EXPERIMENTAL INVESTIGATION ON THE STRUCTURAL PROPERTIES OF CONCRETE REINFORCED WITH STEEL AND COIR FIBERS

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ABSTRACT

The conventional cement concrete is usually low in tension, has no ductility, and possesses a small capacity to resist cracking because of the microcracks inherent in the structure of the material. As is known, their structural behaviour can be enhanced by the addition of fibers. This research utilizes steel and coir fibers, and the study is aimed at examining the reinforcement of concrete and its mechanical behaviour in terms of durability. It is hoped that this research aims at creating a stronger, more durable, and more economical concrete with the help of steel and coir fibers and to compare the strength of the concrete supported by the same percentage of the respective fibers. The fiber content in the concrete mixtures was varied at 0%, 0.50%, 0.75%, and 1% by volume, while an additional mix incorporating 1% steel fiber was combined with recycled concrete aggregate (RCA) at replacement levels of 15%, 30%, and 45% by weight of natural coarse aggregate. In this experimentation, concrete samples were taken and experimented on to learn the way their compressive, tensile as well as flexural strength evolved with time. Measurements of the strength were made after 7, 14, and 28 days of curing and also the mode of failure in the process of testing. It was noted that the regular strength of the concrete was made stronger with the incorporation of steel fibers. The best strength values came with the sample that consisted of about 1 percent of steel fiber. Conversely, addition of coir fibers at 0.50%, 0.75% and 1% resulted in a significant decrease strength in comparison with the control sample. Of the concrete mixes which were of the recycled concrete aggregate (RCA), the concrete mix with the steel fiber of 1% and the RCA of 15 percent gave the best balance between strength and workability. Generally, the application of steel fibers can significantly increase the mechanical performance and contribute to more sustainable building, since the necessity to discard waste in landfills will be lowered and it helps to reduce environmental impact.

Keywords: *Steel fiber, Coir fiber, Recycled aggregate, Construction waste, Compressive, Tensile and flexural Strength*

1. INTRODUCTION

The cities which are a creation of human civilization have grown in size; to this end, massive areas are being paved or covered with impervious substances like concrete. It is popular in construction because it can easily be altered into different forms depending on the work one wants. Since sustainable construction has become relevant and more infrastructures are being developed, a greater demand has emerged to use construction materials which are durable and strong in the long term. Ordinary cement concrete has certain issues, including low tensile strength, limited ductility and an ability to crack when loaded. Such imperfections would produce additional microcracks in the materials and cause brittle fracture during loading (Anas et al., 2022; Fang et al., 2023).

During the recent years, studies on concrete have been on the increase and attempts at enhancing the structural and durability characteristics of concrete in order to achieve the desired overall performance. The current search of the concrete with the high level of strength and durability is clear. Though the concrete made of Portland cement has a high compressive strength, concrete has a high compressive resistance, nevertheless, it cannot withstand high tensile ability and has a brittle nature thus embracing the tendency of cracking under tension (Bhat et al., 2018). The mitigation of this tensile weakness can be achieved by using conventional steel reinforcement bars, in addition to by incorporating a sufficient amount of particular fibers. As is seen the incorporation of fiber types increases the strength, durability, as well as performance. This has led to the increased use of fiber-reinforced concrete in most construction works where it has superior tensile strength and an improvement on ductility. The fiber reinforced concrete (FRC) concept is not a novel one. In mortar and straw in mud bricks, the fiber reinforcement was done long ago with horsehair. The world has been keen on incorporating as many types of fiber concrete as it can to ensure that it is more tough, durable and more economical (Chen et al., 2023). The reasons why the construction projects use fiber-reinforced concrete material include its capacity to increase toughness, fatigue resistance and homogenous crack pattern that has the capacity to reduce the width of a crack. Numerous studies (Anas et al., 2022; Khan et al., 2023) have investigated various types of fibers to improve the strength of concrete. Among them, steel fiber and coconut fiber are particularly noteworthy, as they are abundantly available and contribute to sustainability while improving the mechanical and durability properties of concrete.

Coir fiber has versatility, and it is used as one of the natural fibers since it is found abundantly all over the world. It is removed from the husk of coconut fruit, the characteristics of a composite of concrete where coconut fiber is used as reinforcement. More advantages of it are that coir is used as waste material, so by using this, it will get low-cost construction and eliminate the need for waste disposal in landfills. Steel fiber reinforced concrete has more popularity because it increases ductility and bonds the concrete matrix and reinforcement material. As a result, fiber concrete exhibits greater toughness and performance. With the hardness and toughness characteristics of concrete, steel fibers provide better protection against abrasion. The formation of steel fibers generally includes carbon steel or stainless steel. The short steel fiber concrete mixture works better than the long steel fiber mixture with the same ratio (Seervi et al., 2017). In many developing countries, the widespread availability of natural fibers and other local materials creates an opportunity for engineers to adopt suitable technologies that maximize their effective and economical use. This approach to the production of superior-quality, economical fiber-reinforced cementitious composites ensures efficient material enhancement and affordability in housing and various related uses (Afroughsabet et al., 2016).

