Flexural Behavior of Recycled Aggregate Concrete Beam Strengthened with Steel Fiber

Abstract: Natural resource scarcity and demolition waste suggest that recycled stone aggregates to be used instead of fresh aggregates as an alternatives. Recycled aggregate provides less strength to concrete than natural aggregate. Fiber such as steel fibers can be added to concrete at a low percentage volumetric addition to fill the strength gap. The purpose of this study is to investigate the flexural behaviors of recycled stone aggregate concrete using steel fiber with a length of 30 mm by volume fractions of 0.45%, 0.90%, 1.35%, and 1.80% of concrete. Coarse aggregates specially recycled stone was obtained from demolished concrete structures and laboratory waste. The desired concrete strength was 30 MPa and the water to cement ratio of 0.46 were chosen based on the mix design, and such concrete was expected to be used for structural beams. The slump test was carried out to ensure the workability of the designed concrete. Compressive strength of cubes was measured at 7 and 28 days. From mean compressive strength, deviation, coefficient of variance (COV), standard error, and lower and greater range of 95% confidence interval analysis, it is found that 1.35% of steel fiber can be used as optimal percentage along with 100% recycled aggregate. Finally, for large scale beams, a combination of recycled stone aggregate and an optimal percentage of steel fiber was used to evaluate flexural behaviors such as first cracking load, ultimate load, load-deflection behavior, and cracking pattern for future practical application. When compared to the reference specimen, the first cracking load and ultimate load bearing capacity of the beam strengthened with steel fiber increased by 11.60% and 14% compared to reference beam with 0% fiber content. Furthermore, the degrees of diagonal tension cracking in strengthened beams were less severe than reference beam. To summarize, optimal dosages of steel fiber with recycled stone can provide sufficient flexural performances of recycled stone aggregate concrete beams.
Keywords: Steel fiber; Recycled aggregate; Reinforced concrete beam; Failure pattern.

1. Introduction

Reinforced concrete is utilized as components of structural construction throughout the world and reinforced concrete beams are structural elements of a structure that makes the structures durable. A reinforced concrete beam should provide safety towards happening of collapse and remain stable in order to serve a structural purpose. Serviceability necessitates that deflection be kept to a minimum, cracks, if any, be kept to a minimum, and the beam's strength be sufficient to withstand all foreseeable loads. It is possible to prevent crack propagation through proper material use, as materials have an impact on beam strength-gaining characteristics as well as failure control. However, conventional concrete is more expensive and depletes more natural resources. As the world faces environmental challenges and sustainable approaches are being implemented wherever and whenever possible, the use of recycled stone as coarse aggregate for structural use, such as in beams, can be implemented. Generally, brick chips, stone chips and similar kind of materials are used as coarse aggregates. Using recycled stone from demolished concrete structures may save the extra costs incurred as well as act as sustainable materials because of its characteristics. Researchers discovered that recycled stone aggregate (RSA) has superior absorption capacity but lower abrasion resistance than natural crushed stone [1]. Although such aggregate has lower strength than fresh natural aggregates, steel fiber addition can enhance the properties such as mechanical properties of concrete. In fact, fiber of shorter length and a lower aspect ratio can be mixed homogeneously with recycled stone aggregate in concrete. Fibers significantly contribute to the structural integrity and structural stability of concrete elements such as beams, extending their durability [2]. The main conveniences of steel fiber reinforced concrete (SFRC) are that it prevents macro crack propagation and micro crack growth The concrete with 1.5% steel fibers and a higher aspect ratio of 80 demonstrated an increase in flexural strength that can reach approximately 150% in high strength concrete (w/c = 0.25) [3]. Furthermore, beams with steel fibers of volumetric fraction higher than 1.0% had higher flexural strength than beams without fibers [4]. As a result, it is obvious that steel fiber can be utilized in concrete to lessen the effect of cracks. For adequate seismic energy dissipation, RC members are naturally bound to undergo large inelastic deformation. As flexural capacity and post-cracking behavior of an RC member are largely controlled by steel reinforcing bar and concrete materials, combining recycled stone with steel fiber may be a sustainable option for use, as cracking behavior like post-cracking is effectively increased with fiber usage in several types and grades of concrete [5]. In addition, the recycled aggregate concrete (RAC) beam exhibits a greater recovery in deflection value when the long-term loading is withdrawn. This result may have been influenced by the creep effect of long-term and the sustained load value of beams [6]. Steel fiber, in fact, improves the flexural strength of recycled aggregate concrete beams [7]. Many researchers have demonstrated that including steel fibers provides greater flexural strength, capacity of deflection and post-peak ductility compared to normal concrete, and that these strengths and ductility increase as the fiber percentage increases [8].

