Hybrid Fiber Reinforced Concrete using Sugarcane Bagasse and Banana Fibers: A Review

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Abstract

Hybrid fiber reinforced concrete has emerged as a promising route for improving crack resistance, toughness, and sustainability in cement-based materials. This review synthesizes the uploaded corpus of 57 papers with a focus on sugarcane bagasse ash (SCBA), sugarcane bagasse fiber, banana fiber, and hybrid systems that combine agricultural residues with conventional binders or secondary supplementary cementitious materials. The screened studies consistently show that properly processed SCBA can act as a beneficial cement replacement or additive, most often at low-to-moderate replacement levels, while banana fibers are particularly effective in bridging microcracks and improving post-crack behavior, flexural toughness, and impact resistance. However, both materials introduce practical challenges: SCBA can alter workability and setting kinetics, whereas banana fibers often reduce flowability and require treatment to improve bond durability. The hybrid studies indicate that combining agricultural by-products can create synergistic behavior when the mix proportion, fiber length, and surface processing are optimized. Across the corpus, the strongest results are usually associated with fine grinding or thermal treatment of ash, limited replacement percentages, short-to-medium fiber lengths, and careful control of water demand and dispersion. The review also identifies major research gaps, especially in long-term durability, standardized hybrid mix design, fiber degradation, life-cycle assessment, and field-scale validation. Based on the evidence, sugarcane bagasse- and banana-based hybrid concrete systems are technically feasible and can support circular, low-carbon construction when processing quality and dosage limits are respected.

Keywords—Hybrid concrete, sugarcane bagasse ash, banana fiber, natural fibers, sustainability, crack resistance, supplementary cementitious materials.

1. Introduction

Concrete remains the most widely used construction material because it is inexpensive, durable, and easy to cast; however, it is also carbon intensive, brittle in tension, and vulnerable to microcrack propagation. The search for low-carbon binders and crack-controlling reinforcements has therefore shifted toward agricultural residues that can replace part of the cementitious matrix or serve as natural fibers. The uploaded corpus reflects this trend clearly: a large share of the papers examine sugarcane bagasse ash as a cementitious replacement, while another substantial group evaluates banana fiber as a crack-bridging reinforcement. A smaller but highly valuable set of studies explores hybridization, where two agricultural resources are combined to balance strength, toughness, and sustainability.

Sugarcane bagasse is a by-product of the sugar industry. When it is burned, processed, ground, and properly screened, the resulting ash may contain reactive silica and fine particles that contribute to pozzolanic reactions. Banana fiber is obtained from the pseudostem, leaf, or fruit-processing waste and is attractive because of its low density, renewable origin, and ability to improve post-cracking performance. In principle, SCBA can refine the matrix while banana fiber can arrest crack growth, so the two materials address different weaknesses of concrete.

The reviewed papers show that the technical success of these materials depends less on the idea itself and more on the processing route. Raw ash with excess carbon or coarse particles can perform poorly, whereas re-ground or thermally treated ash can behave as a useful supplementary cementitious material. Likewise, untreated banana fibers may absorb water, agglomerate, or degrade in the alkaline pore solution of concrete. Chemical treatment, controlled fiber length, and volume fraction selection therefore become decisive variables. The present review organizes the uploaded papers around these recurring themes and translates them into design guidance for hybrid fiber reinforced concrete.

1.1 Corpus snapshot

Theme	Approx. count in uploaded ZIP	Interpretation
SCBA / sugarcane waste studies	14	Dominant binder-modification theme
Banana fiber studies	9	Dominant reinforcement theme
Hybrid banana/bagasse studies	1	Direct hybrid theme
Biochar / geopolymer context	6	Broader sustainable-concrete background
Other contextual sustainable-material papers	27	Supporting evidence for mix design and durability

2. Material Background and Processing Routes

Sugarcane bagasse ash is most useful when it behaves as a fine, reactive supplementary cementitious material rather than as an untreated waste. Several papers in the corpus show that grinding, sieving, or controlled re-burning can increase its pozzolanic contribution and reduce the amount of unburned carbon or fibrous residue [3], [4], [7]. In practice, SCBA works best when particle fineness and replacement percentage are balanced so that the ash contributes to matrix densification without excessive dilution of clinker.

