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FABRICATION OF HYBRID COMPOSITE WITH ALUMINUM AND SUGARCANE BAGASSE REINFORCEMENT FOR INVESTIGATION OF ITS PROPERTIES

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Abstract

This research work was carried out to prepare hybrid-type polymer composites by introducing aluminum (Al) and sugarcane bagasse as reinforcements and ***polypropylene*** *as the matrix phase. The hybrid composite was PP-Al-Bagasse. Here, the percentage of reinforcements varied (10-40 wt.% %), and the reinforcements were used to investigate the changes in different properties. UTM was used to determine the tensile strength and impact strength. OM SEM was used to examine the morphological characteristics of the hybrid composites. According to experimental research, the PP-Al-Bagasse hybrid composite possesses less mechanical strength than virgin polypropylene. Although mechanical properties are decreasing, we found that (30 weight percent of reinforcement) the hybrid composite gave comparatively higher values than other wt. Percentage of reinforcements. And the results of tensile strength and impact strength were 24.57and 3861.85 MPa, respectively.*

Keywords: *aluminum powder, sugarcane bagasse, polypropylene, hybrid composite, UTM, OM, SEM*

Introduction

When two or more materials are combined, the result is a composite material, which has superior qualities over the individual components [1]. The reinforcing phase and the matrix phase are the names of the two segments, respectively. The material used in the reinforcing phase might include fibers, particles, flakes, powder, etc. In general, polymeric substances like epoxy, polypropylene, polyethylene, and polystyrene make up the matrix phase [2]. According to previous materials engineering technology, a "composite material" is usually characterized as consisting of a matrix phase reinforced by natural fibers [3]. Most recent composite materials are formed by reinforcing the matrix phase with both natural fiber and metal, which possess superior properties, and this type of composite is termed a “hybrid composite.” A hybrid composite's effectiveness is the result of the interaction between the components that make it up. However, the individual cannot show the property when they are alone. Many hybrid composites are used today for ultra-demanding applications such as spacecraft engineering [4, 5]. In recent years, the use of natural fibers and metallic powders in polymer matrix composites has gained significant attention due to their potential for enhancing mechanical properties while maintaining sustainability [6,7]. Among various natural fibers, sugarcane bagasse has emerged as a promising reinforcement owing to its availability, biodegradability, and cost-effectiveness [8]. Studies have shown that alkali-treated bagasse fibers, when incorporated into polypropylene (PP), can improve

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stiffness and reduce material cost, although the tensile strength may be affected by poor interfacial bonding [9].

Hybrid composites incorporating both natural fibers and metal particles, such as aluminum, have shown potential in achieving a balance between strength and toughness [10]. Aluminum's high strength-to-weight ratio and thermal stability make it a suitable candidate for reinforcement in thermoplastics [11]. However, challenges remain in achieving good dispersion and bonding of aluminum powder in a polymer matrix, often leading to particle agglomeration and stress concentration [12].

Several experimental studies over the last three years have explored the effects of hybrid reinforcements on the mechanical performance of PP-based composites. One study observed that while bagasse fiber improved flexural and tensile modulus, the addition of untreated aluminum powder tended to reduce tensile strength due to poor particle-matrix adhesion [13]. Other researchers have reported that the use of compatibilizers such as maleic anhydride-grafted polypropylene (MAPP) significantly enhances interfacial bonding, leading to improved tensile and impact performance [14,15]. Despite the challenges, we have tried to make hybrid composites reinforced with both natural fibers and metal powders to show promise in applications requiring moderate mechanical strength, lightweight structure, and environmental sustainability.

Materials and Methods

Raw materials are the major ingredient for the quality development of composites. After that, processing methods are used to create the new materials, and characterization methods are used to guarantee their quality. The materials and techniques utilized to process each composite will be covered in this section.

Raw Materials

The main raw materials used for the composite preparation were polypropylene (PP), aluminum powder (Al), sugarcane, and bagasse.

