

Experimental Investigations on Sustainable Concrete with Bamboo Flakes AshManu S E¹, Dasarathy A K²¹Research Scholar, ²Professor¹Research Scholar, Department of Civil Engineering, JAIN (Deemed-to-be University), Bengaluru- 562112, Karnataka, India²Professor & Head, Department of Civil Engineering, JAIN (Deemed-to-be University), Bengaluru- 562112, Karnataka, India

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Abstract

Concrete remains one of the most extensively utilized construction materials worldwide; however, its production demands large amounts of natural resources, with cement manufacturing being the primary contributor to CO₂ emissions. The environmental footprint of cement is considerable, as it accounts for nearly 7% of global greenhouse gas emissions, intensifying climate change concerns. In response, the construction industry has increasingly turned to sustainable alternatives, particularly the incorporation of Supplementary Cementitious Materials (SCMs), to reduce dependency on conventional cement.

In this context, bamboo flakes—a type of agricultural by-product—were collected, sun-dried, and subsequently subjected to controlled combustion in a specially designed barrel to obtain Bamboo Flake Ash (BFA). Chemical analysis revealed that BFA is rich in silica (SiO₂), alumina (Al₂O₃), and ferric oxide (Fe₂O₃). According to ASTM C618:2003 specifications, a material qualifies as pozzolanic when the combined proportion of these oxides exceeds 70%. BFA exhibited a combined content of 80.02%, confirming its strong pozzolanic reactivity. For experimental investigation, cement was partially substituted with BFA at replacement levels of 5%, 10%, and 15% by weight. Compressive strength testing was performed after 7, 14, and 28 days of curing, while split tensile strength was assessed at the optimal mix corresponding to the 28-day strength achieved with 5% BFA. Durability studies further showed that BFA concrete, particularly at 5% replacement, absorbed less water compared to control specimens. Although several SCMs have been explored globally, the application of Bamboo Flake Ash in cementitious composites offers a novel and sustainable approach to concrete technology.

Keywords—Sustainable; Bamboo; Bamboo flakes ash (BFA); Pozzolanic; SCM.**Declaration:** Authors declare that they have no known competing interests or any specific grant from funding agencies that could have appeared to influence the work reported in this paper.**1. Introduction**

The use of Supplementary Cementitious Materials (SCMs) is steadily rising in the concrete industry as part of the shift toward high-performance, low-carbon construction. When combined with Portland cement, SCMs enhance the durability and long-term compressive strength of concrete. Commonly used SCMs include silica fume, pulverized fly ash (PFA), ground granulated blast-furnace slag (GGBS), and metakaolin (MK) Liu[9].

In recent years, the demand for civil construction has significantly increased, making cement one of the most produced and widely consumed materials globally. However, its manufacturing process generates substantial waste, both from raw material extraction and industrial operations. Notably, the calcination phase requires extremely high temperatures, making cement production accountable for approximately 7% of global carbon dioxide (CO₂) emissions Silva[10].

The incorporation of Bamboo Leaf Ash (BLA) notably enhances concrete performance, with a reported increase of up to 18% in 28-day compressive strength and a reduction of up to 71.2% in non-steady state chloride penetration. Overall, BLA produced at 600 °C significantly improves both the mechanical and durability properties of concrete, demonstrating its potential as a viable supplementary cementitious material derived from agro-waste Junior[11].

Global cement production reached an estimated four billion tons in 2024, a significant increase from 1.39 billion tons in 1995. This sharp rise reflects the substantial growth of the construction industry over the past few decades. In 2024, India ranked as the second-largest cement producer, with an output of 450 million metric tons. As expected, companies from China and India dominate the global cement industry in terms of revenue, reflecting their significant roles in production and market presence[12].

Cement production involves heating a blend of minerals to temperatures exceeding 1400°C in a kiln, a process that consumes a tremendous amount of energy. As a result, cement manufacturing is one of the major contributors to global greenhouse gas emissions. Over the decades, carbon dioxide emissions from this sector have steadily increased, reaching approximately 1.57 billion metric tons in 2023[12].

