

Jute Fiber as a Sustainable Reinforcement for Improving the Performance of RCA Concrete

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Abstract

Concrete demand growth in construction keeps pushing the construction industry to exploit natural aggregates beyond safety levels while damaging the environment and raising carbon pollution levels. The use of recycled Concrete Aggregate (RCA) as a sustainable solution results in compromised mechanical values and durability because of its high porosity together with weak interfacial transition zones (ITZ). The research investigates Jute Fiber (JF) reinforcement systems as a method to boost mechanical characteristics in concrete made from recycled concrete aggregates. This investigation evaluated the effect of changing JF levels from 0.15 to 0.35 percent and the use of 25 to 100 percent RCA while studying concrete workability, compressive strength, split tensile strength, and water absorption. Seventeen mixtures of concrete were tested which showed that workability alongside strength performance reduced because of the porous characteristics of RCA. JF showed its best mechanical impact when used with a combination of 0.15% concentration and 25% RCA content in the mixtures (J0.15R25). Fiber compressive strength and water absorption levels increased with greater than 0.25% fiber addition because the fibers clustered together while the JF absorbed more water. Research findings demonstrate that JF and RCA merged as an effective method to provide durable concrete which presents improved durability and tensile strength as well as crack resistance. The successful implementation of this method depends on precise control of fiber content combined with correct replacement ratios between RCA and cement. Research findings enable progress in developing sustainable efficient construction concrete materials for the building sector.

Keywords

Recycled concrete aggregate, jute fiber, sustainability, concrete properties, compressive strength, water absorption

INTRODUCTION

The remarkable durability coupled with high compressive strength along with its expansive usage tolerance makes concrete the first choice for construction professionals [1]. The growing concrete market has outstripped sustainable limit of natural aggregate removal which has caused multiple issues including land destruction while also contributing to resource shortage and increased atmospheric carbon release [2]. The construction sector now seeks to replace traditional building materials with recycled concrete aggregate (RCA) together with natural fibers for creating environmentally sustainable concrete structures [3].

RCA functions as concrete aggregate to decrease virgin aggregate requirements as it allows C&D waste management to avoid landfilling and contributes to circular economic strategies [4]. RCA includes tiny holes that make it absorb water readily so it becomes weaker in structure and presents shorter service life together with enhanced material shrinkage [5]. Research proves that reinforcing

concrete with fibers effectively enhances both mechanical strength and operational life expectancy of materials made from recycled concrete aggregates [6].

The use of Jute Fiber as a reinforcement material has been demonstrated to be highly practical because it delivers superior strength along with economic value and shows capacity to break down naturally [7]. Laboratory findings prove that jute fibers boost concrete characteristics through stronger flexural strength together with improved impact resistance and material toughness thus they represent ideal replacements for synthetic polypropylene and steel fibers [3]. Building more efficient sustainable construction methods depends on jute fiber integration with concrete because it leads to better crack control and reduced plastic shrinkage effects and strengthened post-crack performance [8].

Jute fiber naturally appears in bast plant resources that primarily cultivate in South Asian nations such as Bangladesh and India and Nepal [2]. The renewable biodegradable fiber quality of jute makes it standout

because it enables a sustainable approach by substituting synthetic non-biodegradable expensive fibers [7]. Jute fiber demonstrates tensile strength of 250–300 MPa with low density that allows its use for strengthening cementitious composites based on the information presented in [3].

Structured concrete becomes more resistant to cracking and dynamic forces because jute fibers improve ductility and energy absorption according to research [1]. The durability of concrete structures improves with jute fibers because they provide crack-bridging ability which heightens both structural strength and longevity [4]. Jute fibers possess natural hydrophilicity that leads to severe water absorption until they receive specific treatment [5].

RCA presents sustainable solutions through the use of recycled materials yet multiple technical difficulties diminish its end result properties regarding mechanical strength and durability. The enhanced porosity of RCA particles leads to weak interfacial transition zones (ITZ) resulting in increased water absorption which generates decreased compressive strength and flexural strength and generates increased shrinkage [3]. According to [5] the enhanced permeability found in RCA-based concrete diminishes both freeze-thaw resistance and chloride penetration resistance performance.

Researchers explored multiple approaches using supplement cementitious materials combined with chemical admixtures reinforced by fibers to improve concrete's performance regarding both workability and long-term durability aspects and mechanical characteristics [6]. Research has shown that jute fibers with RCA concrete reaches two significant benefits because they overcome workability challenges and provide strong reinforcement for engineering properties and durability characteristics [7].

