 38.28% and 83.49% for N3.5S0.5, N3.5S1.5, N3.5H0.5 and N3.5H1.5 respectively if compared with N3.5R specimen (normal concrete beam).

As in the previous group, it can be drawn that the modulus of elasticity have govern the relevant initial stiffness and its supremacy.

It is drawn that the initial stiffness for the group two (a/d=2.5) is more than of group one (a/d= 3.5) due to the nature of loading since the resulted yielding deflection in group two is less than those of group one.

10.2.5. Mode of Failure Visual Observation

As reported in the previous group, the mode of failure that observed by visual inspection is shear failure for N3.5R. Once again, the steel fibers enabled the change to flexural mode of failure as shown in Figure (11). It is deduced that such change was happened due to the bridging role between the fragments of concrete and this matter has many prior indicators in the load – mid span and load – strain response.



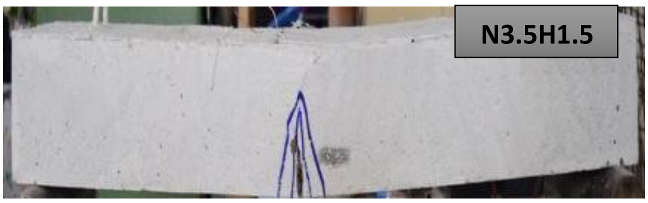


Figure 11. Cracking pattern of group two

10.3. Group Three

10.3.1. High Strength Concrete – a/d= 2.5

The specimens that were included within this group are N3.5R, H2.5S0.5, H2.5S1.5 H2.5H0.5 and H2.5H1.5, which are normal concrete beam with a/d =2.5 as a reference, 0.5% Staggered SFRCB, 1.5% Staggered SFRCB, 0.5% End hocked SFRCB and 1.5% End Hocked SFRCB respectively.

10.3.2. Yield Load, Ultimate Strength and 1st Crack Load,

Table (10) and Figure (12) show a comparison between the proposed specimens within this group with respect to 1st crack load, ultimate strength and yield load. It can be stated that 1st crack loading increased by 7.25%, 21.74%, 15.95% and 36.23% for H2.5S0.5, H2.5S1.5, H2.5H0.5 and H2.5H1.5 respectively if compared with reference H2.5R. In the other hand, the relevant yield load increased by 6.75%, 19.02%, 9.20% and 32.55 for the same set of specimens as well as increase in ultimate load strength by 7.98%, 22.09%, 15.95% and 38.65%. It can be drawn that in the high strength specimen, the matter of the flexural rigidity is also a function of the mechanical strength levels and levels array the order between the specimens. However, the End hocked specimens have proved the excellency against staggered specimens. If each one the specimens within this group was compared with the corresponding within the first group, it can easily report that the levels / rate of increase concerning first cracking, yielding and ultimate load are higher due to the difference in strength gain of concrete.

Table 10. Group three comparisons with respect to 1st crack load, ultimate strength and yield load

Specimens Designation	First Cracking Load kN	Increase in first Cracking Load %	Yielding Load in kN	Increase in Yielding Load %	Ultimate Load in kN	Increase in Ultimate Load %
H2.5R	17.25	/	81.5	/	81.5	/
H2.5S0.5	18.5	7.25	87	6.75	88	7.98
H2.5S1.5	21	21.74	97	19.02	99.5	22.09
H2.5H0.5	20	15.95	89	9.20	94.5	15.95
H2.5H1.5	23.5	36.23	108	32.5	113	38.65

* At peak load.

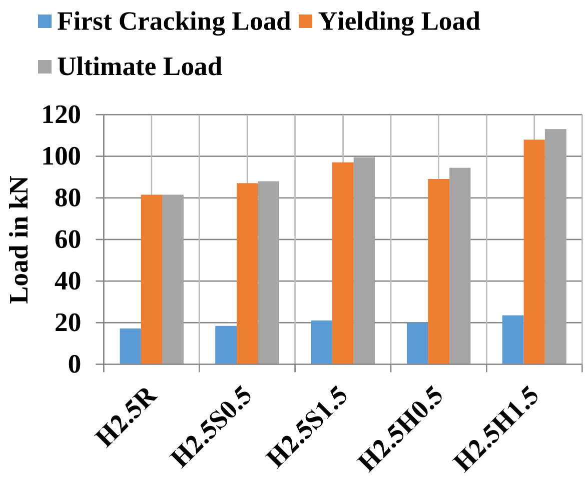


Figure 12. 1st crack load, ultimate strength and yield load levels of group three

