

# 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 for the production of 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 recycle high-density polyethylene (rHDPE) with bamboo fibre. The water absorption and tensile strength of the material were evaluated. 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 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 study highlighted the potential of rHDPE and bamboo fibers as products with added value for building construction from socio-eco and environmental perspectives.

*Keywords: Bamboo Fibre, Recycle HDPE, Composite, Reinforcement, Mechanical Properties*

## 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 were recycled. The remaining 76% were either landfilled or discarded in open dumpsites. The Malaysia 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.

The growing need for new building materials with enhanced mechanical properties appropriate to their application, cost, manufacturing ability and sustainability are in demand to support sustainable consumption and production patterns [2]. 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 [22]. Bamboo fibre is like other natural fibers such as coir, jute, kenaf, pineapple and others. The eco-friendly and biodegradable nature of these fibers has a positive impact on the environment. Instead of conventional fibers, natural fiber-reinforced polymeric materials are attracting the attention of researchers and engineers. It is due to the numerous benefits of natural fibers, which include degradability, environmental friendliness, biodegradability, excellent stiffness to weight ratio, low cost, and low weight [3, 4, 5].

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 [10,11]. Previous studies [7, 8] have demonstrated exceptional results with the use of various types of polyethylene and natural fibre. Other authors [9] demonstrate a high application potential for various recycled fibers (waste bananas, cotton, and rice) with virgin LDPE arrays. In addition, a previous study conducted on the utilization of rHDPE composites reinforced by Zalacca Midrid fiber under the effect of tropical climate exposure [12]. [13] 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 [14]. Flexural strength of hybrid plywood panels increased significantly at 30% with increase of bamboo fibre content (14 to 18%) with improved interfacial adhesion. [15] 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. [16, 17] 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/mm<sup>2</sup>, 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.

Water absorption can adversely affect the bamboo fibre and recycled plastic composite's mechanical properties, such as tensile strength, flexural strength, and rigidity. The absorbed water molecules may affect the interfacial bonding between the bamboo fibers and the recycled HDPE matrix, resulting in a decrease in the composite's strength. 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.

## METHODOLOGY

### Materials

The composites are developed by taking recycle 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 fiber (Semantan) used is obtained from the production of the local community in Kedah, Malaysia as shown in Fig.1 The bamboo fiber has a diameter range of 0.2 to 0.3 mm and is ready for size reduction. Reducing the size of the bamboo fiber is done using scissors until the fiber 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 [18].

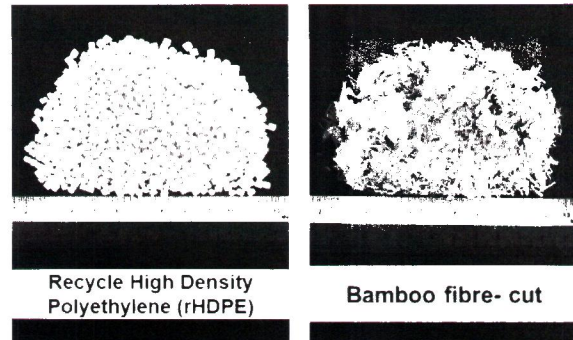


Fig.1 rHDPE (left) and bamboo fibre (right).

### 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°C. The dog bone shaped mould of the specimen was designed according to the American Society for Testing Materials (ASTM) standard related to the testing of mechanical properties such as ASTM D638-22 Standard Test Method.

Table 1 Composition of rHDPE and bamboo fibre composite

Composite	rHDPE	Bamboo Fibre (%wt)
Control	0	0
rHDPE /BF3		3
rHDPE /BF5	8	5
rHDPE /BF7	10	7

### Physical characteristic of the composites

The dimensions (thickness, width, and length) at three different locations of samples were measured

using 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 on the color change of the composite samples has also been made.

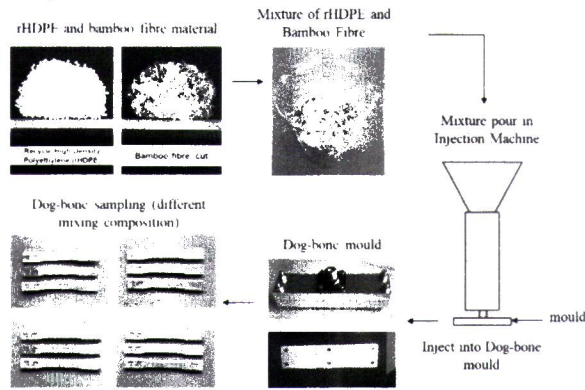


Fig.2 rHDPE and bamboo fibre composite preparation

### 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. Equation (1) was used to calculate water absorption.  $W_1$  is the sample's initial weight, and  $W_2$  is the sample's final weight after immersion.

$$\text{Water absorption (\%)} = \frac{W_2 - W_1}{W_1} \quad (1)$$

### Tensile test

The tensile 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 moulding were tested in tension mode at a single strain rate of 10 mm/min at room temperature (25°C).

## RESULTS AND DISCUSSIONS

In this section, the results are summarized and the discussions for the experimental evaluations of the considered properties are provided.

### Physical characteristic of the composites

Several factors can influence the physical characteristic and color change 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 week. Fig. 4 show the photos of 5% BF composites before and after the immersion in rainwater in duration of 1 week and 4 week. 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. 5 show 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 5% 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.

