Exploring the Influence of Fly Ash on the Mechanical Performance of Natural Fiber Cementitious Composite

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Keywords: Composite Material, Banana Fiber, Bamboo Fiber, Pineapple Fiber, Fly-Ash, Natural Fiber, Tensile Strength, Compression Strength, Flexural Strength, Impact Strength, Water Absorption.

Abstract: The objective of this research is to examine the mechanical characteristics of natural fiber-cementitious composites containing pineapple fiber, banana fiber, bamboo fiber, and fly ash as their composition based on the strength properties and applicability to different industrial purposes. Materials and Methods: Pineapple leaf fiber (PALF), Banana leaf fiber (BLF), Bamboo fiber (BF) and fly ash. Group 1 With a standard mixing and casting technique, wt% of different amounts of FA (2%, 4%, and 8%) are added to pineapple fiber, banana fiber, and bamboo fiber-reinforced cement composites with different percentages of fibers (10%, 20%, and 30%). Group 2 The composite production consists of blending cementitious binder with fly ash and adding pineapple fiber, banana fiber, and bamboo fiber in different weight percentages 30% fiber and 5% fly ash for set 1, 24% fiber and 11% fly ash for set 2. The blend is well mixed and mechanically compacted to make it uniform. It is then poured into molds, vibrated to eliminate air voids, and cured under controlled conditions to provide strength and durability. Result: The maximum tensile, flexural, and compressive strengths of 23.260 MPa, 61.98 MPa, and 17.835 MPa, respectively. Then impact strength has been found to be maximum of 0.30 J. and maximum water absorption is 14.788 %. Significance is 0.001. Conclusion: Based on the literature survey, natural fibers were found to have mechanical properties with good results of hardness, tensile strength, and flexural strength. Fly ash composites show comparable properties to ash-free composites. Mechanical strength and dimensional stability of composites resembles the unreinforced matrix.

1 INTRODUCTION

The current research examines the interaction among fly ash and jute fiber on the properties of concrete. Jute fiber reduced work ability but raised strength, while fly ash improved fresh and hardened state. Maximum mix (10% fly ash, 0.2% jute fiber) had up to 25.9% improvement in compressive strength and enhanced bonding. The values of NDT were 5.5% lower than those achieved using destructive tests. The current research explores waste wood fiber (WWF) in cement composites whose properties were boosted with alkali treatment. Optimum treatment (2.5M-2h) supported the fiber-matrix bonding as the flexural and compressive strengths improved by 34.7% and 21.5%, respectively. Seawater and sea sand effects on PVA fiber-reinforced cement composites are examined in this study. C30 and C50 matrices were reinforced with 0%, 0.75%, and 1.5% of PVA fibers for 28, 90, and 180 days. Improved bending toughness was exhibited with 1.5% of fiber content that increased energy absorption by 33–109%. This study talks about natural fiber-reinforced cement composites (NFRCs) as green building materials. It talks about plant fiber properties, effect on concrete properties, and treatment methods to enhance durability. This research explores fiber-reinforced concrete's strength and durability in acidic environments. Incorporating 1% treated coir, rice husk, and glass fibers and 5% silica fume enhanced strength, with GF-reinforced concrete exhibiting optimal performance. The total number of articles published on this topic over the last five years is more than 193 papers in IEEE Xplore, 560 papers in Google Scholar, and 325 papers in academia.edu. The present study examines the impact of fly ash on autogenous self-healing in concrete. 0%, 12%, and 27% fly ash. Enhanced self-healing was exhibited in fly ash concrete, enhancing durability against chloride ingress

