Sundaresan Suresh Babu, Pitchaipillai Neelamegam, Elaiyawar Maheswari, Rajendran Karthick*

Department of Civil Engineering, SRMValliammai Engineering College, Kattankulathur, Chennai, 603203, Tamil Nadu, India

Scientific paper
ISSN 0351-9465, E-ISSN 2466-2585
https://doi.org/10.62638/ZasMat1375

Zastita Materijala 67 (3)
419 - 426 (2026)

Enhancement of concrete properties using banana fibers and banana leaf ash: A sustainable approach

ABSTRACT

The current study synthesizes current research on the incorporation of banana fibers and banana leaf ash (BLA) in concrete, focusing on their potential to replace conventional materials partially and enhance concrete environmental footprint.The banana leaf ash was substituted partially for cement at proportions of 5%, 10%, 15%, 20% and 25% respectively and also banana fibers were added in the concrete at proportions of 0.1%, 0.2%, 0.3%, 0.4% and 0.5% respectively. The optimised proportions of banana leaf ash and banana fiber were found out. The incorporation of BLAat an optimum percentage of 10% by weight of cement has enhanced15.5% compressive strength, 5.74% split tensile strength and reduction in rate of water absorption.The results highlighted that optimal proportions of banana fibers can significantly enhance the tensile properties of concrete, making it less prone to cracking and more durable under tensile load.
Keywords:*Sustainable concrete, Strength of concrete, Durability of concrete, Banana fibre, Banana leaf ash, Natural fibres, Eco-friendly construction.*

1. INTRODUCTION

Concrete remains the most ubiquitous material in construction, valued for its robustness, versatility, and cost-effectiveness. However, the environmental ramifications of traditional concrete production are substantial, contributing significantly to global CO_2 emissions due to the energy-intensive nature of cement manufacturing [1]. This has driven a surge of interest in sustainable construction practices aimed at reducing the environmental impact associated with construction materials.Many industrial wastes such as flyash[2], silicafume[3], paperwaste sludge[4-6],banana leaf ash [7], sugarcane bagasse ash [8], was utilised as supplementary cementitious material.Banana plants are abundant in tropical and subtropical regions, where the cultivation and processing of bananas generate substantial organic waste. Traditionally, these by-products have been viewed as a disposal challenge. Particularly when used as a partial replacement in mortars and conventional concrete, recent studies [9] have investigated the possibilities of using banana leaf ash (BLA) as a pozzolanic material.

Particularly when BLA is included up to a 10% replacement level, these trials have produced encouraging findings. This replacement not only improves some mechanical qualities but also supports sustainability by lowering cement use. Particularly in areas where agricultural waste management presents a difficulty, using BLA in concrete mixtures can be a reasonably affordable and environmentally friendly substitute. Likewise, studies on sugarcane bagasse ash (SCVA) used in self-compacting concrete (SCC) have shown that substituting 10% SCVA for cement can produce mechanical performance on par with control mixtures devoid of any ash [10]. Higher replacement levels like 40% tend to somewhat lower strength, although the values stay within reasonable bounds for structural application. Apart from mechanical performance, SCVA was shown to increase SCC durability by greatly lowering electrical conductivity and chloride ion penetration [11]. These advances help to reduce the risk of steel reinforcement corrosion, hence prolonging the service life of reinforced concrete constructions. The replacement of cement by BLA compared to control concrete, the optimum content of BLAC is found as 10% for the mechanical properties [12].However, recent studies have begun to explore their potential in concrete applications. The growing need for sustainable construction materials

*Corresponding author: Sundaresan Suresh Babu
E-mail: ssb.srmvec@gmail.com
Paper received: 16. 02. 2025.
Paper corrected: 02. 04. 2026.
Paper accepted: 10. 05.2026.

has led researchers to explore agricultural waste as an alternative to cement. One such material is banana leaf ash (BLA), which has gained attention due to its high silica (SiO_2) and calcium oxide (CaO) content, allowing it to act as a pozzolanic material when partially replacing cement [13].