Materials and Methods

The research was structured into three distinct phases. Initially, the focus was on producing Bamboo Flakes Ash (BFA), followed by comprehensive characterization of the ashes to assess their mineralogical, physical, chemical, and pozzolanic attributes. Subsequently, the second phase involved scrutinizing the hydration process of cement partially substituted with bamboo thatch ash through paste production. Finally, the third phase entailed fabricating mortars with partial cement replacement using bamboo ash, which were then evaluated in both fresh and hardened states.

MATERIALS**Portland Cement**

The fineness of cement important factor that affects the rate of hydration, strength gain, water content, and the setting time of the cement. The cement's specific gravity was determined according to the This specific gravity of Portland cement is about 3.15 and can be measured by using the Le-Chatelier Specific gravity flask or specific gravity bottle. As kerosene was not available we have used diesel in place of it.

Fine Aggregate

Fine aggregate is a granular material of size less than 4.75mm. Sieve analysis for fine aggregate test help to determine the fineness modulus and grain size distribution (grading) of fine aggregates. The grading of fine aggregate should be as per the specified limit mentioned in Table 4 of IS: 383. The specific gravity of fine aggregate is determined using Pycnometer and it is 2.65g/cm³. As M-sand used in the test and the value of water absorption was more and it was 8.6%.

Coarse Aggregate

The Fineness modulus of coarse aggregates represents the average size of the particles in the coarse aggregate by an index number. The Fineness modulus of coarse aggregate was found that 6.98. The specific gravity test was conducted on coarse aggregate and it was found that 2.7. Water absorption of coarse aggregate was 0.8%.

Bamboo Flakes Ash

Bamboo flake is a sustainable and renewable resource, as bamboo is a fast-growing grass that can be harvested and regenerated in as little as 3-5 years. Bamboo also has a low environmental impact compared to other crops, as it requires less water and pesticides. Bamboo flakes are defined as the extruded waste parts of bamboo culms while making bamboo products such as mats, trays, and many more. Mainly they are generated from the bamboo processing industry. Bamboo flake can be used as a natural raw material in a variety of applications, such as in the production of bamboo-based products, biofuels, and as soil amendments. In addition, bamboo flakes can also be used in animal feed as a source of fiber and protein. Bamboo flake is also used in the paper and pulp industry, as it can be used to make high-quality paper products.

In this research, the Bamboo flakes were collected from the local street of KR market, Bengaluru which is shown in figure below. The process of ash preparation, storage, sieving, and chemical testing was done. Apart from this, we collected 25kg of bamboo flakes which after burning came out as 1.5kg ashes.

In this paper, It was used bamboo flakes by burning them using a burn barrel and making their ash. After that sieve it through a 90-micron sieve as specified in IS Code book. Thus the ash produced was used to replace cement partially.



Fig.2.1. Bamboo flakes, K.R Market

Fig.2.2. Burning of bamboo flakes at FCRC

Fig. 2.3. Bamboo flakes

The fineness of bamboo leaf ash is a measure of bamboo leaf ash particle size and is denoted in terms of the specific surface area of the ash. The fineness of BFA is responsible for the rate of hydration and rate of evolution of heat and hence on the rate of gain of strength. The finer the grains the more is the surface area and the faster the development of strength. The Test is done by sieving bamboo leaf ash samples through a standard IS sieve. The weight cement particle whose size is from 45 microns to 90 microns is determined and the percentage of the retained particle is calculated. This is known as the Fineness of bamboo leaves ash.