Globally, consumption of concrete is rising day by day. For this reason, the production of construction and demolition (C&D) waste or recycled aggregate significantly increases. Utilization of recycled aggregate represents an environmentally sustainable solution. That reduces environmental impact and minimizes landfill use (Ahamed et al., 2024; Islam et al., 2025). Waste concrete is less strong and more porous than the normal concrete aggregates. These disadvantages can be overcome through the addition of reinforcing fibers, which enhance structure performance of the RCA based concrete. It is estimated that around 25 billion tons of concrete are created annually. This production scale corresponds to nearly 1.7 billion truckloads annually, equivalent to about 6.4 million truckloads per day, translating to approximately 3.8 tonnes of concrete per person per year across the globe (WBCSD, 2009). Increasing this demand presents a sustainable amount of construction and demolition waste, which is reaching an estimated 2.2 billion tons annually by 2025 (Malladi et al., 2025). The European Commission reports that Europe produces approximately 450 to 500 million tonnes of construction and demolition waste annually, with concrete accounting for at least one-third of this total (CEMBUREAU, 2024). The United States produces about 30% of construction and demolition waste globally per year while China is responsible for about 30% to 40% of the total amount (Aslam et al., 2020). The top user's country of concrete China and India are producers of construction waste. Bangladesh has some similar problems, with major urban areas generating about 3.71 million tons of construction and demolition rubbish annually, the majority of which is disposed of in landfills (Rafiq et al., 2025). Dhaka City in Bangladesh generates over 3340 tons of solid waste per day, and approximately 1520 percentage of the same is generated through construction and demolition. (Afroz et al., 2011). A significant percentage of this waste is deposited in landfills with grave environmental and economic consequences. Therefore, the purpose of this study is to determine the applicability of the recycled C&D waste as a partial substitute of natural aggregates in conjunction with steel or coir fibers to compare and evaluate the strengths of the fiber-reinforced concrete.

2. METHODOLOGY

2.1 Materials

Crushed Gujarati stone conforming to ASTM C33 was used as coarse aggregate. In addition, construction and demolition waste concrete is used as a recycled coarse aggregate (RCA), which is collected from discarded construction elements. Concrete was broken down with the help of a jaw crusher, then pieces were cleaned manually by removing all remaining plastic mortar, wood, and other particles which could alter the behavior of the newly made concrete. It is observed that RCA has a lower specific gravity and significantly higher absorption capacity compared to natural aggregates (Duan et al., 2022). The porosity of RCA is 10–20 times greater than that of a natural aggregate (Théréné et al., 2020). Sylhet sand was also used in this study as fine aggregate.

Table 1: Material Properties

Physical Properties	Test method	Fine Aggregate	Natural Coarse Aggregate	Recycle Coarse Aggregate
Bulk Specific Gravity (Oven-Dry Basis)	ASTM C127	2.649	2.823	2.200
Apparent Specific Gravity	ASTM C127	2.80	2.863	2.72
Absorption Capacity	ASTM C127	2.10%	0.5%	8.93%
Dry Rodded Unit Weight	ASTM C29	1626.5 kg/m³	1670 kg/m³	1212 kg/m³
Fineness Modulus (FM)	ASTM C136	2.4		
Maximum Size		Less than 4.75mm	20mm	20mm
Moisture Content (at time of testing)		0.4%	0.2%	4%

Cement Coarse Aggregate Recycled Aggregate Fine Aggregate

Figure 1: Materials used in this study

2.2 Steel fiber and Coir fiber

Modern steel fibers have mostly replaced straight, smooth types with rough or hooked-end designs for better performance. Carbon steel fibers would be capable of supporting five times more tensile strength than steel and are about 75% lighter (Rai & Joshi, 2014). Two shapes of steel fiber were utilized in this study: straight-shaped steel was used for recycled aggregate, and spring-shaped (0.52 mm diameter) for standard aggregate (**Figure 2**). Both steel fibers were 30 mm in length and sourced locally. Straight-shaped steel fibers are used because they give better workability and less obstruction during mixing and compaction.