Several studies have assessed the performance of BLA in concrete, indicating that incorporating up to 10% BLA as a replacement for Ordinary Portland Cement (OPC) improves compressive strength by refining the microstructure of concrete [14]. This enhancement is primarily due to the formation of additional CSH gel, which strengthens the cementitious matrix. However, increasing BLA content beyond 15% leads to a reduction in strength, attributed to higher porosity and decreased cement content [15]. For concrete structures subjected to acidic and sulfate-rich environments, durability is a crucial factor. Research findings suggest that BLA-enhanced concrete exhibits better resistance to acid and sulfate attacks compared to conventional concrete [16]. This improved durability is due to BLA's pore-filling ability, which reduces permeability and limits the intrusion of aggressive ions. The concrete mixes with 10–15% BLA demonstrate superior performance under acidic and sulfate conditions, as the matrix densification and formation of secondary CSH gel contribute to reduced deterioration [17]. These characteristics make BLA-modified concrete ideal for marine structures, sewage treatment plants, and industrial applications. The addition of BLA also influences workability and water absorption. Due to its high specific surface area, concrete containing BLA generally exhibits lower slump values, resulting in reduced workability.

However, once hardened, BLA-incorporated concrete displays lower water absorption, enhancing its impermeability and moisture resistance [18]. This property makes it a suitable material for hydraulic structures and environments exposed to high moisture levels. The cement industry significantly contributes to CO_2 emissions, necessitating the search for environmentally friendly alternatives. Studies have shown that replacing 10% OPC with BLA can lead to a 7–10% reduction in CO_2 emissions, supporting the development of sustainable construction materials [19]. Since BLA is an agricultural byproduct, its use in concrete helps reduce waste, support circular economy practices, and promote sustainable resource utilization. In the current research the banana leaf was utilised as partial replacement for cement. Additionally banana fibre with treated and without treatment is employed to the concrete.

2. RESEARCH GAPS AND FUTURE RECOMMENDATIONS

The optimal replacement level of Banana Leaf Ash (BLA) in concrete has been shown to vary across different studies, typically ranging from 5% to 25%. This variation suggests that further research is crucial to establish a universally accepted mix design tailored to the diverse requirements of both structural and non-structural concrete elements. While the incorporation of BLA and banana fibers into concrete has demonstrated promising improvements in mechanical properties, durability, and sustainability, several critical research gaps remain that hinder their full integration into construction practices. First, the effects of BLA and banana fiber in concrete need further investigation, particularly regarding the synergistic interactions between the two materials. Existing studies have mainly focused on individual applications, but a comprehensive understanding of how BLA and banana fiber combine to influence concrete strength, shrinkage characteristics, and toughness is lacking. It is essential to explore how these materials interact at the microstructural level, as their combined effects could lead to significant improvements in both fresh and hardened concrete properties. Additionally, the impact of varying BLA replacement levels on concrete long-term durability, including resistance to chemical attack, water absorption, and freeze-thaw cycles, requires more detailed study.

The optimization of mix designs considering local environmental conditions, material availability, and performance criteria is needed to ensure the best results for both residential and industrial applications. Furthermore, the economic feasibility of large-scale production and widespread use of BLA and banana fiber in concrete remains unclear. Research should focus on the scalability of these materials, evaluating the cost-effectiveness of their production processes, transportation, and incorporation into concrete production. The economic implications of using BLA and banana fiber in place of traditional supplementary cementitious materials, such as fly ash or slag, need to be thoroughly assessed to gauge their potential for large-scale implementation in the construction industry.Although BLA and banana fiber offer significant potential as sustainable construction materials, more comprehensive research is necessary to develop optimized mix designs, understand their synergistic effects, and evaluate their long-term performance and economic viability for both structural and non-structural concrete applications.