10.3.3. Load - Deflection Relationship

Table (11) shows a comparison between the proposed specimens within this group with respect to the yield deflection, ultimate deflection, and ductility ratio for the proposed specimens within this group. As in the previous group, it is seen that the load deflection response of the reference beam H2.5R includes a linear elastic load district till the first cracking while the second one is started after that limit until failure as the reference beam in the last two groups. Moreover, regarding the SFRCBs within this group, it can be noticed from the figure that the load – deflection response encompassed three distinct zones, the first zone is also linear elastic to first crack load, the second zone is originated behind the elastic zone until yielding of tensile rebar while and final zone is initiated after yielding of tensile steel reinforcement when the fluctuation of residual strength is also clear as in the previous groups until the specimen's failure. However, the relevant yield deflection increased by 5.58%, 13.67%, 6.42% and 19.42% for H2.5S0.5, H2.5S1.5, H2.5H0.5 and H2.5H1.5 respectively if compared with H2.5R while the ultimate deflection increased by 7.25%, 15.58%, 13.50% and 19.83% for the same order of the defined specimens of this group. In addition, Figure (13) illustrates the load – mid span deflection curves for H2.5R, H2.5S0.5, H2.5S1.5, H2.5H0.5 and H2.5H1.5, respectively. The SFRCBs viewed more stiffness levels than the normal (RC) for the same a/d ratio as reported in the first and second group. The ductility ratio levels were increased for SFRCBs specimens and report 1, 1.14, 1.34, 1.21 and 1.49 for H2.5R, H2.5S0.5, H2.5S1.5, H2.5H0.5 and H2.5H1.5 respectively. It is viewed from a general comparison between the specimens of the current group and the corresponding specimens of the first group that the high strength specimens illustrate yielding and ultimate deflections less than the normal strength specimens as an expected result to the strength gain.

Table 11. Group three comparisons with respect to the yield deflection, ultimate deflection, and ductility ratio

Specimens Designation	Yield Deflection Δy (mm)	Decrease in Δy %	Ultimate Deflection Δ u (mm)	Ratio of Ductility Δu/Δy	Δ u % and Increase
H2.5R	12	/	12	1	/
H2.5S0.5	11.33	5.58	12.87	1.14	**7.25**
H2.5S1.5	10.36	13.67	13.87	1.34	**15.58**
H2.5H0.5	11.23	6.42	13.62	1.21	**13.50**
H2.5H1.5	9.67	19.42	14.38	1.49	**19.83**

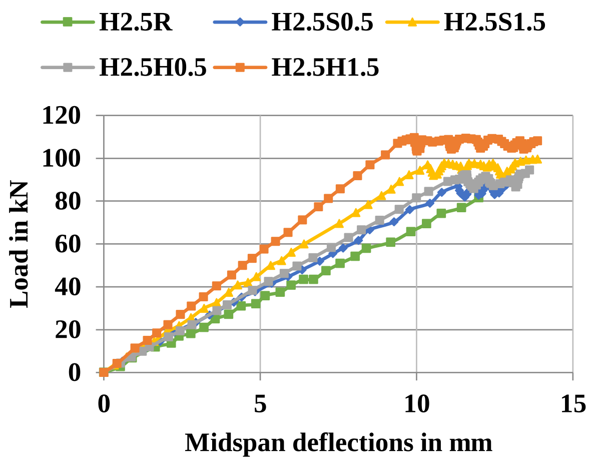


Figure 13. Group two load deflection curves

10.3.4. Initial Stiffness

Views the variation in initial stiffness for the beam within this group.

It is reported that the initial stiffness of the specimens increased by 13.11%, 37.85%, 16.79% and 64.51% for H2.5S0.5, H2.5S1.5, H2.5H0.5 and H2.5H1.5 respectively if compared with H2.5R specimen (normal concrete beam).

If the levels of initial stiffness (of this group) compared with the corresponding specimens of group one, there is a clear excellency of this group (as reported in the modulus of elasticity levels) due to the difference in strength gain.

10.3.5. Mode of Failure Visual Observation

As reported in the previous group, the mode of failure that observed by visual inspection is shear failure for N3.5R. once again, the steel fibers enabled the change to flexural mode of failure as shown in Figure (14). It is deduced that such change was happened due to the bridging role between the fragments of concrete and this matter has many prior indicator in the load – mid span and load – strain response.

