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INFLUENCE OF IMMERSION WEATHERING ON THE MECHANICAL PROPERTIES OF rHDPE COMPOSITES REINFORCED BY BAMBOO FIBRES

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ABSTRACT: Growing demands for housing, limiting natural resources, concern about plastic waste, and increasing awareness of the environment have drawn the modern world's attention to the recycling of waste plastics to produce an alternative and sustainable building construction material. The paper aim to investigate the properties of natural fibre- reinforced composited for structural applications. The composites were developed by combining recycled high-density polyethylene (rHDPE) with bamboo fibre using an injection machine. The water absorption test was performed. The tensile strength test of the dog-bone-shape composites was determined using Instron 5569A Universal Testing Machine and in compliance with ASTM D638-22 Standard Test Method. The results showed that immersion in rainwater may cause negligible color change, whereas immersion in acidic solutions can result in discoloration or fading. In addition, bamboo fibre improves the tensile strength of composites. The greatest improvement was observed at 3% of BF. As BF percentage increased, these properties tends 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 water absorption in composite due to immersion weathering affects the tensile strength by reducing the strength bamboo fibre as a reinforcement or filler can affect the water absorption capacity of composites due to the hydrophilic properties of bamboo fibre. The study highlighted the potential of rHDPE and bamboo fibres as products with added value for building construction from socio-eco and environmental perspectives.

Keywords: Bamboo Fibre, Recycle HDPE, Natural Fibre Composite, Green Construction Material, Mechanical Properties

1. INTRODUCTION

Global plastic waste has reached alarming levels, posing significant environmental and sustainability challenges. Malaysia is one of the countries where post-consumer plastics, including plastic bags, cups, and straws, are widely generated. According to the Ministry of Environment and Water, Malaysia generated 671,000 metric tons of plastic waste in 2019 [1]. From the amount, only 24% of the plastic waste was recycled. The remaining 76% were either landfilled or discarded in open dumpsites. The Malaysian government has set a target to achieve zero single-use plastics by 2030, which is in line with the global Sustainable Development Goals (SDGs) to ensure sustainable consumption and production patterns. Therefore, innovative solutions are urgently required to resolve this issue and transition to a more sustainable and circular economy.

This research aligns with several Sustainable Development Goals (SDGs), emphasizing environmental sustainability, responsible consumption, and innovation. SDG 9 (Industry, Innovation, and Infrastructure) targets by 2030 to upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes [2]. It is relevant to this research that contributes to understanding the sustainability of composite materials and informs the development of innovative, environmentally friendly technologies in the materials and construction industries. The objective of SDG 14 (Life below water) is to prevent and substantially decrease all forms of marine pollution, particularly those originating from activities on land, such as marine debris and nutrient pollution, by the year 2025. So, this research aims to mitigate the potential environmental consequences of materials, namely by addressing the issue of marine pollution caused by the deterioration of composite materials, especially plastic waste.

There is an increasing demand for novel construction materials that have improved mechanical properties that are suitable for the application they are intended for, cost, manufacturing capabilities, and sustainability. These materials are needed to promote sustainable consumption and production patterns [3]. Bamboo fibre and recycled plastic can be combined to create a composite material that can be used as green building materials. The composite offers the benefits of both materials. Bamboo fibre is a versatile and sustainable natural material that has gained popularity in recent years as a reinforcement of composite [4]. The eco-friendly and biodegradable nature of these fibres has a positive impact on the environment. Instead of conventional fibers, natural fibre-reinforced polymeric materials are attracting the attention of researchers and engineers. It is due to the numerous benefits of natural fibres, which include degradability [5], environmental friendliness [6], biodegradability [5, 6], excellent stiffness to weight ratio [6, 7] low cost and low weight [5, 8].