Banana fiber behaves differently. It is not primarily a binder replacement but a discrete reinforcement that carries tensile stress after matrix cracking. The review papers and experimental studies emphasize delignification, alkali treatment, or other pretreatments to reduce fiber surface impurities and improve interfacial bonding [9], [10], [13]. Untreated fibers can still provide mechanical benefit, but the best performance usually appears when moisture uptake and surface roughness are managed.

A recurring message across the corpus is that both materials are highly sensitive to dosage and preparation. For SCBA, the critical variables are particle size, calcination history, carbon content, and replacement level. For banana fiber, the key variables are fiber length, orientation, treatment, and volume fraction. This sensitivity helps explain why some studies report major strength improvements while others observe workability loss or slight compressive-strength reductions. The hybrid challenge is to find the processing window in which the ash improves the matrix and the fiber improves the fracture response.

2.1 Sugarcane Bagasse Ash

Processed SCBA can act as an effective filler and pozzolan. In the 3D-printed mortar study, bagasse ash reduced flowability but accelerated hydration and shortened setting time because of its fine particles and reactivity [2]. In other studies, low-to-moderate SCBA replacement improved compressive strength, splitting tensile strength, and microstructure, especially when the ash was ground or otherwise refined [3], [4], [5]. High-volume replacement was also feasible in selected systems when combined with silica fume or other reactive admixtures [5].

The broader implication is that SCBA is best treated as a processed ingredient rather than a raw waste. The difference between raw ash, ground ash, and re-burned ash is not minor; it changes pozzolanic reactivity, particle packing, water demand, and the extent of calcium hydroxide consumption. In the corpus, the most favorable results generally appear when SCBA is used as a partial replacement or an admixture rather than as a full cement substitute [3], [4], [6], [7].

2.2 Banana Fiber

Banana fiber is attractive because it is lightweight, renewable, and capable of improving ductility. The review on banana fiber reinforced concrete notes higher bending strength and improved post-crack load-bearing capacity when the fibers are properly dispersed and treated [9]. Experimental work on beams and flexural members consistently shows reduced cracking and improved toughness, although the modulus of rupture may not always increase at the same rate as toughness [10], [12]. In self-compacting or highly flowable matrices, banana fiber can still be used, but mix rheology must be adjusted carefully [11].

One recurring experimental observation is that the mechanical response of banana-fiber concrete can be mixed: compressive strength may remain unchanged or decrease slightly, while flexural toughness and crack control improve substantially. This is not a failure of the material; it is a sign that the fiber is doing its intended job, namely bridging cracks and redistributing stress after matrix cracking. For structural design, this means the success criteria should include fracture energy, toughness index, and crack width control rather than compressive strength alone [10], [12], [13].

3. Fresh-State Behavior and Workability

Workability is one of the first properties to deteriorate when SCBA and banana fiber are introduced together. Fine ash particles raise water demand and can reduce slump or flow, while fibers create mechanical interference and increase internal friction. The 3D-printed mortar study reported a clear reduction in flowability as SBA content increased from 0% to 20%, but the same material sharply reduced setting time and accelerated cement hydration [2]. This is important for printable and rapid-setting systems, where controllable open time is needed.

The self-compacting concrete study combining bagasse ash, metakaolin, and glass fiber illustrates the role of mix synergy. The optimum flowability occurred around the 10% BA + 5% MK blend, showing that one mineral addition can compensate for the negative rheological effect of another [1]. Similarly, the processed SCBA concrete study found that small additions of ash, rather than direct cement replacement, could preserve workability while still improving the fresh-state response and early hydration [3], [4].

For banana-fiber mixtures, fiber length and surface treatment are especially influential. Shorter fibers disperse more easily, but longer fibers provide greater crack bridging. The challenge is to prevent balling, ensure uniform distribution, and maintain enough paste coating around each filament. In the reviewed literature, workable hybrid mixes generally used low fiber dosages, controlled lengths near 30-50 mm, and additional water-reducing strategy where needed [10], [11], [14].

4. Mechanical Performance of SCBA-, Banana-, and Hybrid-Reinforced Concrete

The mechanical results across the corpus can be summarized in one sentence: SCBA tends to improve the matrix when it is fine and used at the right dosage, while banana fiber tends to improve toughness and crack resistance even when compressive strength changes little or slightly decreases. This difference is not a contradiction; it reflects the different roles of a pozzolanic filler and a discrete reinforcement.

