Proceedings of International Conference on Planning, Architecture and Civil Engineering, 12 - 14 October 2023, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

Paper ID: CE 0259

Applicability of Steel Fiber and Recycled Stone in Compressive Strength Development of M30 Concrete

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Abstract

Natural resource scarcity and demolition waste suggest that recycled aggregates to be used instead of fresh aggregates. 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 concrete beam using steel fiber with a length of 30 mm by volume fractions of 0.45%, 0.9%, 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. Finally, Finally, the compressive strength of concrete cubes was measured after 7 and 28 days. The results showed that the concrete obtained the desired strength and performed somewhat better in compressive strength, with steel fiber being used at 1.35% of the volume of concrete being the optimum percentage. To summarize, steel fiber mixed at an optimal ratio with recycled stone may be an environmentally benign alternative for RCC structures.

Keywords: *Recycled stone; Steel fiber; Compressive strength; Concrete.*

1 Introduction

Recycled aggregate and steel fiber are currently utilized as components of structural construction throughout the world. To meet the demand for concrete, natural resources like aggregates are being used more and more excessively on a global scale. The demand for building aggregates is anticipated to increase progressively on a global scale. Besides, processing and recycling this waste is a serious concern nowadays. So, rcecycling of aggregate might be an alternative solution which can lessen natural aggregate extraction and save environment. Researchers have found that recycled stone aggregate concrete showed comparatively higher compressive strength than the natural aggregate concrete. This happened for the firm RSA-new mortar bond (Butler et al., 2011). On the other hand**,** the replacement of aggregate in percentage does not hamper the strength like compressive parameter of concrete, impacted within quality of the recycled stone aggregates utilized (Olivito and Zuccarello, 2010).

In this case, steel fiber can be integrated into concrete at a volumetric percentage to maintain safety while utilizing recycled aggregate concrete. The addition of steel fibers to concrete, represented in volume fractions, improves both strength and ductility but decreases workability (Olivito and Zuccarello 2010)**.** Whereas, the compressive strength of the fiber-reinforced concrete attained maximum at 1.5% volume fraction, being a 15.3% betterment (Thomas and Ramaswamy, 2007). According to a recent study, the compressive strength of concrete increased by about 2.71-4.85% when compared to the reference specimen, and 1.35% of steel fiber served as an optimum percentage for the compressive strength parameter, as the rate of increase in strength slowed dramatically after this percentage. Furthermore, another great convenience of steel fiber reinforced concrete are the interruption in macro crack propagation, obstruction to growth of micro cracks (Abbass et al., 2018). One thing must be noted that the post-cracking reaction of concrete is significantly raised with fiber dosages for several concrete grades (Jang and Yun, 2018).
So, the research aims to determine the most effective steel fiber dosage that can be used in concrete and to evaluate the performance of concrete containing recycled stone aggregate and steel fiber. As the modern world has begun to adopt cost-effective materials, design, and sustainable construction, this work may serve as a guide for

researchers who want to widely implement the combination of recycled stone aggregate and steel fiber for structural use (Chowdhury and Islam, 2022).

2 Materials and Methods

2.1 Cement

Locally available 43G Ordinary Portand Cement (OPC) was used in this research. The constituents of OPC are shown in Table 1.

Table 1. Chemical constituents of OPC

Constituents	Weight (%)
Calcium Oxide	65
Silica	20.8
Alumina	4.8
Ferric Oxide	3.36
Others	6.04

2.2 Fine Aggregate and Coarse Aggregate

Silica sand and recycled stone was used as fine and coarse aggregate respectively, for the preparation of fiber reinforced concrete. The physical properties of both aggregates are shown in Table 2.

Table 2. Physical properties of aggregates

Parameters	Fine Aggregate	Coarse Aggregate
Fineness modulus	2.61	6.1
Relative density	2.63	2.78
Water (%)	1.83	2.01
Loose unit weight (Kg/m^3)	1465	1457
Bulk unit weight (Kg/m^3)	1555	1572
Void content (%)	40.75	43.33

The preparation of recycled stone aggregate is simply illustrated below:

Step 1. Demolished concrete collection

Step 2. Manual crushing

Step 3. Impure stone

Step 4. Soaking of stone in 0.1 M HCl solution (Tam et al., 2007)