Furthermore, as fiber percentage increases, so does flexural strength, toughness, and the equivalent flexural strength ratio. The amount of steel fibers in the tensile zone of a prismatic beam specimen has the greatest influence on the flexural performance of steel fiber reinforced concrete (SFRC) [9]. According to a researcher, incorporating steel fibers into reinforced concrete beams increases their moment capacity and ductility [10]. Besides that, some studies discovered that in the case of static flexural strength experiments, a maximum increase in static flexural strength of the order of 100% occurred [11]. Furthermore, the flexural strengths of SFRC are 3–81% higher than the control mix [12]. Other researchers expressed that the flexural strength of concrete with a steel fiber content of 0.5% to 1.5% has increased from 100% to 150% for fibers with a smaller aspect ratio. Besides, beams having steel fibers greater than volume fraction of 1.0% exhibited higher flexure strength, capacity of deflection and post-peak ductility compared to the beams without fiber and strength and ductility enhanced with the rise in the fiber content. So in this study, the prime objective was to utilize the optimal percentage of steel fiber along with recycled stone aggregate and establish the load-deflection behavior and cracking pattern of beam. To evaluate the flexural behavior of RCC beams, the appropriate dosage of steel fiber was chosen and applied based on the workability and compressive strength of various concrete mixes in comparison to the reference mix.

2. Materials

OPC is very useful in steel fiber reinforced concrete because of high initial compressive strength [3]. The experiment was performed with locally available premier cement that is ASTM Type – II, Ordinary Portland cement (OPC) of 43 grade according to ASTM C150. For frequent and common use, more specifically when moderate sulfate resistance is desired, This cement is finely powdered substance usually gray colored composite largely of artificial crystalline. The chemical composition of ASTM Type – II OPC that was used for this work is shown in Table 1.

Table 1. Chemical composition of cement [13]

Constituents	Weight (%)
Silica (SiO_2)	20.76
Alumina (Al_2O_3)	4.76
Ferric Oxide (Fe_2O_3)	3.32
Calcium Oxide (CaO)	65.12
Magnesium Oxide (MgO)	1.20
Sulfur trioxide (SO_3)	2.23
Insoluble Residue (IR)	0.36
Free Lime	0.94
Loss of Ignition (LOI)	0.52
Ratio of Al_2O_3 to Fe_2O_3	1.43

Physical properties of fine aggregate (Sylhet sand) and coarse aggregate (Recycled stone) that were utilized in this research is summarized in Table 2.

Table 2. Physical properties of aggregate

Parameters	Fine Aggregate	Coarse Aggregate
Fineness modulus	2.61	6.1
Specific gravity	2.63	2.78
Moisture content (%)	4.83	9.01

For the preparation of recycled stone (coarse aggregate), we have undergone several steps. First of all, demolished concrete having stone was collected from various sites. The concretes were the waste from building demolition and laboratory waste shown. Then manual crushing of stone was done for the preparation of recycling. After that, impure stone aggregate was collected after crushing of waste concretes. Precaution was taken while crushing and collecting aggregates. After the collection of stone, they were sun-dried for a 24 hour period of time before further treatment. The stone aggregates were then soaked in 0.1M HCl solution [14]. Then aggregates were washed with distilled water to remove the impurities that were separated after soaking in HCl solution. Washing is very necessary for the enhancement of surface textures and characteristics of stone. Without proper washing, it is quite impossible to get the desired results from concrete. Finally, fresh recycled stone aggregate were obtained after sun drying. Fig. 1 illustrates the procedures of preparing recycled stone.