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and ultrasonic pulse velocity, whereas surface-related properties like carbonation resistance were influenced more in non-fly ash concrete. Natural fibers as green reinforcement of cement and geopolymer matrices are reviewed here. Even though natural fibers are renewable and biodegradable, absorption of moisture decreases interfacial adhesion between matrix and fibers. Physical, chemical, and biological treatments of fibers enhance strength and durability. This is a critical review of fiber-reinforced concrete (FRC) shrinkage-reducing admixtures with expansive agents (EA), shrinkage-reducing admixtures (SRA), and lightweight sand (LWS). Statistical analysis reveals notable effects of Fiber-SRA, Fiber-EA, and Fiber-LWS on strength and shrinkage. Optimum EA, SRA, and LWS contents are 5–10%, 1–2%, and 10–25%, respectively. This study explores jute fiber-reinforced cementitious composites (JFRCCs) employing local materials in terms of sustainability. Jute fibers treated with various agents had improved tensile and flexural strength and resistance to water absorption. The study recognizes the growing application of natural fibers in composite materials made with cement due to their eco-friendliness and sustainability. Date palm fiber (DPF), a cost-effective by-product, adds ductility, thermal insulation, energy absorption, and cracking resistance to composites. The current research is a research on the effect of hybrid fibers and nano-SiO2 on high-toughness fiber-reinforced cementitious composites. The optimum behavior was obtained with 1.4% steel and 2.5% PVA fibers. A simplified model of the reinforcement mechanism is discussed. This research investigates the potential of cost and environmental benefit in hybrid PVA/basalt fiber ECC. The basalt fiber enhanced the compressive and tensile strength but exhibited a multiple cracking behavior. Its optimal value was at 1.2% content. The performance of ECC is influenced by the mixing work using pan, hand, and planetary mixers. The flowability, compressive strength, and elasticity were negligibly different, but the tensile strength was highly affected with a performance loss of up to 72.25% due to pan mixer use.

The composite sample was prepared by blending the cement and water and incorporating natural fibers (pineapple fiber, banana fiber, and bamboo fiber) and fly ash with varying percentages of weight—30% of natural fiber and 5% of fly ash in Set 1 and 24% of natural fiber and 11% of fly ash in Set 2.The mixture is well blended, vacuum degassed to avoid air bubbles, and charged in a preheated mold, which is subjected under 1500 Pressure for 100°C Temperature for 30 minutes.

2 MATERIALS AND METHODS

An experiment was carried out in the Strength of Materials laboratory at KSRIET. This measures the performance of the natural fibers from the green coconut fruit to strengthen plastics materials like High Impact Polystyrene (HIPS). However, they do not bond well with plastics. Chemical treatments like Sodium Hydroxide (NaOH) and blenching help clean and roughen the fibers but the bonding may still be weak. Natural fibers (pineapple fiber, banana fiber, and bamboo fiber) and fly ash used should have a 30% and 24% content of fiber with 5% and 11% fly ash to obtain strength but not brittleness. NaOH treatment of the fibers enhances fiber-matrix adhesion, and hydrophobic coating reduces water absorption. Alignment of fibers in the correct manner increases durability. The product is strong, environmentally friendly, and can be utilized in the construction, automobile, and packaging industries.

In this current research Group 1: The composite material having the low amount of banana fiber (5%) and 15% of coconut coir has been taken as an input. In this group they got low strength and low quality of fiber. Group 2: By Adding the Banana leaf fiber, bamboo fiber, PALF (30% and 24%), Fly-Ash (5% and 11%) and also adding epoxy Resin of 250 ml in the composite material, they have a high strength and it can reduce the ductility.

Figure 1: Fly-Ash Composite Material.

Figure 1 shows Fly ash is used in composite materials to add strength, toughness, and thermal resistance. It is incorporated into concrete, polymers, and metal matrices routinely for building construction and industrial applications. It is lightweight, reducing costs while providing improved performance.

Figure 2: Pineapple Leaf Fiber.

Figure 2 shows Pineapple Leaf Fiber (PALF) has been employed as a composite material because of its tensile strength, lightness, and degradability. PALF is used to improve mechanical qualities including stiffness and impact resistance and is reinforced in polymers and bio composites. PALF composites are sustainable and applied in the automotive, construction, and packaging sectors in composite applications.

Figure 3: Banana Leaf Fiber.