4.1 Compressive Strength

Several studies report an optimum low-to-moderate SCBA replacement where compressive strength matches or exceeds the control mix. The high-volume bagasse ash and silica fume study found that 20% BA in a binary blend and 33% BA + 7% SF in a ternary blend outperformed the control at selected ages, supported by denser microstructure and lower porosity [5]. The processed SCBA study also identified improved strength and cohesion when the ash was finely ground and used as a partial cement replacement [3], [4]. In the stone dust plus GSCBA paper, a 10% GSCBA mix remained comparable to control concrete up to 90 days, demonstrating that SCBA can contribute to sustainable aggregate-cement hybrid systems [6].

For banana fiber systems, compressive strength is more sensitive to voids and dispersion than the fiber itself. In the banana stem and sugarcane hybrid NFRC paper, a 1.5% banana pseudo-stem fiber dosage reduced compressive strength but increased flexural strength markedly, while sugarcane bagasse fiber at 0.75% improved both compressive and flexural strength in the studied matrix [14]. This points to a practical rule: natural-fiber dosage should be conservative when the target is structural compressive capacity, but slightly higher when energy absorption and post-crack stability are the priority.

4.2 Tensile, Flexural, and Toughness Response

Tensile and flexural behavior are where banana fiber contributes most clearly. The beam study using banana fiber bars showed roughly 25% higher flexural strength than plain concrete and significantly better crack resistance [12]. The finite-element study with banana and hybrid fibers also reported reduced cracking and improved flexure behavior relative to conventional reinforcement layouts [13]. Likewise, the flexural-load study using 50 mm banana fiber at 5% by weight observed an increase in flexural toughness index even though the modulus of rupture decreased relative to ordinary concrete [10]. This pattern is common in fiber reinforced concretes: peak load may not always grow dramatically, but the energy absorbed before failure increases substantially.

SCBA can also enhance tensile and flexural response indirectly by refining the pore structure and boosting matrix quality. In the Scientific Reports study, the best-performing high-volume BA mix and the BA-silica fume blend showed higher compressive and tensile strengths, lower water absorption, and denser microstructure [5]. The 2025 study that added SCBA as an admixture instead of a cement replacement reported enhanced early-age strength and a denser, more cohesive matrix at 4.5% SCBA [3]. The implication is that SCBA is not just a waste substitution; it can become an active participant in load transfer if processing and dosage are correct.

4.3 Hybrid Synergy

The direct hybrid paper in the corpus is especially important because it combines banana pseudo-stem fiber and sugarcane bagasse fiber in the same concrete matrix [14]. That study reported that a 75% banana / 25% sugarcane fiber blend improved compressive and flexural strength simultaneously, indicating that the two natural reinforcements may complement one another when their stiffness, aspect ratio, and distribution are balanced. The banana component appears to contribute crack bridging and ductility, whereas the bagasse component appears to enhance internal distribution and matrix cohesion. This is the clearest experimental evidence in the corpus that a hybrid natural-fiber system can outperform single-fiber systems when proportioned correctly.

A similar hybrid logic appears in related non-concrete studies in the uploaded corpus. In polymer composites, banana fiber and sugarcane bagasse powder were combined to improve tensile, compression, flexural, and impact response [16]. Although the matrix is different, the stress-transfer idea is the same: one constituent improves continuity while the other improves crack tolerance. That analogy supports the use of sugarcane and banana materials as a complementary pair in cementitious systems.

Table 1. Representative Studies from the Uploaded Corpus and Their Main Outcomes

Ref.	Study / system	Typical dosage or variable	Main finding
[2]	3D-printed mortar with SBA	0-20% SBA	Flowability dropped; setting time shortened; hydration accelerated.
[1]	SCC with BA + MK + GF	10-20% BA, 0.1% GF	10% BA + 5% MK gave the best flowability.
[3]	Concrete with raw and processed SCBA	Up to 30% SCBA	Grinding / reprocessing improved pozzolanic activity.
[4]	Concrete with processed SCBA	Partial cement replacement	45 min grinding increased reactivity and durability.
[5]	High-volume BA + silica fume concrete	20% BA or 33% BA + 7% SF	Best mixes outperformed control at selected ages.
[6]	Stone dust + GSCBA concrete	0-40% GSCBA; 100% SD	10% GSCBA retained comparable strength.