Step 1: Demolished concrete collection **Step 2:** Manual crushing **Step 3:** Impure stone



Step 4: Soaking of stone in 0.1 M HCl solution **Step 5:** Washed stone with distilled water **Step 6:** Fresh stone after sun drying

Fig. 1. Preparation of recycled stone (coarse aggregate)

Steel fiber was collected from nearby market and then processed to use. ACI 544.3R defines the specification of steel fiber to vary between 12.7 mm to 63.5 mm, to be used in Fiber Reinforced Concrete (FRC) and diameter of fiber varies mostly from 0.45 mm to 1.0 mm [15]. The aspect ratio is defined as the ratio of length (ℓ) and diameter (d) or the equivalent diameter (de) in certain cases. The code specifies that the value of aspect ratio should lie between 30 and 100. The above stated specifications for steel fiber also comply with the ASTM-A 820/A 820 M standard [16]. Table 3 shows the physical properties of steel fiber and Fig. 2 shows the steel fibers that is used in this study.

Table 3. Physical properties of steel fiber

Properties	Steel Fiber
Length (mm)	30
Diameter (mm)	0.65
Aspect ratio	46

Fig. 2. 30 mm steel fiber

Along with these materials, nano $CaCO_3$ carbonate was used in this study in concrete mix at 4% addition by weight of cement [17]. This is used rapidly as additives in concrete because of its void filling and strength gaining capacity and accelerating effect on hydration process as well as mechanical performance enhancing capability. Nanoparticles function like core, thus it densifies the microstructure and helps to enhance cement hydration [18]. The collected Nano $CaCO_3$ is white in color but has slightly yellow tint shown in Fig. 3.

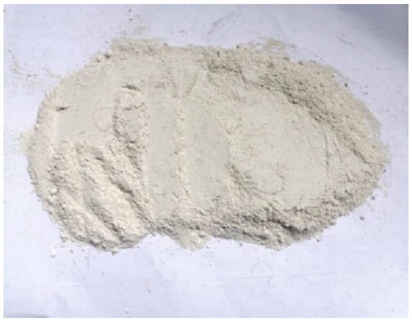

Fig. 3. Nano $CaCO_3$

Fresh potable water of PH 6.7 was used in this study for concreting works. Also reinforced concrete beams were created using Thermo-mechanically-treated (TMT) 500 W grade steel of 12 mm main bar and 10 mm stirrup @ 115 mm spacing.

3. Experimental Investigations

3.1 Mix Design of Concrete

Concrete mix proportions were calculated according to ACI 211.1-91 [19]. Concrete mix proportions of 1:

1.90: 2.50 (Cement: FA: CA) were obtained and was utilized for making M30 concrete. Nano calcium carbonate was used as additive. Fibers were added by following above stated standard to obtain a proper mix of steel fiber reinforced concrete. Requisite materials per cubic meter concrete are detailed in Table 4.

Table 4. Estimated quantity of materials

Specimen type	Cement (Kg)	Water (L)	W/C	Fine Aggregate (Silica Sand) (kg)	Coarse Aggregate (Recycled Stone) (Kg)	Fiber Ratio (%)	Steel Fiber (Kg)	Nano $CaCo_3$ (kg)
Reference	386	185	0.46	762	1006	0	0	16
S-1	386	185	0.46	762	1006	0.45	10.6	16
S-2	386	185	0.46	762	1006	0.90	21.20	16
S-3	386	185	0.46	762	1006	1.35	31.80	16
S-4	386	185	0.46	762	1006	1.80	42.40	16

3.2 Test on Fresh Concrete: Workability Test

This test was carried out using slump cone and tamping rod according to ASTM C143 [20]. Slump test on control and fiber reinforced concrete demonstrates the effect of adding steel fibers on concrete workability.

3.3 Test on Hardened Concrete

According to ASTM C140, compressive strength test of concrete cube was carried out at 7 days and 28 days.

Concrete cubes of 150 mm x 150 mm x 150 mm were prepared by implementing the mix design for reference sample and fiber reinforced sample. For each percentage of steel fiber, three cubes were tested. The compressive strength was measured by the following expression:

$F = P/A$ (N/mm^2)

Where P = Ultimate load (N) and A = Cross sectional area (mm^2)

Reinforced beam specimens were prepared for reference mix and optimum fiber mix. The dimension of the beams was 150 mm x 200 mm x 1200 mm. In these beams 12 mm bars were used as main reinforcement bar and 10 mm bars were used as shear reinforcement (stirrup). The stirrups were placed at 115 mm intervals ensuring 25 mm clear cover both at top and bottom. The typical cross section of the beam is shown in Fig. 4 and the detailed beam reinforcement is shown in Fig. 5.

