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Research Article

Influence of Steel Fiber on Compressive Strength and Crack Pattern of Recycled Aggregate Concrete

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Abstract

The use of recycled aggregates rather than new aggregates is suggested by the depletion of natural resources and demolition trash. Compared to natural aggregate, recycled aggregate gives concrete less strength. Concrete can be strengthened by adding fiber, such as steel fibers, at a low volumetric proportion. This study aims to determine the concrete's compressive strength by adding steel fiber (30 mm in length) to volume fractions of 0.45%, 0.9%, 1.35%, and 1.80% of the concrete. Coarse aggregates specially recycled stone was obtained from demolished concrete structures and laboratory waste and used after proper treatment. Based on the mix design, a concrete strength of 30 MPa and a water to cement ratio of 0.46 were selected. This type of concrete was anticipated to be utilized for RCC beams. To make sure the designed concrete was workable, the slump test was conducted. The slump showed decreasing value when steel fiber was added accordingly. After seven and twenty-eight days, the concrete cubes' compressive strength was finally measured. With steel fiber utilized at the ideal proportion of 1.35% of the volume of concrete, the results demonstrated that the concrete achieved the required strength and slightly improved in compressive strength. In conclusion, steel fiber combined with recycled stone in the right proportion could be a sustainable substitute for RCC structures.

Keywords

Recycled Aggregate, Steel Fiber, Compressive Strength, Workability

1. Introduction

Around the world, steel fiber and recycled aggregate are now used as building materials for structures. Globally, natural resources like aggregates are being used excessively to supply the demand for concrete. It is projected that the global demand for building aggregates would gradually rise. Furthermore, these days, processing and recycling this trash are major concerns. Therefore, recycling aggregate could be a substitute that reduces the need for natural aggregate extraction while also protecting the environment. Researchers discovered that the compressive strength of recycled stone aggregate concrete is somewhat higher than that of natural aggregate concrete. This phenomenon happened for the firm recycled stone aggregate (RSA)-new mortar bond [1]. 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 [2].

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

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concrete, represented in volume fractions, improves both strength and ductility but decreases workability [2]. Whereas, the compressive strength of the fiber-reinforced concrete attained maximum at 1.5% volume fraction, being a 15.3% betterment [3]. 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 [4]. One thing must be noted that the post-cracking reaction of concrete is significantly raised with fiber dosages for several concrete grades [5].

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 [6].

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:

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 [8]. 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 [8]. 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 [9]. Nanoparticles function like core, thus it densifies the microstructure and helps to enhance cement hydration [10].

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. 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 $CaCO_3$ (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

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 [11]. 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. 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 63 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 [12]. 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.

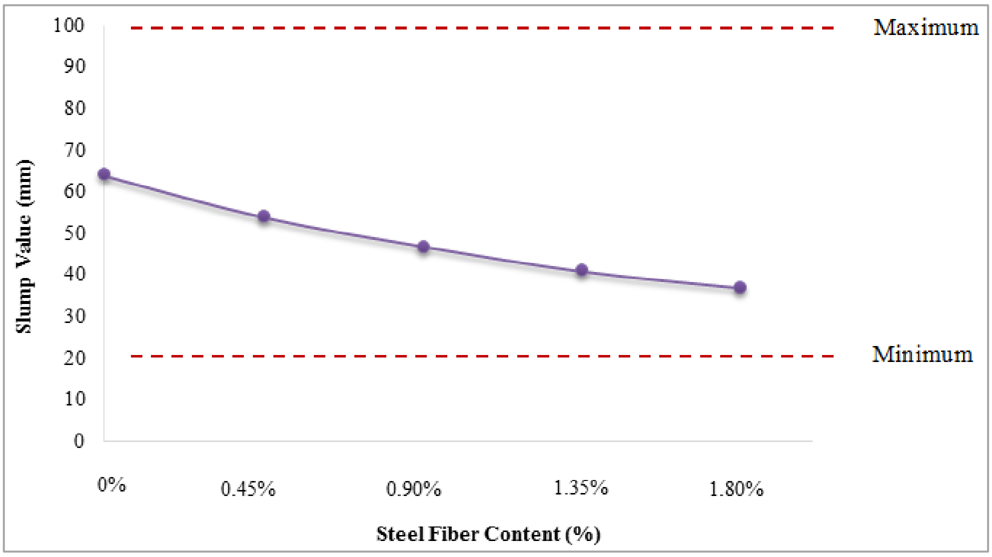

Figure 3. Fluctuation of slump with respect to steel fiber content.

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.

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	19.99
	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

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.

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 [13]. 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 [14].

