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Enhancing Mechanical Properties of Natural Fiber Composites Through the Incorporation of Ash Particles: An Experimental Investigation

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Abstract

In the recent development in materials, composites find major applications in the domestic and Engineering sector. Considering its superior material properties and biodegradability, natural fibre epoxy resin composites has become significant in recent years as a potential industrial resources. In this research work composites with banana and coir fibres added with ash particles are studied for the Mechanical properties. The Mechanical property evaluation is done based on ASTM standards described by various testing labs approved by NABL. There are numerous Manufacturing methods available for composites like compression moulding, spray process, pultrusion, Hand layup. For this work easiest method is used i.e. hand layup process. The composites are manufactured for various combinations in terms of fibre length and volume fraction. To reduce the biodegradability and increase the life chemical treatment is carried out on fibre using alkali solution of 1% NaOH. The effect of ash particle percentage is studied using mechanical tests like tensile test, flexural test and impact test. The results shown significant improvement is mechanical properties.

Keywords— ASTM, Mechanical Properties, Tensile strength, Flexural Strength, Impact Strength, Fiber length, Volume fraction, Banana fibre, Coir fibre, NABL, NaOH.

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I. INTRODUCTION

As a result of the increasing demand for environmentally friendly materials and the desire to reduce the cost of traditional fibers (i.e., carbon, glass and aramid) reinforced petroleum-based composites, new bio-based composites have been developed. Researchers have begun to focus attention on natural fiber composites (i.e., biocomposites), which are composed of natural or synthetic resins, reinforced with natural fibers. Natural .bers exhibit many advantageous properties, they are a low-density material yielding relatively lightweight composites with high specific properties. These fibers also significant cost advantages and ease of processing along with being a highly renewable resource, in turn reducing the dependency on foreign and domestic petroleum oil. Recent advances in the use of natural fibers (e.g., Banana, cellulose, jute, hemp, straw, switch grass, kenaf, coir and bamboo) in composites has been significant.

Incorporating glass fibers into permeable concrete significantly impacts its properties. Optimal results are achieved with 5-10 mm aggregate particles, and the addition of fly ash enhances compactness. Varying fiber lengths influence strength and permeability, with the best performance observed at a 6 mm length and 2 kg/m^3 dosage[1].Adding 10-15% FA along with 0.25-0.5% RTSF improved concrete's ductility and impermeability. The most significant improvements in splitting-tensile strength (fSP) and modulus of rupture (MOR) were observed with 10% FA. However, excessive FA levels above 15% decreased overall mechanical strength and RTSF efficiency. A high-strength concrete mix with 10% FA and 0.5% RTSF exhibited remarkable enhancements, with 83% higher MOR, 49% higher fSP, and 19% higher compressive strength (fCS) compared to the reference mix. Additionally, all levels of FA (10-35%) reduced the electrical conductivity of RTSF-reinforced concrete compared to the reference mix[2]. Incorporating 5 wt.% carboxymethyl cellulose (CMC)-hybridized fly ash (FA) and cetyltrimethylammonium bromide (Ctab)-treated FA into polypropylene (PP) composite led to remarkable improvements in tensile (13% and 7%) and flexural (30% and 25%) strength, with a confirmed increase in melting temperature by ~3°C. ATR-IR analysis verified FA surface functionalization, and FE-SEM indicated successful FA adhesion to CMC and graphene oxide (GO) surfaces. TGA analysis supported enhanced thermal stability. Molecular dynamics (MD) simulations predicted the highest interfacial