The introduction of high-strength materials (fibres) as reinforcement media can enhance the mechanical performance of plastics, which typically have inferior mechanical properties [9]. Additionally, many studies examined how to improve the mechanical, physical, and thermal properties of plastics by reinforcing them with various kinds of natural fibres [10]. Previous studies have demonstrated exceptional results with the use of various types of polyethylene and natural fibre [11, 12]. In addition, a previous study conducted on the utilization of rHDPE composites reinforced by Zalacca Midrid fibre under the effect of tropical climate exposure [13]. The performance of a post-consumer plastics with wood twigs used as reinforcement under exposure to the coastal weather in Thailand has been studied by [14]. The effect of polymer type, namely polypropylene (PP) and high-density polyethylene (HDPE), and bamboo fibre content (10%, 30%, and 50%), on the physical, mechanical, and thermal properties of Melia dubia (hybrid) plywood was studied by [15]. Flexural strength of hybrid plywood panels increased significantly at 30% with increase of bamboo fibre content (14 to 18%) with improved interfacial adhesion. Researcher utilized rice husk reinforcement in recycled high-density polyethylene (rHDPE) [16]. 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. Some studied analysed the mechanical parameters of recycled HDPE reinforced with bamboo fibre [17, 18]. It was discovered that the tensile strength of rHDPE material with 0% fibre loading is 8.3 N/mm^2, 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.

The mechanical properties of bamboo fibre and recycled plastic composite, such as tensile strength, flexural strength, and stiffness, might be negatively impacted by water absorption. The presence of water molecules that are absorbed may affect the bonding between the bamboo fibres and the recycled HDPE matrix at the interface, leading to a reduction in the strength of the composite. The composite's resistance to water absorption is crucial to its performance in a variety of environmental conditions. Long-term exposure to high humidity or immersion in water increases the susceptibility of composites to moisture-related degradation. To ensure the composite's long-term durability and the continued existence of its mechanical properties in wet or humid environments, it is essential to comprehend and control its water absorption.

Therefore, this study aims to investigate the influence of water immersion on the physical and mechanical properties of rHDPE composites reinforced by bamboo fibres. The findings will provide valuable insights into the durability and performance of these composites in wet environments, contributing to their potential applications in various industries.

2. RESEARCH SIGNIFICANCE

The investigation into the influence of immersion weathering on the mechanical properties of rHDPE composites reinforced by bamboo fibres holds several significant in research. This research offers valuable insights into the durability of rHDPE and bamboo fibre composites, a promising sustainable material, when exposed to environmental issues, including immersion weathering. The investigation of the effects of immersion weathering on rHDPE and bamboo fibre composites is essential for improving the development of environmentally friendly alternatives in engineering applications, given the growing need for sustainable materials. The research can provide valuable guidance to engineers and designers in the selection of suitable materials for specific applications. The research also supports SDG’s by offering essential knowledge for the development and implementation of eco-friendly materials.

3. METHODOLOGY

3.1 Materials

The composites are developed by taking recycled high-density polyethylene (rHDPE) plastic with incorporation of bamboo fibres as reinforcement. The rHDPE in pellet form has a size range of 4 to 5 mm (Fig.1). The bamboo fibre (Semantan) used is obtained from the production of the local community in Kedah, Malaysia as shown in Fig.1 The bamboo fibre has a diameter range of 0.2 to 0.3 mm and is ready for size reduction. Reducing the size of the bamboo fibre is done using scissors until the fibre size becomes 40 to 60 mm. A study comparing the effects of bamboo flour and BF on the mechanical properties of HDPE indicates that BF performs better than bamboo flour [19].

3.2 Preparation of Recycle HDPE and Bamboo Fibre Composite Specimen.

In experimental design, the composites were prepared using procedure as shown in Fig.2. The weight of composites consists of rHDPE plastic pellets and bamboo fibres as taken according to Table 1. The rHDPE and BF as per their percentage of weights were then placed into the beaker for dry mixing. The mixture is then placed into the injection machine and injected into the mould. The control temperature in the melting box of the injection machine was between 200 to 220^{o}C. The specimen was manufactured with a dog bone-shaped mould in accordance with the American Society for Testing Materials (ASTM) standard, specifically ASTM D638-22 Standard Test Method, and this is used for testing mechanical properties.

