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Mechanical Properties of a Composite Formed from Bamboo Granules and Glass Fiber

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Abstract - **Bamboo powder-reinforced polyethylene (PE) composite was developed as an ecologically friendly engineering material, and its mechanical properties were systematically investigated. To enhance adhesion between bamboo powder and the polyethylene matrix, maleic anhydride-grafted polyethylene (MAPE) was used as a compatibilizer. Given the growing demand for high-density polyethylene (HDPE) products, integrating natural and synthetic reinforcements, such as bamboo powder and glass fiber, presents a sustainable alternative in materials engineering. In this study, a composite matrix composed of HDPE, bamboo powder (BP), and glass fiber (GF) was fabricated using compression molding. The mechanical performance of the samples was assessed through flexural and compressive tests, considering different mass ratios of the components. Results indicate that the inclusion of BP and GF enhances compressive and flexural strengths by 20%, making the composites suitable for load-bearing applications, such as stress-bearing sheets, films, and pipes. However, a decrease in tensile and impact strengths was observed due to insufficient interfacial adhesion between the reinforcements and the HDPE matrix, highlighting a trade-off in mechanical performance. The findings suggest that optimizing fiber-matrix compatibility, potentially through improved surface treatments or alternative compatibilizers, could further enhance the overall mechanical performance of these composites. This research contributes to the advancement of sustainable composite materials by demonstrating the potential of BP/GF/HDPE composites in structural applications while addressing environmental concerns associated with plastic waste and non-renewable materials.**
Keywords: **Bamboo Powder-Reinforced Polyethylene (PE), Mechanical Properties, High-Density Polyethylene (HDPE), Compression Molding, Sustainable Composite Materials**

I. INTRODUCTION

A composite material is created by combining two or more materials, each of which has unique chemical and physical properties. The term "composite material" refers to the material produced as a result of this combination. Despite this, the finished product can still clearly differentiate between the different components. A composite material, known as a polymer composite, is created when high-strength fibers such as glass, basalt, aramid, and other similar materials are incorporated into a polymer matrix. The most widely used polymers worldwide are polyester resins, vinyl ester resins, polyethylene resins, and epoxy resins [1]. The creation of natural fiber-reinforced composites represents a significant step forward in materials science, driven by the increasing demand for high-quality, naturally sourced materials. The market for natural fiber composites is expected to grow at a compound annual growth rate of 8.2% from 2015 to 2020 [2]. Bamboo fibers, a type of natural fiber reinforcement, are extensively used due to their range of applications. Known as "nature's glass fiber" because of their strong cell walls, rigid structure, and superior microfibrillar angle with the fiber axis, bamboo fibers offer numerous advantages [3].

Studies have shown that bamboo and glass fibers can be combined to produce a hybrid material. The interlayer technique is the simplest and least expensive method for creating hybrid composites, and it is also the most ecologically beneficial. It is crucial to note that the order in which the layers are arranged significantly impacts the composite material's overall performance [4-5]. Most solid materials expand when heated and contract when cooled [6]. A rigid framework is used to define the geometry of fiber-reinforced polymer (FRP) components. Typically, a tool or mold assists in the fabrication of FRP components. Methods such as wet layup, bladder molding, compression molding, mandrel wrapping, and filament winding are commonly used to produce various products [7].

Recent research has increased interest in using natural fibers as an alternative reinforcement in polymer composites. This trend is primarily driven by the rising cost of synthetic materials and growing environmental concerns. Natural fibers include both plant and animal fibers. Examples of plant fibers include sisal, flax, hemp, jute, coir, cotton, wool, bamboo, and banana fibers [8]. Bamboo fiber, a type of regenerated cellulose fiber, is produced by processing the starchy pulp of bamboo plants, which is extracted from bamboo culms. Bamboo fiber is known for its durability and resilience [9]. Its exceptional properties, including high tensile strength, cost-effectiveness compared to synthetic fibers, ease of availability, and eco-friendliness, have been well documented [10]. There has been a significant increase in interest in composite materials within the field of materials engineering in recent years. Applications of composite materials span various industries, including the manufacturing of sports equipment and aerospace components [11-12]. Over the past several decades, there has been a notable surge in solid waste production and the use of robust packaging materials due to rapid developments in conservation. As a result, it is crucial to make efficient use of solid waste, which includes agricultural waste, plastic waste, bamboo powder, and other materials [13-14]. The objective of this research is to create a novel composite material as an affordable alternative to wood. The material, bamboo powder-reinforced plastic composite (BPRP), was chosen because bamboo is abundant in Asia and its mechanical properties are comparable to wood. Bamboo matures in approximately six to eight months, much faster than wood, which can take up to ten years. Engineers have used thermoplastic matrix composites in semi-structural applications. One of the key aspects of thermoplastic polymers is their ability to be recycled. Furthermore, these materials are easy to process using various forming techniques [15-21].

