Sustainable Fiber-Reinforced Concrete Using Jute Fibers and Recycled Aggregate: A Review

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Abstract

The incorporation of recycled aggregate (RA) and natural jute fiber in concrete offers clear circular-economy benefits, yet their combined use is constrained by porosity, fiber clustering, and reduced workability. This paper reviews the literature on the mechanical and durability performance of jute fiber-reinforced concrete, with particular attention to mixes containing recycled aggregate. The evidence indicates that jute fiber improves performance only within a narrow, low-dosage range. In recycled aggregate concrete, the most favorable results were obtained at 0.15% jute fiber with 25% RA, where compressive, split tensile, and flexural strengths exceeded those of the control by more than 4% (Mahi & Hossen, 2025). In contrast, concrete with 100% RA and no fiber showed a 12.8% reduction in compressive strength, and higher fiber contents increased water absorption and other durability penalties (Jamil et al., 2023). Across other concrete systems, jute fibers consistently enhanced tensile resistance and crack control. Improvements of 21% in splitting tensile strength and 18% in flexural strength were reported for self-consolidating concrete (Hasan et al., 2023). In conventional concrete, compressive strength increased by up to 30.10% and splitting tensile strength by up to 12.64% when fiber dosage and length were optimized (Bhushal et al., 2025). The response depends strongly on fiber dosage and geometry: short fibers at low volume fractions are generally beneficial, while larger contents tend to reduce strength and increase absorption (Islam & Ahmed, 2018; Zakaria et al., 2016). Overall, the findings support the cautious use of jute fiber as a sustainable reinforcement in recycled aggregate concrete. However, the durability behavior, optimal dosage windows, and long-term performance of these composites remain insufficiently understood, and further research is needed to address these gaps.

Keywords: jute fiber; recycled aggregate concrete; mechanical properties; durability; workability; sustainable construction

1. Introduction

Concrete remains the dominant construction material, yet its reliance on virgin aggregate and conventional reinforcement is increasingly difficult to reconcile with sustainability goals. The search for lower-carbon, lower-waste alternatives has therefore turned to recycled aggregate concrete, which diverts demolition waste from disposal streams, and to natural fibers, which can improve crack resistance while reducing dependence on synthetic reinforcements. Among plant-based fibers, jute is especially attractive because it is locally available in several contexts, relatively inexpensive, and renewable, making it a plausible candidate for sustainable concrete design (Zakaria et al., 2016), (Ahmad et al., 2022).

The attraction of jute fiber reinforcement is not simply environmental. The reviewed studies suggest that jute can modify concrete behavior at both fresh and hardened states, influencing flow, segregation resistance, tensile response, compressive strength, and durability-related transport properties. However, the same literature also shows that these benefits are highly dosage-sensitive. Small additions can improve mechanical performance, while excessive fiber content may trigger balling, poor dispersion, or reduced fluidity, undermining the intended reinforcement effect (Islam & Ahmed, 2018), (Zakaria et al., 2016). In recycled aggregate systems, these trade-offs become more pronounced because recycled aggregates already introduce higher porosity and weaker interfacial transition zones, conditions that can amplify absorption and reduce strength if fiber content is not carefully controlled (Mahi &Hossen, 2025), (Jamil et al., 2023).

Despite a growing body of experimental work, the evidence remains fragmented across conventional concrete, self-consolidating concrete, high-strength concrete, recycled aggregate concrete, and fiber-confined structural members. Studies vary in fiber length, dosage, aggregate replacement level, and outcome measures, making it difficult to determine when jute reinforcement is truly synergistic with recycled aggregate and when it simply adds another source of variability. A thematic synthesis is therefore needed to clarify the performance envelope of sustainable fiber-reinforced concrete using jute fibers and recycled aggregate, with particular attention to mechanical efficiency, durability trade-offs, and the conditions under which the combined system is most viable.