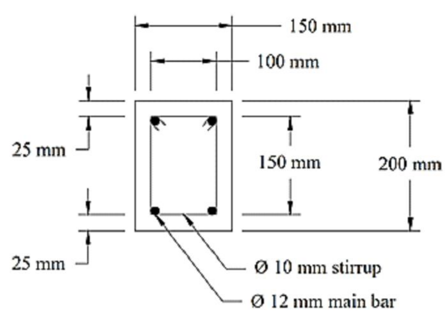

Fig. 4. Cross section of beam reinforcement

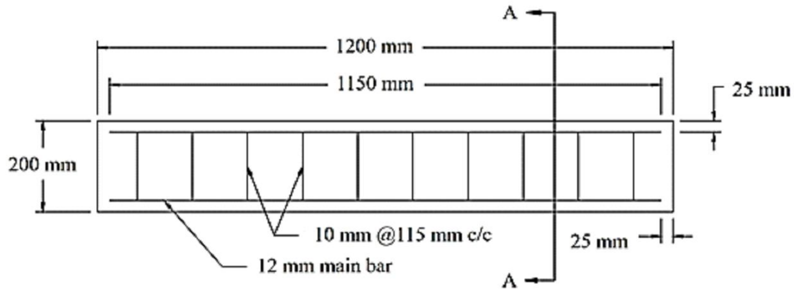

Fig. 5. Details of beam reinforcement

Four point bending test was carried out using "Universal Testing Machine" to observe the failure pattern and load-deflection behavior of beams. Continuous loading was provided at 1.5 KN/sec till failure. This set up includes two roller supports, steel I section beam and loading cell. In the set up, the effective span of the beam was divided in three equal length (L/3). As a result, the loading condition and the two roller supports ultimately made the arrangement "four-point bending set up". Fig. 6 shows the set-up of beam for bending test.

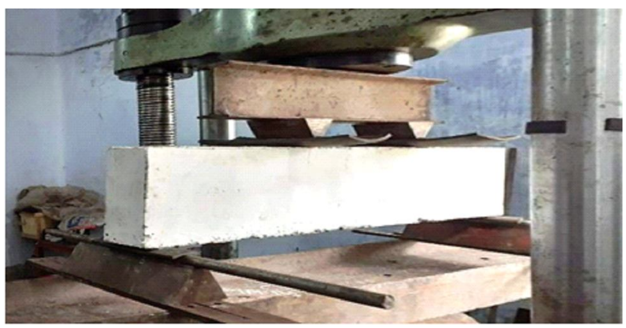

Fig. 6. Four point bending test of beam

4. Results and discussion

4.1. Workability of steel fiber reinforced concrete

Fig. 7 illustrates the graphical representation between slump value and steel fiber content for all the concrete mixes. From the experimental inquiry, it is evident that the slump test shows a decreasing trend when the percentage of steel fiber increased in the concrete mix. The maximum slump value of 64 mm was found for the reference mix of F0, while 54 mm, 47 mm, 41 mm and 37 mm slump values were observed for the mixes of F0.45, F0.9, F1.35, F1.8 respectively. Besides, it is noteworthy that an average of 30% slump was fallen for fiber reinforced concrete mixes compared to the reference mix. The identical findings were also noticed in the decreasing trend of the slump by the addition of steel fiber in the concrete mixes [13]. This reduction in slump value is imposed to the metallic fiber incorporation in the concrete mix. In other words, steel fibers become stiffer as the concrete made with different concentrations of fiber compared to the reference mix. This happened as they absorbed much water from the concrete mix and interlocking of fiber that can influence its slump value. In addition, higher fiber percentage in freshly mixed concrete leads to a tendency of fiber balling, which substantially lessened the slump value. However, the trends of the slumps were accomplished true slump for all of the concrete mixes. Figure 7 also reflects the minimum range of slump is 20 mm and maximum is 100 mm as per concrete mix design. As the designed concrete was of higher grade, it was more dense and showed value from 64 mm to 37 mm. This happened due to the increase of percentage of steel fiber in the concrete. These values of slump satisfy the expected designed range, even utilizing steel fiber in concrete.

