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RESEARCH ARTICLE

Tensile Bond Strength of Reinforced Concrete Beams Reinforced with Steel Fibers

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ABSTRACT: The effects of steel fibers, or SF, on the tensile bond strength of the reinforced concrete beams, were studied in an experimental investigation, the findings of which are presented in this paper. Tests show that the steel fibers enhanced both the tensile bond strength of reinforced concrete beams and some of the mechanical properties of concrete. The addition of steel fibers in the concrete mix improves some of the engineering properties of concrete such as the compressive strength of cube, cylinder, and modulus of rupture, and decreases other properties namely: the modulus of elasticity, and the indirect tensile test. The addition of steel fibers too leads to an increase in the ultimate bond strength of the beams and delivers a lower deflection in the steel fibers reinforced concrete beams compare to the control beams. This study led to the fact that It is recommended that a beam with a 43Ø lap length will fail at a load similar to the datum beam, i.e. beam without lap. All the lapped beams reported bond failure lower than the datum beam. The presence of steel fibers diminishes the slippage within the laps.

Keywords: Tensile bond strength; steel fibers; compressive strength; deflection.

1. INTRODUCTION

An understanding of the impact of polypropylene, PP, and steel fibers, SF, on plain and reinforced concrete are fundamental for the plan, design, and repair of different concrete structures. Concrete is well known as a naturally brittle construction material. Typical stresses such as fatigue, loading, and impact, cause cracking and lead to failure. The addition of reinforcement bars to the concrete reduces these stresses and prohibits the formation of cracks, therefore enhancing the ductility and the load-carrying capacity of the concrete structures. When loading concrete structures enforced with steel fibers, compressive and tension stresses, start to build in both the tension and compression zones. As the load increases and the stress reaches a critical point small cracks start to appear in the tension zone and propagate upwards toward the compression zone. Steel fibers interact within the concrete and reduce the tensile force. When the crack propagates upward, the hooked ends of the fibers stay secured on each side of the crack, acting as stress transfer media. The pull-out takes full effect once the maximum bond strength with the concrete is reached, this enables the next fibers to take over, delaying cracks from growing and therefore leading to failure at a higher ultimate load than that of the unreinforced concrete structures [1].

The main aim of Bencardino, F., Rizzuti, L., et. al. investigation is to study the contribution of steel fibers to the post-cracking and fracture behavior of plain and fibers concrete samples tested under three-point or four-point bending tests. Strength properties such as fracture behavior, crack tip, post-cracking, and crack mouth opening displacement were observed [2].

The authors concluded that the results obtained from the specimens reinforced with steel fibers and subjected to a four-point loading gave a higher stress value than the results recorded from the three-point bending test. It has also been concluded that the crack strength values of the two tests are

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within 10% of the European standard value. Bencardino et. al. studied the fracture properties and fracture behavior of concrete containing polypropylene and steel fibers [2]. Their author's carried out their experiment on notched prismatic samples and cube samples. The samples are cast from sound concrete and fiber concrete. The latter consists of 1% and 2% of steel or polypropylene fibers. The primary goal of the Aminuddin Jamerana et. al. study is to comprehend the underlying behavior of FRC under high temperature conditions [3]. However, this study suggested combining two distinct types of fibers with concrete before exposing it to elevated temperatures at normal temperature, such as 27 °C (room temperature), 200 °C, and 400 °C. Steel and propylene fibers, which are two different forms of fiber, have different properties. The experimentation is the main emphasis of the study. Additionally, the steel-to-propylene ratio was adjusted with percentages of (100-0), (75-25), (50-50), (25-75), and (0-100) at 1.5% of the fibers proportion from the volume of the concrete. The investigation came to the conclusion that concrete loses strength when samples are exposed to rising temperatures. This is because the concrete started to disintegrate and experience a spalling effect. The concrete becomes more fragile as a result. The impacts that occur in the concrete, however, were reduced by the inclusion of fibers to the concrete mixture.