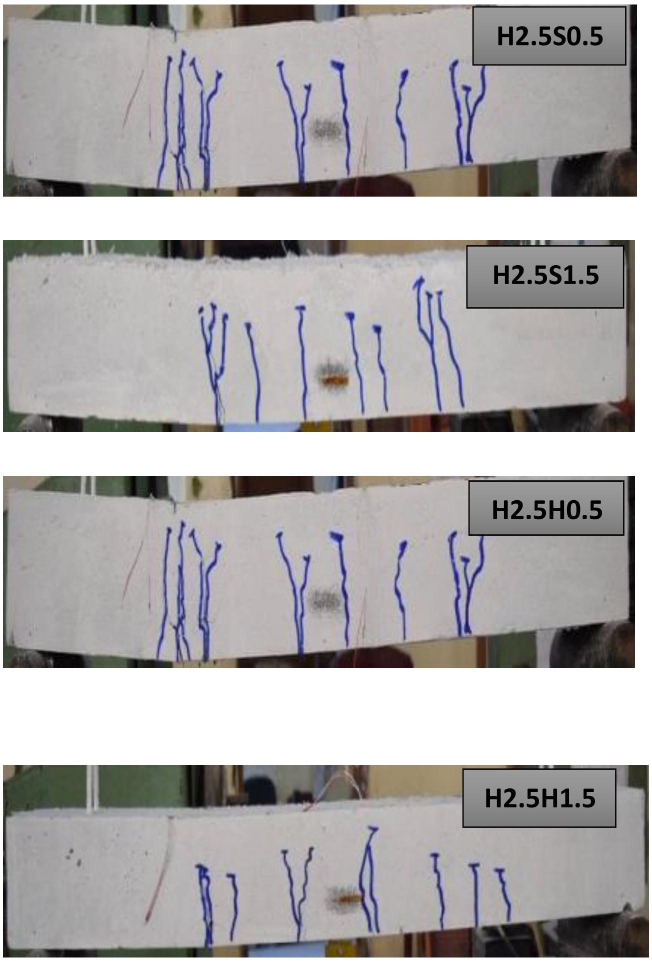


Figure (14) Cracking pattern of group three

10.4. Group Four

10.4.1. High Strength Concrete – a/d= 3.5.

The specimens that were included within this group are N3.5R, H3.5S0.5, H3.5S1.5 H3.5H0.5 and H3.5H1.5, which are normal concrete beam with a/d=2.5 as a reference, 0.5% Staggered SFRCB, 1.5% Staggered SFRCB, 0.5% End hocked SFRCB and 1.5% End Hocked SFRCB respectively.

10.4.2. Yield Load, Ultimate Strength and 1st Crack Load

Table (12) and Figure (15) show a comparison between the proposed specimens within this group with respect to 1st crack load, ultimate strength and yield loading. It can be stated that the first crack load increased by 10.17%, 28.815, 16.95% and 45.76% for H3.5S0.5, H3.5S1.5, H3.5H0.5 and H3.5H1.5 respectively if compared with reference H3.5R.

In the other hand, the relevant yield load increased by 7.14%, 21.43%, 11.43% and 37.865 for the same set of specimens as well as increase in ultimate load strength by 10%, 29.29%, 16.43% and 43.57%. As expected, the End hocked beam specimens within the current group illustrated a clear supremacy against the staggered specimens again due to high level of strength gain and consequent flexural rigidity. The comparison with the second group have proved the mentioned conclusion when the strength gain gives high limits of first cracking, yielding and ultimate load in group four.

Table 12. Group four comparisons with respect to 1st crack load, ultimate strength and yield loading

Specimens Designation	First Cracking Load kN	Increase in First Cracking Load %	Yielding Load in kN	Increase in Yielding Load %	Ultimate Load in kN	Increase in Ultimate Load %
H3.5R	14.75	/	70	/	70	/
H3.5S0.5	16.25	10.17	75	7.14	77	10
H3.5S1.5	19	28.81	85	21.43	90.5	29.29
H3.5H0.5	17.25	16.95	78	11.43	81.5	16.43
H3.5H1.5	21.5	45.76	96.5	37.86	100.5	43.57