Spring-shaped Fiber Straight-shaped Fiber Coir Fiber

Figure 2: Different types of fiber used in this work

Young coconuts on the other hand tend to be white and tender in nature but with lower mechanical strength. The brown coir fibers are primarily applied in engineering. According to the report of the International Year of Natural Fibers, 500,000 tons of fibers are produced annually on the global scene. Some of the key producers are India and Sri Lanka. This production has a total market worth approximated to be 100 million USD (Ali et al., 2012). Mature brown fibers of diameter 0.48 mm and length 30 mm were used in this research.

Table 2: **Mix proportions**

Batch No	Percentage of steel fiber	Percentage of Coir Fiber	Natural Coarse aggregate	Recycle d concrete aggregat	Test of strength	Curing days
A	0.5%	-	100% Natural Coarse Aggregate	-	Compressive strength	7, 14, and 28
	0.75%	-		-		
	1%	-		-		
B	-	0.5%		-		
	-	0.75%		-		
	-	1%		-		
C	1%	-	85%	15%	Compressive, Split tensile and Flexural strength	14 and 28
	1%	-	70%	30%		
	1%	-	55%	45%		
D	As a control sample, natural aggregate was used without any fiber					7, 14, and 28

All fiber percentages were calculated based on the weight of coarse aggregate

2.3 Materials Mixing, Casting and Curing Procedure

Some of the factors that affect the properties of FRC include fiber type, quantity, geometry, distribution, orientation and concentration. FRC, being a composite material, improves structural integrity through the integration of fibrous components in the concrete body. Discontinuous fibers act as crack-bridging elements, which enhance toughness and ductility following cracking (Mukhopadhyay & Khatana, 2015). In this study, FRC was made with 0.5, 0.75 and 1 percent weights of coarse aggregate, with the fiber of steel and coir respectively **(Table 2)**. Demolding and water-curing of all the samples were performed after 24 hours in 7, 14 and 28 days at room temperature to measure their mechanical performance. The concrete mixing and curing in this study followed ASTM C192. All aggregates, including RCA, were used in a dry state. GI (steel) fibers (1% by weight of coarse aggregate) were added after dry blending of coarse and fine aggregates for 2–3 minutes to ensure even distribution. Cement was then incorporated and dry-mixed for another 2 minutes. Water was added in two stages. Minor water adjustments were made as needed, water–cement ratio was 0.56. After being cast for 24 hours, the concrete specimens were gently removed from their molds and immersed in a curing tank for pond curing. Clean water was used for curing, and the room temperature was 27 ± 2°C.

Figure 3: Concrete specimen preparation and curing at different coir and steel fiber dosages

2.4 Experimental Program for Mechanical Testing

Compressive and tensile strength was tested by use of a cube with dimensions of 100×100×100 mm, and flexural strength was tested by using a beam of dimensions of 100×100×500 mm. Compressive strength tests were performed in accordance with ASTM C109 and ASTM C39.

Splitting tensile strength tests followed ASTM C496, which is typically applied to cylindrical specimens. **Flexural strength** was determined following ASTM C78 using the third point loading method. Compacted in layers according to ASTM C31.

2.5 Workability test

The workability (slump) of fresh concrete was measured immediately after mixing in accordance with ASTM C143. In the case of this test, it was noted that slump value reduced with increase in percentage of recycled aggregate. This has been the trend in a previous study (Kachouh et al., 2019). This trend is explained by the fact that recycled aggregates are more porous and have higher water absorption capacity, hence the less free water in the mixture and, hence, the lower workability. The initial slump of the control mix was 55 mm, which reduced to 28 mm at 45 percent of RCA replacement **(Table 2)**.

Table 2: Slump value at different proportion

Proportion	Natural Aggregate (RCA 0%)	RCA 15% + 1% Fiber	RCA 30% + 1% Fiber	RCA 45% + 1% Fiber
Slump Value (mm)	55	43	34	28

3. RESULTS AND DISCUSSIONS

3.1 Evaluation of compressive strength of concrete

At day 7, the conventional sample compressive strength measured 13.56 MPa (**Figure 4**). Incorporating steel fiber produced varied results, with 0.5% lowering the strength to 11.61 MPa, 0.75% increasing it to 15.33 MPa, and 1% reducing it to 10.36 MPa. The amount of coir fibers progressively mitigated compressive strength. The values were 12.50 MPa, 9.83 MPa, and 7.00 MPa at fiber contents of 0.5%, 0.75%, and 1%, respectively. Overall, steel fiber at 0.75% enhanced early-age strength, while coir fiber caused notable declines across all dosages.