II. MATERIAL AND EXPERIMENTAL

CIPET Bhopal supplies homo-polyethylene of compression molding grade in accordance with manufacturer standards. Its density is 0.953 g/cm³, and the melt flow index (MFI) is 2.1 g/min at 190°C and 2.16 kg load. Vruksha Composite, Andhra Pradesh, produced bamboo powder and glass fiber.

A. Mechanical Property Experiment Study

Bamboo powder was used as the primary reinforcement. Composite samples were fabricated using the manual lay-up method and compression molds. The samples were prepared according to ASTM guidelines for testing. A tensile test was conducted following ASTM D638, with a test speed of 2 mm/min. Flexural and impact tests were performed in accordance with ASTM D790 and ASTM D256, respectively. Finally, a compressive test was conducted following ASTM D695.

B. Composite Fabrication

The components used in this investigation, along with the procedures applied to treat these components, are as follows:

1. Recycled high-density polyethylene (rHDPE)
2. Bamboo powder
3. Maleic anhydride-grafted polyethylene (MAPE)

C. Fabrication Methods

The initial steps involved combining powdered bamboo with HDPE and MAPE. A release agent was applied to polish the iron mold before placing the mixture inside. This was done to prevent the composites from adhering to the mold during removal. The mixture was then slowly placed into the mold. The mold was subsequently placed in a compression molding machine at 210°C. Once the designated time elapsed, the mold was allowed to set before being removed. Using the fabricated composite sheets, tensile, flexural, and impact specimens were cut in accordance with ASTM standards.

D. Determination of Mechanical Properties of Composite.

The test specimens were subjected to mechanical testing in accordance with ASTM standards.

1. Mechanical Testing

The polyethylene and bamboo powder, glass fiber-reinforced polyethylene composite specimens were subjected to four distinct types of mechanical testing to determine their overall performance. These tests included tensile, flexural, impact, and compressive evaluations. Three specimens of each composite were analyzed, and the average value of these specimens was reported.

2. Tensile Strength

To determine the tensile strength of composite samples in accordance with ASTM D638, an Instron 3382 model testing machine was used. Rectangular composite samples were selected for the evaluation. The samples were subjected to a stress test and evaluated until failure, with the crosshead speed set at 1.5 mm/min. An extensometer was attached to the gauge section of the sample to measure the strain. Five distinct samples were tested to ensure reproducibility of the results. Both the tensile strength and the elongation at the points of fracture were measured.

3. Flexible Properties and Characteristics

Following the guidelines outlined in ASTM D790, the composite samples were subjected to a three-point bending test. The samples were tested using an Instron Model 3382 machine to conduct the flexural test. At room temperature, rectangular samples were tested with the crosshead moving at a speed of 3 mm/min. During the flexural test, the support span was set to 51.00 mm. The results are based on the average of three samples from each category.

4. Impact Test

The durability of the polymeric material is directly related to its impact properties, which contribute to its overall durability. In the context of polymer durability, we refer to its ability to absorb various types of energy. The term “impact energy” is used to assess durability. As the impact energy of the material increased, its durability also improved, and vice versa. These two variables are correlated.

5. Compression Test

Compressive testing is essential to determine how a material responds to compression. This testing evaluates the material’s behavior when subjected to crushing stresses. Additionally, it helps assess the plastic flow behavior and the ductile fracture limits of the material. Compression tests are a key diagnostic technique used to identify the elastic and compressive fracture properties of brittle materials or those with limited ductility. These tests can also be used to determine the modulus of elasticity, the proportional limit, the compressive yield point, compressive yield strength, and compressive strength of a material. Considering these attributes is crucial to assess whether the material is suitable for specific applications or if it will fail under particular pressures. The standard testing process for the compressive properties of stiff polymers is defined in ASTM D695.