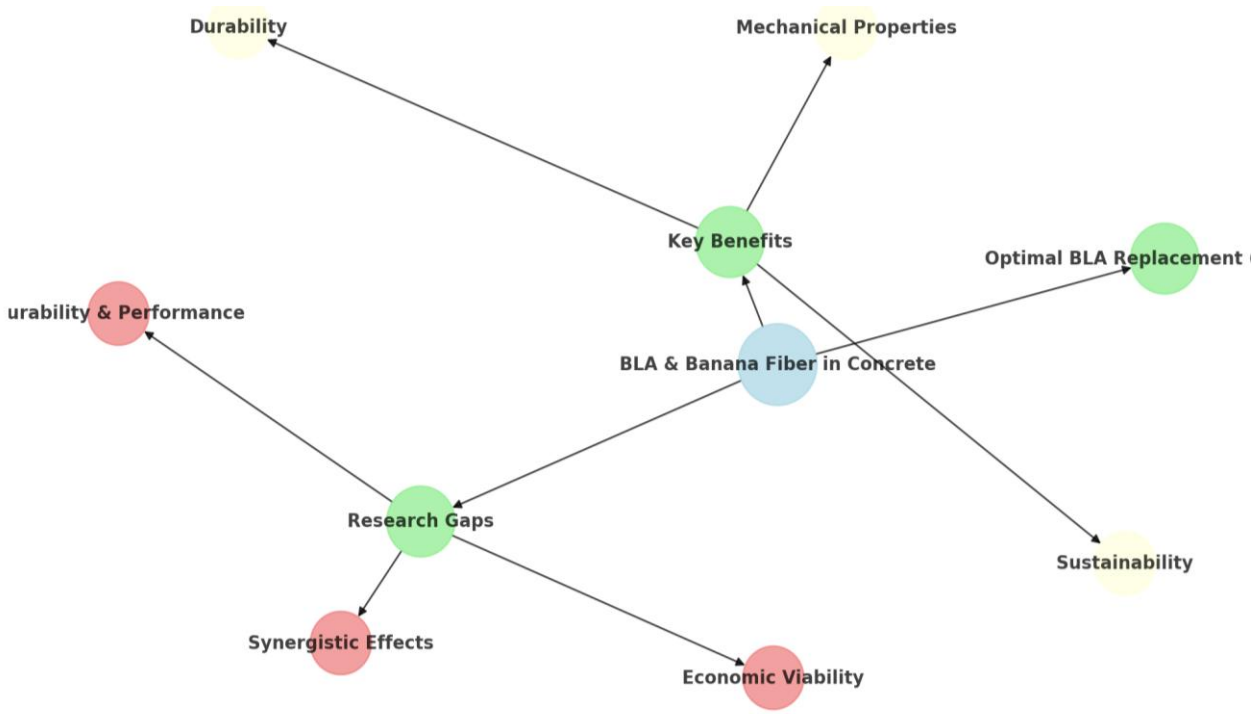

Figure 1. Integration of BLA and banana fibre in concrete

3. MATERIALS AND METHODS

3.1. Materials

Ordinary Portland Cement (OPC) conforming to standards was used for all concrete mixes. For fine aggregate, river sand of zone-II and 20mm size coarse aggregate was utilized. Banana leaves were collected, dried, and burnt in a controlled environment to produce ash. The ash was then ground to achieve a particle size similar to that of Portland cement. Fibers extracted from the pseudo-stem of the banana plant were cleaned, dried, and cut into lengths of 25-50 mm. A commercial superplasticizer (PCE) was used to enhance the workability of the concrete mix. The grade of concrete M30 was designed for concrete mix and its mix proportion is shown in Table 1.

Table.1. Concrete mix proportion for 1m^3

Mix Id	w/b	Banana leaf ash, (kg/m^3)	Cement, (kg/m^3)	FA, (kg/m^3)	CA, (kg/m^3)	SP, (%)	Water, (kg/m^3)
CC	0.45	0	365	675	1207	1.2	186
BLA05	0.45	18	347	675	1207	1.2	186
BLA10	0.45	37	329	675	1207	1.2	186
BLA15	0.45	55	310	675	1207	1.2	186
BLA20	0.45	73	292	675	1207	1.2	186
BLA25	0.45	91	274	675	1207	1.2	186

3.2. Preparation of banana leaf ash

In this study, banana leaves were sourced from local lands in erode, Tamilnadu. The leaves were meticulously gathered, air-dried for about 30 days to reduce moisture content. After drying it was then crushed and the leaves were subjected combustion in a muffle furnace at 600°C for 5 hours. The powdered ash is allowed to cool at room temperature and the sample is sieved through 90micronswhich is suitable for use as a supplementary cementitious material. The process involved in preparation of banana leaf ash is shown in the Figure 2. The natural fiber treatment process is shown in Figure 3.