Polypropylene

The thermoplastic polymer polypropylene (PP) finds extensive utility, particularly as a matrix in composites. In many ways, particularly in terms of behavior and electrical characteristics, polypropylene and polyethylene are comparable. While chemical resistance declines, mechanical qualities and heat resistance are enhanced by the methyl group. The molecular weight and molecular weight distribution, crystallinity, type and amount of co-monomer (if any), and isotacticity all affect polypropylene's characteristics. For instance, the methyl groups in isotactic polypropylene are oriented on the opposite side of the carbon chain. Compared to atactic polypropylene and polyethylene, this configuration produces a higher degree of crystallinity and produces a stiffer material that is more resistant to creep[16].

Aluminum powder

Aluminum powder is a finely ground form of aluminum metal, typically used in various industrial and manufacturing processes. It comes in different types, such as flake, granulated, and atomized powders, each with unique characteristics, and is considered to be remarkable due to its resistance to corrosion and low density. Aluminum and its alloys are used to make structural components that are essential to the aerospace industry as well as other fields of building and transportation. In general, scientists have attempted to evaluate these composites' thermal characteristics as well as the function of aluminum incorporation in polymer composites. Aluminum filler may have numerous advantages when used in polymer composites, but its application to enhance mechanical qualities has not yet been documented [17]

Sugarcane Bagasse. Bagasse is a hydrated, thus mushy, fiber material that is left behind after the juice from stalks of sorghum or sugar cane is crushed [18]. It is utilized as a biofuel to make construction materials and pulp, as well as to generate heat, energy, and power. Low-cost and environmentally friendly factors have accelerated efforts by materials science experts to find green materials with low pollutant indices. It has been demonstrated that a variety of SCB components can be used as raw materials to create composite materials with a range of characteristics and capabilities. Moreover, Bangladesh is producing sugar bagasse from sugar mills.

Preparation of reinforcement materials

Powdering and screening

The sugarcane bagasse was introduced into the grinder to produce powder, and the powders were subjected to passing through a screen with a sieve of 70 and opening microns**.** All the dust was properly cleaned with the help of the screening.

Preparation of composites

We used the extruder machine here to prepare the samples of hybrid composites due to its well-mixing capacity, ease of operation, low cost, and high efficiency.

Extrusion refers to the process of squeezing material out by applying pressure. In the experiment, it is utilized to push composite materials through a small opening. For this purpose, an electrically operated custom extruder is employed. A hopper, nozzle, motor, gear controller, rotating shaft, heating coil, and temperature display board make up the extruder. Depending on the kind of composites, the temperature is set at the proper level. For displaying the set value and present value, respectively, there are three display units called SV and PV. The heating coil automatically stops when the PV reaches SV, and the motor then helps squeeze the composite materials out through the nozzle. Then the molten sample was placed on a desired device to prepare the sample with the help of a roller, which was made of stainless steel.

Preparation of composites for different compositions

To prepare the desired composite with a specific composition, first, polypropylene, aluminum powder, and sugarcane bagasse were mixed properly and gradually poured into the hopper in modest amounts each time. These then came into contact with the rotating shaft, where they were mixed and heated by the heating coils present over the shaft. The set temperatures of the 1st, 2nd, and 3rd heating coils were 150 °C, 200°C, and 250°C, respectively. The speed of the shaft was maintained by the motor, which helped to squeeze out the mixture through the nozzle. Shaft speed is carefully controlled for proper and uniform mixing.

Table 1. Composition of PP-Al-bagasse hybrid composites

polypropylene (wt.%)	Aluminum powder (Al) (wt. %)	sugarcane bagasse (wt. %)
90	5	5
80	10	10
70	15	15
60	20	20

Sample preparation and characterization

Preparation of composite samples for characterization

The composite samples with different compositions (as in the table) were first prepared as thick, square-shaped bars with the help of dice from the extruder machine. The thick samples were hot-pressed to achieve the desired thickness of the samples. Pictures of the samples are given below:

Fig. 1. Composites from the extruder machine

Fig. 2. Composites after hot press

The characterization of the fabricated composites

Morphological Test

The morphological properties of the hybrid composites have been investigated using an optical microscope (OM) and a microscope with scanning electron microscopy (SEM).

