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Mechanical Properties of Sustainable Bamboo Fibre and rHDPE Composites Exposed to Water Immersion.

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ABSTRACT

The use of bamboo fibres as a reinforcement in polymer composites has gained significant attention due to their sustainability and renewable characteristics. However, the long-term performance of these composites under tropical weather exposure, such as immersion weathering, remains a crucial area of research. The present study involved the preparation of rHDPE composites with different percentage of bamboo fibres were prepared and subjected to accelerated immersion weathering to simulate outdoor conditions. The tensile strength of composites was evaluated at different time intervals during the weathering process. The results demonstrate that immersion weathering significantly influences the mechanical properties of the rHDPE composites reinforced with bamboo fibres. Tensile strengths of the composites showed a reduction with increasing exposure time. This reduction was more pronounced in composites with higher bamboo fibre content, suggesting a synergistic effect between the composite composition and weathering conditions. Understanding the degradation mechanisms and the complex interaction between composite composition and weathering exposure is essential for optimizing the design and application of these eco-friendly materials in outdoor environments. Further research in this field is needed to develop strategies to enhance the weathering resistance of such composites and expand their potential applications in areas such as construction, automotive, and outdoor furniture, where durability and environmental sustainability are of paramount importance.

1. Introduction

The research and development of sustainable and environmentally materials have led to significant progress in composite technologies in recent years. Recycling of polymers, particularly recycled High-Density Polyethylene (rHDPE), has become more important as an attractive option for producing green materials. In addition to this trend, the incorporation of natural fibers, such as bamboo, in these composites provides an additional aspect of sustainability. The resulting rHDPE composites reinforced with bamboo fibres offer an appealing option for a wide range of applications, which includes from construction to consumer goods. Although the mechanical properties of these composites have been investigated under standard settings, the impact of environmental exposure on their performance remains an interesting area of research. The immersion of these composites in different environments provides a scenario that is both significant and challenging, given the wide range of applications of these materials in real conditions.

Bamboo fibre is a sustainable and continuously fast-growing natural resource, has gained acknowledgement for its potential to reinforce polymer matrices effectively [1,2]. When combined with recycled HDPE, a polymer derived from post-consumer waste, the resulting composite not only utilizes recycled materials but also benefits from the improved strength and sustainability of bamboo fibers. The investigation and development of composite materials has received significant interest as an opportunity to enhance the sustainability of construction materials. A composite material, which is composed of recycled plastic with bamboo fibers, has emerged as a sustainable material for green construction. This innovative material combines the strength of recycled plastic with the natural resilience of bamboo fibers, offering a blend of mechanical properties that are both environmentally friendly and functional. Researchers and engineers are increasingly focusing their attention on natural fiber-reinforced polymeric materials as an alternative to traditional fibers. The various advantages of natural fibers, such as degradability, environmental friendliness, biodegradability, superior stiffness to weight ratio, affordability, and lightweight properties, are well-established in literature [3, 4, 5].

The mechanical properties of composites, including their tensile strength, flexural strength, and impact resistance, are crucial factors determining their suitability for specific applications. Furthermore, many research have investigated the potential to improve the mechanical, physical, and thermal properties of recycled plastics through reinforcing with the different types of natural fibers including bamboo fibre [10,11]. However, the impact of environmental conditions, such as immersion, on the behavior of rHDPE composites reinforced with bamboo fibers has not been fully investigated. The immersion of materials in various media, such as water or chemical solutions, is a common environmental exposure that can significantly affect their mechanical properties and to simulate the effects of long-term exposure.

The introduction of high-strength materials (fibers) as reinforcement media can enhance the mechanical performance of plastics, which typically have inferior mechanical properties [6]. Additionally, many studies examined how to improve the mechanical, physical, and thermal properties of plastics by reinforcing them with various kinds of natural fibres [9]. Previous studies [7, 8] have demonstrated exceptional results with the use of various types of polyethylene and natural fibre. In addition, a previous study conducted on the utilization of rHDPE composites reinforced by Zalacca Midrid fiber under the effect of tropical climate exposure [10]. [11] studied the performance of a post-consumer plastics, with wood twigs used as reinforcement under exposure to the coastal weather in Thailand. The effect of polymer type, namely polypropylene (PP) and high density polyethylene (HDPE), and bamboo fiber content (10%, 30%, and 50%), on the physical, mechanical, and thermal properties of Melia dubia (hybrid) plywood was studied by [12]. Flexural strength of hybrid plywood panels increased significantly at 30% with increase of bamboo fibre content (14 to 18%) with improved interfacial adhesion. [13] utilized rice husk reinforcement in recycled high-density polyethylene (rHDPE). The mechanical parameters of a recycled high-density polyethylene composite (rHDPE/rPET) were evaluated. In this study, tensile strength and elastic modulus increased by 4.95 and 162.65%, respectively, when compared to the 100% recycled thermoplastic material. This study found an increase of 4.95 and 162.65% in tensile strength and elastic modulus, respectively, when compared to the recycled thermoplastic material that was 100% pure. [14, 15] analysed the mechanical parameters of recycled HDPE (rHDPE) reinforced with bamboo fibre. It was discovered that the tensile strength of rHDPE material with 0% fibre loading is 8.3 N/mm2, which is greater than that of bamboo fibre containing 30% by weight. This was due to the lack of adhesive substances and the random orientation of bamboo fibres.