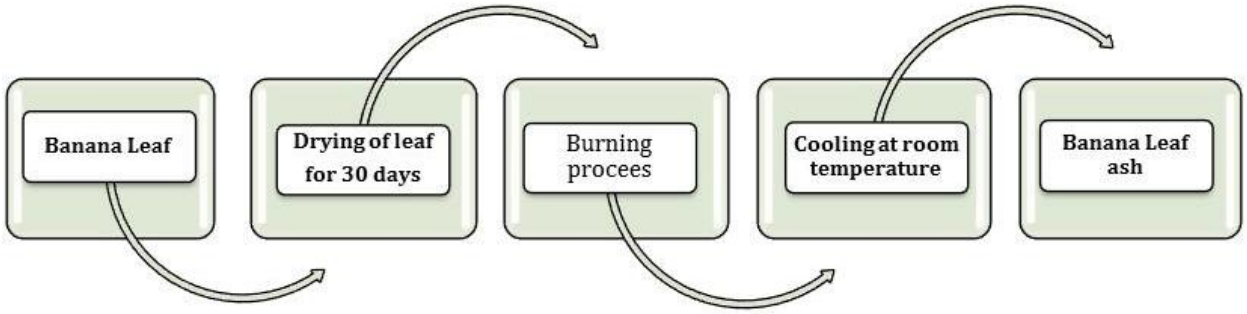

Figure 2. Stages in the processing of banana leaf ash

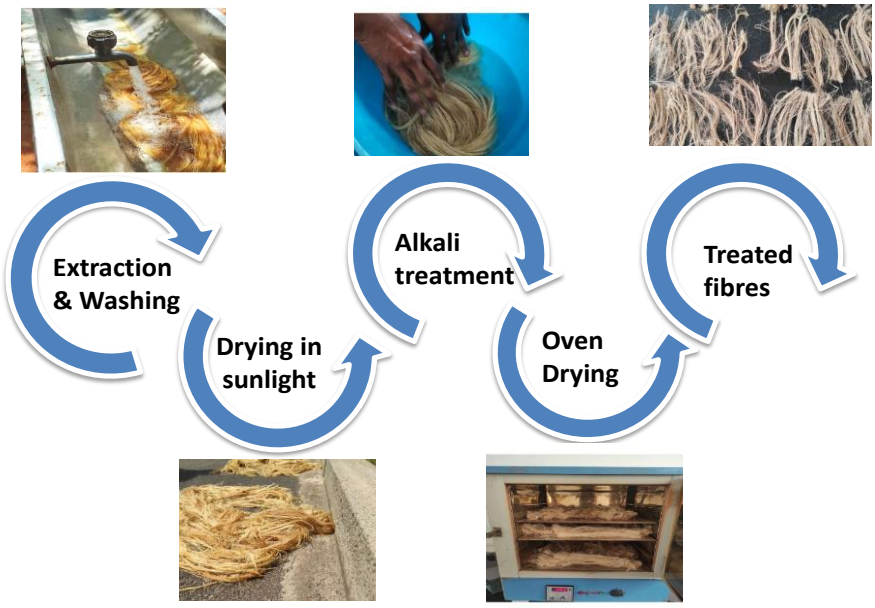

Figure 3. Banana Fiber Treatment process

3.3. Experimental programme

Workability of fresh Concrete was determined using Slump cone method immediately after mixing and the test was conducted by following IS 456:2009. Slump test was conducted on each mix with different cement to BLA ratio in order to understandthevaryingconsistencyoftheconcreteincorporatedwith banana leaf ash.The compressive strength of concrete cube of dimension 150x150x150mm was conducted at different curing periods which were 7, 28, 56 and 90 days. The evaluation was done as per the guidelines of IS 516:1959.Splitting tensile strength was conducted on cylinder of dimension 150 mm diameter × 300 mm height and tested as per IS 5816:1999. Flexural Strength was determined as per IS 516:1959 and tested on prism of dimension 100 mm × 100 mm × 500 mm. The rate of water absorption was measured in the cube sample of dimension 100x100x100mm and tested as per ASTM C642 standards. As per ASTM C1202 the concrete ability to resist the penetration of chloride ion penetration was tested on the cylinder sample of dimension 100 mm diameter × 50 mm thick were tested.

4. RESULTS AND DISCUSSION

4.1. Slump

The workability of the slump value of banana leaf ash incorporated in the concrete is shown in the figure 4. The reduction in workability percentage compared to control concrete is shown in figure 5. With the addition of BLA at an increment of 5%, 10%, 15%, 20% and 25% in concrete reduced the workability of the concrete. This may attributed to high water demand with addition of ash particles. Also the surface area is large for BLA particles, and requires additional water content during mixing process. Previous investigation [15,8] showed the same trend in reduction of workability with the addition of BLA in concrete due to their filling effect, and the irregular particle shape collectively contributed to resistance against flow.