[7]	Durability of bagasse-ash concrete	SCBA structural exposure	Long-term durability depends on processing quality.
[12]	Banana fiber bars in RC beams	Banana fiber reinforcement	Cracking reduced; flexural strength improved by ~25%.
[13]	Hybrid banana and banana-fiber bars	Hybrid fiber bars + FEM	Crack resistance improved; flexure predictions validated.
[10]	Banana fiber in flexural concrete	50 mm fiber, 5% by wt. cement	FTI increased; MOR decreased slightly.
[11]	Banana fiber in SCC	Delignified banana fiber	Mechanical properties improved with controlled dispersion.
[14]	Banana pseudo-stem + sugarcane fiber NFRC	30-50 mm fibers; 0.25-2%	75% banana / 25% sugarcane blend improved both strengths.
[15]	Banana fibre slurry treatment of RCA	0-7% banana fiber in slurry	5% fiber improved strength and aggregate quality.
[16]	Banana fiber + bagasse powder composite	10-20% reinforcement	Hybrid reinforcement improved all major mechanical metrics.
[17]	Banana leaf ash + banana fiber concrete	0-6% BLA; BF addition	Ash replaced cement while BF improved reinforcement.
[18]	SCBF + corn waste ash concrete	1% SCBF optimum	Optimum fiber content improved strength and durability.
[19]	Costus lucanius bagasse fibre concrete	5-20% CLBF	5% CLBF gave the highest compressive/flexural strengths.
[20]	Bagasse ash + polypropylene fibers + sea sand	Hybrid sustainable mix	Sustainable ingredients can be combined without full strength loss.

5. Durability, Microstructure, and Long-Term Behavior

Durability is the area where SCBA shows particularly strong promise. Fine ash particles and pozzolanic reactions can consume calcium hydroxide and form additional C-S-H, which refines pores and reduces permeability. In the high-volume BA plus silica fume paper, the improved strength of the best mixes was directly associated with lower water absorption and apparent porosity, along with denser SEM-EDS observations [5]. The processed SCBA concrete paper and the 2025 admixture study both point to a similar conclusion: if the ash is processed enough, it can densify the interfacial transition zone and improve resistance to transport-related deterioration [3], [4].

At the same time, the corpus also shows that SCBA is not universally beneficial at all dosages. Excess ash can increase unburned residue, decrease workability, and dilute the binder. Long-term durability therefore depends on an optimum replacement range rather than maximal substitution. The report on durability of concrete structures with sugar cane bagasse ash emphasizes the importance of exposure conditions and processing quality, especially when the waste is intended for structural rather than non-structural use [7].

Banana fiber affects durability in a different way. Its main contribution is not pore refinement but crack control. By narrowing crack widths and delaying crack growth, the fibers reduce the pathways for aggressive agents. However, untreated fibers may absorb water and degrade in alkaline environments. The review paper on banana fiber reinforced concrete discusses pretreatments as a central issue because the mechanical benefits of banana fiber must be balanced against moisture sensitivity and chemical durability [9]. The corpus therefore suggests that durability improvements from banana fiber are most credible when the fiber is chemically treated or embedded in a matrix that already has low permeability.

Microstructural studies strengthen this interpretation. Where SCBA is well processed, SEM often shows a denser and more compact matrix, FTIR or TGA indicates stronger pozzolanic development, and pore volume decreases. Where banana fiber is used, the visible improvement is usually crack bridging and better load transfer rather than a directly denser paste. The best hybrid systems therefore combine the matrix-densifying role of ash with the crack-bridging role of fiber, producing a more balanced fracture process than either component alone.

6. Comparative Synthesis Across the Uploaded Corpus

Across the 57 uploaded files, three dominant design philosophies emerge. The first is the mineral-binder route, where sugarcane bagasse ash is used as a cement replacement or additive to improve packing, reactivity, and microstructure. The second is the fiber-bridging route, where banana fiber is used to enhance toughness, crack resistance, and energy absorption. The third is the hybrid route, where both strategies are used together or where banana/bagasse materials are paired with another sustainable constituent such as metakaolin, silica fume, stone dust, or recycled aggregate. The corpus shows that the third route has the highest potential, but also the highest sensitivity to mix design.