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interaction in Ctab-FA-reinforced PP composite[3]. Aluminum-based metal matrix composites (MMCs) incorporating natural fiber ashes, such as Sugarcane bagasse, Groundnut Shell Ash (GSA), Rice Husk Ash (RHA), and Coconut shell (Jute) ash, were investigated. The study explored the effects of various reinforcement percentages and identified optimal compositions. Notably, the highest Ultimate Tensile Strength (UTS) was achieved with a 4% reinforcement of each ash and 84% aluminum [4]. While synthetic fibers like glass and carbon offer high specific strength, they come with limited applicability due to elevated production costs. Recently, there has been a growing interest in natural fillers for composites, leading to research utilizing coal powder, coal fly ash, and bagasse ash as fillers in combination with glass fiber reinforcement for epoxy-based hybrid composites. This study investigates the impact of fiber loading and filler material on the mechanical properties, including tensile strength, tensile modulus, flexural strength, ILSS, hardness, and impact strength of the composites. Additionally, a multi-criteria decision-making approach, TOPSIS, is employed to identify the best alternative based on different mechanical attributes [5]. Studies demonstrate that natural fiber-reinforced composites, particularly through Hand Layup manufacturing and 2% NaOH fiber treatment, offer improved mechanical properties. These composites hold promise for industrial applications [6]. Chemical resistance and tensile properties of glass/bamboo-reinforced polyester composites were explored. Improved chemical resistance and increased tensile strength were observed with higher glass fiber content and alkali-treated bamboo fibers [7]. Analytical and multiquadric radial basis function methods were used to assess banana fiber-reinforced low-density polyethylene/polycaprolacton composites, with a focus on sodium hydroxide-treated fibers for improved mechanical properties [8]. The thermal behavior of banana pseudo-stem (BPS) filled UPVC composites, emphasizing the impact of fiber loading and acrylic resin modification on thermal stability[9]. Investigating Fly Ash Influence on Mechanical Properties and Fracture Analysis in Coir Fiber Composites. Improved Flexural, Tensile, Impact, and Compressive Strength with Ash Integration[10]. Banana fiber, chemically modified for enhanced interfacial interaction, demonstrated improved tensile and flexural properties, attributed to its effective adhesion with the polyester matrix (NaOH treatment proved most effective) [11]. In the presence of 2 wt% MAPP, a bamboo:glass fiber ratio of

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15:15 yielded substantial improvements: tensile, flexural, and impact strength increased by approximately 69%, 86%, and 83%, respectively [12]. Fiber reinforced polymer composites with coir as reinforcement offer strong, lightweight, and cost-effective alternatives for various applications (Keywords: Polymer composites, coir fiber, mechanical behavior, SEM) [13]. the tensile and flexural strength of natural banana fiber composites. Banana fibers offer undeniable advantages, including non-toxicity, low density, affordability, durability, and minimal waste disposal concerns. The research involves fabricating banana fiber-reinforced composites using the hand lay-up process with varying fiber lengths and room temperature pressing. Mechanical tests, including tensile and flexural assessments, are conducted, while SEM analysis explores fiber-matrix interfaces and fractured surface structures [14]. coconut shell-substituted lightweight self-compacting concrete (LWSCC) with banana fiber reinforcement was examined for 28 and 90-day cured specimens. The addition of 1.25% banana fibers significantly enhanced the LWSCC's impact strength without adverse effects on self-compatibility or compressive strength [15]. Manufacturing high-strength refractory ceramic fibers (RCFs) from aluminosilicate-rich fly ash, offers cost-effective and environmentally-friendly materials for insulation. Mechanical properties were assessed and compared to E-glass fibers under similar conditions [16]. Incorporation of banana and glass fibers into polypropylene (PP) matrix, with the addition of maleic anhydride grafted polypropylene (MAPP) as a coupling agent, significantly enhanced tensile, flexural, and impact strength. The hybrid composites exhibited reduced water absorption, improved dynamic mechanical properties, and altered thermal characteristics[17]. Banana fiber-reinforced thermoplastic composites were subjected to various treatments to enhance interfacial bonding and mechanical properties. Sodium hydroxide treatment increased tensile strength, while sebacoyl chloride treatment caused a decline. Composites with higher fiber weight fractions exhibited improved tensile strength and modulus, but reduced elongation at break. Enzymatic degradation tests with Pseudomonas cepacia lipase showed significant weight loss in poly(ε- caprolactone) (PCL) and PCL-blended materials [18]. Coir-reinforced polypropylene (PP) composite panels exhibited enhanced mechanical properties and flame retardancy with 60 wt% coir fiber, 37 wt% PP powder, and 3 wt% MAPP, making them suitable for automotive interior applications[19].

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It reveals that the literature, concerning coir-reinforced PP composites, explores a specific composition, whereas the present work discusses banana and coir composites with ash particles. Additionally, the previous work focuses on mechanical and flammability properties, while the present highlights biodegradability, chemical treatment, and various manufacturing methods, showing the need for further research on a broader range of properties and materials.