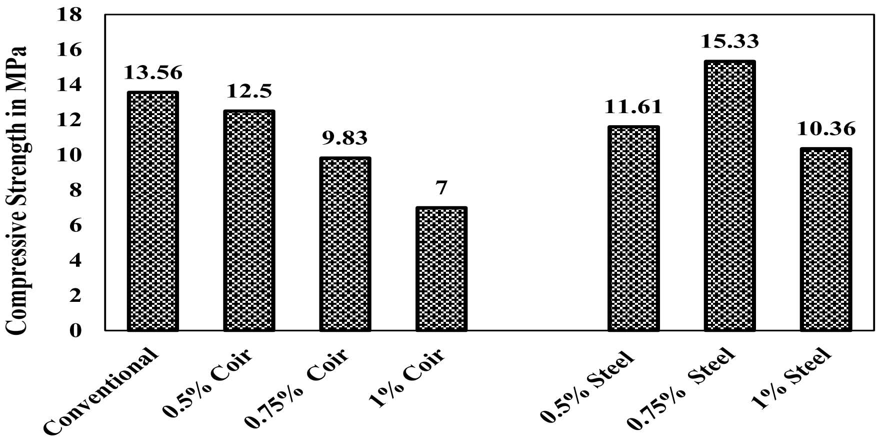


Figure 4: Effect of fiber content on 7-day compressive strength

Figure 5 denotes that the compressive strength of the controlled sample was 16.28 MPa at day 14. The addition of steel fibers enhanced the strength at all doses where 0.5, 0.75, and 1 percent of fibers resulted in 18.00 MPa, 19.42 MPa and 20.83 MPa, which were increases of 10.57% 19.29% and 27.95% over the control sample strength. On the other hand, coir fibers reduced compressive strength, and the 0.5%, 0.75%, and 1% levels attained 13.94 MPa, 15.19 MPa and 9.55 MPa which correlated to 14.37, 6.70, and 41.34 percent reductions. On the whole, steel fiber enhanced concrete performance whereas coir fiber led to significant reductions in high doses.

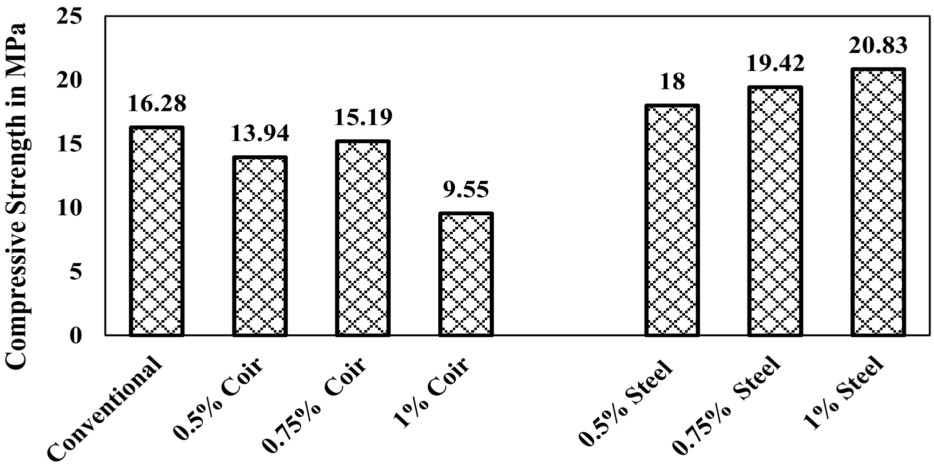


Figure 5: Effect of fiber content on 14-day compressive strength

Figure 6 demonstrates that plain concrete had the compressive strength of 22.23 MPa on day 28. Addition of 0.5% steel fiber slightly reduced the strength to 20.63 MPa, and addition of 0.75 and 1 percent led to a strength of 23.50 MPa and 24.54 MPa which showed an improvement of 5.71 and 10.39 percent respectively over the control. This study reported that compressive strength decreased with the addition of coir fibers at all percentages and exhibiting strength 15.68 MPa, 16.03 MPa, and

13.38 MPa giving percentage changes of 0.5, 0.75 and 1, respectively. The addition of coir fiber improves the strength of concrete first, with the optimum performance observed at 0.75% fiber content. It has been observed that compressive strength decreases as the percentage of coir fibers increases; this falls in line with other past studies (Ahmad et al., 2020), indicating that excessive fiber content can cause poor dispersion and increased voids within the matrix, thereby diminishing the overall strength of the concrete.