Thorough research outcomes are missing from the study field which explores jute-fiber<RCA> concrete for improving concrete mechanical properties [1]. Few researchers have studied jute fiber applications for RCA concrete development despite earlier reports which demonstrated improvements from glass fibers, polypropylene fibers and steel fibers [8].

The study produces inconclusive results regarding optimal fiber content values together with RCA substitution ratios thus creating doubts regarding workability patterns and failure characteristics [5]. This research fills absent knowledge gaps by performing experimental tests which evaluate jute fiber-reinforced RCA concrete mechanical properties.

This research looks at how concrete material with RCA and jute fiber reinforcement behaves mechanically. The tensile characteristics and compressive strength analysis of jute fiber-reinforced RCA concrete leads to complete performance evaluation according to research findings. The assessment of workability and water absorption properties in RCA concrete will help achieve better understanding of durability outcomes during the project. This research establishes optimal combinations of RCA replacement ratio with jute fiber use levels that produce strongest mechanical properties and durability outcomes for sustainable construction applications.

MATERIALS AND METHODOLOGY

A. MATERIALS

▪ Cement

The study uses locally produced regular Portland cement of CEM I 42.5 grade. This cement matches the specifications of E.S.S. 4756-1/2013 CEM I 42.5N and BS EN 197-1:2011 CEM I 42.5N. The ASTM C204 standard indicates that cement fineness comes to 3390 cm²/g whereas its specific gravity matches the ASTM C187 specification at 3.15. Lab standards indicate that both initial set time should be 45 minutes while final set time has an interval of 8 hours matching values from regular Portland cement types.

▪ Aggregates

The research utilizes natural sand as its fine aggregate with crushed dolomite acting as the coarse aggregate. The specific gravity of sand amounts to 2.11 along with a fineness modulus of 2.65. The production source for recycled concrete aggregates (RCA) includes precast concrete rejection materials that undergo industrial crushing. LNEC E 471 standard defines the aggregates which demonstrate densities greater than 2200 kg/m³ along with water absorption values below 7%. The properties of natural and recycled aggregates are summarized in Table 1. Fig. 1. Shows the aggregates used in the study.



Figure 1 Natural and Recycled aggregates used in the study.

Table 1 Properties of aggregates

Property	Natural Aggregate	Recycled Aggregate
Particle Density (g/cm ³)	2.63 (Oven-dry) / 2.66 (SSD)	2.34 (Oven-dry) / 2.48 (SSD)
Water Absorption (%)	1.9%	5.8%
Specific Gravity	2.52	2.40
Fineness Modulus	7.66	6.88
Impact Value (%)	18.0	23.0
Crushing Value (%)	21.05	26.61

▪ Jute Fiber

An analysis of the jute fiber enables a length measurement of 10 mm along with a density value of 1.35 g/cm³. There was no application of superplasticizer or chemical treatment. Adding the fiber works as

reinforcement which delivers elevated tensile strength and better impact resistance to concrete. Fig. 2. shows the jute fiber used in the study.



Figure 2 Jute Fiber.

B. MIX PROPORTIONS

The concrete mixture uses 0.45 water to cement ratio yet follows a 1:1.5:3 proportion of cement to fine aggregate to coarse aggregate. A total of 17 mixtures (J0–J0.35R100) received formulation, as they used recycled aggregate as a natural aggregate replacement at between 25% and 100% combined with jute fibers at ratios ranging from 0.15% to 0.35%. The proportions of mixed material can be found in Table 2.

Table 2 Percentage of replacement of aggregates.

MIX	Designation	Jute Fiber (%)	Natural Aggregate Replacement (%)	Recycled Aggregate (%)
MIX 1	J0	0	0	0
MIX 2	J0R25	0	25	25
MIX 3	J0R50	0	50	50
MIX 4	J0R75	0	75	75
MIX 5	J0R100	0	100	100
MIX 6	J0.15R25	0.15	25	25
MIX 7	J0.25R25	0.25	25	25
MIX 8	J0.35R25	0.35	25	25
MIX 9	J0.15R50	0.15	50	50
MIX 10	J0.25R50	0.25	50	50
MIX 11	J0.35R50	0.35	50	50
MIX 12	J0.15R75	0.15	75	75
MIX 13	J0.15R75	0.25	75	75
MIX 14	J0.15R75	0.35	75	75
MIX 15	J0.15R100	0.15	100	100
MIX 16	J0.25R100	0.25	100	100
MIX 17	J0.35R100	0.35	100	100

C. TESTING PROCEDURES

Fresh Concrete Tests

- Slump Test: The workability of the concrete mixes was evaluated using the ASTM C143 slump test.