II. MATERIALS:

Banana fibres, Coir fibres, ash particles and epoxy resin are the components used in this manufacturing project. Epoxy resin 520 and Epoxy hardener-PAM. Ash is obtained from local sugar factory. Weight combined the epoxy resin and epoxy hardener. The density of the epoxy resin is 1.22 g / cc. Until fiber mats were inserted in the matrix material, epoxy resin and hardener mixture were thoroughly stirred. Each laminate was healed in the mould under constant pressure nearly 24hrs and healed at room temperature at least 12 hours later. The banana fiber is extracted from the banana plant as shown in figure, which was collected from local sources. The extracted banana fiber was then dried in the sun for eight hours and dried in the oven for 24 hours in order to remove free water in the fiber.

Figure 1: Chemical Treatment   Figure 2: Coir Fibres   Figure 3: Banana Fibres

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III. MECHANICAL TESTING

A. *TENSILE TESTING:*

Tensile testing is carried on different specimens manufactured as per the length of the fiber and quantity of ash particles mixed with them. Table 1 and Table 2 shows the results obtained for different combination of banana and coir composites respectively, the results explained in figure 5 and figure 6 shows the continuous improvement in strength with increase in ash percentage.

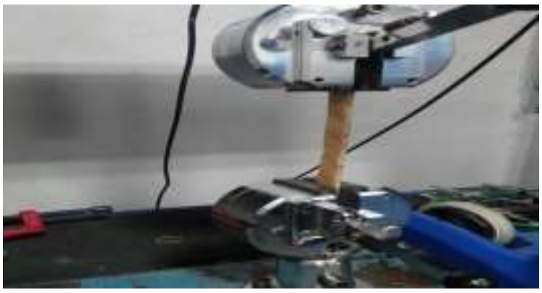

Figure 4: Tensile testing assembly

TABLE 1

RESULTS OF TENSILE TESTING

Composites	Tensile strength (MPa)							
	Coir Composites				Banana Composites			
	No Ash	10 gm Ash	20 gm Ash	30 gm Ash	No Ash	10 gm Ash	20 gm Ash	30 gm Ash
A_1	12.165	13.051	13.154	13.665	09.722	10.012	12.125	13.051
A_2	13.575	14.217	14.675	13.765	10.005	12.905	13.505	14.217
A_3	13.125	13.250	13.375	14.125	10.115	12.175	13.175	13.250
B_1	14.895	14.950	15.250	15.375	10.795	13.715	14.805	14.950
B_2	14.725	14.850	14.950	15.250	11.079	14.075	14.745	14.850
B_3	15.621	16.630	17.035	17.641	11.922	14.921	15.321	17.030
C_1	17.415	17.920	18.425	17.750	12.040	15.490	17.419	18.120
C_2	19.585	21.387	20.591	22.596	12.515	17.515	18.515	20.087
C_3	23.292	23.310	23.974	24.345	14.220	19.272	21.272	21.310

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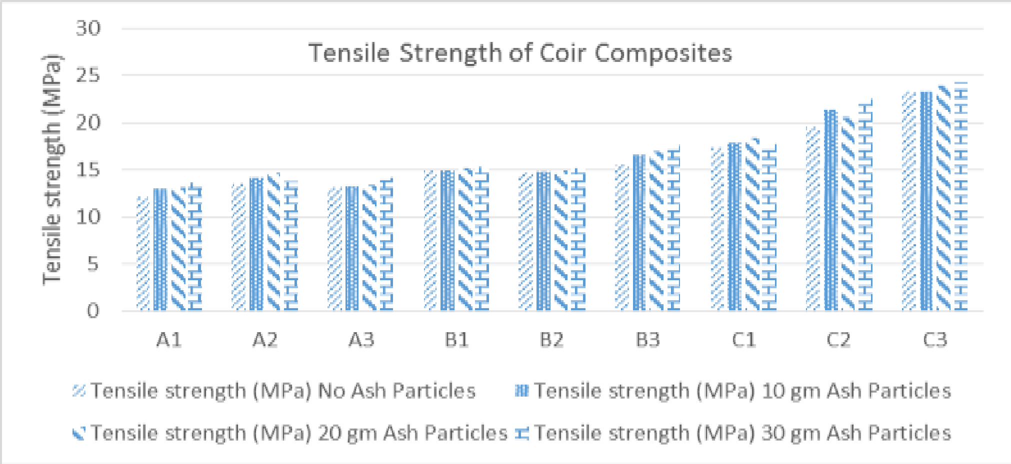