Optical Microscope Analysis

The technique known as optical microscopy (OP) (ML-803, Taiwan) uses visible light to magnify a lens in order to observe a material up close. An optical microscope, sometimes referred to as a light microscope, is an instrument that magnifies images of tiny materials using visible light by using one or a number of lenses. In order to magnify the image and provide a more thorough examination, the lenses are positioned between the sample and the viewer's eye. For the metallographic examination of the samples, at first, the samples were polished with 120 and 1200 sandpapers gradually, where acetone was used for better polishing. Finally, polished with a velvet cloth. After that, the microstructure was observed by using an optical microscope at different magnifications. Using an optical microscope, the distribution of particles inside the polymer matrix for different compositions was investigated.

Analysis using the scanning electron microscopy (SEM)

The surface of the polymer composites was examined using a scanning electron microscope (SEM) (JSM-7600F, Japan). The electron beam interacts with the surface area during the "scanning" process, producing secondary electrons from the composite. It is also possible for the incident electrons to backscatter. The scanned electron beam is compared to the measured intensity of the secondary or backscattered electrons. The surface of the composite, as it shows on the screen, is related to a contrasting image.

Surface roughness, adhesive failure, fractured surfaces, networks, and phase boundaries in blends are just a few of the polymer and composite investigations and applications that have made use of the scanning electron microscope [19].

Mechanical Test

The mechanical tests (tensile and impact) were carried out for **PP-Al-Bagasse** hybrid polymer composites using ASTM.

Tensile strength

The strength of the polymer composites is evaluated using tensile tests. A specimen in the shape of a dog bone that was made in compliance with international standards (ASTM D638-01).

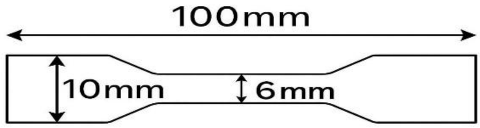

Fig. 3. Dog bone-shaped specimen

A constant tensile force applied along the material's axis can cause the sample to deform as it increases. Mechanical tests of polymer composites were conducted using a universal testing machine (UTM) (H5OKS, Hounsfield, USA). The typical speed at which tensile characteristics are measured is 100 mm min^{-1}. The sample is extended by means of continuous forces.

Impact Strength

Test a moving crosshead for impacts. While the extensometer measures the sample's elongation, the load cell displays the amount of applied load on the sample. The sample's middle part, which has a cons`istent cross-sectional area along its length, experiences deformation during the tensile test. A universal testing machine (UTM) Model D638-01 was used to conduct the tensile test in accordance with ASTM. Three specimens were tested to determine the tensile strength, and the mean value was recorded for each sample. The specimen's measurements were 4 mm in thickness, 9.53 mm in width, and 63.5 mm in length. Two common methods, Charpy and Izod impact tests, can be used to assess the fracture properties of polymer composites. The impact energy of polymers is measured using these techniques. A pendulum with a large striking edge is permitted to strike the specimen during this test. The hammer's potential energy can be measured by its mass and drop height. The process of breaking the sample involves two steps: first, energy is needed to create a crack, and then further energy is required to grow the crack until it fails.

To increase the reproducibility of the manner of failure, the specimen is frequently notched. The presence of a brittle-ductile transition with decreasing temperature in polymer composites can be ascertained by an impact test [20].

In this research work, the impact tests were performed with an Izod test. The samples were prepared from the manufactured composite and milled to the standard size. A single pendulum swing broke the test specimen, and this was supported using a perpendicular horizontal beam. The sample's face is struck by the pendulum. To ascertain the materials' impact strength, an impact test was carried out using an impact tester MT 3016 in compliance with ASTM D 6110-97. Three specimens were tested to determine the impact strength, and the mean value was recorded for each sample. The specimen's measurements were as follows: it was 55 mm long, 15 mm wide, and 4 mm thick.

Water Absorption Testing

Assessing the water uptake properties of natural fiber composites is essential for innovative composite applications and end uses for decking, flooring, and outdoor facilities with high exposure to the atmosphere or interaction with aqueous substances. Due to the hygroscopic properties of natural polymers. The water absorption of composites that incorporate these fibers as reinforcement or fillers may be a limiting factor for a variety of composite applications. A number of mechanical qualities can be negatively impacted by water absorption, which can also increase the moisture content in the fiber cell wall and the fiber–matrix interphase area.