Fig. 7. Fluctuation of slump based on steel fiber content

4.2. Influence of steel fiber content on slump value

Table 5 summarizes the compressive strength test results of various mixes in terms of the mean strength, deviation, coefficient of variance (COV), standard error, and lower and greater range of 95% confidence intervals. It is worth mentioning that three specimens were evaluated in the laboratory for each fiber concentration, and mean values were computed to obtain the final test results for compressive strength at 7 and 28 days. According to statistical analysis, the compressive strength fluctuated from 19.86 MPa to 32.66 MPa. The standard deviation of tested specimens ranges from 0.0203 to 0.201, with corresponding COVs ranging from 6.16% to 7.2% and standard errors ranging from 0.013 to 0.116. Furthermore, the lowest compressive strength was 31.15 MPa with a 95% confidence interval bound of 30.97 MPa to 31.33 MPa and where the highest compressive strength was 32.66 MPa with a 95% confidence interval bound of 32.60 MPa to 32.72 MPa. The summary of compressive strength test results is shown in Table 5.

A standard deviation of strength less than 1 MPa indicates that the concreting work for this study was done with satisfactory quality control, because a deviation of up to 1.3 MPa indicates that the degree of quality control of concreting work complies with the laboratory precision according to the code of ACI [19]. So, comparing the results with the ranges provided by ACI Code, the concreting operations were of proper quality control up to laboratory precision. Again, according to the Table 5, the compressive strength of all SFRRSAC specimens were gained more than 63.75% 28-day compared to at 7 days. The results of this study also demonstrates that the addition of steel fiber in concrete mix gradually increases its compressive strength. Furthermore, the compressive strength of the reference (F0) mix was 19.86 MPa after 7 days, 31.15 MPa after 28 days, and the maximum of 32.66 MPa after 28 days for F1.80 mix represents a 4.85% strength improvement over the reference mix.

Table 5. Compressive strength test results of concrete mixes

Mixes (% Fiber)	Days	Mean Strength (MPa)	Standard Deviation, σ	COV	Standard Error, SE	95% Confidence Interval	
						Lower Range	Upper Range
F 0	7	19.86	0.122	0.614	0.070	19.72	19.998
	28	31.15	0.161	0.517	0.093	30.97	31.33
F 0.45	7	20.345	0.085	0.418	0.049	20.25	20.44
	28	31.995	0.023	0.072	0.013	31.97	32.02
F 0.90	7	20.715	0.039	0.188	0.023	20.67	20.76
	28	32.12	0.150	0.467	0.087	31.95	32.29
F 1.35	7	21.05	0.185	0.879	0.107	20.84	21.26
	28	32.645	0.201	0.616	0.116	32.42	32.87
F 1.80	7	20.98	0.125	0.596	0.072	20.84	21.12
	28	32.66	0.056	0.171	0.032	32.60	32.72

However, optimal fiber concentration might be considered as 1.35% of fiber dosages because after this percentage, the compressive strength enhancements become flat. This finding is consistent with the findings of a recent study that was carried out by experimental investigations, and revealed an increasing trend in the compressive strength of fiber reinforced concrete with varying concentrations [21]. Also, another study found that the presence of steel fibers had a momentous impact on high-performance concretes the compressive strength [22]. However, this may not always be the case due to material properties, experimental conditions, and the various parameters used in various studies.

4.3. Failure of Beam Specimens

Fig. 8 depicts the failure pattern of reference beam, which was constructed without the inclusion of steel fiber. When the applied load exceeded the tensile stress of concrete, the very first crack emerged on the beam surface [23]. At a load of about 79 KN, the first flexural crack in the beam was generated at mid span at the bottom of the beam. Some earlier researches made an identical assessment of the first crack's initiation [24]. During final failure, flexural cracks formed near the left and right beam supports, whereas web shear cracks began near the left and right beam supports. Permanent pen was used to mark the cracks and the corresponding loadings were saved. The beam eventually failed at a load of 182 KN. The reference beam is shown in Fig. 8.