Figure 5: Comparison of tensile strength results of coir composites

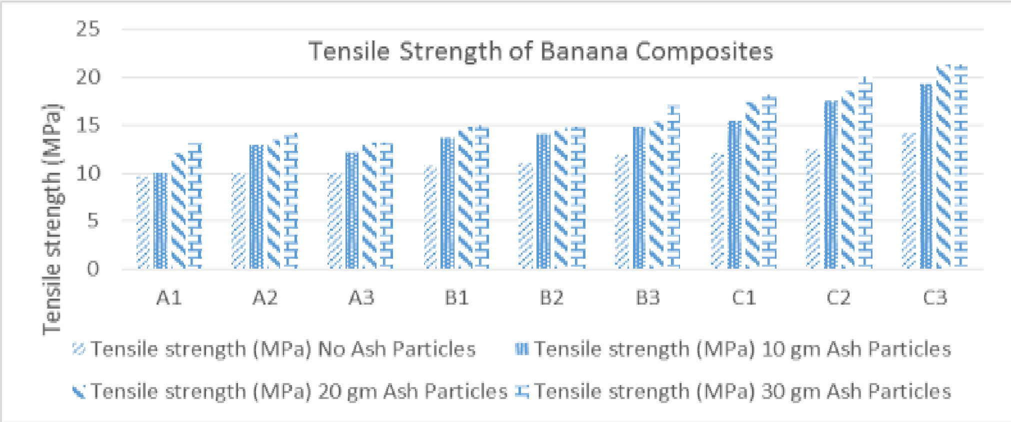

Figure 6: Comparison of tensile strength results of Banana composites

B. FLEXURAL TESTING:

Similar to tensile testing flexural testing is also carried on different specimens manufactured as per the length of the fiber and quantity of ash particles mixed with them. Table 5 and Table 6 illustrates the results obtained for different combination of banana and coir composites respectively, the results explained in figure 11 and figure 12 shows the significant improvement in strength.

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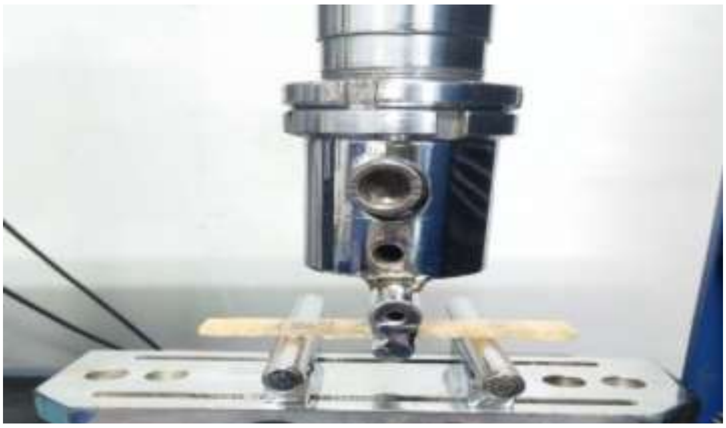

Figure 12: Flexural testing assembly

Table 5

RESULTS OF FLEXURAL TESTING

Composites	Flexural strength (MPa)							
	Coir Composites				Banana Composites			
	No Ash	10 gm Ash	20 gm Ash	30 gm Ash	No Ash	10 gm Ash	20 gm Ash	30 gm Ash
A_1	26.11	26.14	26.20	27.11	26.14	26.94	27.01	27.98
A_2	31.58	31.62	31.68	32.78	26.24	26.68	27.24	27.68
A_3	29.18	33.21	32.25	34.30	26.94	27.01	27.28	28.03
B_1	34.58	35.63	36.65	39.70	27.28	28.01	28.68	28.62
B_2	37.56	37.58	37.61	37.66	27.40	28.24	28.88	29.03
B_3	36.14	38.18	39.24	39.70	29.18	33.21	32.25	34.30
C_1	38.02	39.05	41.08	43.09	34.58	35.63	36.65	36.98
C_2	42.02	46.05	48.07	48.09	37.56	37.88	37.97	38.06
C_3	41.18	43.22	48.28	49.30	37.72	39.02	40.74	41.03