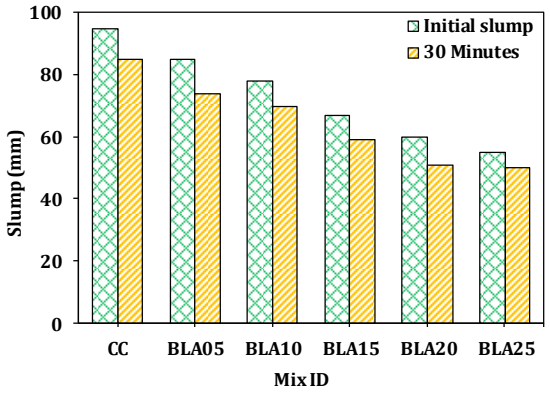

Figure 4.Slump value of BLA replacement

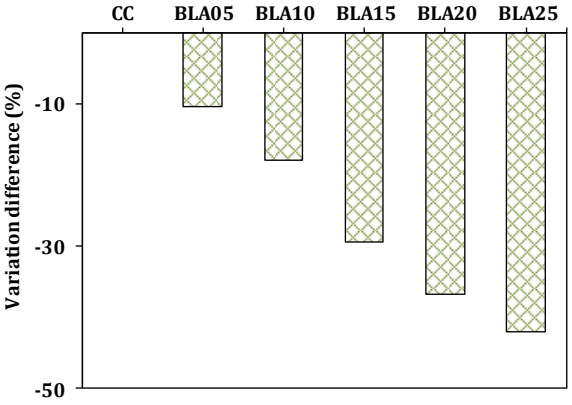

Figure 5.Slump variation of BLA concrete

4.2. Compressive strength

The compressive strength of specimen with varying percentage of BLA at various testing age is shown in figure 6. From the figure it is evident to know the influence of BLA in concrete and the strength factor related to compression. The BLA was added at 5%, 10%, 15%, 20% and 25% in concrete as partial replacement for cement. With the addition of BLA there is an increase in compressive strength of the concrete. With addition of BLAupto 10% enhance d the compressive strength when compared to control concrete. There is increase in strength of 15.5% with compressive strength of 37.7Mpa at 28 days.Due to the amorphous nature of BLA the pozzolanic reaction takes place, which facilitates the formation of additional calcium silicate hydrate gel (CSH), which is a main cause of strength in concrete.Beyond that percentage addition of BLA for partial replacement for cement the strength gets reduced compared to control concrete. There are various factors for the reduction in strength if the BLA is added beyond 10%.When replacing the cement by BLA at high percentage in concrete the BLAparticles tend to cause particle agglomeration due to the larger specific surface area of its particles. This agglomeration has an adverse effect on the structural integrity of the concrete [13]. Cement is the main source of primary hydration products and if the content is reduced by increasing the content of BLA. The main product for the initiation of pozzolanic reaction gets reduced with addition of higher percentage of banana leaf ash in concrete.From the test results the optimum percentage of BLA is identified as 10%, as percentages higher than this threshold result in a loss of compressive strength due to above mentioned reasons. These findings align with the study[19,21] on the use of banana leaf ash as a partial replacement for cement in eco-friendly concrete.

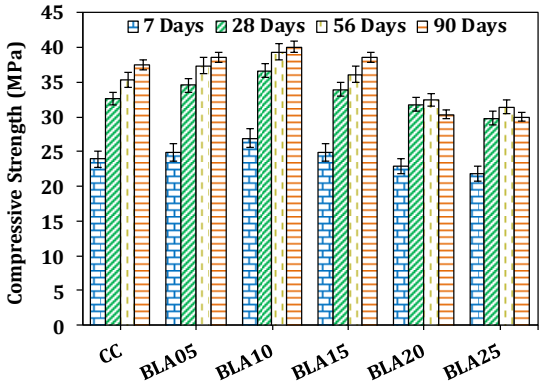

Figure 6. Compressive strength of BLA concrete at different curing period

4.3. Split tensile strength

Figure 7 illustrates the changes in split tensile strength as the concentration of BLA replacement varies in comparison with the control concrete at 7 and 28 days respectively. Over a period of 7 and 28 days, the concrete mixes with addition of BLA enhanced the split tensile strength by 1.59%, 5.49% at 5% replacement and 2.60%, 5.74% at 10% replacement. Beyond 10% addition the strength gets reduced as -0.75%, -19.20%, -25.19% with 15%, 20% and 25% at 28 days strength. However the increase in strength was insignificant with addition of 10% BLA in concrete.