In Muneer K. Saeed's paper, the impact of steel and polypropylene fibers on heat of hydration and early-age cracking in mass concrete buildings is examined experimentally and statistically [4]. The evolution of strength, Young's modulus, and adiabatic heat increase in fly ash concrete mixes with steel and polypropylene fibers were investigated experimentally. A variety of concrete mixtures were examined, including those using regular Portland cement, 40% fly ash in place of cement, 40% fly ash mixed with 0.3 and 0.5% steel fibers, and 40% fly ash mixed with 0.3 and 0.5% polypropylene fibers. Using a semi-adiabatic calorimeter, the evolution of compressive and tensile strength, modulus of elasticity, and adiabatic heat increase for all blends were measured. Two full-scale mass concrete blocks with conventional concrete and fly ash concrete saw their temperature change at various points throughout time. The study came to the conclusion that, as compared to steel fibers, polypropylene fibers significantly improve performance for early-age cracking.

1.1 Research Significances

This study's goal was to investigate how steel fibers affected the tensile bond strength of reinforced concrete beams that were being loaded by static forces. To investigate the impact of the Steel Fibers, SF, on the tensile bond strength, 10 reinforced concrete beams were cast. The center of the bending zone was used to cast the beam with four lap lengths. Additionally, two reference or datum beams with continuous reinforcing in the tension zone were cast. The engineering properties of the concrete mix utilized for this investigation were also studied.

2. EXPERIMENT PROGRAM

2.1 Details Of The Tensile Bond Test Specimens

The impact of the steel fibers on the tensile bond strength of reinforced concrete beams was investigated. The experimental program consists of five 120x100x1300-mm beams with distinctive lap lengths at the middle of the uniform bending zone. Each beam is enforced with two 6-mm-diameter mild steel bars in the compression zone, whereas the tension zone was enforced with two 8-mm-diameter deformed high-tensile steel bars. The shear zone only was enforced with 2.5mm mild steel bars as stirrups. There were no compression reinforcements or links in the bending zone. Four lap lengths were utilized of 5, 10, 20, and 30 times the diameter of the bars. One beam with continuous tension reinforcement considers a reference for the other lapped beams. The latter 5 beams were cast using steel fibers concrete and they were compared with another identical 5 beams cast from sound, control, concrete, i.e. without steel fibers. The two bunches of beams were tested in a comparative way. A typical detail is shown in Figure 1. Figure 1 also shows load arrangement of beams for inverstigation of bond failure.

2.2 Concrete Mixes and Material Properties

Two mixes were utilized throughout this research namely Steel Fibre, SF, and Control, C, Mixes. Table 1 shows the mixing degree of the concrete mix used, which contains 400 kg/m^3 of cement and uses a water-cement proportion of 0.5. The substance of steel fibers is 0 kg/m^3 and 20 kg/m^3, for the control and Steel Fibers, SF, reinforced beams, mixes respectively.

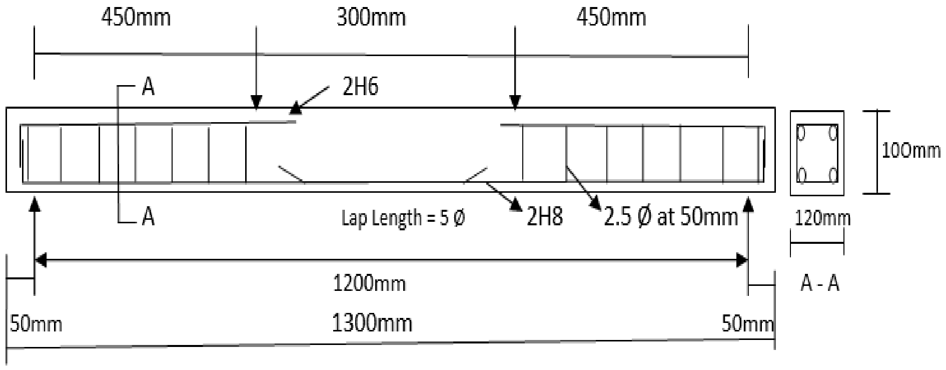

Figure 1: Beam B1, lap lenght=5xbar diameter (Ø) = 5x8 = 40 mm.

Table 1: The control and Steel fibers mix proportions.