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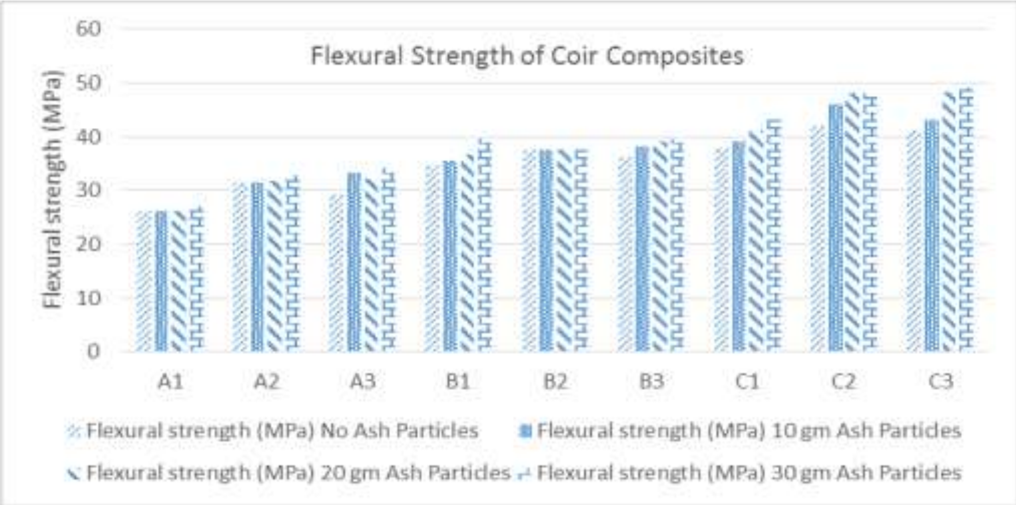

Figure 13: Comparison of flexural strength results of coir composites

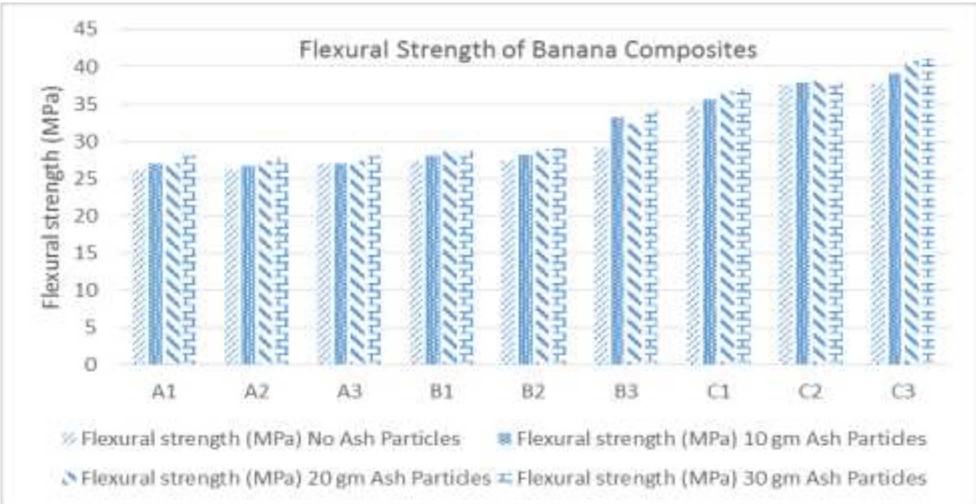

Figure 14: Comparison of flexural strength results of Banana composites

C. *IMPACT TESTING:*

To determine the strain energy of final composites impact testing was carried out on both the composites. Table 7 and Table 8 shows the results obtained for different combination of banana and coir composites respectively, the results explained in figure 11 and figure 12 shows the not much gain due to addition of ash particles but good gain due to change in fiber length.

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TABLE 6

RESULTS OF IMPACT TESTING

Composites	Impact strength (J)							
	Coir Composites				Banana Composites			
	No Ash	10 gm Ash	20 gm Ash	30 gm Ash	No Ash	10 gm Ash	20 gm Ash	30 gm Ash
A_1	10.55	10.41	10.71	10.95	08.45	09.73	10.23	10.69
A_2	8.39	11.12	12.31	12.79	09.25	09.73	10.21	11.25
A_3	11.25	12.03	13.21	13.75	10.05	10.37	11.21	11.75
B_1	12.57	13.77	14.41	14.51	10.75	10.97	11.21	11.75
B_2	11.89	12.03	12.23	14.89	11.75	11.79	11.91	12.05
B_3	15.25	16.98	17.21	17.78	12.05	12.43	12.91	13.05
C_1	15.91	16.89	18.21	17.91	12.25	12.73	13.21	13.75
C_2	16.21	16.81	17.29	18.03	12.59	13.78	14.43	14.52
C_3	16.92	17.45	18.01	18.78	14.71	15.23	15.29	16.69