Cell wall accumulation of moisture may cause fiber swelling and compromise the composite product's structural stability. If required, acetylation of some of the fiber's hydroxyl groups can decrease the amount of moisture absorbed in the cell wall [19]. The movement and volume of water absorbed in the composite's interphase area can be reduced by adequate fiber–matrix bonding and good matrix wetting of the fiber. In order to conduct the water absorption test, rectangular specimens measuring 18 mm by 12 mm by 4 mm were used. After an hour of drying at 105 °C in an oven, the samples were cooled in a desiccator and promptly

weighed. The weight was measured with an accurate electronic balance. In accordance with ASTM D 570-99, the dried and weighed specimens were submerged in hot distilled water for a full day. Following submersion, a gentle towel was used to wipe away any extra water from the specimens' surface. After that, the specimens' final weight was determined. After that, the specimens' weight gain was computed.

The following formula was used to determine the water absorption percentage (eq. 1).

$$(W_w - W_d)/W_d \, 100\% = W_t \tag{1}$$

where, respectively, W_d and W_w represent the initial dry weight and the weight following a 24-hour water soak [21, 22].

Equipment used for the research work

Mixer Grinder

The Panasonic (MX-AC400) mixer grinder was used for powdering bagasse.

Extruder machine

Extrusion is used mainly for thermoplastics, but elastomers and thermosets may also be extruded. For this research purpose, a customized extruder was prepared, which image is given below. A rotational shaft, heating coil, temperature monitoring board, hopper, which was a nozzle, motor, and gear controller make up this device. The hopper, which is positioned above the machine with wide holes, is one foot in size. The length of the rotating shaft is 4 feet 5 inches. There are temperature display boards, manually adjusting their temperature by three individual regulators. The gear controller controls the shaft speed, and with the help of this, it is possible to reverse the shaft rotation. There are three heating coils placed around the shaft. In this machine, a powerful motor is used, which is 7.50 HP, and its maximum speed is 1450 RPM. The total length of the machine is 4 feet 4 inches, and its height is 3 feet.

Results and Discussions

Effect of sugarcane bagasse and Al powder loading on tensile strength of PP-sugarcane bagasse-Al hybrid composites

Applying the stress/strain curve, for each amount of reinforcement (10%, 20%, 30%, and 40%), the composite specimens' tensile properties were measured. It is evident from Fig. 4 that the hybrid composites' tensile strength first increases and subsequently decreases. It's also evident that raising the percentages of Al and bagasse reinforcement helps the composite reach 30% of the mixture's reinforcement, which strengthens the polymer matrix.

However, a decline of tensile strength was observed for 40 % Al and bagasse-reinforced hybrid composite due to agglomeration and casting defects [23].

The impact strength of the PP-sugarcane bagasse-Al hybrid composites at various reinforcement percentages is shown in Fig. 5. The hybrid composite's impact strength with 10% reinforcement weight was 3254.8MPa, whereas the 40 wt.% sugarcane bagasse-Al of the hybrid composite was 3861.85 MPa, which shows that there is an increase in impact strength.