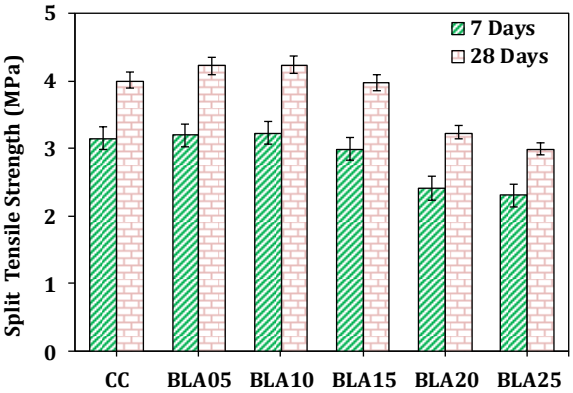

Figure 7. Split tensile strength of BLA concrete

4.4. Correlation between compressive strength and split tensile strength

The correlation between compressive and split tensile strength at 7 and 28 days is shown in figure 8. With high determination coefficients of R^2 = 0.9076 and 0.9453, the results show a significant positive linear association. With both experimental and analytical quantifications, the prediction is very accurate, as seen by the higher coefficients of determination.

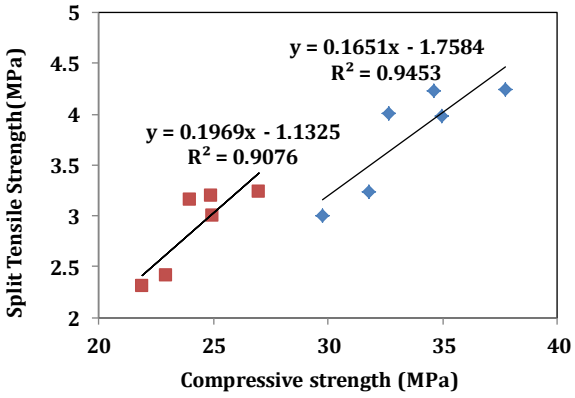

Figure8.Correlation between compressive and split tensile strength

4.5. Water absorption

Figure 9 shows the relationship between the water absorption of concrete and the replacement fraction of cement with ash from banana leaves. As the fraction of BLA replacement increases, the studies reveal that concrete absorbs less water.

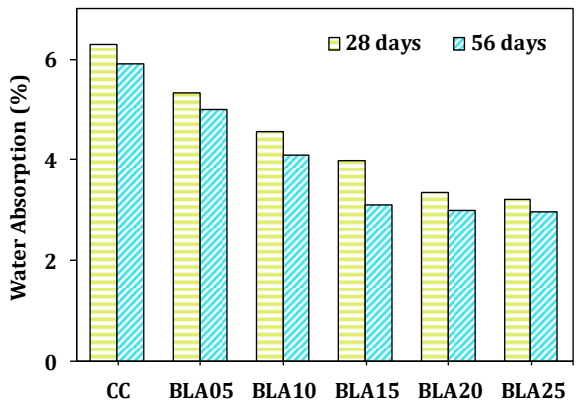

Fig. 9.Water absorption of BLA mix at 28 and 56 days

The micropore filling capabilities of banana leaf ash, which reduce water infiltration by filling up these pores within the concrete matrix, may be responsible for this good performance. The end result was longer-lasting concrete with enhanced resistance to water absorption. This development coincides with the findings [20,21], which show that mineral admixtures, such as BLA, enhance the water-repellent durability of concrete by refining the pores in its matrix.