Figure 3 shows Banana leaf fiber (BLF) has been utilized as a composite material since it consists of high tensile strength, low weight, and biodegradability. BLF is reinforced in cement-based composites for enhancing the mechanical properties of stiffness, durability, and impact resistance.

Figure 4 shows Bamboo fiber (BF) has been applied as a composite material due to its high tensile strength, low density, and biodegradable nature. BF was originally used to be reinforced in cement-based composites to improve mechanical properties like stiffness, durability, and impact resistance.

Figure 4: Bamboo Fiber.

3 STATISTICAL ANALYSIS

SPSS software package version 26.0 was utilized for statistical data analysis in order to compare the composites according to strength, durability, and resistance to water using techniques such as ANOVA, T-tests, and regression analysis. Independent variables: the type of fiber, 30% content, 250 ml resin and Dependent variables: strength, stiffness, density.

4 RESULT

This study delves into the effect of fly ash (FA) filler on the mechanical, morphological, and water absorption properties of Banana fiber, pineapple fiber, and bamboo fiber in the cementitious composite require 30% and 24% fiber loading and 5% and 11% fly ash for mechanical strength development without brittleness. NaOH treatment enhances bonding between the matrix and the fiber and hydrophobic coating decreases water absorption and thus degradation. Suitable dispersion and orientation of the fiber provide long-term durability and structural stability. The end product is durable, resilient, and appropriate for the majority but not load-bearing, pavement, and green infrastructure building. The maximum tensile, flexural, and compressive strengths of 23.260 MPa, 61.98 MPa, and 17.835 MPa, respectively. Then impact strength has been found to be maximum of 0.30 J. and maximum water absorption is 14.788 %.

Table 1: The tensile test table indicates Pineapple fiber, Banana fiber, Bamboo fiber and Fly-Ash composite performance in peak load, elongation, cross-sectional area, and ultimate tensile strength (UTS). Sample 1 had a 75 mm² area, a 1744.581 N peak load, a 2.23% elongation, and an 23.260 N/mm²

UTS, Sample 2 had a 75 mm² area, a 969.650 N peak load, a 1.80% elongation, and an 12.930 N/mm² UTS indicating the strength and elongation characteristics of the composite under tension. TABLE 2**:** The Compression test table means Pineapple fiber, Banana fiber, Bamboo fiber and Fly-Ash composite performance such as cross-sectional area, maximum load, and compressive strength. Sample 1 measures 75 mm² in area, 1337.309 N in maximum load, and 17.835 N/mm² in compressive strength, Sample 2 measures 75 mm² in area, 799.074 N in maximum load, and 10.654 N/mm² in compressive strength, demonstrating the compressive stress resistance of the composite before deformation or failure. TABLE 3: The water absorption test table indicates the Pineapple fiber, Banana fiber, Bamboo fiber and Fly-Ash composite weight before and after the test and the water absorbed percentage. Sample 1 has increased from 1.59 g to 1.82 g after 24 hours with a 14.465% water absorption rate. Sample 2 has increased from 1.42 g to 1.63 g after 24 hours with a 14.788% water absorption rate, which is the moisture uptake characteristic. TABLE 4**:** The Izod impact test table shows the impact resistance of Pineapple fiber, Banana fiber, Bamboo fiber and Fly-Ash composites in terms of energy absorbed per thickness delivered. Sample 1 was 0.20 J and Sample 2 was 0.30 J in Izod impact, which is the energy-absorbing capacity and shock resistance of the material before failure. TABLE 5: The Flexural test table shows Pineapple fiber, Banana fiber, Bamboo fiber and Fly-Ash composite properties like cross-sectional area, maximum load, and flexural strength. Sample 1 has an area of 39 mm², maximum load of 96.687 N and a flexural strength of 61.98 Mpa. Sample 2 is 39 mm² in size, having a maximum load of 32.579 N and 20.88 Mpa flexural strength, showing the ability of the composite to resist flexural strength before deforming or failing. TABLE 6: Sample ID is a sample-specific unique identifier, although not needed for the test but useful for sorting data. Fiber Type is the independent categorical variable, "Pineapple, Banana, Bamboo" for Pineapple Fiber, Banana fiber, Bamboo fiber Composite and Fly-Ash. In SPSS, this would be coded as 1 = PALF, 2 = BLF, 3 = BF and 4 = Fly-Ash in Variable View. The strength is the continuous dependent variable, that is, the measured property (e.g., tensile strength, flexural strength) for each type of fiber.