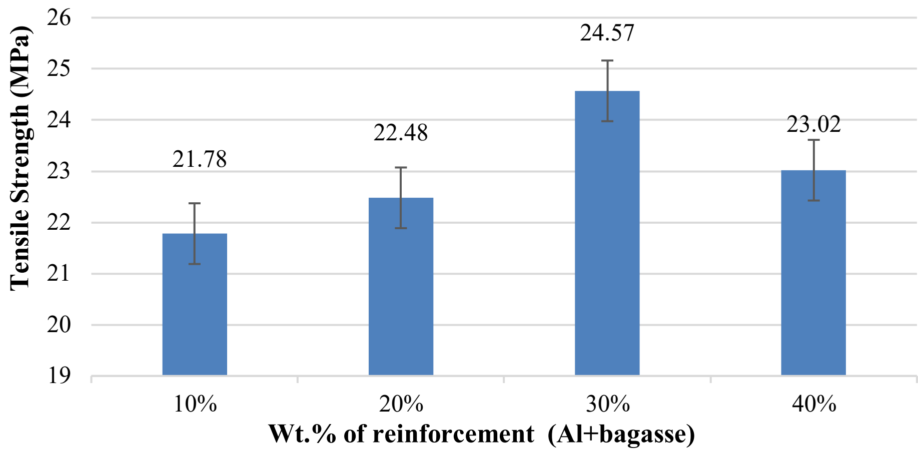

Fig. 4. Tensile strength of PP-Sugarcane Bagasse-Al hybrid composites at different wt. % of reinforcement

Impact properties of PP-Sugarcane Bagasse-Al hybrid composites.

As the percentage of reinforcement increases, the hybrid composites' impact strength declines. Since more of the load is supported by the high-stiffness reinforcement particles in the composite, the PP matrix's limited plastic flow was found to be the cause of the increase in hardness. As a result, the matrix material in the composites will experience less stress than a comparable matrix material in the unreinforced composite [24].

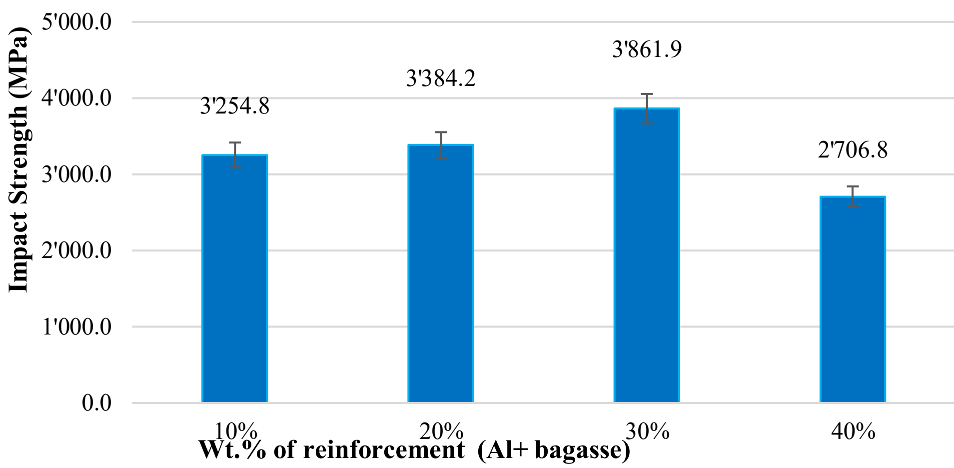

Fig. 5. Impact strength for PP-Sugarcane Bagasse-Al hybrid composites at different wt. % of reinforcement

The combination of matrix deformation, fiber pullouts, and fiber fractures dissipates the impact energy when the composites experience an abrupt force [25, 26].

Water Absorption Test

Fig. 6 shows the water absorption characteristics of each composite at different weight percentages of fiber loading. The natural fiber's propensity to absorb water is due to the hydrophilic hydroxyl groups found in cellulose, hemicelluloses, and lignin. The figure shows that as the fiber content grew, so did the degree of water absorption. Since the primary component of bagasse is cellulose fiber, the hydrophilic character of the composites increases as fiber loading rises. As a result, the composite steadily increases its water absorption. Every cellulose fiber has a lumen in the middle of it.