Fig.1 rHDPE (left) and bamboo fibre (right)

Table 1. Composition of rHDPE and bamboo fibre composite

Composite rHDPE	Bamboo Fibre (%wt)
Control	0
rHDPE/BF3	3
rHDPE/BF5	5
rHDPE/BF7	7

3.3 Physical Characteristics of The Composites

The dimensions (thickness, width, and length) at three different locations of samples were measured using a digital caliper with a precision of 0.01 mm. The dimensional changes were measured before and after immersion in rainwater and acidic solution. Visual examination of the color change of the composite samples has also been made.

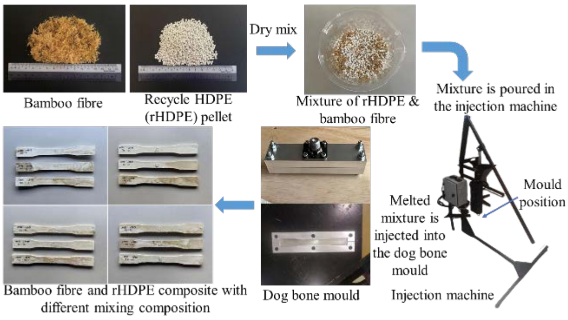

Fig.2 rHDPE and bamboo fibre composite preparation

3.4 Water Absorption Test

The water absorption test was performed to investigate the weight increase of the material after immersion. The weight of composite specimen was measured before and after immersion in rainwater and acidic solution at room temperature. The weight changes were measured and recorded. Composite sampling was immersed in rainwater and acidic solution for 1 week and 4 weeks at room temperature. Eq. (1) was used to calculate water absorption. W1 is the sample's initial weight, and W2 is the sample's final weight after immersion.

$$\text{Water absorption} = \frac{w_2 - w_1}{w_1} x\ 100\% \quad (1)$$

3.5 Tensile Strength Test

The tensile strength test of the composites was determined using Instron 5569A Universal Testing Machine and in compliance with ASTM D638-22 Standard Test Method. The dog-bone-shape samples prepared by injection machine molding were tested in tension mode at a single strain rate of 10 mm/min at room temperature (25^{o}C). The following is an equation of tensile strength Eq. (2) and Young Modulus Eq. (3) was used to calculate tensile strength. σ is tensile strength (MPa), F is load (N), A is cross-sectional area (mm^2), E is young modulus and ϵ is strain Tensile strength and young modulus are measured from an average of 5 (five) specimens.

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

$$\text{Young Modulus (MPa)}, E = \frac{\sigma}{\epsilon} \quad (3)$$

4. RESULTS AND DISCUSSIONS

4.1 Physical Characteristics of the Composites

Several factors can influence the physical characteristics and color changes of rHDPE reinforced with bamboo fibre composites after immersion in rainwater and acidic solutions. The results and color changes observed depend on the composition of the composite, the duration of immersion, and the pH level of the acidic solution.

Immersion in rainwater caused minimal dimensional changes, including an insignificant increase in size. Immersion in acidic solutions, on the other hand, resulted in more noticeable dimensional alterations, including considerable minimal swelling of the composite. These changes imply that the dimensional stability of the composite was harmed more severely in the acidic environment than in rainfall.

Immersion in rainwater and acidic solutions has the potential to alter the color of composites. Fig.3 show the photos of 0% BF composites before and after the immersion in rainwater in duration of 1 week and 4 weeks. Fig.4 show the photos of 3% BF composites before and after the immersion in rainwater in duration of 1 week and 4 weeks. The composite showed minimal color changes after immersion in rainwater. A slight darkening or lightening of the composite's original color was observed. Overall, the color change was relatively insignificant.