Ingredients	Source	Unit	Weight
Ordinary Portland Cement	UCC	kg/m^3	400
Mixing Water	MUN	kg/m^3 or m^3	200 or 0.20
Aggregate: 20mm	RAK	kg/m^3	700
Aggregate: 10mm	RAK	kg/m^3	330
Aggregate: 5mm	RAK	kg/m^3	515
Find Sand	RAK	kg/m^3	295
Steel Fibers	Dramix	kg/m^3	20
Control Steel Fibers	Dramix	kg/m^3	0

Steel fiber concrete is stronger than regular concrete produced with a similar mixing schedule. The fibers are not consumed in the primary climate of concrete and the fiber aspect ratio (length/diameter = L / d) mainly affects the function. Three unique steel fibers with diverse L/d proportions of 45, 65, and 80 can be utilized to meet essential necessities, quality control, and least single execution. The last mentioned L/d proportion was utilized for this examination [5]. These bonded fibers provide the ultimate flexibility, absorption of energy, and tear control.

Steel fiber is made from stainless steel wire or cold-drawn steel wire with little carbon content. Their nature is more flexible and 1.100 N/mm^2 is its tensile strength. They are available in flat, hooked, and undulated designs. The steel fibers can be utilized in anti-seismic buildings, shotcrete, precast concrete, tunnel lining, airport runways, and highway pavements, among other applications.

2.3 Production of The Specimens

The 10 reinforced beams used in this study were designed to focus on the effect of the fiber on engineering properties and the tensile bond strength of R. C. beams are designed in wooden formwork. These samples use a table vibrator to vibrate for a specified period [1]. After leveling the concrete surface, the beam was placed under the polyethylene sheet. After 1 day, each sample was de-molded and then transformed into a tank of water at 20 °C and 100% relative humidity for 28 days. The test was completed within 1 hour after removing the sample from the water tank.

2.4 Materials Properties

The control samples used to investigate the engineering properties of the two concrete mixes with their dimensions are shown in Table 2 [5-8].

2.5 Apparatus and Test Procedure

The specimens for examining the mechanical properties of steel fibre-reinforced concrete were tried in a compression machines. The capacity of the latter is 3000kN and the load rating, according to the BS, was 0.3N/(mm^2.s) [5-9]; all the samples were situated on the inflexible bed of the machine. The 10 beams utilized to examine the tensile bond strength of steel fibers reinforced concrete were tested statically under four-point bending. The shear span-to-effective depth ratio was 6.6 and the moment zone of 300mm. The anchorage was 3.1 times the bar diameter and the supports were 50mm from the ends of the beam as shown in Figure 2. The load was applied to the beams in increments of 2kN up to failure. The deflection was measured as the load was applied to the beams. For each beam, the load at which the first crack was visible to the naked eye, the progress of cracking, the failure mode, and the maximum load to failure were recorded.

3. TEST RESULT AND DISCUSSION

3.1 The Effect of Steel Fibers on The Engineering Properties of Plain Concrete

The results of the static tests carried out to explore the impact of steel fibre, SF, on the mechanical properties of plain concrete are appeared in Table 2, though the results of the impact of steel fibre on the tensile bond strength of reinforced concrete beams are appeared in Tables 3 and 4, respectively.

Table 2: The engineering properties of Sound and SF concrete mixes.

Concrete Properties	Control Mix (0 kg/m^3)	Steel Fibers Mix (20kg/m^3)
Cube Compressive Strength (N/mm^2) – Sample 150 x 150 x 150 mm^3	52.58	58.34
Cylinder Compressive Strength (N/mm^2) Sample 300 x 150mm^2	21.44	29.67
Indirect Tensile Test (N/mm^2) Sample 100 x 200mm^2	6.64	5.43
Modulus of Rupture (N/mm^2) Sample 100 x 100 x 500 mm^3	12.35	13.25
Modulus of Elasticity (N/mm^2) Sample 150 x 300mm^2	42.27	22.12
Water Absorption (g) Sample 150 x 150 x 150 mm^3	0.11	0.11
Slump (mm)	140	140

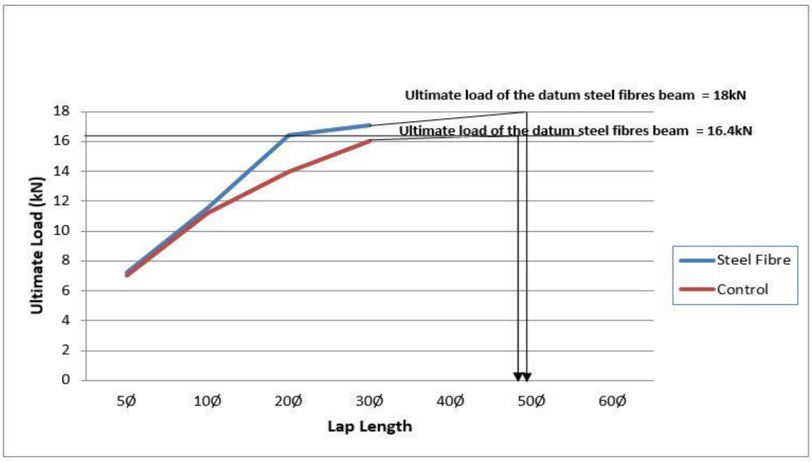

Figure 2: Ultimate load versus lap length of control and steel fiber reinforce concrete beams.