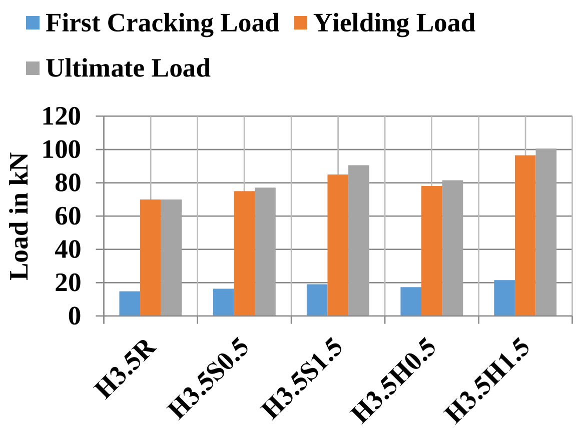


Figure 15. 1st crack load, ultimate strength and yield loading levels of group four

10.4.3. Load - Deflection Relationship

Table (13) shows a comparison between the proposed specimens within this group with respect to the yield deflection, ultimate deflection, and ductility ratio for the proposed specimens within this group. As noticed in the previous groups, it can be viewed that the load deflection curve of the reference beam H3.5R comprises a linear elastic load zone till the first cracking while the second district is begun after such limit until failure as reported in the last three groups. Furthermore, for the SFRCBs of this this group, it can be recognized from the figure that the load – deflection curves exhibited three characteristic districts, the first district is again linear elastic to first crack load, the second district is initiated behind the elastic zone until yielding of tensile reinforcement while and final district is started after yielding of tensile steel reinforcement when the fluctuated fashion of residual strength is also visible till failure. However, the consequent yield deflection increased by 3.8%, 8%, 6.7% and 10% for H3.5S0.5, H3.5S1.5, H3.5H0.5 and H3.5H1.5 respectively if compared with H3.5R while the ultimate deflection increased by 10%, 12.48%, 13.12%, 12.66% and 13.5% for the same order of the defined specimens of this group. In addition, Figure (16) illustrates the load – mid span deflection curves for H3.5R, H3.5S0.5, H3.5S1.5, H3.5H0.5 and H3.5H1.5, respectively. As previously deduced in this chapter, the SFRCBs viewed more stiffness levels than the normal (RC) for the same a/d ratio. The ductility ratio levels were increased for SFRCBs specimens and report 1, 1.3, 1.43, 1.36 and 1.5 for H3.5R, H3.5S0.5, H3.5S1.5, H3.5H0.5 and H3.5H1.5 respectively. The strength gain in the high strength concrete have led to illustrate less deflection levels if compared with group two (normal strength concrete) which is an expected results as discussed within this chapter.

Table 13. Group four comparisons with respect to the yield deflection, ultimate deflection, and ductility ratio

Specimens Designation	Yield Deflection Δy (mm)	Decrease in Δy %	Ultimate Deflection Δ u (mm)	Ratio of Ductility Δu/Δy	Δ u % Increase
H2.5R	10	/	10	1	/
H2.5S0.5	9.62	3.8	12.48	1.3	**4.8**
H2.5S1.5	9.20	8	13.12	1.43	**31.2**
H2.5H0.5	9.33	6.7	12.66	1.36	**26.6**
H2.5H1.5	9	10	13.5	1.5	**35**

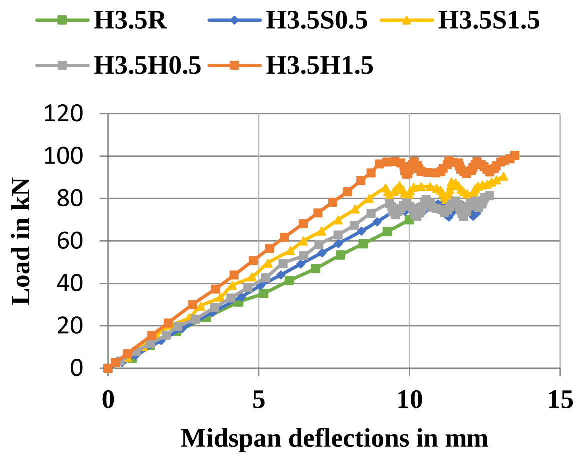


Figure 16. Group four load deflection curves

10.4.4. Initial Stiffness

Views the variation in initial stiffness for the beam within this group.

It is reported that the initial stiffness of the specimens increased by 11.43%, 32%, 19.43% and 53.14% for H3.5S0.5, H3.5S1.5, H3.5H0.5 and H3.5H1.5 respectively if compared with H3.5R specimen (normal concrete beam)

Within the current group, the levels of initial stiffness are also more than those of the corresponding in group two which is can be ascribed also to the difference in strength gain as interpreted earlier.