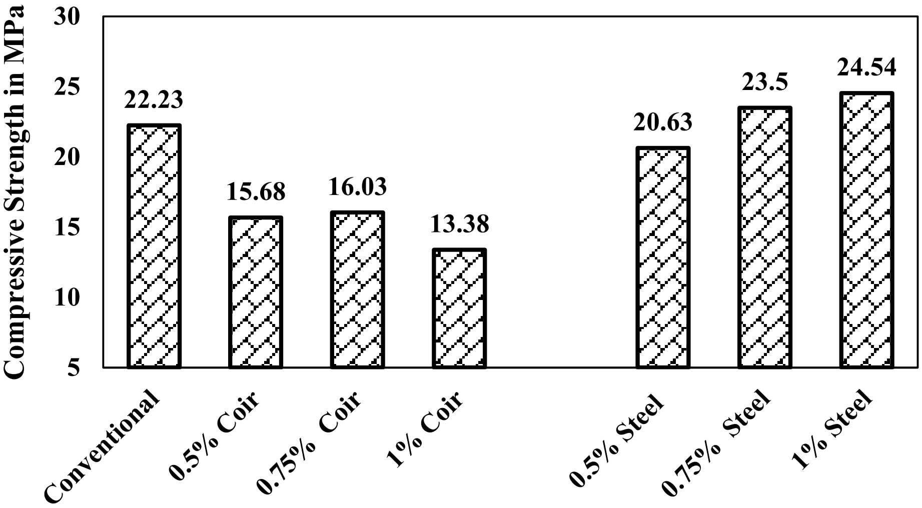


Figure 6: Effect of fiber content on 28-day compressive strength

Figure 7 Figure 7 shows the effect of steel fiber content on compressive strength of concrete with reference to days 7, 14 and 28. On day 7, the strength of plain concrete was 13.6 MPa, whereas strength decreased to 11.6 MPa with 0.5 per cent fiber and 15.3 MPa at 0.75percent and 10.4MPa at 1 percent respectively. Fiber additions at day 14 increased strength to 18.0 MPa, 19.4 MPa, and 20.8 MPa of 0.5, 0.75 and 1 percent. On day 28, 0.5% fiber had a slight decrease to 20.6 MPa whereas 0.75 percent and 1 percent had 23.50 and 24.5 MPa, respectively, exceeding plain concrete, which is significantly improved as the dosage was increased and shows significant improvement as the cured age increased.

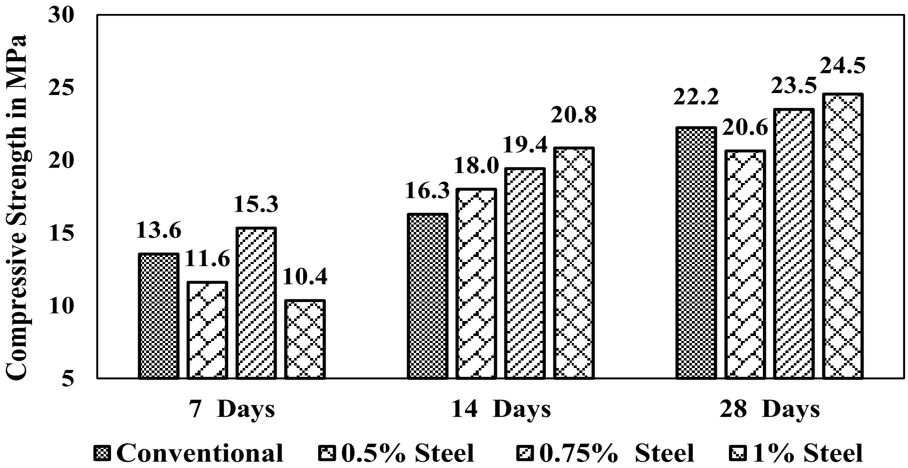


Figure 7: Comparison of compressive strength (conventional and steel)

Figure 8 illustrates compressive strength at days 7, 14, and 28. Increasing coir fiber consistently exhibits lower strength except for 0.75%. At day 7, strength declined from 13.56 MPa in plain concrete to 12.50 MPa, 9.83 MPa, and 7.00 MPa for 0.5%, 0.75%, and 1% fibers. The day 14 strength values were 13.9 MPa, 15.19 MPa, and 9.55 MPa compared to 16.28 MPa in the control, while at day 28, fiber-reinforced mixes reached 15.7 MPa, 16.03 MPa, and 13.38 MPa against 22.23 MPa in plain concrete. Overall, higher coir fiber content caused greater reductions, with 1% showing the most pronounced effect.