Fig. 2.4. Fineness test of BFA using 90µ IS Sieve

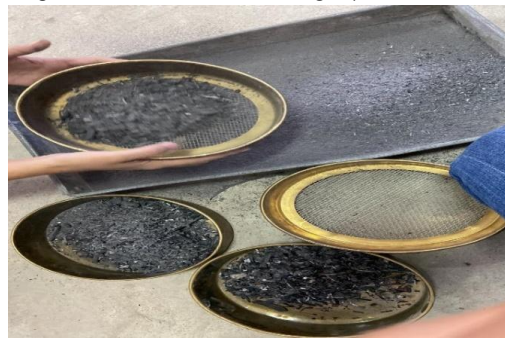


Table 2.1: Fineness Test of Cement

Sl.No.	Weight of sample taken W (in g.)	Weight of residue (R) (g)	%age of residue =R/W*100%
1.	100	1.2	1.2%

Table 2.2:

Sl.No	Quantity of water added (ml)	Penetration of plunger (From Bottom) mm
1.	104ml (26%)	12
2.	108ml (27%)	10
3.	112ml (28%)	7

Consistency Test

Table 2.3: Initial Setting Time

Initial setting time = 55 minutes and Final setting time = 490 minutes

Time in min	0	10	20	30	40	50
Depth of Penetration in mm	0	0	0	0	2	5

Table 2.4: Sieve Analysis Fine Aggregates

Weight of fine aggregate taken (Wf): 3Kg					
Sl.No.	Sieve Size	Weight retained (in Kg)	%age retained = (C3*100%)/Wf	Cumulative %age retained	Percentage passed (100-C5)
C1	C2	C3	C4	C5	C6
1	4.75 mm	0	0	0	100
2	2.36 mm	0	0	0	100
3	1.18 mm	185	18.5	18.5	81.5
4	600 micron	160	16	34.5	65.5
5	300 micron	290	29	63.5	36.5
6	150 micron	250	25	88.5	11.5
7	75 micron	90	9	97.5	2.5
8	Pan	25	2.5	100	0
Sum of Cumulative % retained(exclude pan) ΣC5				302.5	
Fineness Modulus = ΣC5/100				3.025	
Zone to which fine aggregate belongs:				Zone-II	

Table 2.5: Sieve Analysis of 20mm downsize Coarse Aggregates

Chemical Composition of OPC and BFA

Weight of fine aggregate taken (Wf): 3Kg					
Sl.No.	Sieve Size	Weight retained (in Kg)	%age retained = (C3*100%)/Wf	Cumulative %age retained	Percentage passed (100-C5)
C1	C2	C3	C4	C5	C6
1	20 mm	0	0	0	100
2	10 mm	2.96	98.67	98.67	0.013
3	4.75 mm	0.040	0.013	100	0
4	Pan	0	0	0	0
Sum of Cumulative % retained(exclude pan) ΣC5				198.67	
Fineness Modulus = ΣC5/100+5				6.98	

Bamboo Flake ash (BFA) is primarily composed of silica, alumina, iron, and potassium with small amounts of calcium and magnesium. It contains some trace elements which include Na₂O, P₂O₅ and Mn₂O₃. The source and species of bamboo flakes control the chemical composition of bamboo flake ash.

Table 2.6: Chemical Composition of OPC and BFA

Physical Properties of Superplasticizer

The Physical properties of BUILDPLAST-SP are given below:

System	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	N ₂ O	TiO ₂	SO ₃	IR	LOI
OPC	21.40	5.03	4.40	61.14	1.35	0.48	0.24	-	2.53	1.65	1.29
BFA	66.10	6.02	3.21	7.29	2.28	-	-	-	8.84	-	8.84

Table 2.7: Physical properties of Superplasticizer

Name	BUILDPLAST-SP
Color	Dark Brown
Standard	Conforming to IS:9103-1999
State	Liquid
SP.Gravity	1.15-1.17
PH value	6-7

Experimental Procedure:

In this research, total number of three cubes was cast for each of ordinary Portland cement as a control mix and for each of replacement by BFA. Therefore, for each batch, total numbers of 9 cubes were cast and cylinder were casted for optimum percentage of BFA. For compressive strength, 150mm*150mm*150mm size cubes were cast and for split tensile strength 100mm*200mm size cylinder was cast and three specimens were tested for each age in a particular mix (i.e. tested at 7, 14, and 28 days respectively). All freshly cast specimens were left in the molds for 24 hours before being molded and then submerged into water for curing until it is time to be tested.

A total of 36 cubes and 3 cylinders is cast for the optimum percentage of BFA and along with this 1 cube is cast for the water absorption test.