10.4.5. Mode of Failure Visual Observation

As reported in the previous group, the mode of failure that observed by visual inspection is shear failure for N3.5R.once again, the steel fibers enabled the change to flexural mode of failure as shown in Figure (17). It is deduced that such change was happened due to the bridging role between the fragments of concrete and this matter has many prior indicator in the load – mid span and load – strain response.

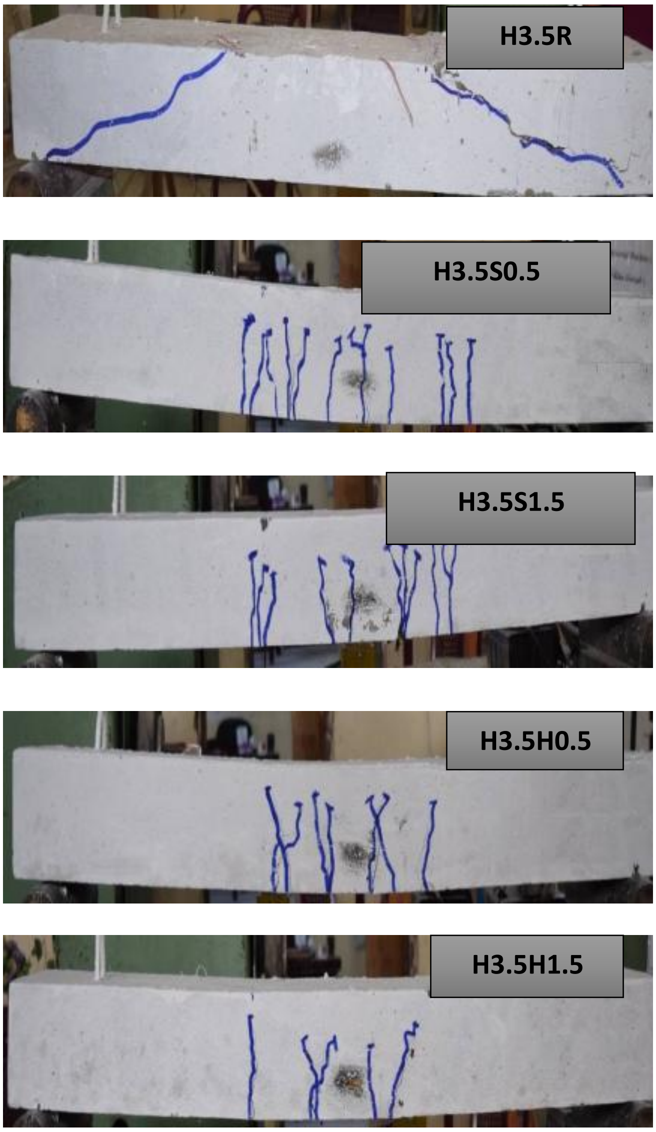


Figure 17. Cracking pattern of group three

11. Conclusions

The major conclusions that can be drawn throughout the entire study are summarized as follows:

1. Adding "End Hocked" and "Staggered" steel fibers enhances the consequent mechanical properties of the concrete.
2. Producing SFRCWBs by adding "End Hocked" and "Staggered" steel fibers modifies the mode of failure from "shear" to "flexural."
3. Producing SFRWCBs wide beams by adding "End Hocked" and "Staggered" steel fibers increases the first cracking, yielding and ultimate load according to the steel fibers volume fraction and compressive strength level.
4. Producing SFRCWBs by adding "End Hocked" and "Staggered" steel fibers increases ductility of beams.
5. In normal strength concrete, adding 0.5% and 1.5% increases compressive strength 10.94% and 28.13% respectively in "End Hocked" steel fibers specimen and 7.82% and 23.44% in "staggered."
6. In high strength concrete, adding 0.5% and 1.5% increases compressive strength 6.25% and 15.63% respectively in "End Hocked" steel fibers specimen and 4.69% and 12.97% in "staggered."
7. In normal strength concrete, adding 0.5% and 1.5% increases splitting tensile strength 20.63% and 52.34% respectively in "End Hocked" steel fibers specimen and 17.46% and 46.03% in "staggered."
8. In high strength concrete, adding 0.5% and 1.5% increases splitting tensile strength 25% and 62.5% respectively in "End Hocked" steel fibers specimen and 20% and 50% in "staggered."
9. In normal strength concrete, adding 0.5% and 1.5% increases modulus of rapture 16.22% and 51.35% respectively in "End Hocked" steel fibers specimen and 12.16% and 47.30% in "staggered."
10. In high strength concrete, adding 0.5% and 1.5% increases modulus of rapture 20% and 44% respectively in "End Hocked" steel fibers specimen and 14% and 36% in "staggered."
11. In normal strength concrete, adding 0.5% and 1.5% increases modulus of elasticity 10.06% and 25.79%

respectively in "End Hocked" steel fibers specimen and 8.81% and 22.01% in "staggered."