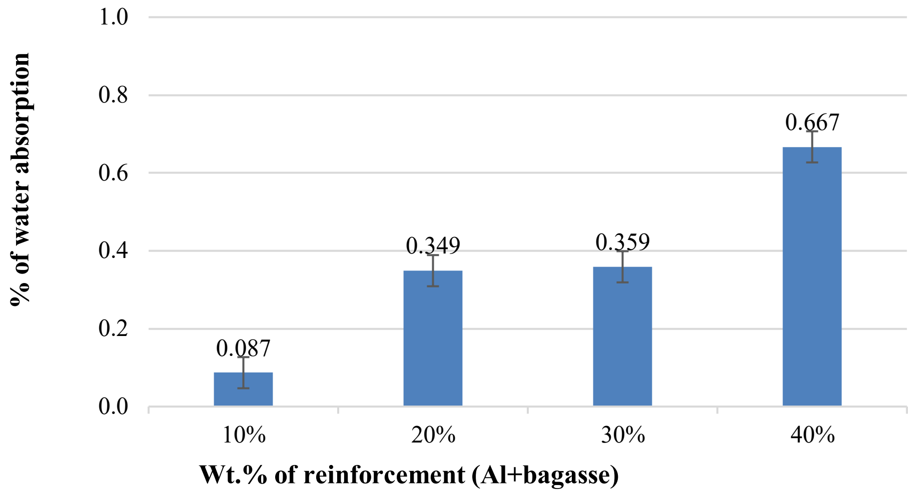

Fig. 6. Water absorption by PP-sugarcane bagasse-Al hybrid composites

The three main locations where the absorbed water in the composites can be found are the lumen, the cell wall, and the opening or flaw at the fiber-polymer interface. Due to the fiber's inferior wettability and dispersion, the gap and fault at the interface would widen as the fiber content increased. The result was an increase in the lumen, the cell wall, and the gap. Consequently, as both fiber contents increased, the degree of water absorption increased substantially [27].

Morphological Analysis:

Morphological observation of PP-Sugarcane Bagasse-Al hybrid composite by optical microscope (30% reinforcement)

Optical microstructural observations of the PP-Sugarcane Bagasse-Al hybrid composite. From the figure, the spatial arrangement of the aluminum and bagasse particles inside the polymer matrix, the existence of inclusions or voids, and the presence or absence of particle clustering and coagulation were all visible. The stiffness and hardness behavior may be superior due to proper binding between the matrix and reinforcements. From Fig. 7, it is observed that good distribution took place between the reinforcements and the polymer matrix. But there is a void or agglomeration, so the hybrid composite showed less impact and tensile strength than virgin PP.

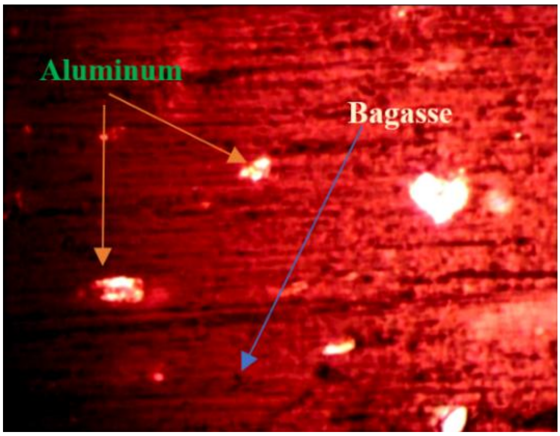

Fig. 7. Optical microscope image (50X magnification) of PP-Sugarcane Bagasse-Al hybrid composite (30% reinforcement)

Morphological Analysis of PP-Sugarcane Bagasse-Al Hybrid Composite by Scanning Electron Microscope (SEM). (30% reinforcement)

Fig.8 (a) This scanning electron microscope (SEM) image captures the surface of a composite material made from bagasse fibers and aluminum. The red arrow points to a bagasse fiber, which is a by-product of sugarcane, and the orange arrow highlights the aluminum (Al) phase. The image shows the bagasse fiber's distinct shape, which appears fibrous and elongated. The interaction between the bagasse fiber and aluminum is evident. At this magnification of 1000× (scale bar: 8 mm), we can observe that the aluminum phase seems to wrap around or bond with the bagasse fibers. The strong adhesion between the two materials could be an indicator of the composite's enhanced mechanical strength and stability.