Table 2.8: Number of cubes and cylinders

Curing age (Days)	BFA	0%	5%	10%	15%	5% BFA cylinder
	OPC	100%	95%	90%	85%	95%
7	1:1.64:3.04	3	3	3	3	1
14	1:1.64:3.04	3	3	3	3	1
28	1:1.64:3.04	3	3	3	3	1
Total	1:1.64:3.04	9	9	9	9	3

Casting of cubes and cylinders

In this research, a total of 36 cubes were with 0%, 5%, 10%, & 15% replacement of cement by using BFA, and the cylinder was cast based upon optimum percentage i.e. 5% BFA where we got maximum strength for concrete cubes.

Curing of cubes and cylinders

As we know freshly casted cubes do not have complete hydration so it is cured in order to required amount of moisture to complete the hydration process and hence help to attain maximum strength at 28 days. During this research, all the cubes cast were cured inside a water tank for 7 days, 14 days, & 28 days.

2. Results and Discussion

The average compressive strength for conventional concrete cubes and BFA-based concrete cubes is given below:

The graph for the strength comparison of conventional concrete cube and BFA is given below. The graph shows that the 5% replacement of Bamboo flake ash gives optimum strength and goes on decreasing with an increase in BFA percentages.

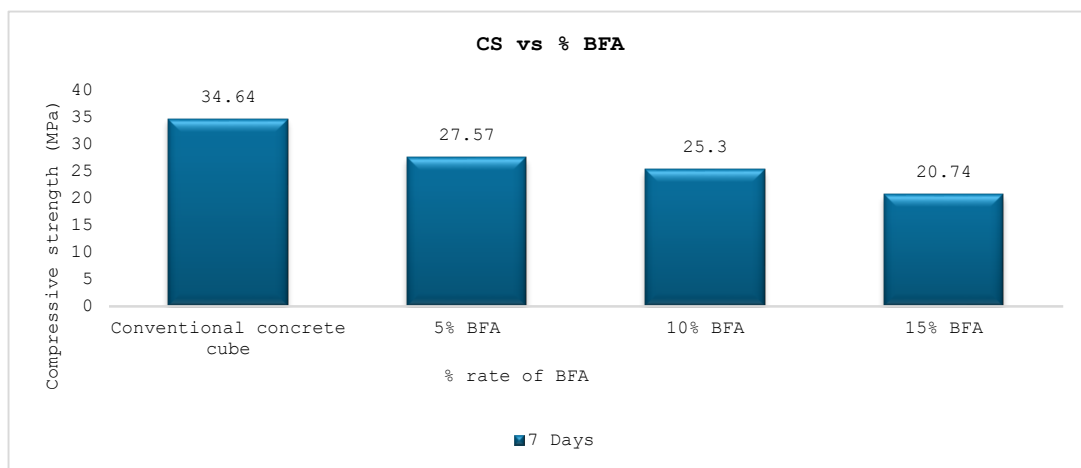
Table 3.1: 7 Days Strength of Conventional Concrete and BFA-based concrete cube

Sl.No	Compressive Strength	Conventional Cube (N/mm ²)	BFA 5%	BFA 10%	BFA 15%
1	7 days	34.64	27.57	25.3	20.74

Fig.4.1: 7day Compressive strength of cubes for varying BFA%

Sl.No	Compressive Strength	Conventional Cube (N/mm ²)	BFA 5%	BFA 10%	BFA 15%
1	14 days	42.28	35.68	33.1	27.53