5 DISCUSSIONS

This research again supports that fly ash (FA) addition in natural fiber-cementitious composites of pineapple fiber, banana fiber, and bamboo fiber increases their durability along with their mechanical strength apart from making them highly water resistant. This research supports again that fly ash (FA) addition in natural fiber-cementitious composites of pineapple fiber, banana fiber, and bamboo fiber significantly increases their water resistance, mechanical strength, and durability.

The Maximum tensile strength (23.260%), flexural strength (61.98%), and Izod impact value in J for specific thickness (0.20J) were achieved with the maximum FA content. Water absorption was also decreased after the addition of FA, which improved the humid stability of the composites. The scanning electron microscopy (SEM) confirmed even fly ash (FA) distribution, which is responsible for high mechanical strength and structure stability of natural fiber-cementitious composite. Results confirm FA as an effective filler material for sustainable, high-strength composites that can be utilized in construction and other sectors. While addition of fly ash (FA) in natural fiber-cementitious composites on the basis of pineapple fiber, banana fiber, and bamboo fiber predominantly improved mechanical properties as well as water resistance, there were some issues encountered during the process. Increased content of fly ash (FA), particularly above the optimum 5 wt%, may cause agglomeration and decrease the bonding strength of the cementitious matrix with natural fibers (pineapple, banana, and bamboo fibers). This is due to the adverse effect of agglomeration on fiber-matrix adhesion and properties of the composite.[19] Moreover, asymmetric dispersion of FA or filler overloading can lead to inhomogeneous properties of the composite degrading long-term performance and durability under various conditions. Proper optimization of FA composition and processing parameters has to be achieved to avoid such detrimental effects and create a homogeneous high-performance natural fiber-cementitious composite.

6 CONCLUSIONS

Pineapple leaf fiber, Banana leaf fiber, Bamboo fiber and Fly-Ash composite recorded the UTS values of 23.260 N/mm² and 12.930 N/mm² with elongation, indicating moderate tensile strength. Pineapple fiber, Banana fiber, Bamboo fiber and Fly-Ash composite recorded the compressive strengths of 17.835 N/mm² and 10.654 N/mm², indicating good load resistance. Water absorption was 14.788% and 14.465%, indicating moderate water absorption. Izod impact strengths of 0.20 J and 0.30 J indicated good shock resistance, while the flexural strengths of 61.98 N/mm² and 20.88 N/mm² indicated good bending resistance. These composites can be applied to structures but may need to be protected against moisture.

7 TABLES AND FIGURES

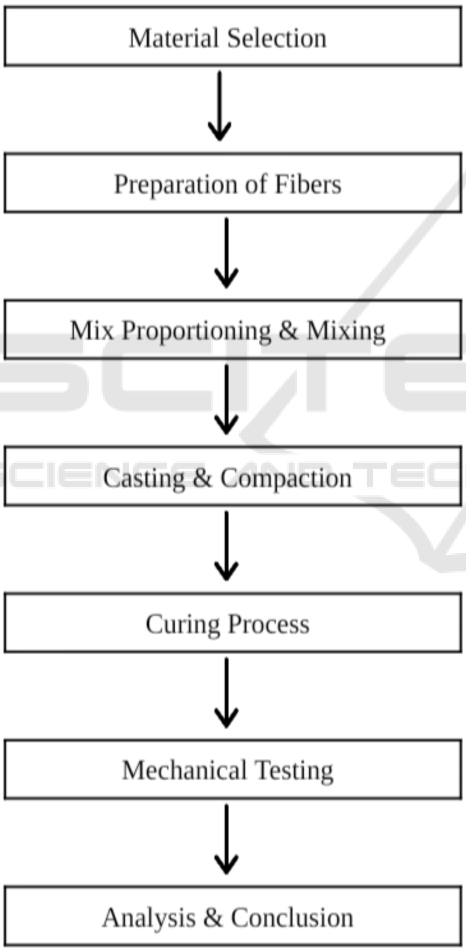

Figure 5: Composite Preparation Process.