Table 2 shows that the addition of the steel fibers to the concrete mix, SF mix, increases the cube compressive strength, cylinder compressive strength, and modulus of rupture by 9.9%, 27%, and

22.28%, respectively, compared with the control samples. In contrast, the indirect tensile strength and the modulus of elasticity are reduced sharply by 22.23% and 47.67% respectively. The slump test and the water absorption are not affected by the addition of steel fibers [10].

3.2 The effect of Steel Fibers on The Tensile Bond Strength of Reinforced Concrete Beams

The impact of steel fibers on the tensile bond strength of reinforced concrete beams appears in Tables 3 and 4. The experimental ultimate load of the steel fibers reinforced concrete beams and their control, column 3, as well as the calculated ultimate load according to BS8110 [9], column 9, are shown up within the same tables. Column 5 shows the percentage changes in the ultimate load of the steel fibers concrete beams compared to the unlapped, datum, reinforced concrete beam. The load arrangement of the beams for the examination of tensile bond strength appeared in Figure 1.

Table 3: The impact of SF on the R. C. beam's tensile bond strength (B1-SF = Beam No. 1 Steel fibers, B1-C = Beam No. 1 Control, Bar diameter = Ø = 8 mm, ß = 0.5 theoretical value according to BS811 =1.4xßx√fcu).

Beam No.	Length of the lap (Ø=8mm)	Final Load (kN)	Percentage different (%)	Surface area of the bars, πdl (mm²)	Bond Strength (N/mm²)	Calculated Final Load (kN) (BS811)	Mode of Failure
B1 – SF	5Ø	7.2	2.78%	1005.31	12.47	3.16	Flexure Failure
B1 – C	5Ø	7.0			12.22	3.00	Flexure Failure
B2 – SF	10Ø	11.5	2.61%	2010.62	10.47	6.15	Flexure Failure
B2 – C	10Ø	11.2			10.37	5.83	Flexure Failure
B3 – SF	20Ø	16.4	14.63%	4021.24	8.11	11.65	Flexure Failure
B3 – C	20Ø	14.0			6.72	11.00	Flexure Failure
B4 – SF	30Ø	17.1	6.43%	6031.86	5.57	16.50	Flexure Failure
B4 – C	30Ø	16.0			5.27	15.37	Flexure Failure
B5 – SF	No Lap	18.0	8.89%	-	-	-	Flexure Failure
B5 – C	No Lap	16.4			-	-	Flexure Failure

Table 4: Detail of specimens and test results. (B1-SF = Beam No. 1 Steel fibers, B1-C = Beam No. 1 Control, Bar diameter = Ø = 8 mm, ß = 0.5 theoretical value according to BS811 =1.4xßx√fcu)

Beam No.	Length of the lap (Ø=8mm)	Final Load (kN)	Percentage difference (%)	% Change related to datum B5-S	% Change related to Datum B5-C	Bar surface area πdl (mm²)	Tensile Bond Strength (N/mm²)	Calculated Ultimate Load (kN) (BS8110)
B1-SF	5Ø	7.2	2.78%	60.0%	-	1005.31	12.47	3.16
B1 – C	5Ø	7.0		-	56.1%		12.22	3.00
B2–SF	10Ø	11.5	2.61%	36.11%	-	2010.62	10.47	6.15
B2 – C	10Ø	11.2		-	31.71%		10.37	5.83
B3–SF	20Ø	16.4	14.63%	8.89%	-	4021.24	8.11	11.65
B3 – C	20Ø	14.0		-	14.63%		6.72	11.00
B4–SF	30Ø	17.1	6.43%	5.0%	-	6031.86	5.57	16.50
B4 – C	30Ø	16.0		-	2.44%		5.27	15.37
B5–SF	No Lap	18.0	8.89%	-	-	_	-	-
B5 – C	No Lap	16.4		-	-		-	-

The previous results show some interesting effects of steel fibers on the tensile bond strength of reinforced concrete beams tested statically in this research:

1. The ultimate bond strength of reinforced concrete beams increased due to the addition of steel fiber. The increase in bond strength shown by beams B1-SF, B2-SF, B3-SF, B4-SF, and B5-SF are 2.78%, 2.61%, 14.63%, 6.43%, and 8.89%

compared to their corresponding control specimens, respectively.