2. Methods

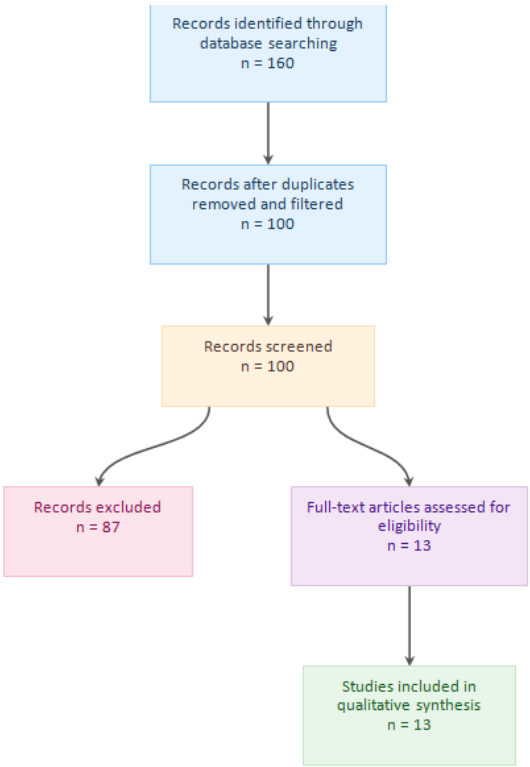
2.1 Search Strategy

We performed a comprehensive search across academic papers, search strategy employed hybrid semantic and keyword-based retrieval to maximize coverage.

Search queries included:

- "Sustainable fiber reinforced concrete with jute fibers and recycled aggregate"
- "Jute fiber reinforced concrete with recycled aggregate review"
- "Mechanical properties durability jute fiber recycled aggregate concrete"
- "Natural fiber reinforced recycled aggregate concrete sustainability"

Figure 2.1 PRISMA Flow Diagram



2.3 Data Extraction and Synthesis

Data extraction focused on the following variables:

- **Material system:** The study focused on concrete, mortar, or related cementitious composites.
- **Jute fiber:** The study investigated jute fiber as reinforcement or confinement material.
- **Recycled aggregate or waste utilization**: Studies combining jute with recycled aggregate were treated as core evidence. Studies on jute-fiber concrete without recycled aggregate were retained as supporting evidence for dosage and geometry effects.

- **Outcomes:** The study reported mechanical performance (compressive, tensile, or flexural strength, toughness, modulus), durability-related outcomes (absorption, permeability, shrinkage, chemical resistance), or both.
- **Study type:** Peer-reviewed experimental, structural, or review articles**.**
- **Sustainability:** The study discussed waste utilization, renewable materials, or circular-economy aspects.

Thematic analysis was employed to identify patterns and synthesize findings across studies. Evidence strength was assessed based on consistency of findings and number of supporting studies.

3: Characteristics of Included Studies

Table 3.1 Characteristics of Included Studies

Study and Year	Study Type	Material System	Key Focus	Jute Details	Recycled Aggregate Details
Zakaria et al. 2016	Experimental	Jute fiber reinforced concrete composites	Mechanical performance and workability trade-offs	Untreated jute; 10, 15, 20, 25 mm; 0, 0.1, 0.25, 0.50, 0.75%	Crushed bricks used as coarse aggregate
Islam & Ahmed 2018	Experimental	Jute fiber concrete	Fresh and hardened properties	Locally produced jute; 10 and 20 mm; 0, 0.25, 0.50, 1.00%	Not specified
Zhang et al. 2019	Experimental	High-strength concrete with jute fiber	Mechanical enhancement and microstructure	Jute plant fiber; optimum length/content not reported	Not applicable
Tiwari et al. 2020	Experimental	Jute fiber reinforced concrete	Mechanical and acid-curing durability	Chopped jute; dosage 0.5, 1.0, 1.5%	Not specified
Hasan et al. 2023	Experimental	Jute fiber reinforced self-consolidating concrete	Rheology and mechanical behavior	20 mm; 0.1, 0.25, 0.50, 0.75, 1%	Not specified

Study and Year	Study Type	Material System	Key Focus	Jute Details	Recycled Aggregate Details
El Ouni et al. 2022	Structural/experimental	Jute fibre-reinforced recycled aggregate concrete elements	Axial compressive performance	Jute fiber details not fully specified	Recycled aggregate concrete from demolished infrastructures
Gao et al. 2022	Experimental	Sisal fiber-reinforced recycled aggregate concrete confined with jute fiber-reinforced polymer tube	Confined compressive performance	Jute as polymer tube; orientation 0°, 30°, 45°	Recycled aggregate concrete from waste
Ahmad et al. 2022	Review	Jute fiber reinforced concrete	Fresh, strength, and durability synthesis	Typical optimum dose 1% to 2%	Not specified
Hossain et al. 2023	Experimental	Fly ash and jute fiber sustainable concrete	Fresh, mechanical, NDT, microstructure	0.2 and 0.4%; form/length not specified	Not applicable
Jamil et al. 2023	Experimental	Jute fiber-reinforced recycled aggregate concrete	Strength and durability	0, 0.15, 0.30, 0.45, 0.60%	0, 50, 100% RCA
Bhushal et al. 2025	Experimental	Jute fiber concrete	Mechanical and durability performance	10 and 12 mm; 0.6, 0.8, 1.0%	Not specified