In the mineral-binder studies, strength gains are generally reported at low to moderate replacement levels, especially when the ash is finely ground or thermally processed. In the fiber studies, the most consistent benefits are crack control and toughness rather than raw compressive strength. In the hybrid studies, the strongest systems typically keep the ash fraction high enough to refine the matrix but the fiber fraction low enough to avoid balling and excessive water demand. This balance is why the best-performing hybrid papers often use a mineral optimization step first and only then introduce natural fiber reinforcement.

The corpus also shows that the same agricultural residue can play multiple roles. Bagasse may appear as ash, fiber, or powder, while banana appears as stem fiber, pseudo-stem fiber, leaf ash, or bar reinforcement. This diversity matters because each form behaves differently in concrete. Ash is mostly a binder modifier, fiber is mostly a reinforcement, and powder or bar forms sit somewhere between those two roles. A publishable review should therefore treat each residue by function, not just by name.

Finally, the evidence suggests that hybridization should be viewed as an engineering problem rather than a material-fashion trend. The aim is not simply to add more natural material to concrete, but to solve specific performance deficits: low tensile strength, brittle post-peak behavior, waste disposal, and cement-related emissions. When the mix is designed with those goals in mind, the uploaded studies collectively support the feasibility of sugarcane-bagasse- and banana-based hybrid concrete systems.

7. Recommended Experimental Matrix for a Future Publishable Study

A strong next study should not test only one or two trial mixes. It should map the factor space systematically so that optimization is reproducible. For the binder phase, a practical SCBA series would include 0%, 5%, 10%, 15%, and 20% cement replacement. For the fiber phase, banana fiber can be tested at 0%, 0.25%, 0.50%, 0.75%, and 1.00% by volume, with at least two fiber lengths, such as 30 mm and 50 mm. Surface treatment can be treated as a third factor with levels such as untreated, alkali-treated, and coated fiber. That structure would make it possible to identify whether the observed gains come from the ash, the fiber, or the interaction between them.

The recommended test program should include fresh-state workability, density, compressive strength, splitting tensile strength, flexural strength, fracture energy, water absorption, sorptivity, RCPT/chloride penetration, shrinkage, and elevated-temperature response. Microstructural tests such as SEM, EDS, FTIR, and TGA should be used to explain why a mix performed well rather than simply reporting numbers. This is especially important for hybrid systems, because the matrix-fiber interface is often the key variable and is not visible in ordinary strength tests alone.

For publication-quality evidence, the study should also report statistical significance and model validation. Response-surface methodology, regression, or machine-learning models can be used to optimize the factor combination, but the final recommendation should still be confirmed by physical testing. Such a workflow would move the field from isolated experimental anecdotes toward a reproducible design framework.

Table 2. Suggested Parameter Matrix for a Hybrid SCBA–Banana Fiber Program

Factor	Suggested levels	Purpose
SCBA replacement	0, 5, 10, 15, 20% by mass of cement	Find optimum pozzolanic contribution

Banana fiber content	0, 0.25, 0.50, 0.75, 1.00% by volume	Balance toughness and workability
Fiber length	30 mm and 50 mm	Study crack bridging efficiency
Fiber treatment	Untreated / alkali-treated / coated	Improve bond and durability
Curing age	7, 28, 56, 90 days	Track early and later-age performance
Exposure	Water, sulfate, chloride, thermal cycling	Assess durability
Microstructure	SEM, EDS, FTIR, TGA	Explain mechanism
Optimization method	ANOVA / RSM / regression / ML	Develop reproducible design rules

8. Practical Design Guidance for Engineers

The most practical design rule emerging from the corpus is to avoid unprocessed materials. Sugarcane bagasse ash should be dried, sieved, and ground to a consistent fineness before use, while banana fibers should be cleaned and preferably treated to improve interfacial bonding. In plant-scale production, the mixing sequence should introduce the ash with the dry binder first and the fibers later to reduce clumping. When possible, a superplasticizer or viscosity-modifying admixture should be used so that the fresh-state loss caused by fiber addition does not dominate the mix.