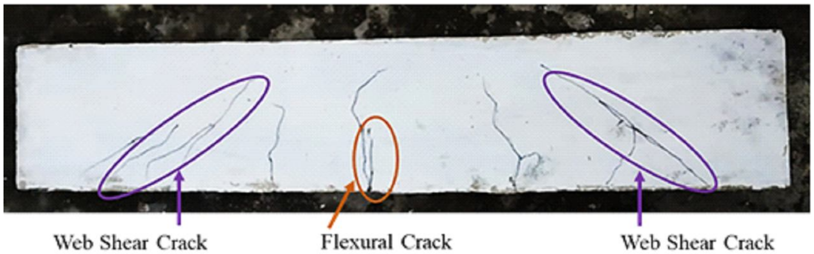

Fig. 8. Failure pattern of reference beam

Fig. 9 depicts the failure pattern of beam 02, which was strengthened with 1.35% steel fiber. At a load of approximately 87 KN, the first flexural crack in the beam was derived at mid span somewhere at bottom of the beam. During final failure, flexural cracks formed near the left and right beam supports, whereas web shear cracks began near the left and right beam supports. The beam eventually failed at a load of 207 KN. Although the cracks in the strengthened beam were almost identical to the cracks in the reference beam, the cracks in the strengthened beam were less severe than the initial ones. This occurred because the addition of steel fiber to the concrete matrix strengthens its engineering characteristics, particularly its tensile strength, impact resistance, fracture toughness, and serviceability [25]. Also, steel fiber serves as a crack connector in concrete. That is why cracks become less visualized in fiber strengthened beam and provided more first cracking load and ultimate load bearing capacity compared to reference beam. Fig. 9 shows the failure pattern of strengthened beam.

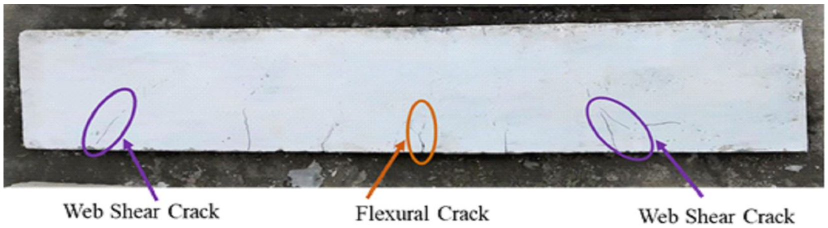

Fig. 9. Failure pattern of steel fiber strengthened beam

It was experienced from the bending test of beams that the inclusion of steel fiber enhances both first cracking and ultimate load of beam strengthened with steel fiber. In case of steel fiber strengthened beam (beam 02), the cracking load increases up to 11.60% and the ultimate load increases up to 14% compared to reference beam (beam 01) without steel fiber. The introduction of steel fiber managed to improve the beam's capacity for bearing loads. According to several scholars, incorporating steel and other fibers appears to increase the ultimate load - carrying capacity of reinforced concrete beams when compared to reference specimens [26].

4.4. Load-deflection behavior of beam specimens

Fig. 10 visualizes the load-Deflection curve for reference (B1) and strengthened beam (B2). The mid-span deflection of beam B1 was higher than the mid-span deflection of beam B2 for any load increment. Beam B1 had a first cracking load of 79 KN and a mid-span deflection of 0.53 mm. Beam B2 had a first cracking load of 87 KN and a mid-span deflection of 0.37 mm. Beam B1 had an ultimate load of 182 KN and a mid-span deflection of 1.775 mm. While beam B2's ultimate load was 207 KN, the respective mid-span deflection was 1.725 mm. Besides that, several scholars found that the maximum deflection of the plain concrete is 15.7 mm, while the maximum deflection of the steel fiber reinforced beam is 12.9 mm [10]. The result is better compared to their study due to use of recycled stone as coarse aggregate and steel fiber resisted deflection for the proper combination with other materials. In addition, concrete grade and water cement ratio also has an effect. The load-deflection curve for beams is shown in Fig. 10.

Fig. 10. Load-Deflection curve for reference (B1) and strengthened beam (B2)

5. Conclusions

From the experimental study, following conclusions can be drawn from the test results and discussions:

1) Incorporation of steel fiber lessened slump value gradually. For F0-F1.8 mixes, the slump value decreased from 64 to 37 mm.

2) The addition of 1.35% steel fiber served as an optimum percentage for the compressive strength, because rate of strength development slowed dramatically after this percentage.

3) Beam strengthened with optimum content of steel fiber showed greater increase of cracking load at about 11.60% and ultimate load at about 14% compared to beam without steel fiber.

4) The mid span deflections at various stages of strengthened beam were comparatively less than that of reference beam specimen.

5) The propagation and visibility of diagonal cracks were less severe for beam strengthened with optimum steel fiber.

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