Establishing understanding of the behavior of rHDPE composites reinforced with bamboo fibers when subjected to immersion is important for predicting their performance in applications where exposure to moisture or liquids is a potential issue. The objective of this study is to address a significant knowledge gap regarding the influence of immersion on the mechanical characteristics of rHDPE composites reinforced with bamboo fibre. The findings will provide valuable insights into the durability and performance of these composites in moisture environments, contributing to their potential applications in various industries.

2. Experiments

2.1 Fibre materials

The bamboo fiber (Semantan) used in the present study is sourced from the production of the local community in Kedah, Malaysia as indicated in Figure.1 The bamboo fibre has a diameter ranging from 0.2 to 0.3 mm and is prepared for size reduction. The bamboo fibre is trimmed using scissors until it reaches a length of 40 to 60 mm, thus reducing its size.

2.2 Recycled plastic materials

The rHDPE is used as the matrix for the investigation. The rHDPE in pellet form has a size range of 4 to 5 mm (Fig.2).

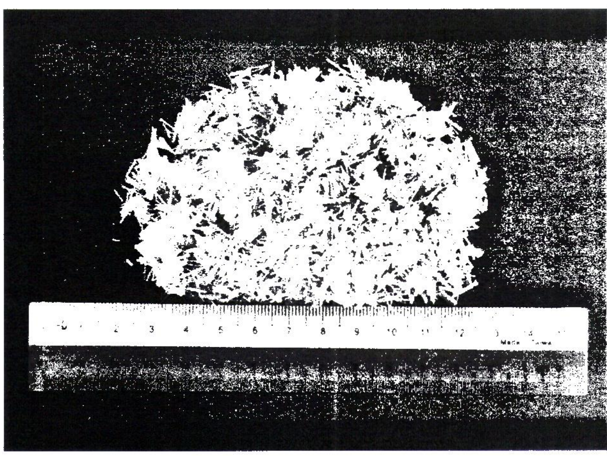

Fig. 1. Bamboo fibre materials

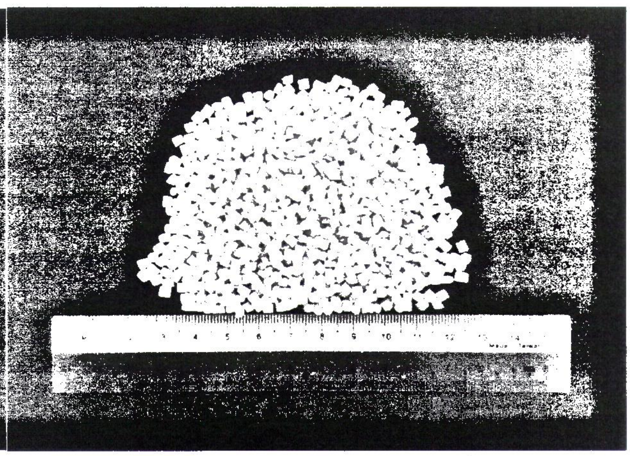

Fig. 2. rHDPE materials

2.3 Preparation of composite specimen

In the experimental design, the composites were prepared using the process shown in Fig. 3. The weight of composites is determined by including a mixture of rHDPE plastic pellets and bamboo fibres as specified in Table 1. The rHDPE and BF were combined in the beaker according to their respective weight percentage and then dry mixed. Next, the blend is transferred to the injection mold through injection. The temperature control within the melting box of the injection machine ranged from 200 to 220 °C. The specimen was molded into a dog bone shape, according to ASTM D638-22 [16].