Fig.3 The 0% BF composite sample before and after immersion with rainwater solution (1 week and 4 week)

Fig.4 The 3% BF composite sample before and after immersion with rainwater solution (1 week and 4 week)

Figure 5 shows the photos of 0% BF composites before and after the immersion in acidic solution in duration of 1 week and 4 weeks. Fig.6 show the photos of 3% BF composites before and after the immersion in acidic solution in duration of 1 week and 4 weeks. On the other hand, resulted in noticeable color changes in the composite. The acidic environment reacted with the pigments or dyes in the composite, causing discoloration, fading, or color changes. The intensity and character of the color changes varied according to the acidic solution used and the composition of the composite.

Fig.5 The 0% BF composite sample before and after immersion with acidic solution (1 week and 4 week)

Fig.6 The 3% BF composite sample before and after immersion with acidic solution (1 week and 4 week)

4.2 Water Absorption of Composites

The effect of the rHDPE and bamboo fibre reinforcement ratio on the water absorption of the composite after immersion with rainwater and acidic solution for 7 days and 28 days is illustrated in Fig.7 and Fig.8. This test measures the weight change of composite samples subjected to varying immersion times. It is apparent from the graph that the water absorption of each sample follows a similar pattern. The composite samples experience rapid water absorption and gain weight within 1 week to 4 weeks of immersion. The rHDPE composites with 7% of BF have the largest water absorption for immersion test in both rainwater and acidic with 3.5%. This observation is primarily linked to percentage BF's presence. In general, composites reinforced with natural fibres are susceptible to water absorption. This fragility is caused by the hydrophilic properties of natural fibres, which give composites a high-water absorption [20]. Using bamboo fibre as a reinforcement or filler can affect the water absorption capacity of composites due to the hydrophilic properties of bamboo fibre [20, 21, 22].

Overall, the percentage of water absorption immersed in acidic shows lower than in rainwater in both 1 week and 4 weeks duration. 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 fibres, 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 [23]. 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 [24]. The presence of water can weaken the interfacial adhesion between the matrix and reinforcement, causing a reduction in the composite's strength and stiffness.

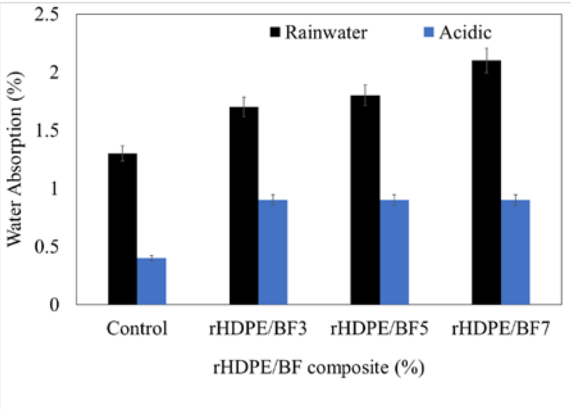

Fig.7 Water absorption of rHDPE and BF composites after immersion with rainwater and acidic solution for 7 days

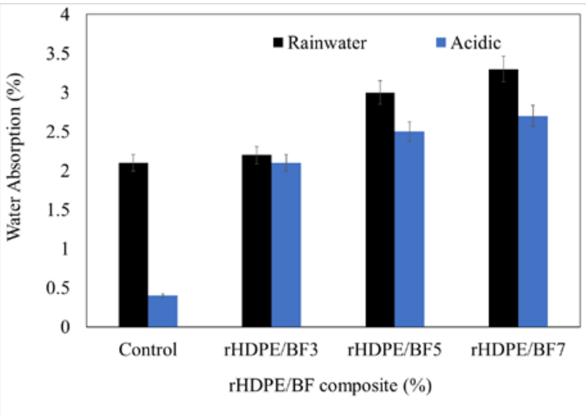

Fig.8 Water absorption of rHDPE and BF composites after immersion with rainwater and acidic solution for 28 days

4.3 Tensile Strength of Composites of Composites

Understanding the mechanical properties of the composite material would aid in identifying appropriate applications and determining the composites' resistance. Fig.9 and Fig.10 represent the variation of tensile strength with percentage of bamboo fibre composition before and after immersion in rainwater and acidic solution in 7 days and 28 days. The unreinforced HDPE has a lower tensile strength than the composites, indicating that the addition of fibres has increased the tensile strength of the matrix. The unreinforced HDPE sample shows tensile strength of 1.3 MPa. At 3% of BF, the tensile strength is the highest with 15.5 MPa which is higher than unreinforced HDPE sample. With a value of 13.0 MPa, 5 wt. % composite demonstrates the next-highest strength.