5. CONCLUSION

The comprehensive experimental investigation presented in this manuscript evaluated the effects of banana leaf ash (BLA) and banana fibers on the mechanical properties of concrete. The study provided significant insights into the potential of these materials to enhance concrete performance while promoting sustainability in construction practices. The following conclusions can be drawn from the experiments:

- The workability of the concrete gets reduced with the addition of banana leaf ash at all percentage replacement levels.
- The compressive strength gets increased upto 15.5% with addition of 10% BLA in the concrete.
- Split tensile strength increased upto 5.74% at 10% addition of BLA, however the increase in strength was insignificant.
- The water absorption of the concrete with addition of BLA at all percentage reduced the rate of water absorption.
- The optimum percentage of banana leaf ash as partial replacement for cement was found to be 10% in all aspects.
- Further studies are recommended to explore the long-term durability of concrete incorporating BLA and banana fibers under various environmental conditions. Additionally, scaling up the production and use of these materials in industrial applications would provide valuable data on their performance in real-world settings

7. PRACTICAL IMPLEMENTATION

An eco-friendly and long-term solution for building infrastructure could be to utilize banana fiber as an additive and banana leaf ash in place of certain cement when making hard pavements. The addition of banana fiber to concrete boosts its tensile strength and crack resistance, making the pavement more durable and capable of withstanding heavy loads. Partially replacing some of the cement with banana leaf ash improves the concrete pozzolanic properties, which in turn improves its long-term performance, and reduces the environmental impact of cement production. An innovative and environmentally friendly approach to pavement construction has been implemented by reducing the thickness of the stiff pavement using concrete fiber and banana leaf ash.

8. REFERENCES

[1] S. Sakthivel, R. Parameswari, M. Gomathi(2019) Experimental investigation on concrete with banana fiber and partial replacement of cement by banana leaf ash,Int. Res. J. Eng. Technol. 6 (3), 3914–3919. doi?

[2] R.Prakash, S. Srividhya, S. Sivakumar, P. Neelamegam(2024) "Experimental Study on Mechanical and Durability Behaviour of a Sustainable Masonry Block Incorporating Agricultural and Industrial Wastes." Indian Journal of Science and Technology, 17(9), 830-840.

[3] D.Vaičiukyniene, V.Vaitkevičius, Ar. Kantautas, V.Sasnauskas (2012) Utilization of by-product waste silica in concrete-based materials." Materials Research 15 , 561-567.

[4] S.Srividhya, R. Vidjeapriya, M. Neelamegam (2021) Enhancing the performance of hyposludge concrete beams using basalt fiber and latex under cyclic loading. Computers and Concrete, 28(1), 93-105.

[5] S.Sundaresan, V. Ramamurthy, N. Meyappan (2021) Improving mechanical and durability properties of hypo sludge concrete with basalt fibres and SBR latex. Advances in concrete construction, 12(4), 327-337.

[6] S.Srividhya, R. Vidjeapriya(2023) Influence of basalt fibres on the flexural performance of hypo sludge reinforced concrete beams with SBR latex. Structural Engineeringand Mechanics, An Int'l Journal, 87(6), 615-624.

[7] J.Tavares, L. Lucena, G. Henriques, R. Ferreira, M. dos Anjos (2022). Use of banana leaf ash as partial replacement of Portland cement in eco-friendly concretes. Construction and Building Materials, 346, 128467.

[8] H.Diniz, M. dos Anjos, A. Rocha, R.Ferreira (2022) Effects of the use of agricultural ashes, metakaolin and hydrated-lime on the behavior of self-compacting concretes.Construction and Building Materials, 319, 126087.

[9] N. J. Meraz, M.Islam, E. Farsangi, M. Mehedi, S. Arafin, K.Shrestha. (2023) Eco-friendly and cost-effective self-compacting concrete using waste banana leaf ash. Journal of Building Engineering, 64, 105581.

[10] J.Prusty, S.K. Patro, S. Basarkar (2016). Concrete using agro-waste as fine aggregate for sustainable built environment–A review.International Journal of Sustainable Built Environment, 5(2), 312-333.

[11] G.Sua-Iam, N.Makul (2017) Effect of incinerated sugarcane filter cake on the properties of self-compacting concrete. Construction and Building Materials, 130, 32-40.

[12] A.Momshad, M. Islam, S. Datta, M. Sobuz, R.Aayaz, M. Kabbo, M. Khan (2025) Assessing the engineering properties and environmental impact with explainable machine learning analysis of sustainable concrete utilizing waste banana leaf ash as a partial cement replacement. Cleaner Engineering and Technology, 24, 100886.

[13] T.Blankendaal, P. Schuur, H. Voordijk(2014) Reducing the environmental impact of concrete and asphalt: A scenario approach. J. Clean. Prod. 66, 27–36.