Table 1 Details of rHDPE and BF composite

Composite fabricated	Bamboo fibre reinforcement (%)
rHDPE with BF (Control)	0
rHDPE with BF3	3
rHDPE with BF5	5
rHDPE with BF7	7

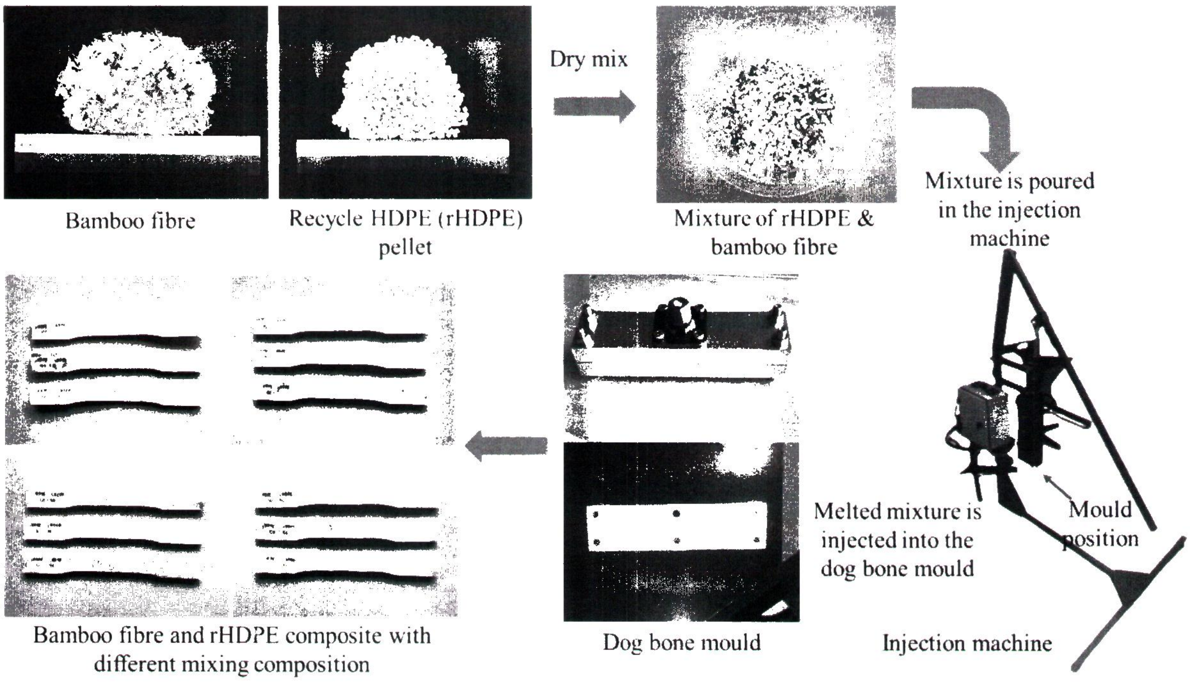

Fig. 3. The process of rHDPE and BF fibre composite preparation

2.3 Water absorption test

A water absorption test was performed to examine the weight variation of the rHDPE and bamboo fibre composite after being immersed. The test was conducted following ASTM D570-22. The weight of the composite specimen was measured before and after immersion in rainwater and acidic solution. The changes in weight have been monitored and recorded. The composite sampling was subjected to immersion in rainwater and an acidic solution for 24 hours, one week and four weeks, at room temperature. The calculation of water absorption was performed using Equation (1).

$$\text{Water absorption (WA) (\%)} = \frac{W_1 - W_0}{W_0} \times 100\% \quad (1)$$

where W_1 is the weight of composite after immersion and W_0 is the weight of the composite before water immersion.

2.4 Tensile strength test

The tensile properties of the composites were measured using an Instron 5569A Universal Testing Machine (UTM) in accordance with the ASTM D638-22 standard test method. The dog-bone-shaped samples which were prepared using an injection moulding machine, were subjected to a tensile test at a constant strain rate of 10 mm/min. the testing was conducted at room temperature (25°C). Equation 2 and Equation 3 were used to compute the tensile strength of rHDPE and bamboo fibre composite. The tensile strength and Young's modulus of the composite material are determined by taking the average of 5 (five) specimens.

Tensile strength (MPa) $\sigma = \frac{F}{A}$ (2)

Young Modulus (MPa) $E = \frac{\sigma}{\varepsilon}$ (3)

where σ is tensile strength (MPa), F is load (N), A is cross-sectional area (mm^2), E is Young Modulus and ε is strain.