12. In high strength concrete, adding 0.5% and 1.5% increases modulus of elasticity 6.35% and 14.29% respectively in "End Hocked" steel fibers specimen and 4.76% and 10.63% in "staggered."
13. In "a/d = 2.5" normal strength concrete, adding 0.5% and 1.5% increases the first cracking load 22.73% and 73.73%respectively in "End Hocked" steel fibers specimen and13.64% and 45.45% in "staggered."
14. In "a/d = 3.5" normal strength concrete, adding 0.5% and 1.5% increases the first cracking load 21.94% and 65.85% respectively in "End Hocked" steel fibers specimen and 12.19% and 43.90% in "staggered."
15. In "a/d = 2.5" high strength concrete, adding 0.5% and 1.5% increases the first cracking load 15.95% and 36.23% respectively in "End Hocked" steel fibers specimen and 7.25% and 21.74% in "staggered."
16. In "a/d = 3.5" high strength concrete, adding 0.5% and 1.5% increases the first cracking load 16.95% and 45.76% respectively in "End Hocked" steel fibers specimen and 10.17% and 28.81% in "staggered."
17. In "a/d = 2.5" normal strength concrete, adding 0.5% and 1.5% increases the yielding load 67.25% and 86.25% respectively in "End Hocked" steel fibers specimen and 60% and 77.5% in "staggered."
18. In "a/d = 3.5" normal strength concrete, adding 0.5% and 1.5% increases the yielding load 15.46% and 54.6% respectively in "End Hocked" steel fibers specimen and 9.28% and 38.14% in "staggered."
19. In "a/d = 2.5" high strength concrete, adding 0.5% and 1.5% increases the yielding load 9.2% and 32.5% respectively in "End Hocked" steel fibers specimen and 6.75% and 19.02% in "staggered."
20. In "a/d = 3.5" high strength concrete, adding 0.5% and 1.5% increases the yielding load 11.43% and 37.86% respectively in "End Hocked" steel fibers specimen and 7.14% and 21.43% in "staggered."
21. In "a/d = 2.5" normal strength concrete, adding 0.5% and 1.5% increases the ultimate load 19.59% and 57.83% respectively in "End Hocked" steel fibers specimen and 11.74% and 39.57% in "staggered."
22. In "a/d = 3.5" normal strength concrete, adding 0.5% and 1.5% increases the ultimate load 23.71% and 65.98% respectively in "End Hocked" steel fibers specimen and 10.52% and 43.81% in "staggered."
23. In "a/d = 2.5" high strength concrete, adding 0.5% and 1.5% increases the ultimate load 15.95% and 38.65% respectively in "End Hocked" steel fibers specimen and 7.98% and 22.09% in "staggered."
24. In "a/d = 3.5" high strength concrete, adding 0.5% and 1.5% increases the ultimate load 16.43% and 43.57% respectively in "End Hocked" steel fibers specimen and 10% and 29.29% in "staggered."
25. In "a/d = 2.5" normal strength concrete, adding 0.5% and 1.5% increases the yielding deflection 3.78% and 8.89% respectively in "End Hocked" steel fibers specimen and 2.22% and 8.33% in "staggered."
26. In "a/d = 3.5" normal strength concrete, adding 0.5% and 1.5% decreases the yielding deflection 16.5% and 15.75% respectively in "End Hocked" steel

fibers specimen and 4.75% and 12.5% in "staggered."

27. In "a/d = 2.5" high strength concrete, adding 0.5% and 1.5% decreases the yielding deflection 6.42% and 19.42% respectively in "End Hocked" steel fibers specimen and 5.58% and 13.67% in "staggered."
28. In "a/d = 3.5" high strength concrete, adding 0.5% and 1.5% decreases the yielding deflection 6.7% and 10% respectively in "End Hocked" steel fibers specimen and 3.8% and 8% in "staggered".

Conflict of interest

The authors confirm that the publication of this article causes no conflict of interest.

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