2. The low percentage change between the steel fibers beams, B1-S and B2-S, and their corresponding control specimens show that the 5Ø, and 8Ø lap length is the fundamental factor. Beams B1-SF, B2-SF, B3-SF, B4-SF, and B5-SF with lap lengths of 5Ø, 10Ø, 20Ø, 30Ø showed a decrease in bond strength of 60%, 36.11%, 8.89%, and 5% respectively, compared with the control beam B6-S, therefore only B1-S with lap length 5Ø showed a reduction more than 50% whereas less than 50% reduction was observed in the other beams.

3. The control beams B1-C, B2-C, B3-C, B4-C, and B5-C, without steel fibers, reported a reduction in the ultimate strength of 56.1%, 31.7%, 14.63%, and 2.44%, individually, compared with beam B6-C, the unlapped datum beam.

4. It is noticeable that the flexural strength for both the control and steel fibers concrete specimens, beams, is reduced due to the incomplete bond strength within the span. Higher flexural strength was obtained due to the increase in the ultimate tension in the bar as the lap length increased. The increase in lap for both the control and steel fibers and datum beams resulted in a decrease in the experimental bond strength.

5. Figure 2 shows the experimental ultimate load plotted against the lap length of the beams. The horizontal lines that represent the experimental ultimate load of the control beams and steel fibers beams were extended to intersect the curves for steel fibers and control, sound, beams. According to this figure, a lap length of 43Ø appears to be required for normal concrete to reach the same ultimate load as continuous reinforcement. This is in line with BS8110’s recommendation for a lap length of 42Ø. On the other hand, for the steel fibers, a concrete lap length of 40Ø is probably required to attain the beam's continuous tension reinforcement strength.

6. All the lapped beams, cast from steel fibers and control concrete failed at a lower load than their respective control beams. The steel fibers reinforced concrete beams failed at a higher load than their corresponding datum beams.

7. The steel fibers seem to increase the flexural strength of reinforced concrete beams without laps, control, only by 8.89% and the percentage reduction decreases as the lap length increases. For short lap lengths, i.e. 5Ø and 10Ø, the steel fibers have only a small effect since the percentage reduction is too small to be significant. Steel fibers enhance the flexural strength of reinforced concrete beams, control, i.e., without laps, by 8.89% while the percentage reduction decreases with the lap length. For short lap lengths, i.e. 5Ø and 10Ø, the steel fibers have only a small effect since the percentage reduction is too small to be significant.

8. Figures 3 and 4 show the deflection against load characteristics of the steel fibers and datum beams. The figures illustrate that the steel fibers reinforced concrete beams had a lower deflection than the control beams at any given point when the steel fibers were present. The figures also demonstrated that the relationship between deflection and bond strength is not linear.

9. Figure 5 shows that the steel fibers and control concrete beams with lap length failed by centre splitting with few cracks in the flexure zone, whereas flexure failure with flexure cracks was observed in the datum beams. Therefore, it is quite clear that the mode of failure is related to the lap length and was not altered by the steel fibers’ presence.