Hardened Concrete Tests

- Compressive Strength: 150 mm × 300 mm cylinder specimens were tested at 7 and 28 days following ASTM C39.
- Split Tensile Strength: 150 mm × 300 mm cylinders were tested at 7 and 28 days following ASTM C496.

- Water Absorption: The water absorption of RCA concrete was determined based on ASTM C642.

This methodology ensures a systematic approach to studying mechanical strength and durability in jute fiber-reinforced recycled aggregate concrete.

RESULTS AND DISCUSSIONS

A. WORKABILITY

The measurements of workability from different concrete mixes appeared in Figure 3 as per ASTM C143 slump test methodology. The laboratory measurements indicate that slump values decrease when the mixture contains RCA and jute fiber. The workability of control mix J0 reached 85 mm because it contained none of the JF nor RCA materials that enhance workability characteristics.

The slump values descended in stepwise fashion when RCA was added to the mixtures between J0R25 and J0R100. Water absorption properties of RCA together with porosity mechanisms result in decreased slump values within the mixture [5].

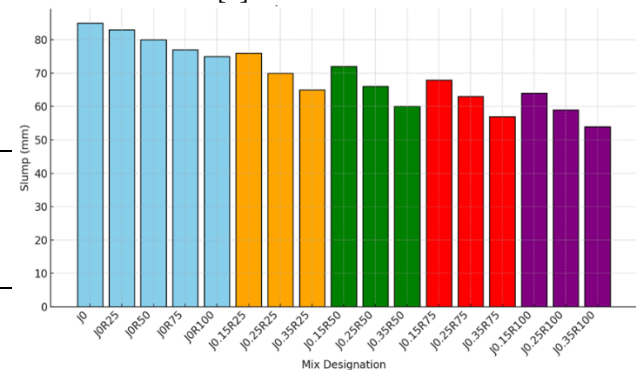


Figure 3 Slump value for different mix designations.

Slump flow values decrease as jute fibers are introduced to compositions ranging from J0.15R25 to J0.35R100. The hygroscopic jute fibers form bonds with cement paste effectively which leads to reduced workability of fresh concrete [3]. Many researchers have established that highly water-absorbing fibers create similar workability reduction effects in fresh concrete according to [9].

Waqar et al. has shown that concrete slump values decrease because of two factors - fiber diameters becoming narrower and surface area-to-volume ratios extending while generating internal friction [8]. Concrete fluidity decreases because of the balling effect that happens when fiber content exceeds 0.5% [10].

Farida Islam et al. researched how adding more than 0.50% jute fiber makes concrete more viscous until it reaches high stiffness and flow-resistance levels [11]. The combination of J0.35R100 resulted in the highest slump decline of 54 mm producing concrete with 36% lower consistency than J0.

The reported slump reduction through JF incorporation at 0.10% yielded 10.5% while the values at 0.25% reached 22.3% and reached 41.1% at 0.50% as reported in [9]. Reinforcing concrete with fibers reduces the workable properties yet leads to enhanced long-term strength properties and exceptional resistance to cracking.

B. COMPRESSIVE STRENGTH

A comparison of compressive strength (CS) measurements at 7 and 28 days is displayed through Figure 04 while corresponding Figure 05 shows percentage changes for concrete mixes using Jute Fiber (JF) and Recycled Coarse Aggregate (RCA). The reference strength for strength evaluation amounts to 27.4 MPa in the control mix (J0) at 28 days.