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 [15]. 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).

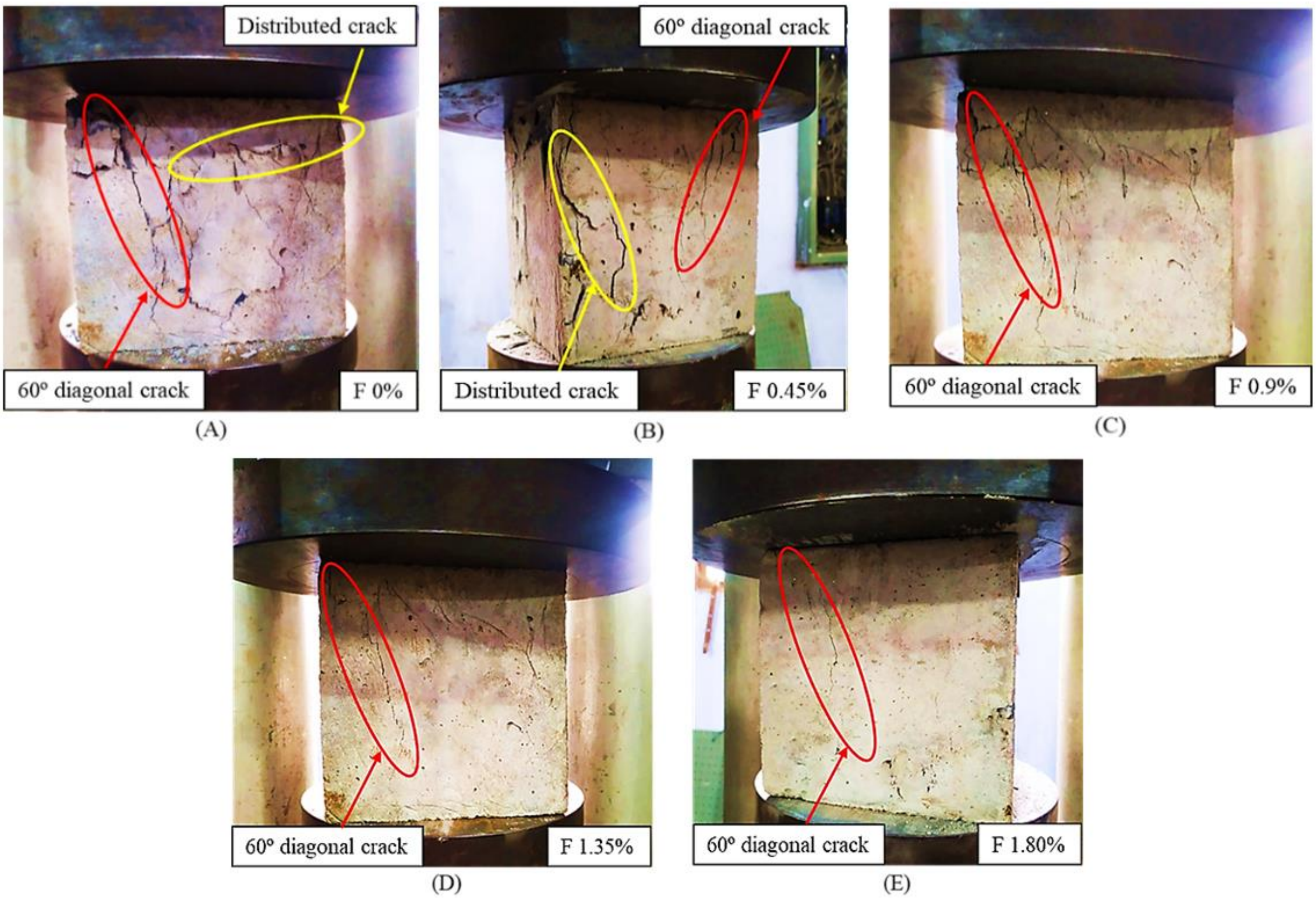

Figure 4. *Observed crack pattern of cubes (F 0 - F 1.8).*

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 63-38 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.

Abbreviations

RSA	Recycled Stone Aggregate
OPC	Ordinary Portland Cement
COV	Coefficient of Variance
W/C	Water to Cement Ratio

Author Contributions

Arifa Akter Swarna: Data curation, Funding acquisition, Investigation, Resources, Validation

Md. Rejoan Chowdhury: Conceptualization, Data curation, Formal Analysis, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing

Md. Saim Hossen Noman: Funding acquisition, Investigation, Methodology, Software, Visualization

Conflicts of Interest

The authors declare no conflicts of interest.

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