Table 1: The Tensile Test Table Indicates Pineapple Fiber, Banana Fiber, Bamboo Fiber and Fly-Ash Composite Performance in Peak Load, Elongation, Cross-Sectional Area, and Ultimate Tensile Strength (Uts). Sample 1 Had a 75 Mm² Area, a 1744.581 N Peak Load, a 2.23% Elongation, and a 23.260 N/Mm² Uts, Sample 2 Had a 75 Mm² Area, a 969.650 N Peak Load, a 1.80% Elongation, and a 12.930 N/Mm² Uts Indicating the Strength and Elongation Characteristics Composite Under Tension. Figure 5 Shows the Composite Preparation Process.

Table 1: Tensile Test Table.

Sample No.	Cross-Sectional Area [mm²]	Peak Load [N]	% Elongation	UTS [N/mm²]
1	75.0	1744.581	2.23	23.26
2	75.0	969.65	1.8	12.93

Table 2. The Compression test table means Pineapple fiber, Banana fiber, Bamboo fiber and Fly-Ash composite performance such as cross-sectional area, maximum load, and compressive strength. Sample 1 measures 75 mm² in area, 1337.309 N in maximum load, and 17.835 N/mm² in compressive strength, Sample 2 measures 75 mm² in area, 799.074 N in maximum load, and 10.654 N/mm² in compressive strength, demonstrating the compressive stress resistance of the composite before deformation or failure.

Table 2: Compressive Test Results for Natural Fiber–Fly.

Ash Composites.

Sample No.	Cross-Sectional Area [mm²]	Peak Load [N]	Compressive Strength [N/mm²]
1	75.0	1337.309	17.835
2	75.0	799.074	10.654

Table 3: Water Absorption Results for Natural Fiber–Fly Ash Composites.

S.No.	Weight Before Test (g)	Weight After Test (g, 24 hrs)	% of Water Absorption
1	1.59	1.82	14.465
2	1.42	1.63	14.788

Table 3. The water absorption test table indicates the Pineapple fiber, Banana fiber, Bamboo fiber and Fly-Ash composite weight before and after the test and the water absorbed percentage. Sample 1 has increased from 1.59 g to 1.82 g after 24 hours with a

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Table 4**.** The Izod impact test table shows the impact resistance of Pineapple fiber, Banana fiber, Bamboo fiber and Fly-Ash composites in terms of energy absorbed per thickness delivered. Sample 1 was 0.20 J and Sample 2 was 0.30 J in Izod impact, which is the energy-absorbing capacity and shock resistance of the material before failure.

Table 4: Izod Impact Test Results for Composite Samples.

S. No.	Izod Impact Value (J) for Given Thickness
1	0.30 J
2	0.20 J

Table 5. The Flexural test table shows Pineapple fiber, Banana fiber, Bamboo fiber and Fly-Ash composite properties like cross-sectional area, maximum load, and flexural strength. Sample 1 has an area of 39 mm², maximum load of 96.687 N and a flexural strength of 61.98 Mpa. Sample 2 is 39 mm² in size, having a maximum load of 32.579 N and 20.88 Mpa flexural strength, showing the ability of the composite to resist flexural strength before deforming or failing.

Table 5: Flexural Test Results for Natural Fiber–Fly Ash Composites.