Table 3.2: 14 Days Strength of Conventional Concrete and BFA-based concrete cube



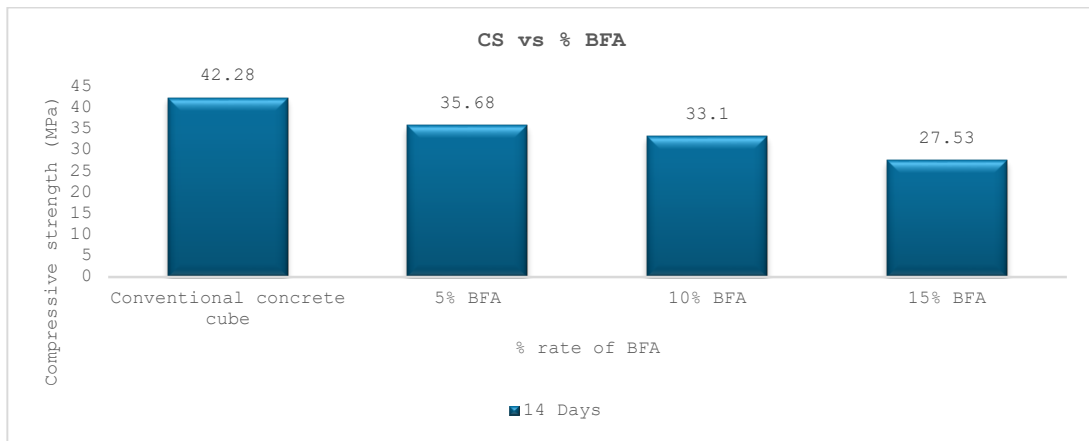


Fig.4.2: 14 day Compressive strength of cubes for varying BFA%

Sl.No	Compressive Strength	Conventional Cube (N/mm ²)	BFA 5%	BFA 10%	BFA 15%
1	28 days	44.05	39.03	35.8	30.7

Table 3.3: 28 Days Strength of Conventional Concrete and BFA-based concrete cube

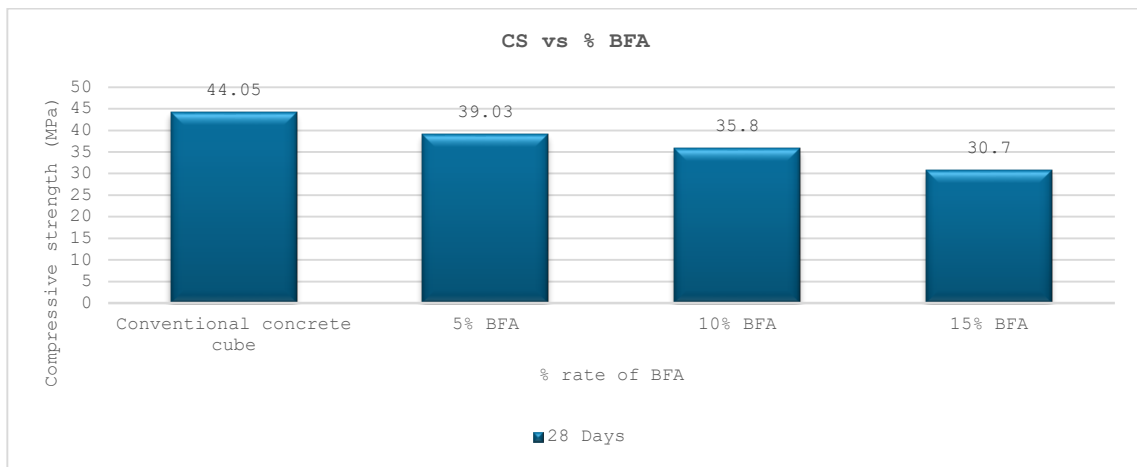


Fig.4.3: 28 day Compressive strength of cubes for varying BFA%

The above graph shows that the change in compressive strength of normal concrete is more as compared to various percentages replaced which are 0%, 5%, 10%, and 15% BFA. The optimum strength is shown by the 5% replacement as compared to the other % replacement.

Table 3.4: Split Tensile Strength of Conventional Concrete cylinder and optimum % of BFA-based concrete cylinder

Sl. No	Split Tensile Strength	Conventional Cylinder N/mm ²	BFA 5% N/mm ²
1	7 days	2.15	1.8
2	14 days	2.6	2.35
3	28 days	2.9	2.67