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. This is because tensile properties are dependent on fibre orientation and fibre/matrix interfacial adhesion [18, 25]. With an increase in fibre weight fraction, agglomeration is more likely to occur [25]. This inadvertently reduces the fibre/matrix interfacial adhesion and the matrix-to-BF tension transfer efficiency. Similar findings have been published in prior research [4, 26]. The absence of adhesive substances and the use of random bamboo fibre directions could all be factors in this r-HDPE/bamboo composite's low tensile strength [18, 27].

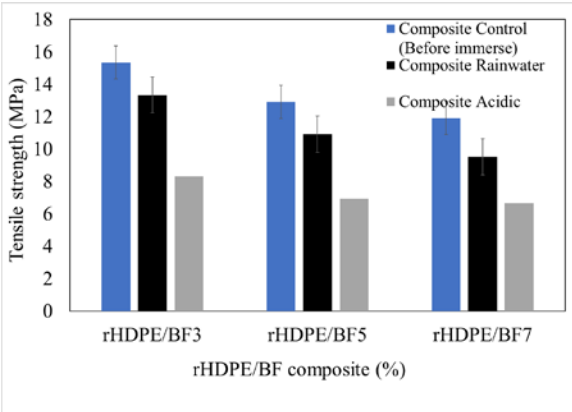

Fig.9 Tensile strength of rHDPE and BF composites after immersion with rainwater and acidic solution for 7 days

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 [27]. 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 [4, 24].

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 [23].

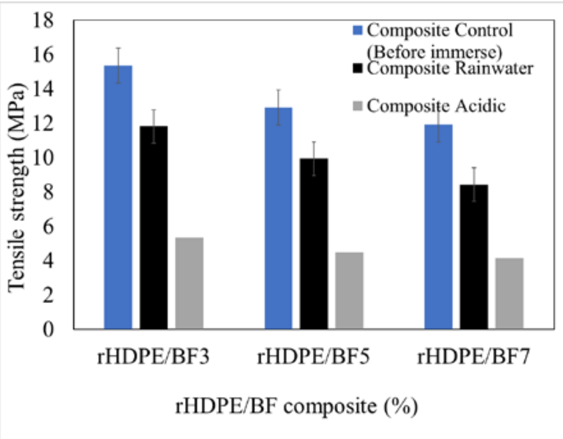

Fig.10 Tensile strength of rHDPE and BF composites after immersion with rainwater and acidic solution for 28 days

The tensile strength and young modulus of were determined and are shown in Table 2. The composition of both the recycled HDPE matrix and the bamboo fibres influences the composite's Young's modulus. Young modulus shows an increasing trend with larger fractions of fibre in the r-HDPE matrix. The reinforcing effect of bamboo fibres increases the stiffness of the composite. It indicates that more bamboo fibre tends to lead the composite to be stiffer and more brittle [18].

Table 2. Tensile strength and young modulus of rHPDE and bamboo fibre composite

Composite	Tensile strength (MPa)	Young Modulus (MPa)
Control	12.3	297
rHDPE/BF3	15.8	352
rHDPE/BF5	13.5	377
rHDPE/BF7	11.9	390

5. CONCLUSIONS

The mechanical properties and water absorption behaviour of rHDPE composites reinforced with bamboo fibres have been investigated. The following conclusions can be obtained:

i. Immersion in rainwater may cause negligible color change, whereas immersion in acidic solutions can result in discoloration or fading.
ii. 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.
iii. Bamboo fibre improves the tensile strength of composites. The greatest improvement was observed at 3% of BF.
iv. 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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