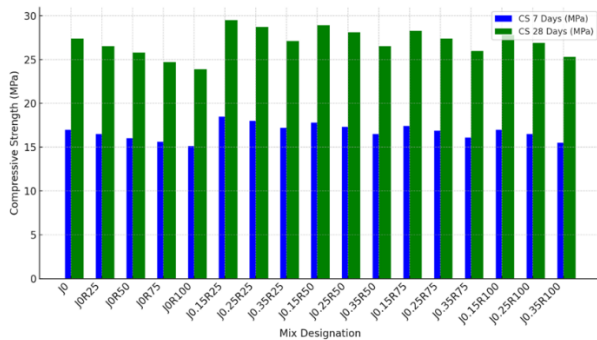


Figure 4 Compressive strength for different mix designations

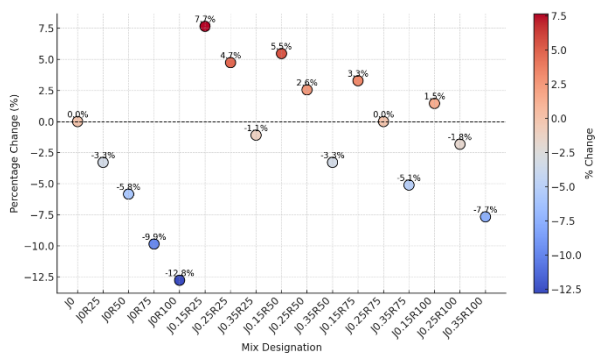


Figure 5 Percentage change in compressive strength at 28 days relative to J0

The 28-day compressive strength variation percentages appear in Figure 05 as a bubble plot where J0 serves as the control mix to illustrate mechanical concrete responses from recycled material usage along with jute fiber implementation. When using recycled aggregate as a replacement material it causes a specific reduction in concrete compressive strength performance. The compressive strength reduction of J0R100 without jute reinforcement reaches 12.8% and maintains significant distance from all mixes between J0R25 to J0R75. Concrete strength diminishes when RCA is used as a replacement because it generates material porosity and weak interfacial transition zones which increases water absorption according to [5], [3]. The weakened bond performance of RCA with cement paste affects the mechanical strength outcomes.

Every concrete mix without jute fibers sustained systematic decreases in compressive strength as researchers added RCA slowly into the mix. The measurement of compressive strength at day 28 for J0R25, J0R50, J0R75, and J0R100 showed percent strength losses compared to J0 amounting to 3.3% for J0R25 up to 12.8% for J0R100. The research by [3] demonstrates that the utilization of RCA leads to reduced concrete strength

because of its high porosity and increased water absorption as well as weak interfacial transition zones (ITZ). Research conducted by Waqar et al. [12] establishes that increasing the amount of RCA in concrete causes structural weakness that leads to microcrack formation during early stages.

Jute fiber (JF) at 0.15% did increase the compressive strength at all RCA replacement ratios evaluated. When Jute fiber was combined with the J0.15R25 mix it resulted in the strongest compressive strength value at 7.7% above its reference value J0. Rakibul et al. [9] confirmed concrete benefits from natural fibers through their findings on load distribution and crack prevention.

The compressive value recorded a decrease when the scientists introduced JF at concentrations exceeding 0.15%. The J0.35R25 mix yielded a 28-day compressive strength value of 27.1 MPa which exceeded J0.15R25 at 29.5 MPa but remained ahead of the standard mix. An increased intake of water and void formation together with fiber cluster formation diminishes strength at high jute fiber dosages per Elgawish et al. [13] and Zhang et al. [14]. Jute fibers take up water strongly through their hydrophilic character bringing about inside voids that damage cement hydration and damages structural properties.

Experimental results obtained from RCA mixed with JF revealed a substantial combined impact on the test outcomes. The utilization of J0.15R25 and J0.25R25 resulted in improved strength yet the addition of more RCA failed to sustain the preferred outcome from both materials. The J0.15R100 specimen performed 1.5% better than J0R100 because its combined suboptimal effect of JF addition exceeded substantial RCA content. Waqar et al. [12] determined natural fibers effectively strengthen RCA materials when used in less than 50% of the original aggregate quantity.

Research indicates that combinations exceeding 0.10% to 0.25% JF dosage in the mixture will cause strength reduction due to fiber agglomeration combined with void formation within the material [14]. Additions of excess fibers create a two-fold deterioration effect which reduces workability and complicates compaction duties yet results in microcrack-filling that enhances initial strength [3]. The study in paper [1] reveals that using RCA causes strength reduction producing outcomes between -3% and -13% that corresponds to the findings of this investigation.