III. RESULTS AND DISCUSSION

A. Mechanical Properties of Composite

The characterization of the composites reveals that bamboo powder and glass fiber have a substantial impact on the mechanical properties of the composites. The attributes of the composites studied are presented in Fig.1-2. The results demonstrate the influence of bamboo powder and glass fiber, with MAPE compatibilizer, on the tensile, flexural, impact, and compressive properties. It was found that the composite material containing bamboo powder (BP) and glass fiber (GF) in addition to HDPE exhibited the highest compressive and flexural strength compared to HDPE in its unmodified state. Table I presents the mechanical properties of HDPE with varying compositions of BP and GF additives. As the proportion of additives increases, the tensile and impact strengths of the material decrease, indicating reduced ability to withstand tension and impact. In contrast, the flexural strength and flexural modulus show consistent improvement, reflecting enhanced resistance to bending and increased stiffness. Compressive strength also increases slightly with higher additive content, suggesting better performance under compressive loads. These trends highlight a trade-off between different mechanical properties depending on the additive levels, enabling material optimization based on specific application requirements.

TABLE I OPTIMIZATION OF HIGH-DENSITY POLYETHYLENE COMPOSITE WITH BAMBOO POWDER AND GLASS FIBER

Composition			**Tensile Strength**	**Flexural Strength**	**Flexural Modulus**	**Impact Strength**	**Compressive Strength**
HDPE (%)	**B.P (%)**	**G.F (%)**	**(MPa)**	**(MPa)**	**(MPa)**	**(J/m)**	**(MPa)**
100	0	0	20.7	14.54	460.23	24.66	88.3
90	5	5	19.5	19.34	465.03	20.86	90.2
80	10	10	17.8	24.54	470.32	18.92	92.8
70	15	15	12.3	28.14	475.83	13.06	93.5
60	20	20	9.8	31.85	479.92	11.15	95.8

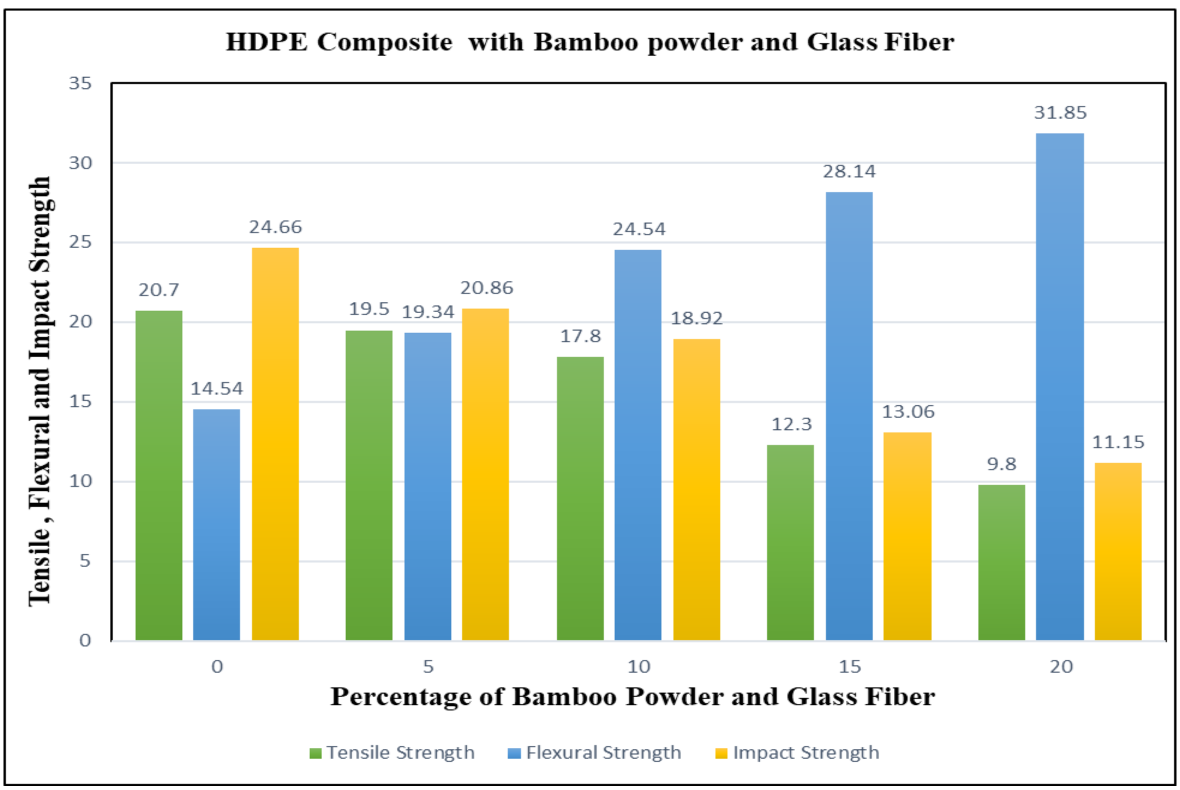

Fig. 1 Tensile Strength, Flexural Strength and Impact Strength of BP/GF/HDPE Composite