Overall, the evidence base is dominated by experimental concrete studies, with one review providing broader synthesis. Jute fiber dosages are typically low to moderate and fiber lengths are commonly short, although some studies do not report complete fiber geometry. Recycled aggregate is present in a smaller subset of studies and is most often framed as part of a sustainability strategy rather than as a deeply characterized material system.

3.2 Thematic Findings

3.2.1 Jute fibers generally strengthen concrete in tension more reliably than in compression, but only within narrow dosage windows

Across the literature, the clearest and most consistent benefit of jute reinforcement is improved tensile-related performance rather than uniform gains in compressive strength. In conventional concrete, 0.25% jute fiber improved hardened properties, while 0.50% adversely affected fresh properties and did not sustain the same benefit (Islam & Ahmed, 2018). In self-consolidating concrete, 20 mm jute fiber at low volumetric fractions improved compressive strength by 2%, splitting tensile strength by 21%, and flexural strength by 18% at 28 days, but contents above 0.25% significantly impaired passing ability (Hasan et al., 2023). In recycled aggregate systems, 0.15% jute fiber consistently emerged as the favorable dosage, producing more than 4% improvement in mechanical properties with 0%, 50%, and 100% recycled coarse aggregate, whereas higher dosages (≥0.30%) reversed the benefit (Jamil et al., 2023). Similarly, 0.15% jute fiber with 25% recycled aggregate gave the best compressive and tensile response, including a 6.7% increase in split tensile strength (Mahi &Hossen, 2025).

The pattern suggests that jute mainly contributes through crack bridging and stress redistribution, which is more directly reflected in tensile and flexural response than in bulk compressive resistance. However, the performance window is narrow: benefits depend on adequate dispersion and low enough volume to avoid clustering. Confidence: Strong for tensile-related enhancement at low dosages; Moderate for compressive gains because the effect is more context-dependent.

3.2.2 Fiber geometry and content control the transition from reinforcement to defect formation

A recurring finding is that jute can move from being beneficial to detrimental as length or dosage increases. Shorter fibers and lower contents repeatedly produced better outcomes, while longer fibers or larger fractions promoted balling, porosity, and reduced workability. In one study, 10 mm fiber at 0.10% gave the most favorable mechanical response, and larger lengths or contents reduced performance, with the maximum tensile strength increase reaching 35% relative to plain concrete (Zakaria et al., 2016). Another study found 0.25% jute beneficial but 0.50% harmful to fresh properties, showing that the threshold for adverse effects can be low even before mechanical failure becomes apparent (Islam & Ahmed, 2018). Similar dosage sensitivity was reported in later work where higher jute contents reduced passing ability in SCC and increased water absorption in recycled aggregate concrete (Hasan et al., 2023), (Mahi &Hossen, 2025).

This convergence is important because it indicates that jute reinforcement behaves less like a conventional high-volume additive and more like a precision modifier whose effectiveness depends on uniform distribution. The evidence also suggests that performance losses appear abruptly once fiber content exceeds the dispersion capacity of the mix. Confidence: Strong for dosage sensitivity and the risk of clustering/porosity at higher contents.

3.2.3 Recycled aggregate weakens the baseline concrete matrix, but low-dose jute can partially recover lost performance

In recycled aggregate concrete, the baseline penalty from recycled aggregate is clear. One study reported a 12.8% drop in compressive strength when 100% recycled aggregate was used without jute fiber (Mahi &Hossen, 2025). Another found that increasing recycled aggregate and jute content together reduced durability, especially through higher water absorption and worsened transport properties (Jamil et al., 2023). However, the same literature shows that low-dose jute can partially offset this weakness. The best-performing recycled aggregate mix in one study used 0.15% jute with 25% recycled aggregate, while tensile strength improvements of 6.7% were recorded under that condition (Mahi &Hossen, 2025). In another, the combination of 10% fly ash and 0.2% jute improved the interface and crack resistance, with compressive gains up to 25.9% and split tensile and flexural gains of 11.64% and 10.72%, respectively (Hossain et al., 2023).