C. SPLIT TENSILE STRENGTH

The split tensile strength modulus adopted the same directional flow as compressive strength when jute fiber (JF) composition increased in test specimens. Results for the split tensile strength at 7 and 28 days can be found in Figure 06 and the percentage alterations from adding Jute Fiber (JF) with Recycled Coarse Aggregate (RCA) into concrete are presented in Figure 07. At 28 days of testing the control mix (J0) obtained 3.10 MPa strength value while the presence of elevated RA proportions decreased results in the STS readings. J0R100 showed the highest tensile strength reduction effect because it exhibited a decrease in strength level by 11.6% compared to the control sample J0. According to [3] the bond strength reduction and higher porosity of recycled aggregates result in this strength decrease.

When jute fiber reached a concentration of 0.15% it improved concrete STS readings while acting across different replacement levels of recycled aggregate samples. Among different mix compositions the sample utilizing 0.15% jute fiber with 25% recycled aggregate showed the maximum stretch increase at 6.7% relative to J0. The research conducted by Zhang et al. [14] confirms the findings of Elgawish and Zakaria [13] that adding natural jute fibers improves concrete ductility and its capacity for crack-bridging which enhances tensile stress resistance. JF consists of two mechanisms to perform its function by distributing tension and blocking crack propagation which leads to superior tensile strength [11].

The STS levels experienced a continuous decrease when the JF content exceeded 0.25%. The jute fiber composition J0.35R25 produced a modest 0.6% increase in strength compared to J0 while all other jute fiber volumes between J0.35R50 to J0.35R100 led to marginal reductions in strength levels compared to their lower-fiber counterparts. Fatigue test analysis performed by Raval and Kansagra [15] showed that high JF proportions cause clusters which form holes throughout the cementitious material. Void formation in the matrix material leads to weak material and poor stress-transfer which results in reduced tensile strength.

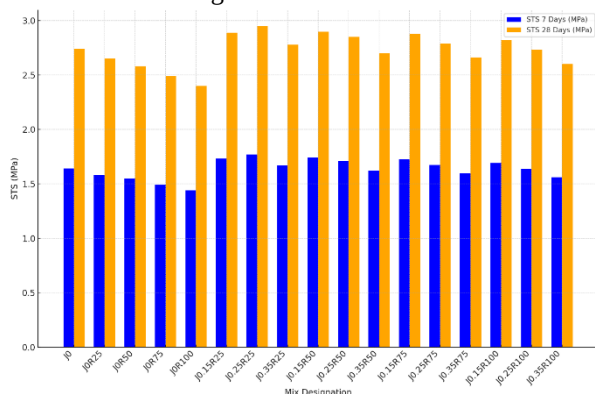


Figure 6 Split tensile strength for different mix designations

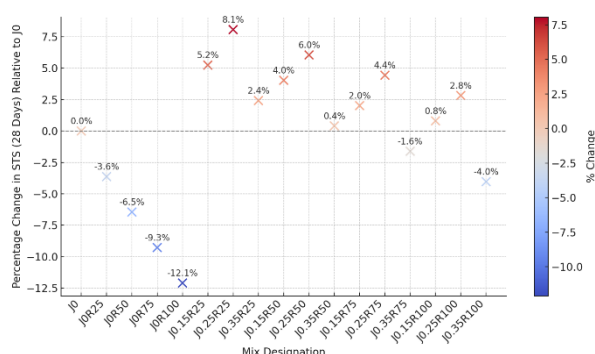


Figure 7 Percentage change in split tensile strength at 28 days relative to J0

The STS changed based on the combination of fiber content and the amount of recycled aggregate used within the mix. The concrete reinforcement capability of JF diminished progressively when the amount of RCA replaced concrete from J0R75 to J0R100 which reduced the quality of interfacial transition zones (ITZ) between cement matrix and RCA particles [8]. The combination of greater aggregate porosity together with weak material

behavior did not improve when JF was added since JF primarily functioned to reduce strength.

Research data establishes that compressive strength (CS) maintains a strong correlation with the STS results. STS exists as a percentage between 10–15% of CS based on Smirnova et al. [16] alongside Chandramouli et al. [17] research findings for aggregate properties alongside fiber usage levels. The STS value for J0 amounts to 3.10 MPa matching 11.3% of the compressive strength of 27.4 MPa which supports the theoretical relationships discussed by [3].

Studies reveal that concrete containing 25–50% recycled concrete aggregate will function optimally when using up to 0.15% – 0.25% JF content. Any increase of JF content beyond 0.35% leads to tensile strength values lower than what fiber reinforcement would provide since mix workability and uniform hydration and well-distributed fiber placement mostly influence tensile strength results. Studies show a need to find the optimal measurement between fiber content and recycled aggregate ratio which will produce sustainable durable results in fiber-reinforced recycled aggregate concrete.