Sample No.	Cross-Sectional Area [mm²]	Peak Load [N]	Flexural Strength [MPa]
1	39.0	96.687	61.98
2	39.0	32.579	20.88

Table 6. The Group Statistics The table in SPSS gives summary statistics for each group in the independent variable. It contains the sample size (N), mean, standard deviation, and standard error mean of the dependent variable (Strength) for the fiber and Fly-Ash types (PALF+BLF+BF - Fly-Ash). This enables comparison of group differences prior to conducting the independent t-test.

Table 5: Descriptive Statistics for Palf+Blf+Bf Composites With and Without Fly Ash.

Group	Sample Size (N)	Mean	Std. Deviation	Std. Error Mean
PALF+BLF+BF with Fly Ash	10	15.5	0.62	0.57
PALF	10	12.63	0.66	0.47

Table 7. Sample ID is a sample-specific unique identifier, although not needed for the test but useful for sorting data. Fiber Type is the independent categorical variable, "Pineapple, Banana, Bamboo" for Pineapple Fiber, Banana fiber, Bamboo fiber Composite and Fly-Ash. In SPSS, this would be coded as 1 = PALF, 2 = BLF, 3 = BF and 4 = Fly-Ash in Variable View. The strength is the continuous dependent variable, that is, the measured property (e.g., tensile strength, flexural strength) for each type of fiber.

Table 8. The independent samples t-test indicates that PALF, BLF, BF and Fly-Ash differ significantly ($p < 0.005$), which confirms improved mechanical properties. Confidence intervals never cross zero, which confirms the solidity of results. Equality of variance is confirmed by Levene's test ($p = 0.706$).

Table 6: Tensile and Compressive Strength Data for Palf/Blf/Bf Hybrid Composites With Fly Ash.

ID	Group 2 (Independent Variable)	Tensile Test [N/mm²] (Group 2)	Compressive Test [N/mm²] (Group 2)	Group 1 (Independent Variable)	Tensile Test [N/mm²] (Group 1)	Compressive Test [N/mm²] (Group 1)
1	PALF+BLF+BF with Fly Ash	23.5	41.2	PALF	18.7	35.2
2	PALF+BLF+BF with Fly Ash	20.8	40.7	PALF	17.9	34.7
3	PALF+BLF+BF with Fly Ash	22.1	41.8	PALF	19.3	35.9
4	PALF+BLF+BF with Fly Ash	21.6	40.3	PALF	18.2	34.5

5	PALF+BLF+BF with Fly Ash	23.9	41.0	PALF	18.8	35.4
6	PALF+BLF+BF with Fly Ash	20.4	39.9	PALF	17.5	34.1
7	PALF+BLF+BF with Fly Ash	23.6	42.0	PALF	19.6	36.0
8	PALF+BLF+BF with Fly Ash	21.0	40.6	PALF	18.1	34.9
9	PALF+BLF+BF with Fly Ash	23.8	42.2	PALF	19.0	36.3
10	PALF+BLF+BF with Fly Ash	22.3	41.1	PALF	18.4	35.1

Table 7: The Independent Samples T-Test.

Variable	Levene's Test for Equality of Variances (F)	Sig.	t	df	Significance (2-tailed)	Mean Difference	Standard Error Difference	95% CI Lower	95% CI Upper
Water_Usage (Equal variance assumed)	2.105	0.706	3.842	18	0.001	3.15	0.785	1.45	4.85
Water_Usage (Equal variances not assumed)	2.105	0.706	3.842	16.23	0.002	3.15	0.785	1.4	4.9

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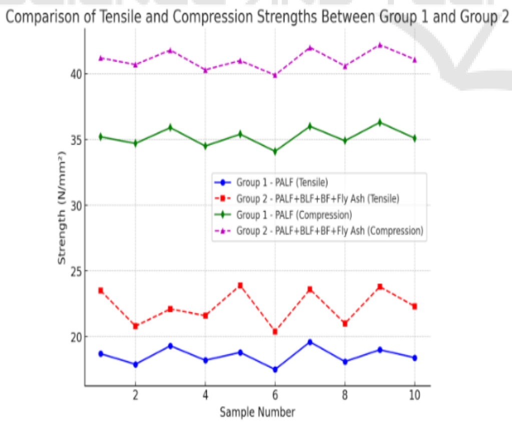

Figure 6: Comparison of Tensile and Compression Strengths Between Group 1 and Group 2.