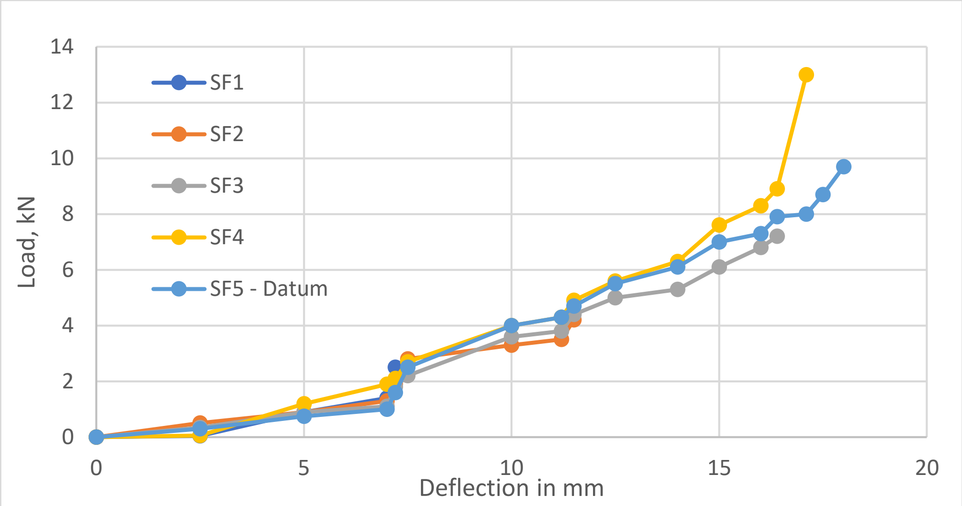

Figure 3: Ultimate load versus lap length of steel fiber reinforced concrete beams.

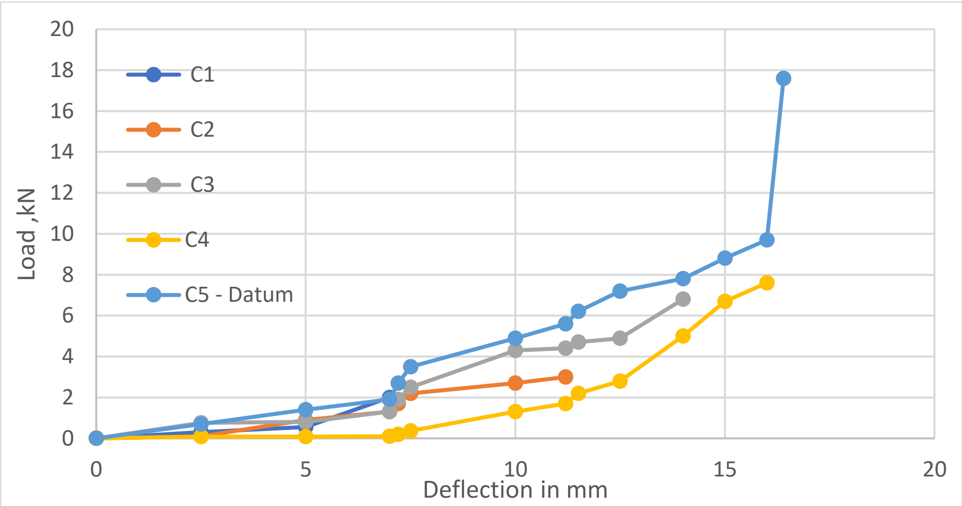

Figure 4: Ultimate load versus lap length of control reinforce concrete beams.

Figure 5: Failure mode under static load, for the steel fibers, reinforced concrete beam, B4 – S, and control beam B4 – C

4. CONCLUSION

In combination with the empirical examination in the previous paragraphs, the following can be concluded:

1. The presence of steel fibers in the concrete improves the compressive strength of both the cube and cylinder as well as the modulus of rupture. On the other hand, it reduces the values of the modulus of elasticity and the indirect tensile test. The change in the engineering properties could be due to the improvement in the bond between concrete and steel fibers. The fiber's orientation also hindered the propagation of the cracks due to stacking, therefore delaying the final destruction. The increase in water absorption is unnoticeable in both mixes.

2. The ultimate bond strength of the beams increased due to the addition of the fibers and produce a lower deflection in the steel fibers reinforced concrete beams than in the control beams. This could be due to the ductile behavior of the steel fibers on the tension zone of the beams that alter the normally elastic distribution of stress and strain over the beam depth and therefore shift the neutral axis of the beam toward the compression zone.

3. It is obvious that a normal concrete beam with a 43Ø lap length will lead to a failure load similar to that of a beam without a lap in the tension zone. This complies with BS 8110 guideline for 42Ø minimum lap length. Similarly, steel fibers reinforced concrete beam with 40Ø lap length is anticipated to fail at a similar ultimate load.

4. Bond failure at a load lower load than the datum beam load was recorded in all the lapped beams. The addition of steel fibers reduces the slippage in the laps.

Author Contribution: The authors carried out the practical and written parts of the research.

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Conflict of Interest: The authors declare no conflict of interest.

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