The synthesis indicates that jute does not erase the intrinsic limitations of recycled aggregate, but it can improve crack control and interface quality enough to recover part of the lost performance. The best results appear when recycled aggregate replacement remains moderate and jute content remains very low. Confidence: Moderate for partial recovery of recycled aggregate weakness; Strong for the conclusion that excessive recycled aggregate remains a performance penalty.

3.2.4 Durability benefits are less consistent than strength gains, and higher fiber content often increases transport-related vulnerability

Durability evidence is more limited and more mixed than mechanical evidence. Some studies support improved resistance to cracking and damage progression, but transport-related measures show a clearer downside when fiber or recycled aggregate content rises. In recycled aggregate concrete, durability declined as both recycled aggregate and jute dosages increased, with higher water absorption reported at greater fiber contents (Jamil et al., 2023), (Mahi &Hossen, 2025). In jute concrete more generally, water absorption increased with larger fiber size (Bhushal et al., 2025). Acid-curing tests likewise showed reduced compressive strength under aggressive exposure, even though jute improved strength under normal curing (Tiwari et al., 2020).

These findings do not invalidate the mechanical benefits; rather, they show that jute's crack-bridging action does not necessarily translate into lower permeability or better chemical resistance, especially if fiber connectivity introduces voids. The durability picture is therefore more vulnerable to mix design quality than the strength picture. Confidence: Moderate for increased absorption and transport vulnerability; Limited for durable long-term protection because few studies directly test such outcomes.

3.2.5 Sustainability claims are conceptually consistent, but direct environmental quantification is absent

Every study that engaged the sustainability question framed jute and recycled aggregate as environmentally preferable because they reduce reliance on natural resources, utilize waste, or substitute for synthetic reinforcement. Jute is repeatedly presented as locally available, renewable, and inexpensive (Zakaria et al., 2016), (Ahmad et al., 2022), while recycled aggregate is treated as a waste-stream solution for demolition material (Jamil et al., 2023), (Mahi &Hossen, 2025). Fly ash was also used as a waste-derived cement replacement alongside jute, strengthening the circular-economy framing (Hossain et al., 2023).

However, the sustainability argument remains largely qualitative. None of the included evidence provides life-cycle assessment, embodied carbon accounting, or environmental payback analysis. As a result, the literature supports a plausible sustainability rationale but not a quantified environmental superiority claim. Confidence: **Moderate** for the conceptual sustainability case; **Limited** for quantified environmental benefit.

3.3 Summary of Evidence

Theme	Key Finding	Population Applicability	Effect Direction	Confidence Level	Supporting Studies
Low-dose jute improves mechanical performance	0.15% jute with 25% RCA improved split tensile strength by 6.7% and outperformed higher fiber contents	Jute-fiber reinforced recycled aggregate concrete	Positive	Strong	Mahi &Hossen et al. (Mahi &Hossen, 2025), Jamil et al. (Jamil et al., 2023)
Tensile benefits exceed compressive benefits	20 mm jute at low fractions improved splitting tensile strength by 21% and flexural strength by 18%	Jute-fiber concrete and SCC	Positive	Strong	Hasan et al. (Hasan et al., 2023), Islam & Ahmed et al. (Islam & Ahmed, 2018)

Theme	Key Finding	Population Applicability	Effect Direction	Confidence Level	Supporting Studies
Excess fiber reduces workability and may impair strength	0.50% jute adversely affected fresh properties and higher contents reduced passing ability	Fresh and hardened concrete with jute	Negative / Mixed	Strong	Islam & Ahmed et al. (Islam & Ahmed, 2018), Hasan et al. (Hasan et al., 2023)
Recycled aggregate weakens baseline concrete	100% RCA without JF reduced compressive strength by 12.8%	Recycled aggregate concrete	Negative	Strong	Mahi &Hossen et al. (Mahi &Hossen, 2025), Jamil et al. (Jamil et al., 2023)
Durability is more sensitive than strength	Higher RCA and jute increased water absorption and other durability penalties	Jute-fiber RCA concrete	Negative	Moderate	Jamil et al. (Jamil et al., 2023), Bhushal et al. (Bhushal et al., 2025)
Sustainability rationale is qualitative	Jute and RCA are framed as renewable/waste-utilizing materials, but no life-cycle data are reported	Sustainable concrete systems	Positive	Limited	Ahmad et al. (Ahmad et al., 2022), Hossain et al. (Hossain et al., 2023)