3. Result and discussion

3.1 Water absorption

The water absorption test was determined by calculating the increase in weight relative to the initial dry weight of the samples. Figure 4 shows the water absorption of rHDPE and BF composite for different percentage of bamboo fibre of specimens over a period of 7 days to 28 days of immersion. It is apparent from the graph that the water absorption of each sample follows a similar pattern. The percentage of water absorption for 3% BF, 5% BF and 7% BF is 1.7%, 1.8% and 2.1% respectively at the beginning of 7 days of the test. The rHDPE composites containing 7% BF exhibit the highest water absorption during immersion tests in both rainy and acidic environments. This observation is mainly associated with the presence of BF percentage. In general, composites reinforced with natural fibers are susceptible to water absorption. The fragility of composites is a consequence of the hydrophilic nature of natural fibers, which leads to a significant water absorption [17]. The hydrophilic nature of bamboo fibre may influence the water absorption capacity of composites when used as a reinforcement or filler. Using bamboo fibre as a reinforcement or filler can affect the water absorption capacity of composites due to the hydrophilic properties of bamboo fibre [17, 18].

Rainwater is generally considered to be a relatively neutral or slightly acidic solution with a pH close to 7. It may contain dissolved gases and impurities that can contribute to water absorption in the composite. The hydrophilic nature of natural fibers, such as bamboo fibre, can also increase the tendency for water absorption in the composite. As a result, rainwater can be readily absorbed by the composite, leading to swelling and potential changes in mechanical properties. Acidic solutions, on the other hand, can cause chemical degradation of the polymer matrix, which may result in some absorption of the acid solution [19]. However, acidic solutions are typically used in controlled laboratory environments or specific industrial applications. The concentration and type of acid used, as well as the exposure duration, will influence the extent of absorption and potential degradation of the composite. The duration of the absorption experiment can also impact the rate. Immersion for 4 weeks shows higher water absorption than 1 week for both types of water. Initially, the absorption rate might be higher, but it can gradually decrease as the material reaches its saturation point [20]. The presence of water can weaken the interfacial adhesion between the matrix and reinforcement, causing a reduction in the composite's strength and stiffness.

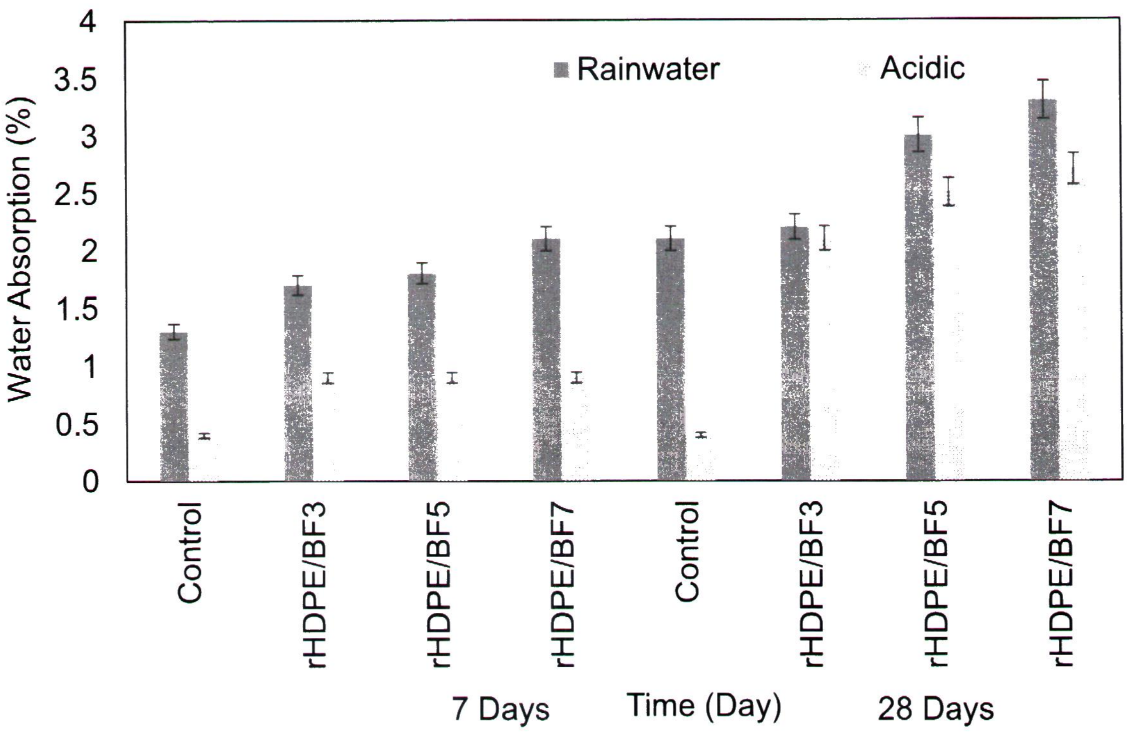

Fig.4. Water absorption of rHDPE and BF composites.