From a construction perspective, these materials are most attractive in applications where crack control and sustainability matter more than very high compressive strength. That includes lightweight blocks, non-load-bearing panels, thin precast elements, self-compacting repair mortars, and low-carbon structural concrete in controlled production environments. For ordinary site-cast concrete, the principal challenge is quality control, because natural fibers and agricultural ashes are more variable than industrial by-products such as silica fume or fly ash.

An engineer implementing a hybrid mix should therefore think in terms of performance classes rather than material labels. The question is not whether banana fiber or bagasse ash is ‘good’ in general. The real question is whether the mix satisfies the target slump, strength, durability, and cost for the specific project. The uploaded literature shows that, under that performance-based approach, sugarcane bagasse and banana-derived concrete can move from experimental curiosity to legitimate sustainable design.

9. Conclusion

The uploaded corpus shows that sugarcane bagasse ash and banana fiber are both technically useful and environmentally compelling ingredients for sustainable concrete. SCBA mainly strengthens the matrix through pozzolanic refinement and microstructural densification, while banana fiber mainly improves crack control, toughness, and post-crack load carrying capacity. When the two are combined in a hybrid system, the best outcomes arise from moderate ash replacement, low-to-moderate fiber content, controlled fiber length, and careful surface treatment. The evidence does not support indiscriminate high-volume substitution, but it does support a design philosophy in which agricultural residues are processed into engineered components rather than treated as low-grade waste.

The main research needs are standardized hybrid optimization, long-term durability studies, structural-scale validation, and sustainability assessment. With those pieces in place, hybrid sugarcane bagasse and banana fiber concrete can become a realistic option for circular and low-carbon construction. Overall, the corpus suggests that a publishable review can legitimately frame these materials not as isolated additives but as complementary tools: sugarcane bagasse-derived products improve the cementitious matrix, and banana fibers improve fracture resistance. That pairing is the central message of this review.

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Appendix A. Mechanistic Notes on SCBA and Banana Fiber

At the particle level, SCBA contributes through two mechanisms. First, its fine particles fill voids between cement grains and aggregates, improving packing density. Second, its silica-rich fraction reacts with calcium hydroxide to form additional calcium silicate hydrate. The first mechanism is immediate and physical; the second is slower and chemical. This is why many studies report that the ash improves later-age strength more consistently than very early strength, unless the ash is extremely fine and partially calcined. The practical design message is that SCBA should be characterized by fineness, loss on ignition, and particle chemistry rather than by mass alone.

Banana fiber works primarily through bridging. Once a microcrack forms, the fiber transfers stress across the crack plane and slows crack opening. If the bond is adequate, the fiber can also pull out gradually, which absorbs energy and creates a more ductile response. If the bond is too weak, the fiber slips too early and contributes little. If the bond is too strong and the fiber is brittle, the fiber may snap rather than pull out. The ideal interfacial condition is therefore controlled pull-out, not total bond failure or total fiber rupture.

The hybrid response occurs when the ash strengthens the matrix enough to let the fiber develop its crack-bridging capacity without premature matrix crushing. A weak matrix cannot fully mobilize the fiber, while an overly brittle matrix can still fail before the fiber acts. This is why the best hybrid systems in the corpus are not the ones with the highest raw additive content, but the ones that keep the matrix dense, the fibers dispersed, and the fresh mixture workable enough to cast properly.

Appendix A.1 Mechanism-to-Property Map

Mechanism	Observed effect	Design implication
SCBA filler effect	Lower porosity and improved packing	Use fine grinding and controlled replacement
SCBA pozzolanic reaction	More C-S-H and denser ITZ	Allow sufficient curing age
Banana fiber crack bridging	Higher toughness and post-crack resistance	Keep fiber length and dosage moderate
Banana fiber pull-out	Energy absorption before failure	Favor treated fibers with controlled bond
Excess fiber clustering	Lower workability and voids	Use good dispersion and admixtures
High ash dilution	Strength loss at high dosage	Avoid indiscriminate high replacement
Hybrid synergy	Balanced strength and ductility	Optimize ash and fiber together
Poor processing	Large variability in results	Standardize treatment and characterization

Appendix B. Practical Mix-Design Workflow for a Future Study

Step 1 is material characterization. SCBA should be checked for fineness, carbon content, and basic chemistry. Banana fiber should be checked for diameter, length distribution, moisture content, and the effect of the chosen surface treatment. Without this stage, it is impossible to explain why one mix outperforms another.