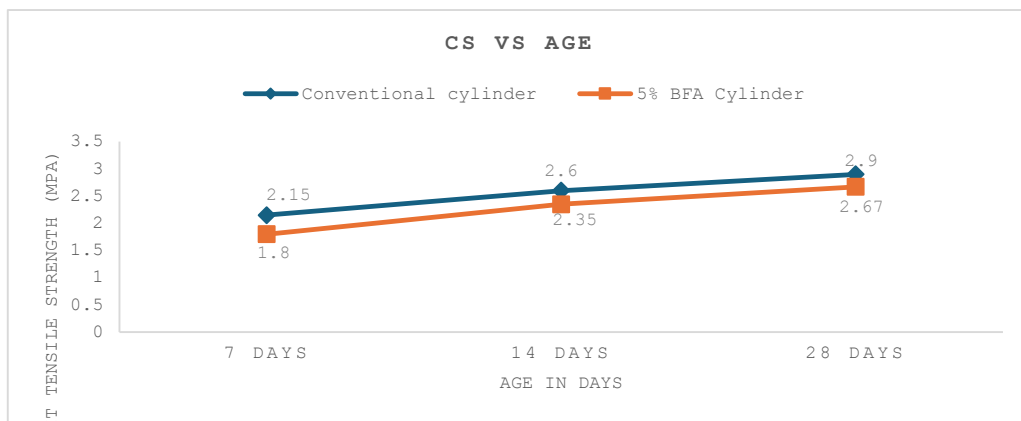


Fig.4.4: Split tensile strength of cylinder for 5% BFA

Table 3.5: Water absorption of conventional cube and 5% BFA

Mix	Dry weight (Kg) W1	Weight of Specimen after immersion in water (Kg) W2	% Water absorption
Conventional	7.753	8.141	5 %
5% BFA	7.957	8.305	4.37 %

3. Conclusion

The incorporation of Bamboo Flakes Ash (BFA) as a partial cement replacement significantly influenced the fresh, mechanical, and durability properties of concrete.

The workability of the concrete mixes was observed to decrease progressively with increasing BFA content. This reduction is attributed to the high specific surface area and porous nature of BFA particles, which demand more water for lubrication during mixing. Similar behavior is commonly reported with other pozzolanic materials such as rice husk ash and silica fume, where the fineness and angularity of the particles reduce the fluidity of the mix. This suggests that BFA-based mixes can be optimized for practical applications without compromising fresh concrete properties.

Among all mixes, the 5% BFA replacement exhibited the optimum compressive strength, achieving 27.57 MPa, 35.68 MPa, and 39.03 MPa at 7, 14, and 28 days of curing, respectively. The initial increase in strength at this replacement level can be explained by the pozzolanic reaction of BFA with calcium hydroxide (Ca(OH)₂) liberated during cement hydration. This secondary reaction forms additional calcium silicate hydrate (C-S-H), which is primarily responsible for strength development in concrete. Beyond 5% replacement, the dilution effect tends to dominate, as excessive cement replacement reduces the availability of calcium hydroxide, slowing down hydration and strength gain. Thus, 5% BFA is identified as an optimum balance point where the pozzolanic contribution outweighs dilution effects.

A similar trend was observed in the split tensile strength results, with 5% BFA yielding 1.80 MPa, 2.35 MPa, and 2.67 MPa at 7, 14, and 28 days, respectively. This improvement can be linked to the densification of the microstructure due to additional C-S-H formation, which enhances the bond between aggregate and cement paste. Since tensile strength is more sensitive to microstructural discontinuities and voids than compressive strength, the role of BFA in refining pore structure and improving the interfacial transition zone (ITZ) becomes critical in achieving better tensile properties.

Durability assessment revealed that BFA-based concrete exhibited lower water absorption compared to conventional concrete. The presence of BFA leads to pore refinement and a denser matrix, reducing the connectivity of capillary pores and limiting the ingress of water. Lower permeability is highly advantageous as it enhances resistance to deleterious agents such as chlorides, sulfates, and CO₂, thereby improving long-term durability. This aligns with the general benefits of pozzolanic materials in concrete technology.

First, it utilizes an agricultural waste product that otherwise contributes to environmental pollution through open burning or land disposal. Second, the partial replacement of cement directly reduces CO₂ emissions associated with cement production, which is one of the most energy-intensive and carbon-intensive industries. The widespread availability of bamboo in Asian countries such as India, China, and Nepal ensures that BFA can be locally sourced, minimizing transportation costs and promoting circular economy practices.