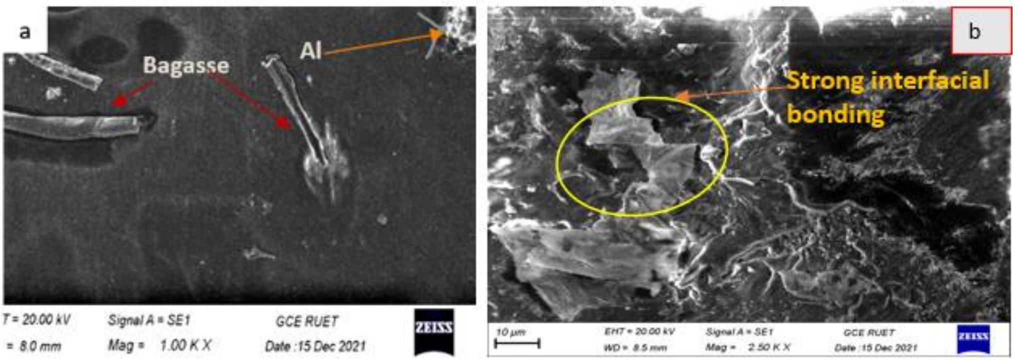

Fig. 8. SEM Image of PP-Sugarcane Bagasse-Al Hybrid Composite. (30% reinforcement)

Fig.8(b) focuses on the interfacial bonding between the aluminum matrix and the bagasse fiber. The circle highlights an area of strong interfacial bonding. At a higher magnification of 2500× (scale bar: 10 µm), we can see the fine details of the interface, where the aluminum appears to tightly bond with the bagasse fibers. The smooth and continuous transition between the two materials suggests that the fiber-matrix interaction is robust, which could lead to improved composite properties such as tensile strength, durability, and resistance to fracture. The strong bonding may be a result of mechanical interlocking or chemical interactions at the interface, which are critical in ensuring the structural integrity of the composite material [28,29].

Discussions

From the experimental investigation, we have found that virgin PP has higher tensile strength and impact strength. When PP was incorporated with treated bagasse or combined with aluminum powder, the tensile strength and impact strength were increased. The data are as follows:

Table 2. Tensile & Impact Strength of PP + 30 wt.% Bagasse & Aluminum Composites

Sample	Tensile Strength (MPa)	Impact Strength (MPa)	References
Virgin PP	30 – 35	3750 – 5000	[30]
PP + 30 wt.% Untreated Bagasse	33 – 35	2500 – 3250	[30]
PP + 30 wt.% Treated Bagasse (NaOH-treated)	36 – 39	4000 – 4500	[31]
PP + 30 wt.% Aluminum Powder(nano)	35 – 40	4500 – 5250	[32]

But we have found that our prepared hybrid composites showed less tensile strength and impact strength, 24.57 and 3861.85 MPa, respectively. This may have happened as we did not treat the bagasse with alkali, and moreover, Al powder was used as raw not in nano form, or Al_2O_3 was not added. The mechanical performance of PP–bagasse–aluminum composites can be significantly enhanced through several strategically optimized approaches. Firstly, the application of compatibilizers such as maleic anhydride grafted polypropylene (MAPP) improves interfacial adhesion between the hydrophilic reinforcements (bagasse fiber and aluminum) and the hydrophobic PP matrix, thereby facilitating efficient stress transfer during mechanical loading. Furthermore, the dispersion of aluminum particles must be carefully managed, as their high surface energy often leads to agglomeration. Employing ultrasonic dispersion or high-shear twin-screw extrusion ensures a more homogeneous distribution, minimizing stress concentration sites.

Conclusions

In the present era, we are demanding more new and multidimensional property materials. To meet this need, composite materials can play a great role and also compete with other conventional materials. Self-healing, self-lubricating, lightweight, and self-cleaning materials have been developed as a result of the renewed emphasis on multifunctional materials. For different polymeric matrices, new reinforcement elements such as aluminum powder and natural fibers are being utilized.

The desire for the lightest composites to replace bulkier steel components has led to extensive research on hybrid composites made from aluminum powder and bagasse. This research aims to fabricate three hybrid composites with different combinations and find out the best combination for better or improved properties. In this study, these hybrid composite PP-Al-Bagasse were prepared with a PP matrix and agricultural waste reinforcement compositions. From our investigation, we can say that at 30% reinforcement loading, if bagasse fiber treated with alkali and Al powder is used in nano form with good dispersion, the hybrid composite will give more mechanical strength.

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