Step 2 is trial mixing at the paste level. A few simple mortar trials can identify whether the ash causes unacceptable water demand or whether the fiber causes balling. At this stage, the mix designer should adjust superplasticizer dosage, pre-wetting of fiber, and mixing sequence before moving to full concrete.

Step 3 is mechanical screening. The first mechanical set should include compressive strength, splitting tensile strength, and flexural strength at 7 and 28 days. If the hybrid mix is intended for structural use, fracture energy and modulus of elasticity should be added so that the material can be compared against practical design thresholds.

Step 4 is durability screening. Water absorption, sorptivity, chloride ingress, and shrinkage should be used to judge whether the hybrid system remains viable after curing. A single strong 28-day result is not enough to justify field use if the mix is porous or unstable in aggressive environments.

Step 5 is optimization and validation. Once a promising mix is found, it should be repeated in a larger batch and validated by statistical analysis. The final report should include both performance benefits and the practical cost and carbon implications of adopting the material in real projects.

Appendix C. Expanded Engineering Interpretation

From the standpoint of structural engineering, SCBA is best viewed as a matrix modifier and banana fiber as a post-cracking reinforcer. The former helps the concrete behave less like a porous mineral paste and more like a densely packed composite. The latter helps the hardened material respond less like a brittle ceramic and more like a toughened composite. Their combined value is that they attack two different failure modes at once.

From the standpoint of construction practice, the most attractive applications are elements that benefit from controlled cracking rather than from very high compressive strength. Thin wall panels, repair mortars, lightweight blocks, and precast elements are natural candidates. These products also match the reality of agricultural-waste supply chains better than large mass-concrete pours, because quality control is easier in factory or semi-factory environments.

From the standpoint of sustainability, the best published results are only part of the story. A truly compelling hybrid material should reduce cement demand, recycle waste, maintain or improve usable strength, and remain economical enough to be adopted by contractors. That is why future work must integrate mechanical testing with life-cycle assessment, cost analysis, and field-scale demonstration.

Appendix D. Additional Literature Matrix and Review Takeaways

The main advantage of using a matrix rather than only narrative text is that it helps readers compare studies quickly. In the uploaded corpus, the strongest SCBA papers are the ones that carefully report processing conditions, replacement level, and curing age, while the strongest banana-fiber papers are the ones that report fiber length, treatment, and crack response. Hybrid studies are strongest when they report both the binder state and the fiber state together. This simple reporting rule is useful because it makes studies easier to reproduce.

An effective review paper should therefore tell the reader not only what happened but why it happened. If a paper reports higher strength after SCBA addition, the likely mechanism is matrix densification or pozzolanic activity. If a paper reports higher toughness after banana fiber addition, the likely mechanism is fiber bridging and pull-out. If a hybrid paper reports mixed or contradictory results, the likely cause is usually a trade-off between improved fracture resistance and reduced workability. These explanations are more useful than raw numbers alone because they help the next researcher choose variables intelligently.

Several of the uploaded studies also suggest that the best mix is not necessarily the one with the highest additive content. This is a recurring lesson in sustainable materials research: more waste is not always better. The useful range is usually narrow, and the optimum often shifts depending on particle size, treatment, and curing age. For this reason, a reviewer should emphasize optimum windows rather than maximum replacement levels.

Another key takeaway is that the natural-fiber literature is maturing from proof-of-concept toward design-oriented research. Early studies mostly asked whether banana fiber could work at all. Newer studies ask how it works, how much should be added, and how the matrix should be modified so the fibers can do their job. The same maturity trend is visible in the SCBA literature, where papers are moving from simple replacement experiments to microstructural analysis, machine-learning prediction, and multi-material systems.

Taken together, these trends support a clear publication message: the field is ready for a more systematic hybrid framework that integrates agricultural waste processing, cement chemistry, fiber mechanics, and durability engineering. The papers in the uploaded corpus are already close to that goal; the remaining step is to combine them in a coherent design methodology.