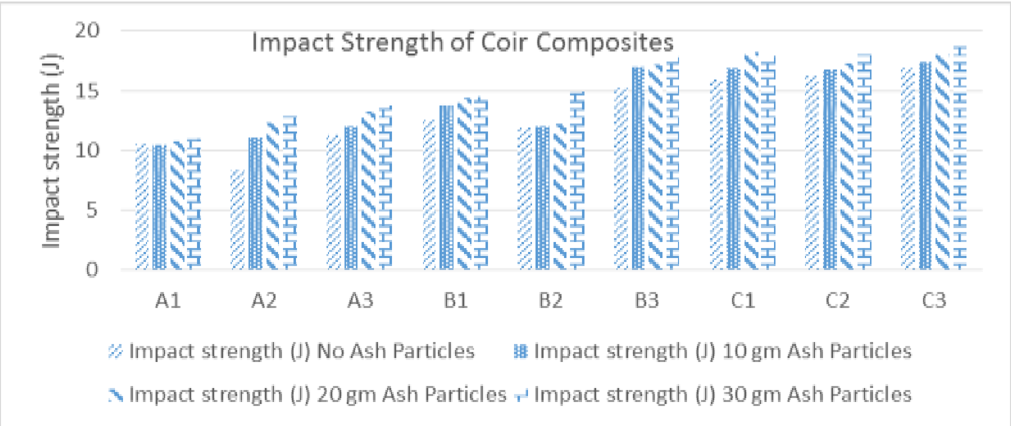

Figure 15: Comparison of Impact strength results of coir composites

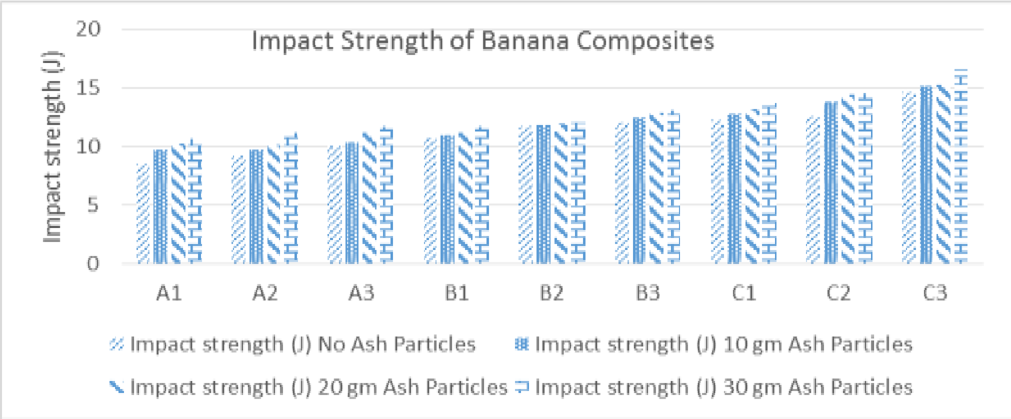

Figure 16: Comparison of Impact strength results of Banana composites

*Notations used: 10% fiber volume fraction 1- 5mm fiber length

A- 20% fiber volume fraction 2- 10mm fiber length

B- 30% fiber volume fraction 3- 15mm fiber length

IV. CONCLUSIONS

The quality of the composite material is strengthened by reducing the fiber length, as proposed by several writers. Increased carbon content will expand the core idea of through steel strength to composites, but its effect is less than that of steel. For the interface tensile transmission the chemical reaction between the filler particles and the matrix is required. Therefore, the impact or energy absorption properties of a composite should not only be calculated for these applications but also the standard design components. The work reveals that natural fiber-reinforced epoxy compound of specific fiber and ash particle lengths is formed effectively through simple hand-shake techniques. The outcomes obtained during the experimental experiments are quite reasonable because the mechanical properties are steadily improving, with additional ash particles being growing for tensile and bending research, although the findings are less relevant for impact measurement, although the results vary for specific fiber lengths.

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