3.3 Tensile strength properties

The tensile strength of a composite material is an important mechanical property that measures its ability to withstand tensile forces (pulling or stretching) without breaking. Figure 5 shows the tensile strength of rHDPE with BF composites compared with the various BF percentages before and after immersion in rainwater and acidic solution. The control sample with 0% BF before immersion shows tensile strength of 12.3 MPa. In 3% BF composite fraction of tensile strength shows that the value is increased to 15.8 MPa, demonstrates the highest strength. With increase of 5% BF in composite, the tensile strength is suddenly reduced to 13.5 MPa. The tensile strength of composites continues to reduce to 11.9 MPa with increment of percentage of BF in composite, 7%. In general, the tensile strength increases with increasing fibre volume fraction up to a weight composition of 3%, after which it decreases below the previously observed trend. The main reason for the reduction in tensile because tensile properties are dependent on fibre orientation and fibre/matrix interfacial adhesion [15, 20]. With an increase in fibre weight fraction, agglomeration is more likely to occur [20]. This significantly reduces the fibre/matrix interfacial adhesion and the matrix-to-BF tension transfer efficiency. Similar findings have been published in prior research [21, 22]. The absence of adhesive substances and the use of random bamboo fibre directions could all be factors in this rHDPE/bamboo composite's low tensile strength [15]. The unreinforced HDPE has a lower tensile strength than the composites, indicating that the addition of fibers has increased the tensile strength of the matrix. The control sample with 0% BF shows tensile strength of 12.3 MPa. At 3% of BF, the tensile strength is the highest and more than 13 percent higher than the control HDPE sample. With a value of 13.0 MPa, 5 wt. % composite demonstrates the next-highest strength.

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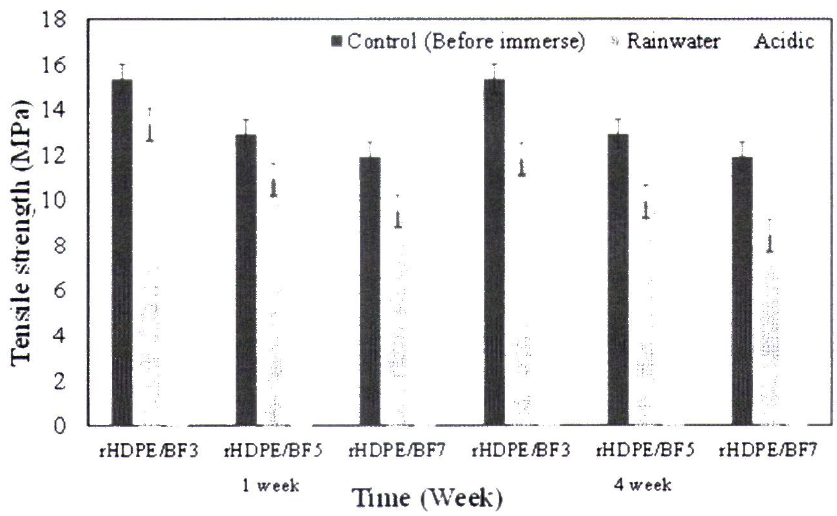

Fig.5 Tensile strength of rHDPE and BF composites after immersion with rainwater and acidic solution.

Rainwater exposure is less likely to cause significant degradation of the tensile strength compared to exposure to acidic solutions. Rainwater, which is typically slightly acidic or neutral, is less aggressive compared to concentrated acidic solutions. While rainwater can contribute to water absorption and potential swelling of the composite, the impact on tensile strength may be relatively minor [24]. On the other hand, exposure to acidic environments can cause chemical degradation of the polymer matrix, which may result in a decrease in mechanical strength and other properties [25]. In general, it is expected that for composites with a higher weight fraction of reinforcement immersed in water, the relative extent of reduction in tensile characteristics will be greater than for dry samples. This could be because excessive amounts of water cause the fibres to swell, filling the spaces between the fibre and the polymer matrix and finally resulting in a deterioration in the mechanical properties of the composites [18].

4. Conclusion

The tensile strength and water absorption behaviour of rHDPE composites reinforced with 3%, 5% and 7% bamboo fibres when subjected to immersion have been investigated. The water absorption test revealed that the weight obtained by all composites increases with immersion time up to 4 weeks, after which they gain weight rather slowly. Bamboo fibre improves the tensile strength of composites. The greatest improvement was observed at 3% of BF. As BF percentage increased, these properties tend to be decreased, likely due to fibre agglomeration at higher loading ratios. However, when compared to the control sample, these properties exhibit significant improvement. The findings of this investigation indicate that treated bamboo fibres are suitable for reinforcing rHDPE.

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