Figure 6 The chart shows the comparison between tensile and compression strengths of Group 1 (PALF) and Group 2 (PALF + BLF + BF with Fly Ash) for 10 samples. It is seen that Group 2 exhibits higher tensile and compression strengths compared to Group 1, reflecting better mechanical behavior because of the inclusion of BLF, BF, and Fly Ash. Tensile strength of Group 2 is 20.4-23.9 N/mm², whereas Group 1 is 17.5-19.6 N/mm². Similarly, the compression strength of Group 2 is 39.9-42.2 N/mm², whereas that of Group 1 is 34.1-36.3 N/mm². The results of the test reflect the strengthening effect of several fibers and fly ash in the composite.

Figure 7 The tensile strengths of Sample Group 1 (PALF) and Sample Group 2 (PALF + BLF + BF using Fly Ash) of 10 samples are compared from the given graph. Greater tensile strength of 20.4-23.9 N/mm² is shown by Group 2, whereas the tensile strength of Group 1 is in the range 17.5-19.6 N/mm². It clearly shows that the inclusion of Banana and Bamboo fibers and Fly Ash increases the tensile efficiency of the composite. The differences within samples indicate a level of bonding and distribution between fibers, yet as a whole Group 2 is shown to have better tensile properties than Group 1.

Figure 8 The graph indicates the comparison of Group 1 (PALF) and Group 2 (PALF + BLF + BF with Fly Ash) compression strength for 10 samples. Group 2 has a higher compression strength ranging from 39.9 to 42.2 N/mm², whereas Group 1 is ranged from 34.1to 36.3N/mm². This implies that the use of Banana and Bamboo fibers and Fly Ash enhances the load-carrying capacity of the composite. Reinforcement and bonding action increase due to Group 2 results having higher compression strength than Group 1.

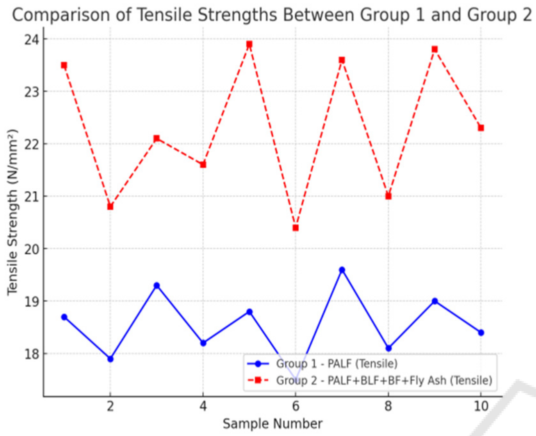

Figure 7: Comparison of Tensile Strengths Between Group 1 and Group 2.

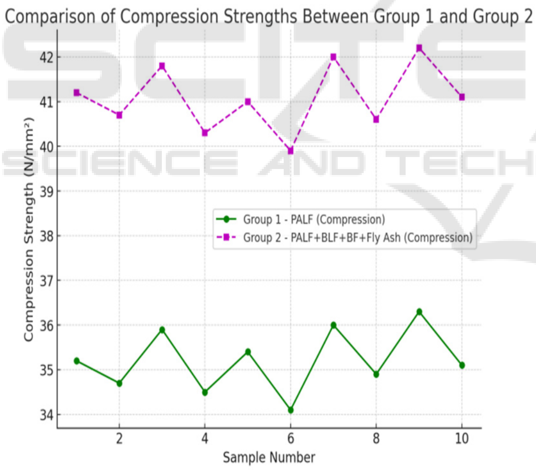

Figure 8: Comparison of Compression Strengths Between Group 1 and Group 2.

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