Appendix D.1. Representative Reporting Variables

Variable	Why it should be reported	Example	Effect on interpretation
SCBA fineness	Controls reactivity and packing	Ground 45 min	Explains later-age strength gain
SCBA calcination history	Affects carbon and silica state	Raw vs re-burned ash	Explains pozzolanic differences

Fiber length	Controls crack bridging	30 mm vs 50 mm	Affects toughness and workability
Fiber treatment	Controls bond and moisture uptake	Alkali-treated fiber	Affects durability
Replacement level	Determines dilution vs benefit	5-20% SCBA	Sets optimum window
Curing age	Shows early and later-age trends	7, 28, 90 days	Reveals long-term behavior
Microstructure	Validates mechanism	SEM, FTIR, TGA	Connects chemistry to performance
Durability tests	Judges field viability	Sorptivity, RCPT	Shows transport resistance

Appendix D.2. Paper-Writing Takeaways for a Student Review

If the goal is to publish a review paper quickly, the safest structure is to make SCBA the binder-focused subsection, banana fiber the reinforcement-focused subsection, and the hybrid system the final synthesis subsection. This mirrors how the literature itself is organized and helps the paper feel logical rather than stitched together.

The review should also avoid overclaiming. It is better to say that a certain mix improved strength under a controlled laboratory condition than to imply that it is automatically superior in every structural application. That wording keeps the paper credible and makes the conclusions harder to challenge during review.

Finally, the review should end with practical next steps rather than only general optimism. The next steps that reviewers and supervisors usually look for are standardized mix design, long-term durability, field-scale testing, and sustainability accounting. A review that clearly states those points reads as thoughtful and publishable.

Appendix E. Short Takeaway Notes for Quick Submission

The shortest credible summary of the whole corpus is this: processed sugarcane bagasse ash improves the matrix, banana fiber improves crack control, and the hybrid system works when the two are tuned to each other. This is the line that should appear in an abstract, conclusion, and presentation slides.

A review paper should also make the practical point that natural materials are not automatically sustainable if they are used inefficiently. Overly high dosages, poor processing, or ignored durability issues can offset the environmental benefit. Sustainability in this context comes from performance per unit waste, not from waste addition alone.

An editor or supervisor usually wants to see that the topic is more than a catalogue of papers. A stronger review turns the evidence into a design rule. In this topic, the design rule is that the ash is the matrix modifier and the fiber is the toughening phase.

Appendix E.1. One-Paragraph Design Rule

For a first-pass laboratory program, start with a moderate SCBA level, keep banana fiber dosage low, use a treated fiber if possible, and validate the resulting mix through compressive, tensile, flexural, and durability tests. If the mix becomes too stiff, reduce fiber content before abandoning the concept. If strength drops sharply, reduce ash dosage or improve ash processing before changing the fiber system. This sequence is simple, economical, and aligned with the trends observed across the uploaded papers.

Appendix E.2. Decision Tree for the Next Experiment

Question	Action
Does SCBA improve strength?	Check fineness, replacement level, and curing age.
Does banana fiber improve toughness?	Check treatment, length, and dispersion.
Does workability fall too much?	Reduce fiber content or add plasticizer.
Is durability adequate?	Run sorptivity, chloride, and shrinkage tests.
Does hybridization help?	Compare matrix-only, fiber-only, and combined mixes.

Appendix F. Closing Notes on Publication Quality

A review paper becomes publishable when it does more than summarize. It should classify the literature, reveal the dominant mechanisms, identify the design window, and state the next experiment with enough clarity that another researcher can reproduce it. The present topic satisfies that requirement because the uploaded papers naturally divide into matrix modification, fiber reinforcement, and hybrid synergy.

In final submission, the safest phrasing is not that the materials always improve concrete, but that they improve selected performance metrics under controlled processing conditions. That wording is both scientifically accurate and editor-friendly. It also leaves room for the future studies that are still needed.

Appendix F.1. Final Submission Checklist

1) Keep the title specific and sustainability-oriented.
2) State the SCBA and banana-fiber roles separately before discussing the hybrid system.
3) Include a table of representative studies and a second table of future research needs.
4) Use cautious conclusions and avoid absolute claims.
5) End with a practical recommendation for optimization, durability, and field validation.