4. Discussion

4.1 Principal Findings and Their Interpretation

The synthesis shows that jute fiber is best understood as a low-dose toughness modifier for sustainable concrete rather than a universal strength enhancer. Its most dependable contribution is crack bridging, which plausibly explains why splitting tensile and flexural properties improve more consistently than compressive strength. This pattern is especially evident in mixes where short fibers are well dispersed and the matrix remains sufficiently workable to allow uniform distribution. When dosage rises, the reinforcing mechanism appears to be overtaken by fiber agglomeration, which increases voids and disrupts compaction, thereby eroding both fresh and hardened performance. The repeated appearance of this threshold effect across conventional concrete, self-consolidating concrete, and recycled aggregate concrete makes the conclusion more robust than any single experiment would allow (Zakaria et al., 2016), (Hasan et al., 2023), (Mahi &Hossen, 2025).

The recycled aggregate studies add an important second layer: the matrix itself is already disadvantaged by porosity and weak interfacial transition zones, so the margin for error narrows further. In that context, jute can partially restore lost performance, but only when aggregate replacement remains moderate and fiber content is carefully constrained. The most defensible interpretation is therefore one of conditional synergy: jute and recycled aggregate can complement each other in sustainable concrete, but only within a tight design window. This is a stronger and more practically useful conclusion than simply stating that both materials are “eco-friendly.” The evidence is strongest for short, low-volume

fibers in moderately recycled matrices and weakest for high-fiber or highly recycled systems. Mechanistic data are limited, but the available microstructural observations on improved bonding interface and crack resistance support a crack-bridging and interfacial-repair explanation rather than a wholesale matrix strengthening mechanism (Hossain et al., 2023).

4.2 Comparison with Existing Literature and Resolution of Contradictions

The included review and experimental studies broadly agree that jute can improve concrete performance, but they also clarify why earlier enthusiasm should be tempered by dosage control. The consistency of the positive findings is meaningful because they span different concrete types and loading regimes, suggesting that the beneficial mechanism is not confined to one mix design. At the same time, the negative findings are not outliers; they recur whenever fiber length or volume increases beyond what the matrix can accommodate. This means the field is not dealing with random experimental noise so much as a genuine process window in which jute behaves as a reinforcement at low levels and as a defect source at higher levels (Ahmad et al., 2022), (Islam & Ahmed, 2018).

The contradictions are therefore best explained by mix design sensitivity rather than by incompatible theories. Conventional concrete, SCC, and recycled aggregate concrete differ in flowability, porosity, and interface quality, so the same fiber dosage may have different consequences across systems. That helps explain why some studies report moderate compressive gains while others emphasize fresh-property deterioration or durability penalties. It also suggests that apparent disagreement is partly methodological: studies that measure only strength may overlook the workability and absorption costs that become visible in more complete testing programs. Publication bias remains possible because sustainable materials research often expects positive outcomes, but the presence of clearly adverse results in the literature reduces concern that only favorable findings are being retained. There is no strong evidence of a methodological evolution toward a single dominant testing paradigm; rather, the literature is expanding into more complete combinations of fresh, mechanical, durability, and microstructural assessment, which improves confidence in the overall pattern while also revealing its limits (Tiwari et al., 2020), (Jamil et al., 2023), (Bhushal et al., 2025).

4.3 Practical Implications

For mix designers and structural engineers, the practical message is not simply to "add jute," but to add it sparingly and only after accounting for matrix quality. The most promising applications are likely those in which low-dose jute can improve tensile resistance and crack control without compromising flow, especially in recycled aggregate systems where moderate replacement levels are used to balance sustainability with performance (Mahi &Hossen, 2025), (Hasan et al., 2023). In SCC, the evidence suggests that jute contents above 0.25% can undermine passing ability, which means fiber use must be aligned with placement method and compaction capacity. In recycled aggregate concrete, higher fiber dosages can increase water absorption, so durability-sensitive exposures should trigger even tighter dosage limits (Jamil et al., 2023).