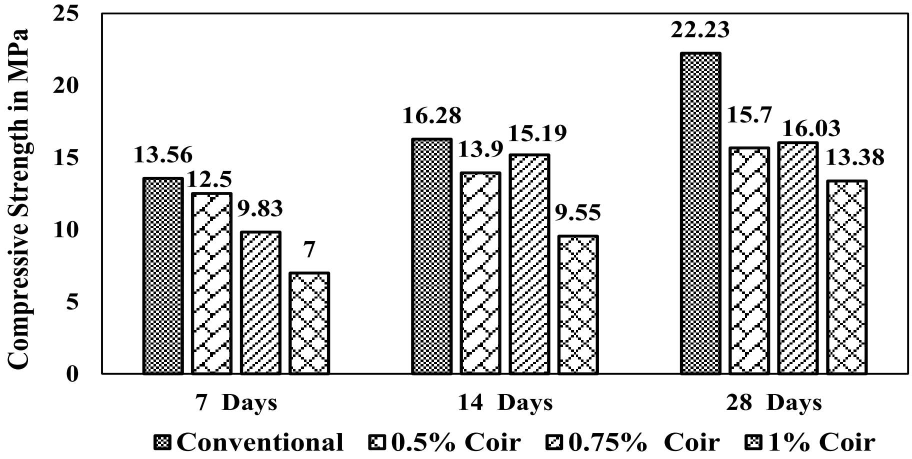


Figure 8: Comparison of compressive strength (conventional and coir)

Figure 9 compares the compressive strength of coir and steel fiber reinforced concrete at different curing ages and fiber contents. At 0.5% fiber, coir showed slightly higher strength at 7 days. At 0.75% and 1% contents, steel fiber consistently outperformed coir. Overall, steel fibers demonstrated greater influence on compressive strength, the effect of higher fiber dosages, and longer curing duration. The tendency is to increase the percentage of steel fibers in order to give the concrete a high strength, a trend also observed in a research (Srikar & Kalyan, 2018). This development is attributed to fibers, the effective load transfer facility, and the capability to bridge cracks within the cementitious structure.

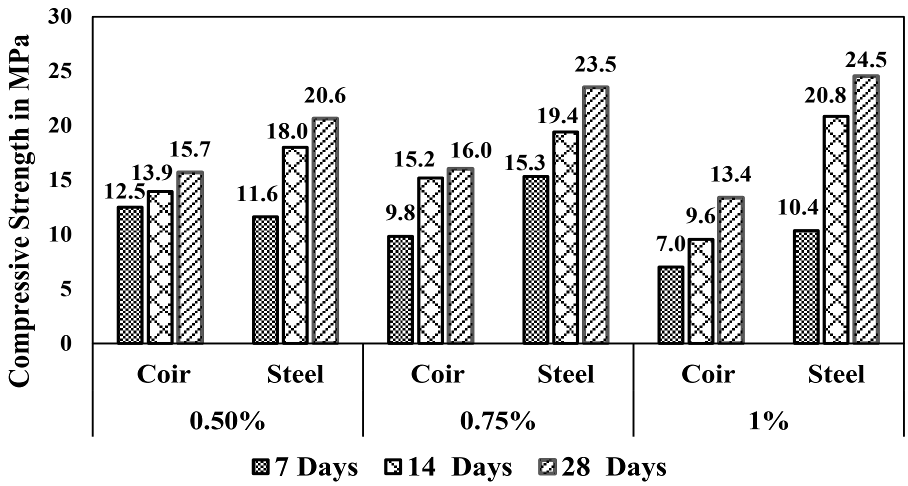


Figure 9: Comparison of compressive strength (coir and steel)

3.2 Evaluation of compressive strength of concrete and recycled concrete

Figure 10 indicates that, on comparison of compressive strength, greater RCA replacements (30% and 45%) leads to lesser strength because more porosity and weak residual mortar exist but the RCA 15% + 1% fiber mix performed better than control. Control compressive strength was 16.28 MPa at day 14, and 18.3, 17.2 and 15.98 MPa were 15%, 30% and 45% recycled aggregate mixes, respectively. The conventional the strength was 22.23 MPa and the RCA mixes measured 22.92 MPa, 22.05 MPa, 21.14 MPa in the RCA mixes on the 28th day (strength) respectively. The 1% steel fiber increased the crack resistance and stress redistribution. The use of recycled concrete and percentage of this concrete makes concrete weaker. This has been observed in a previously conducted research.

(Kachouh et al., 2019). This reduction in concrete strength is explained by the increased water absorption and porosity of the recycled concrete aggregate, which reduces the density and load-bearing capacity of concrete, as well as, weakening the interfacial transition zone.