D. WATER ABSORPTION

Laboratory data about water absorption of concrete with jute fiber (JF) and recycled aggregate (RA) are displayed in the subsequent figure. The findings match past studies because water absorption steadily increases throughout the mixtures as jute fiber and recycled aggregate composition grows. The experimental results regarding water absorption levels in relation to controls appear in Figure 08.

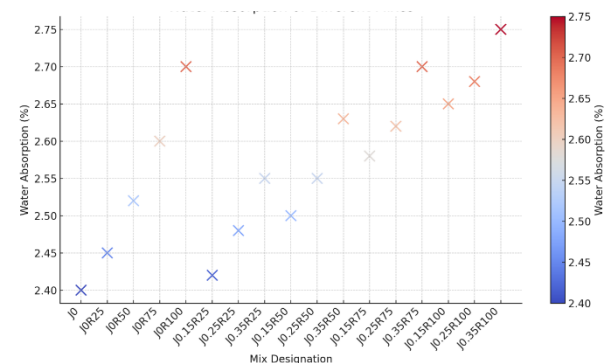


Figure 08. Water absorption of different mixes.

The mix J0 without JF and RA maintains the basic 2.40% water absorption because it does not contain either component. As the recycled aggregate amount in the mixture increases, the water absorption percentage increases continuously up to 2.60% in J0R100. The work of Bheel et al. [18] establishes that recycled aggregate absorbs more water because it has porosity combined with weak interfacial transition zones (ITZ).

The behavior of the absorbing water mixture depends on various jute fiber (JF) quantities applied at 0.15%, 0.25%, and 0.35%. The water absorption percentage of J0.15R25 reached 2.48% but showed a slight decrease compared to J0R25 at 0.15% JF addition. Water absorption decreased through the fiber bridging mechanism because it created better compactness between particles according to Huang and Xie's research [19].

The water absorption rate of the mixture experiences significant enhancement when jute fiber content surpasses 0.25 percent by weight. The J0.35R100 mix attained the maximum water absorption of 2.68% while remaining at 11.67% above J0. The research paper details a theory from Hongfa et al. [20] about fiber clusters and micro-cracks caused by excessive usage which produces higher porosity results. Water-absorption tendencies in jute fibers serve as a natural factor that contributes to concrete permeability problems because jute fibers attract water content.

Use of porous RCA combined with water-absorbing fibers in J0.35R100 mixes results in the maximum water absorption effect. Experimental data indicates that high-fiber concrete composites with trapped air alongside considerable voids promote higher water absorption thus causing long-term durability deterioration according to Bheel et al. [18].

The introduction of JF at 0.15% level enhances compaction characteristics yet produces less water absorption than mixes combining both high dosages of JF and RCA. The research data supports the requirement to determine the optimum fiber content ratio that provides ideal strength improvements while preserving durability according to Hongfa et al. [20]. Water-reducing admixtures or plasticizers enable improvement of long-term concrete performance by lowering the detrimental effects that result from combining high JF and RCA content with concrete mixtures.

CONCLUSIONS

This investigation shows the advantages of integrating Jute Fiber (JF) as reinforcement within Recycled Concrete Aggregate (RCA) concrete for strengthening its mechanical characteristics as well as enhancing its sustainability. Environmentally sustainable concrete with Recycled Concrete Aggregate (RCA) enables decreased natural aggregate consumption but suffers from strength and durability issues because the high porosity and weak interfacial transition zones (ITZ). Research shows JF addition effectively strengthens compressive and split tensile strength particularly at JF dosages from 0.15% to 0.25%. Strategies for enhancing concrete properties become most apparent when researchers introduce 25 percent replacement of reused concrete aggregates. Whenever fiber content exceeds 0.25% the concrete strength decreases through binding fibers together while absorbing more water due to both issues requiring precise dosage management. Concrete with combined RCA and JF suffers from increased water absorption which threatens long-term durability of the material. Research findings indicate that concrete obtains superior strength and resistance to cracks when JF content combines with an ideal RCA replacement ratio. Research must continue to optimize fiber quantity and RCA replacement levels because this advancement will advance the development of sustainable concrete materials for construction applications. Future sustainable building applications can benefit from this research which establishes fundamental principles to use JF-reinforced RCA concrete thereby creating advantages for environment and construction sector alike.

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