The sustainability appeal of jute and recycled aggregate is credible, but it is not yet quantified well enough to justify blanket adoption. Specifiers and procurement agencies can reasonably support pilot use in non-critical or moderately demanding structural elements. Specifications should emphasize trial batching, workability limits, and transport-property testing rather than relying on labels such as "green" or "natural." Performance losses appear quickly once fiber content exceeds the dispersion capacity of the mix. Compliance with compressive strength alone is therefore insufficient if a mix increases absorption or reduces flowability.

4.4 Strengths and Limitations

A major strength of this review is the thematic integration of experimental concrete studies with a review article, allowing mechanical, durability, and sustainability claims to be interpreted together rather than in isolation. The included evidence spans conventional, self-consolidating, high-strength, and recycled aggregate concretes, which helps identify design principles that recur across contexts. Another strength is the explicit attention to dose-response behavior, which is central to understanding why jute sometimes strengthens concrete and sometimes degrades it.

The main limitations lie in the underlying evidence base. Most included studies are laboratory experiments with heterogeneous fiber lengths, dosages, aggregate types, and test protocols, limiting direct comparability. Durability

testing is comparatively sparse and often limited to water absorption or acid exposure, leaving long-term environmental resistance underexplored. Several studies also do not fully report fiber treatment, aggregate processing, or detailed recycled aggregate characterization. For the review itself, the synthesis is constrained by abstract-level extraction and the absence of formal risk-of-bias assessment, so conclusions should be interpreted as evidence-informed rather than meta-analytically definitive.

5. Gaps and Future Directions

The most important gap is the lack of directly comparable studies on jute-fiber reinforced recycled aggregate concrete that jointly optimize fiber geometry, dosage, and recycled aggregate replacement. Current evidence suggests that low-dose jute can improve recycled aggregate concrete, but the exact design window remains uncertain because studies vary in fiber length, aggregate source, and outcome set. Future work should therefore test matched mix series with harmonized recycled aggregate characterization and identical curing, workability, and durability protocols. More complete durability programs are also needed, because the current literature emphasizes strength more than permeability, chloride resistance, freeze-thaw behavior, and long-term transport properties.

A second gap is the absence of environmental quantification. The sustainability argument is strong in principle, but no included study provides life-cycle assessment or embodied carbon accounting, so the true environmental advantage remains assumed rather than demonstrated. Finally, better mechanistic work is needed to explain why some low-dose systems improve both strength and interface quality while others suffer from clustering and absorption penalties. Microscopy and transport testing should be paired with mechanical tests so that the field can move from empirical optimization toward predictive mix design. Research on structural-scale elements under service and ultimate loading would also help determine whether the laboratory benefits of jute translate into durable, code-relevant performance.

6. Conclusion

The literature supports a qualified affirmative answer to the question of whether sustainable fiber-reinforced concrete using jute fibers and recycled aggregate can deliver useful performance benefits: yes, but only within a narrow and carefully controlled design window. The most defensible conclusion is that low-dose jute reinforcement can partially compensate for the mechanical weaknesses of recycled aggregate concrete, especially in tensile and flexural response, while excessive fiber content or high recycled-aggregate replacement can quickly erode both workability and durability. The strongest evidence comes from low-volume mixtures such as 0.15% jute with 25% recycled aggregate, which improved split tensile strength by 6.7%, and from sustainable concrete systems in which 20 mm jute increased splitting tensile strength by 21% and flexural strength by 18% at 28 days (Mahi & Hossen, 2025), (Hasan et al., 2023). At the same time, 100% recycled aggregate without jute reduced compressive strength by 12.8%, and higher jute contents increased water absorption or impaired passing ability, demonstrating that more reinforcement is not necessarily better (Mahi & Hossen, 2025), (Jamil et al., 2023).

This conclusion applies most directly to experimental concrete systems that combine natural-fiber reinforcement with recycled aggregate or other waste-derived constituents. What remains uncertain is the long-term durability and environmental payoff of these mixtures under realistic field conditions, especially for aggressive exposure classes. The broader significance is clear: if jute and recycled aggregate are to support genuinely sustainable construction, their use must be governed by performance-based limits rather than by material provenance alone.

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