Step 5. Washed stone with distilled water

Step 6. Fresh recycled stone after sun drying

Figure 1. Collection and processing of recycled stone aggregate

2.3 Steel Fiber

Steel fiber was collected from nearby market and then it was processed to use. ACI 544.3R defines the length of fiber should vary up to 63.5 mm, which should be used in concrete strengthened with steel fiber and diameter of fiber should be within 0.45-1.0 mm (A01 Committee). Besides, the aspect ratio (l/d) of fiber should be within 30-100. Such criteria for steel fiber is similar with ASTM-A 820/A 820 M (A01 Committee). Figure 2 exhibits the steel fibers and Table 3 describes the properties of fiber:

Figure 2. Steel fiber

Table 3. Properties of steel fiber

Approximate Length (mm)	Approximate Diameter (mm)	Aspect Ratio
30	0.75	40

2.4 Nano Calcium Carbonate

Nano $CaCO_3$ carbonate was used in this study in concrete mix at 4% addition by weight of cement (Al Ghabban et al. 2018). Nanoparticles function like core, thus it densifies the microstructure and helps to enhance cement hydration (Shaikh and Supit 2014).

2.5 Mix Design of Concrete

Concrete mix proportions of 1: 1.90: 2.50 (Cement: FA: CA) were obtained and was utilized for making M30 concrete according to the ACI 211.1-91. Nano calcium carbonate was used as additive. The process of concreting works were performed by following ASTM C192/C192M (Islam et al., 2021). 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 below 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 CaCo3 (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

2.6 Tests on Concrete

2.6.1 Workability Test

This test was executed using slump cone, plate and tamping rod by following ASTM C143 (C09 Committee). Workability test shows the effect of steel fiber on slump value of concrete.

2.6.2 Compressive Strength Test

This test was performed by following ASTM C140 (Islam et al., 2021). Three cubes having standard size of 150 mm x 150 mm x 150 mm were required for each percentage of fiber. Saving cost and easy working process were major concerns regarding the selection of cubical specimens.

3 Results and Discussions

3.1 Workability of Concrete: Slump Test

Figure 3 reflects that 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. An equivalent finding was also noticed in the decreasing trend of the slump by the addition of steel fiber in the concrete mixes (Islam et al., 2021). So, These values of slump satisfy the expected designed range, even utilizing steel fiber in concrete. However, the trends of the slumps were accomplished true slump for all of the concrete mixes.

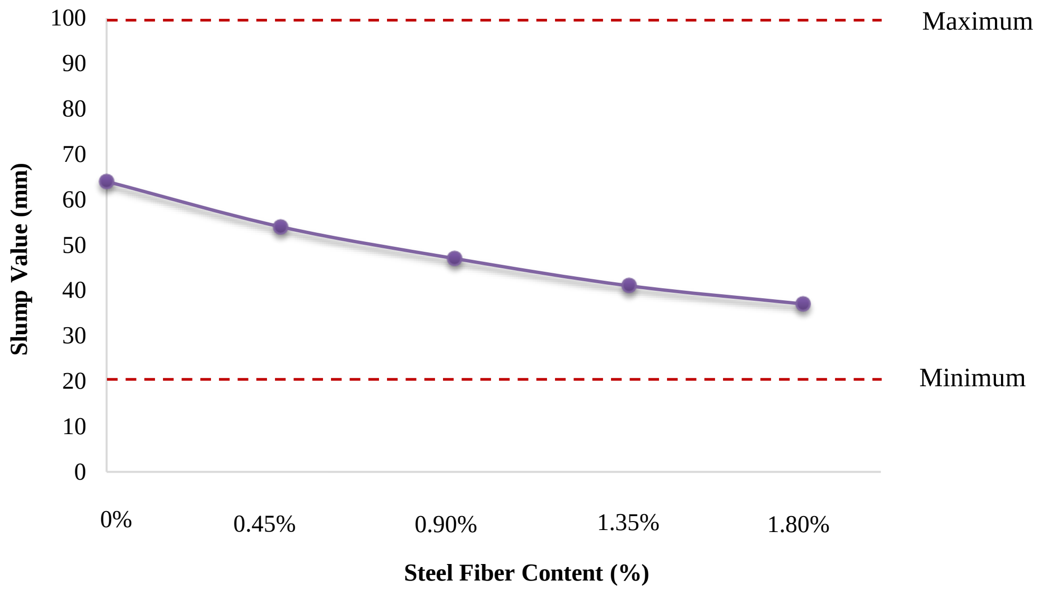

Figure 3. Fluctuation of slump with respect to steel fiber content

3.2 Impact of Steel Fiber Content on Compressive Strength of Concrete

Table 5 summarizes the compressive strength test results of concrete 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.

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

Alongside, 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. Also, 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. Furthermore, 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 (ACI 211.1-91, 1993). According to Table 5, the compressive strength of all specimens 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. 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 (Das et al., 2020).