[14] J.Tavares, L. Lucena, G. Henriques, R.L> Ferreira, M. dos Anjos (2022) Use of banana leaf ash as partial replacement of Portland cement in eco-friendly concretes.Construction and Building Materials, 346, 128467. https://doi.org/10.1016/j.conbuildmat.2022.128467.

[15] K.Madhu, P. Prasad, P.Eswanth (2019). Mechanical and durability properties of concrete by partial replacement of cement with banana leaves ash. International Journal of Innovative Technology and Exploring Engineering, 12, 197–202.

[16] R.Kanning, K. Portella, M.Bragança, M. Bonato, J.Dos Santos (2014). Banana leaves ashes as pozzolan for concrete and mortar of Portland cement. Construction and Building Materials, 54, 460–465. https://doi.org/10.1016/j.conbuildmat.2013.12.030.

[17] I.Ndubuisi (2020). Potentials of banana leaf ash as admixture in the production of concrete. Journal of Sustainable Construction Materials and Technologies, 4(2), 90–100.

[18] N.Gangadhar, P. Krishna, C. Kumar, R. Madhuri, A.Parthiban. (2020). Fiber-reinforced pervious concrete using banana fiber.International Journal of Engineering Research & Technology, 7(2), 66–67.

[19] M.Amin, A. Zeyad, B. Tayeh, I.SaadAgwa (2021). Effects of nano cotton stalk and palm leaf ashes on ultrahigh-performance concrete properties incorporating recycled concrete aggregates. Construction and Building Materials, 302, 124196. https://doi.org/10.1016/j.conbuildmat.2021.124196

[20] N.Bheel, B. Mohammed, M. Ahmed Ali, N. Shafiq, E. Tag-eldin, M. Ahmad (2024). Synergistic effect of recycling waste coconut shell ash, metakaolin, and calcined clay as supplementary cementitious material on hardened properties and embodied carbon of high-strength concrete. Case Studies in Construction Materials, 20, e02980. https://doi.org/10.1016/j.cscm.2024.e02980.

[21] S.A. Zareei, F. Ameri, N. Bahrami (2018) Microstructure, strength, and durability of eco-friendly concretes containing sugarcane bagasse ash, Construct. Build. Mater.184 , 258–268, https://doi.org/10.1016/j.conbuildmat.2018.06.153.

[22] H.H.M. Darweesh (2023) Effect of banana leaf ash as a sustainable material on the hydration of Portland cement pastes 4 (1) ,1–11.

[23] H.T. Le, H.M. Ludwig (2016) Effect of rice husk ash and other mineral admixtures on properties of self-compacting high performance concrete, Mater. Des. 89, 156–166, https://doi.org/10.1016/j.matdes.2015.09.120.

IZVOD

UNAPREĐENJE SVOJSTVA BETONA KORIŠĆENJEM VLAKANA BANANA I PEPELA LISTA BANANA: ODRŽIVI PRISTUP

Sadašnjastudijasintetišetrenutnaistraživanja o ugrađivanjuvlakanabananeipepelaodlistabanane (BLA) u beton, fokusirajući se nanjihovpotencijal da delimično zamene konvencionalne materijale i poboljšaju uticaj betona na životnu sredinu. Pepeo od listabanane je delimično zamenjen cementom u proporcijama od 5%, 10%, 15%, 20% i 25% respektivno, a takođe su dodata vlakna banane u betonu u proporcijama od 0,1%, 0,2%, 0,3%, 0,4% i 0,5% respektivno. Otkrivene su optimalne proporcije pepela od lista banane i vlakana banane. Ugradnja BLA u optimalnom procentu od 10% težine cementa je povećala čvrstoću na pritisak od 15,5%, zateznu čvrstoću 5,74% i smanjenje stope upijanja vode. Rezultati su naglasili da optimalne proporcije v*lakana banane mogu značajno poboljšati zatezna svojstva betona, čineći ga manje sklonim pucanju i izdržljivijim pod zateznim opterećenjem.*

Ključnereči: *Održivi beton, čvrstoća betona, trajnost betona, banana vlakna, pepeo od lista banane, prirodna vlakna, ekološka konstrukcija.*

Naučni rad
Rad primljen: 16.02.2025.
Rad korigovan: 02.04.2026.
Rad prihvaćen: 10.05.2026.