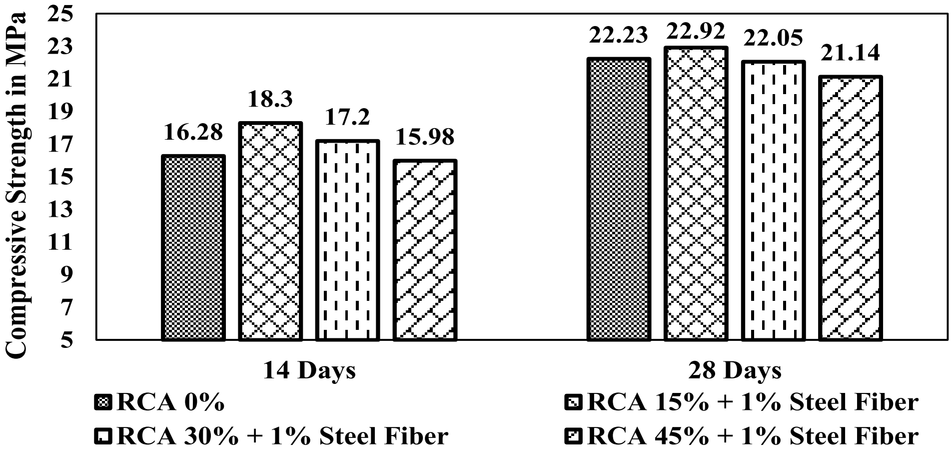


Figure 10: Recycled aggregate concrete compressive analysis

3.3 Evaluation of tensile strength of concrete using recycled aggregates

Figure 11 reveals that, on day 14 the control mix had a record of 3.23 MPa whereas the RCA 15% had a record of 4.62 MPa which is an increment of 43 percent and in day 28 the record of 4.16 to 5.03 MPa was an increment of approximately 21 percent. The RCA 15% tensile strengths were higher than the control even at 30% and 45% of RCA. These findings suggest that RCA in combination with 1 percent GI (steel) fibers has a great effect on tensile performance and crack resistance.

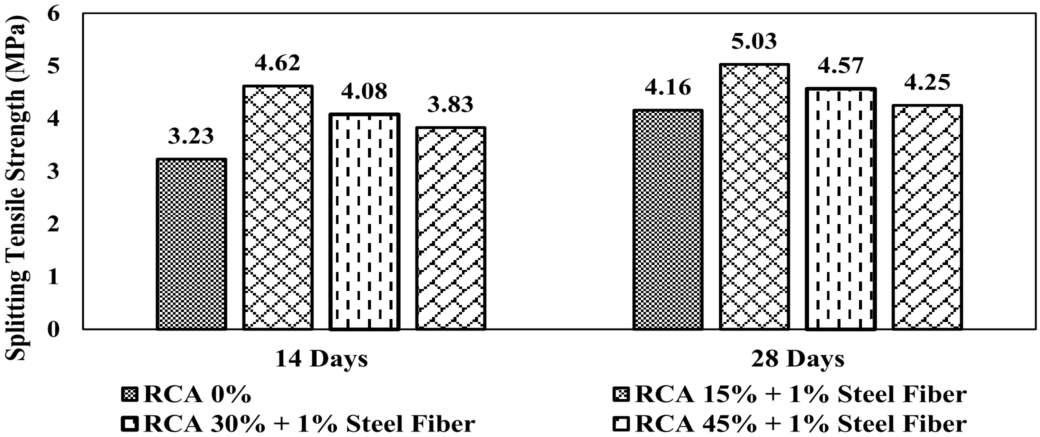


Figure 11: Tensile performance of recycled aggregate concrete

3.4 Evaluation of concrete flexural strength using recycled concrete

Figure 12 depicts that flexural strength is better performed by recycled concrete aggregate mixes than controller concrete. At 14 days, control mix recorded 3.30 MPa, RCA mixes recorded 3.72 MPa (15% RCA), 3.66 MPa (30% RCA), and 3.42 MPa (45% RCA) with improvement between 4-13 percent compared to the control sample strength. On day 28, the control showed 3.54 MPa but the RCA mixes showed 4.02MPa, 3.90MPa and 3.72MPa with a gain of 5% to14%. It is clear that flexural performance was improved due to the steel fiber bridging mechanism that resulted in the increase in ductility, slower rate of crack development, and the increase in the load carrying capacity after the cracking (Yang et al., 2024).