While the cubes were investigated to obtain compressive strength, the cracking patterns were also observed. The reference cube (F0) failed more severely compared to cubes of F 0.45, F0.9, F1.35 and F1.8 mixes. Figure 4 (A-E) demonstrates crack patterns in concrete cubes with steel fiber content ranging from F0 to F1.8. The cracks were initially generated diagonally, but soon after they were propagated on the basis of a 60 degree angle (Fang et al., 2018). The figure shows that the crack openings were distributed for F0 and F0.45 mixes. However, the degree of crack distribution was lower for 0.45% fiber content when compared to the reference cube specimen. The cracks of the F0.9, F1.35 and F1.8 mixes formed by a 60-degree diagonal pattern, and the crack openings were not distributed. Furthermore, the post-cracking ductility improved as the fiber content increased. As a result, crack openings and crack formation on the surfaces were gradually reduced. As a matter of fact, it can be concluded that all of the specimens' crack patterns are similar, but the addition of steel fiber whittled down the degree of crack formation and distribution as the concrete stiffened gradually which is shown in figure 4 (A-E).

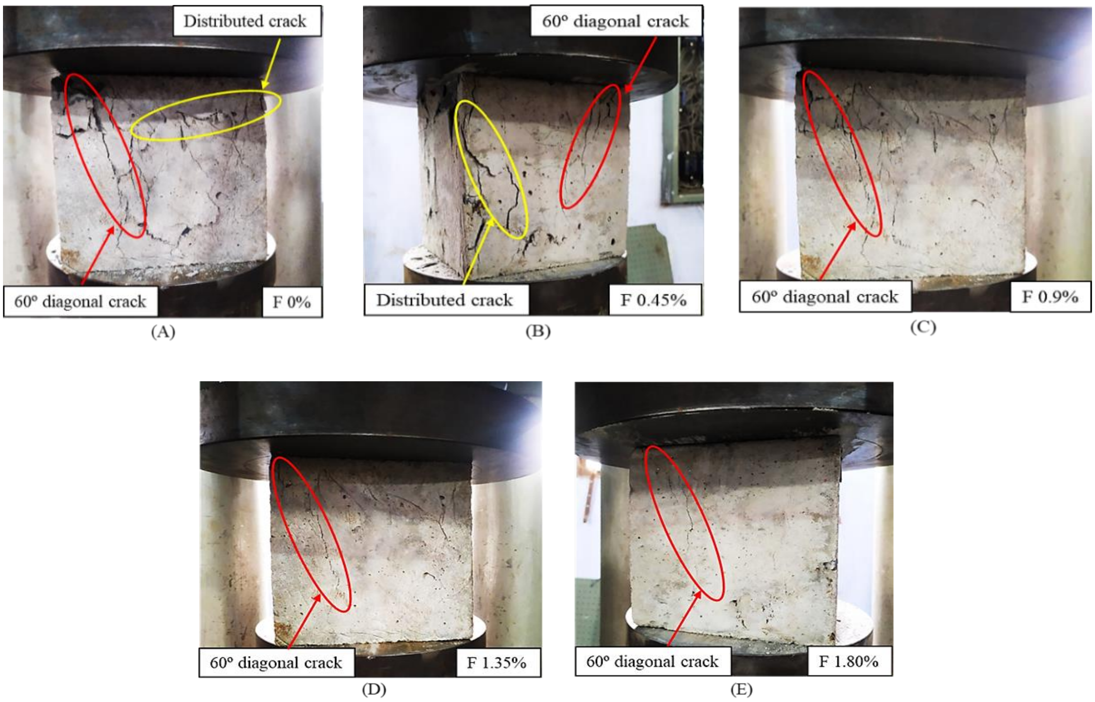

Figure 4. Observed crack pattern of cubes (F 0 - F 1.8)

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4 Conclusions

From the experimental research, following conclusions are drawn:

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

2. Although the enhancement of compressive strength was not so high, the addition of 1.35% steel fiber served as an optimum percentage for the compressive strength parameter, because rate of strength development slowed dramatically after this percentage.
3. The cracks of cubes formed diagonally and the opening of cracks were distributed in nature for F0 and F0.45 concrete mixes. In the case of F0.9-F1.8 mix, cracks formed diagonally but the nature of the openings was not similar as the fiber content increased gradually. Cylinders, on the other hand, failed along a single diagonal. Cracks appeared in the top-bottom diameter surface of cylinders for F0-F0.9 mixtures. Meanwhile, cracks appeared in the top-mid span of the cylinder diameter for F1.35-F1.8 mixes. The severity of these cracks decreased as fiber content increased.

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