### Water absorption of composites

The effect of the rHDPE and bamboo fibre reinforcement ratio on the water absorption of the composite is illustrated in Fig. 7. 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. This observation is primarily linked to percentage BF's presence. In general, composites reinforced with natural fibers are susceptible to water absorption. This fragility is caused by the hydrophilic properties of natural fibers, which give composites a high-water absorption [19]. 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, 23].

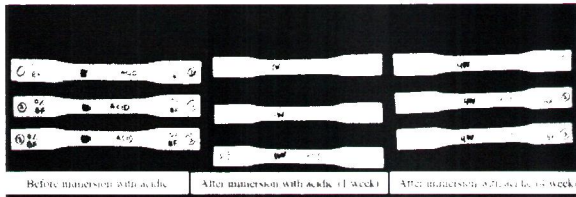


Fig. 3 The 0% BF composite sample before and after immersion with rainwater solution (1 week and 4 week).

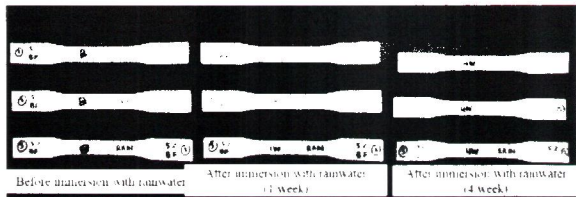


Fig. 4 The 5% BF composite sample before and after immersion with rainwater solution (1 week and 4 week).

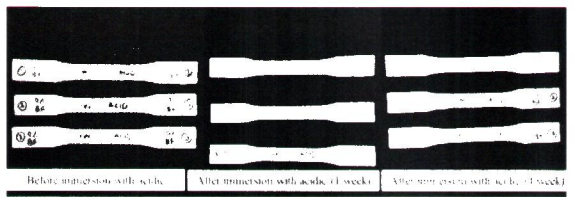


Fig. 5 The 0% BF composite sample before and after immersion with acidic solution (1 week and 4 week).

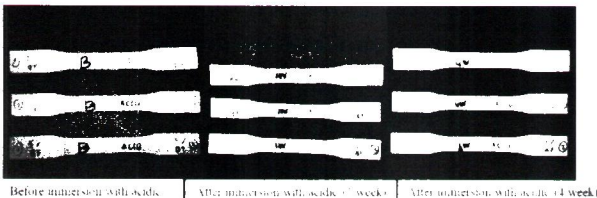


Fig. 6 The 5% BF composite sample before and after immersion with acidic solution (1 week and 4 week).

Overall, the percentage of water absorption immersed in acidic shows lower than in rainwater in both 1 week and 4 week 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 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 [20]. 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.

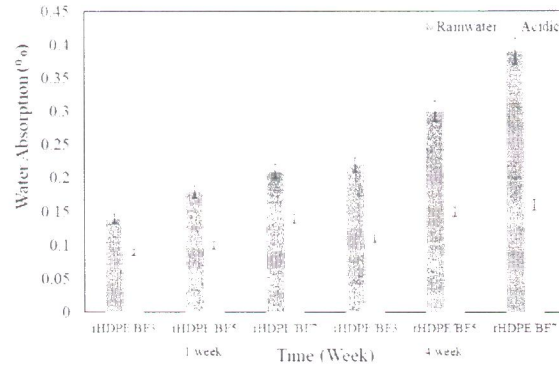


Fig.7 Water absorption of rHDPE and BF composites.

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 [21]. The presence of water can weaken the interfacial adhesion between the matrix and reinforcement, causing a reduction in the composite's strength and stiffness.

### Tensile strength of composites

Understanding the mechanical properties of the composite material would aid in identifying appropriate applications and determining the composites' resistance. Fig. 8 represents the variation of tensile strength with percentage of bamboo fibre composition before and after immersion in rainwater and acidic solution. 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 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 [17, 22]. With an increase in fibre weight fraction, agglomeration is more likely to occur [22]. This inadvertently reduces the fibre/matrix interfacial adhesion and the matrix-to-BF tension transfer efficiency. Similar findings have been published in prior research [24, 25, 26]. The absence of adhesive substances and the use of random bamboo fiber directions could all be factors in this r-HDPE/bamboo composite's low tensile strength [17].

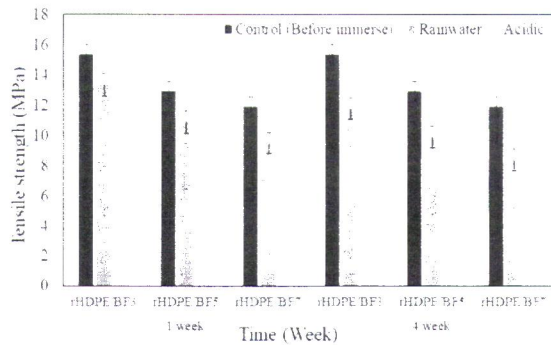


Fig.8 Tensile strength of rHDPE and BF composites after immersion with rainwater and acidic solution.

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 [20].

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 fibers influence the composite's Young's modulus. Young modulus shows an increasing trend with larger fractions of fiber in the r-HDPE matrix. The reinforcing effect of bamboo fibers increases the stiffness of the composite. It indicates that more bamboo fiber tends to lead the composite to be stiffer and more brittle [17].

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

### 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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