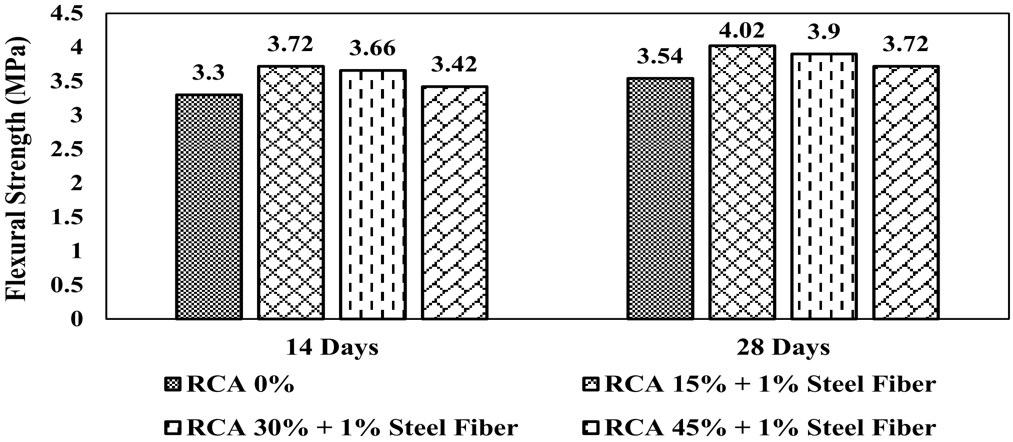
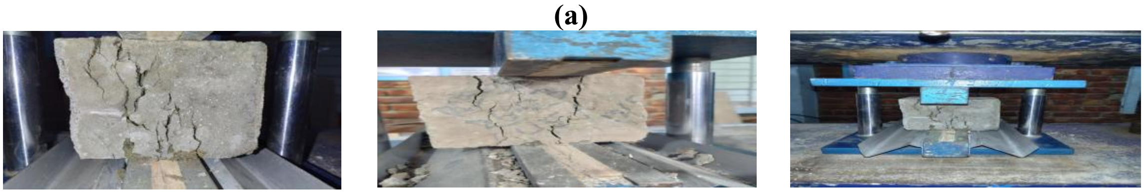


Figure 12: Flexural strength performance of recycled aggregate concrete

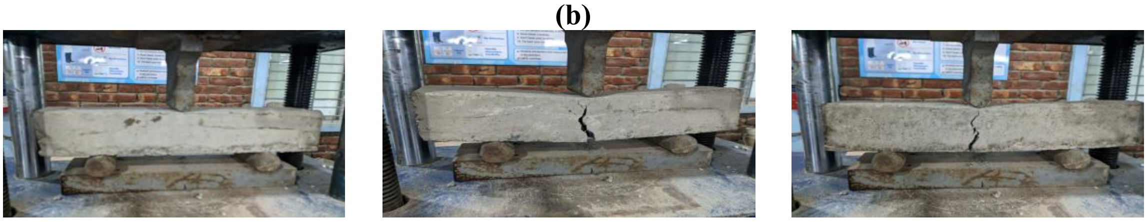
3.5 Failure modes

Figure 13 shows different failure modes of the concrete specimens. In compressive failure, the specimens are cracked in the vertical direction radiating along the edges to the center, where crushing and spalling occur on top and bottom surfaces that represent brittle behavior when subjected to axial compressive forces that are beyond the concrete strength. In tensile failure, vertical splitting occurs along the mold's length, with cracks forming across the diameter where loads are applied, reflecting failure in tension at a lower stress than compression. Beams in flexural failure display mid-span cracks that sometimes extend toward supports, with sagging indicating bending; cracks initiate at the bottom and propagate upward, showing tension in the mid-span region, while crack patterns vary slightly with load distribution.

(a)



(b)



(c)

Figure 13. Concrete specimen (a) compressive, (b) tensile, and (c) flexural failure modes

4. CONCLUSIONS

Based on the findings, the study draws the following conclusions:

- When using more percentages of steel fiber dosage to increase the strength of concrete, steel fibers enhanced its strength. Addition of 0.75 percent and 1 percent steel fibers makes it stronger than the conventional ones. Out of the proportion tested, 1 percent steel fiber had been tested as giving maximum strength increase and 0.75 percent coir fiber had been found to give higher strength than the other percentages of coir fiber.
- The combination of the 15% recycled concrete aggregate (RCA) with 1% steel fiber showed the best effective balance between retention of compressive strength. The tensile and flexural improvement and sustainability are generally improved and better with all percentages of recycled aggregate.
- The spring-shaped steel fibers tend to provide better strength as compared to straight-shaped steel fibers. But straight fibers are easier to work with and do not provide as much of a hindrance in mixing and compaction. Straight steel fibers are deemed to be more appropriate when it comes to large-scale construction work.
- The findings of this paper can be used specifically in the construction projects that focus on recycled materials. The endurance, cost-benefit analysis and performance in different environmental conditions could be examined in a future study to verify the further practicality of fiber-reinforced recycled concrete.

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