The optimum 5% replacement strikes a balance between sustainability and performance, ensuring that concrete meets structural requirements while reducing its environmental footprint.

References

- [1] S.O. Odeyemi, O.D. Atoyebi, O.S. Kegbeyale, M.A. Anifowose, O.T. Odeyemi, A. G. Adeniyi, O.A. Orisadare, "Mechanical properties and microstructure of High-Performance Concrete with bamboo leaf ash as additive", *Cleaner Engineering and Technology* 6 (2022) 100352.
- [2] Miss. Sakshi A. Zambre, Prof. G.D. Dhavale, Asst. Prof. V.A. Kalmegh, "Experimental Investigation On Concrete Using Bamboo Leaf Ash And Pawpaw Leaf Ash", *International Research Journal of Modernization in Engineering Technology and Science*, e-ISSN: 2582-5208, Volume: 04/Issue: 04/April-2022.
- [3] Gashaw Abebaw, Bahiru Bewket, and Shumet Getahun, "Experimental Investigation on Effect of Partial Replacement of Cement with Bamboo Leaf Ash on Concrete Property", *Hindawi Advances in Civil Engineering* Volume 2021, Article ID 6468444.
- [4] Cecielle N. Dacuan, Virgilio Y. Abellana, Hana Astrid R. Canseco, "Assessment and Evaluation of Blended Cement Using Bamboo Leaf Ash BLASH Against Corrosion", (E-ISSN: 2476-3055; ISSN: 2676-6957) Vol. 7, No. 06, June 2021.
- [5] Abraham T. Gebremariam a, Ali Vahidi a, Francesco Di Maio a, J. Moreno-Juez b, I. Vegas-Ramiro b, Artur Łagosz c, Radosław Mróz c, Peter Rem a, "Comprehensive study on the most sustainable concrete design made of recycled concrete, glass and mineral wool from C&D wastes", *Construction and Building Materials* 273 (2021) 121697.
- [6] Odeyemi SO, Anifowose MA, Abdulwahab R, Oduoye WO., "Mechanical Properties of High-Performance Concrete with Guinea Corn Husk Ash as Additive". *LAUTECH J Civ Environ Stud* 2020; 5: 139-54. [https://doi.org/10.36108/laujoces/0202/50\(0131\)](https://doi.org/10.36108/laujoces/0202/50(0131)).
- [7] Onikeku O, Shitote SM, Mwero J, Adedeji AA. Evaluation of Characteristics of Concrete Mixed with Bamboo Leaf Ash. *Open Constr Build Technol J* 2019; 13: 67-80. <https://doi.org/10.2174/1874836801913010067>.
- [8] Zea Escamilla, E., Habert, G., Correal Daza, J. F., Archilla, H. F., Echeverry Fernández, J. S., & Trujillo, D. (2018). Industrial or traditional bamboo construction? Comparative life cycle assessment (LCA) of bamboo-based buildings. *Sustainability*, 10(9), 3096.
- [9] Jin-Cheng Liu et.al (2023), Mechanical and durability performance of sustainable concretes containing conventional and emerging supplementary cementitious materials, *Developments in the Built Environment*, 11 July 2023. <https://doi.org/10.1016/j.dibe.2023.100197>
- [10] Lucas Henrique Pereira Silva et.al (2021), Bamboo leaf ash for use as mineral addition with Portland cement, *Journal of Building Engineering*, 28 May 2021. <https://doi.org/10.1016/j.jobe.2021.102769>
- [11] Felix Krolow Sell Junior et.al (2024), Effects of bamboo leaf ashes on concrete compressive strength, water absorption, and chloride penetration, *Journal of Building Engineering*, 9 October 2024. <https://doi.org/10.1016/j.jobe.2024.110986>
- [12] Production volume of cement worldwide from 1995 to 2024, [Cement production global 2024| Statista](https://www.statista.com/statistics/110986/production-volume-of-cement-worldwide/).