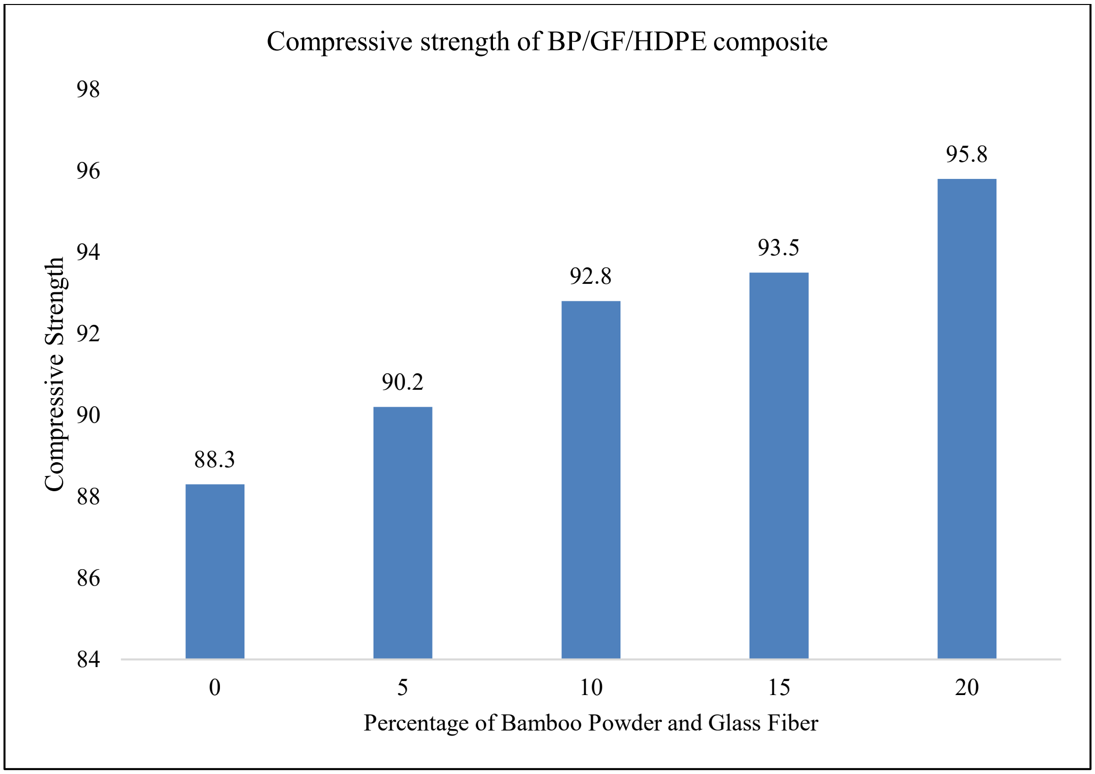

Fig. 2 Compressive strength of BP/GF/HDPE composite

The tensile, flexural, impact, and compressive strengths of the composite (at 0%, 5%, 10%, 15%, and 20% fiber and powder content) increased. The figure and table illustrate the variation in tensile strength with fiber and powder weight percentage.

IV. CONCLUSION

The study focused on developing composites reinforced with recycled plastic fibers using a recycled matrix, influenced by factors such as fiber-matrix interface adhesion, compatibility, and interactions. The results indicate that the addition of a compatibilizer significantly enhances these interactions. Compressive and flexural strengths of the composites improved by 20% with the inclusion of bamboo powder (BP) and glass fiber (GF) in the HDPE polymer matrix. However, tensile and impact strengths decreased due to weak adhesion between BP, GF, and the HDPE polymer matrix, demonstrating a trade-off between these mechanical properties. The enhanced compressive and flexural properties make these composites suitable for applications such as stress-bearing sheets, films, and pipes.

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