Malays. J. Bioeng. Technol. Vol. 2, No. 2, (2025): 99-105
https://doi.org/10.70464/mjbet.v2i2.1617

MALAYSIAN JOURNAL OF BIOENGINEERING AND TECHNOLOGY

Effect of Banana Peel and Titanium Dioxide Hybrid Fillers on Natural Weathering Degradation of Unsaturated Polyester Resin Biocomposites

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ARTICLE INFO

Received:1 June 2025
Accepted:20 June 2025
Online:30 June 2025
eISSN: 3036-017X

ABSTRACT

The composite used nowadays is made up of synthetic fibre, which does not satisfy the sustainability issue and is expensive. The making of a hybrid composite by using organic reinforcement with inorganic filler will show new advantages besides improving properties. The purpose of this research is to investigate the effect of natural weathering degradation study of unsaturated polyester (UPE) hybrid composite materials made up of different percentages of banana peel powder (20, 18, 16, 14 and 12%) and titanium dioxide (2, 4, 6 and 8%). The fabrication method is used to combine banana peel powder and titanium dioxide to produce a hybrid composite by using a hot press machine. The hybrid composites were exposed to natural weathering for two weeks before being tested. The chemical constituents, mechanical properties and surface morphological characterisations before and after natural weathering exposure were also evaluated. Mechanical characterisation done by a universal testing machine (UTM) has found that the U80B12T8 hybrid composite with the highest percentage of titanium dioxide (8% titanium dioxide and 12% banana peel powder) demonstrated the highest tensile properties for both before and after weathering degradation. The surface morphological study conducted by scanning electron microscopy (SEM) shows that a composite with 20% banana peel reinforced 80% UPE (U80B20) presented the highest degradation with high cracking of banana peel fibre inside the UPE matrix, which contributed to the low composites' mechanical properties. A hybrid composite with 12% banana peels incorporated with 8% titanium dioxide reinforced 80% UPE (U80B12T8) demonstrated low degradation, with almost no cracks and voids. This proved that the presence of titanium dioxide could reduce the degradation of hybrid composites against natural weathering.

Keywords: Unsaturated polyester resin; banana peel; titanium dioxide; natural weathering degradation

1. Introduction

Biocomposite materials are formed by a matrix and a reinforcement of natural fibres that are usually derived from plants. In this research, the production of hybrid composite materials is from organic waste and inorganic filler with a polymer matrix. There is a lot of organic waste in Malaysia, but the focus of this research study is on banana peel. Bananas or also known as *Musa Sapientum,* were originally found in South East Asia, mainly in India. Banana is one of the important fruits in the world. People use bananas for a lot of purposes, but the peel is generally discarded. Bananas are easily found in Malaysia since there are a lot of functions. In Malaysia, there are a lot of Small and Medium Industries (SMI) involved in agricultural-based based of banana, such as '*Kerepek Pisang'*, *'Pisang Goreng'* and '*Kek Pisang'* industries.

Fruit waste, including banana, orange, and pomegranate peels, makes up a significant portion of biomass waste, posing environmental concerns. Bananas, the second most-produced fruit worldwide, accounted for 16% of total fruit production in 2018, reaching 115.74 million metric tons [1]. Banana peels alone contribute 30-40% of the fruit's weight, or about 18-33% of total fruit mass, making them a costly solid waste. Research explores the potential of converting banana peels and other fruit waste into valuable biomaterials such as biopolymers, biofuels, and biofibers, highlighting the importance of managing hazardous agricultural waste. Studies by Solangi et al. [2] and El Barnossi et al. [3] provide insights into the role of fruit waste in biomass management and the need for sustainable methods to turn these wastes into bio-based materials derived from natural resources. These eco-friendly solutions can enhance resource efficiency and support a greener future. Additionally, plastic thin films reinforced with natural fibres and various matrices offer versatile properties for applications in packaging and biomedical fields.

In this study, various compositions of banana peel and titanium dioxide hybrid fillers were incorporated into UPE resin to study the effect of natural weathering exposure on the degradation of the hybrid composite. Mechanical and morphological characterisation was conducted to investigate the extent of degradation that had occurred as a result of differences in material composition and natural weathering effects. Comparative analysis between a single type of sample was examined to figure out the effects of weathering degradation by having different compositions for each sample.

2. Materials and Methods

2.1 Materials

The materials used in this study were banana peels, titanium dioxide powder (TDP), unsaturated polyester (UPE) and methyl ethyl ketone peroxide (MEKP). TiO_2, UPE and MEKP were obtained from Teraslab Saintifik Sdn. Bhd, Kota Bharu, Kelantan.

2.2 Preparation, Fabrication, and Characterisation of the UPE Biocomposites

Banana peels were collected from banana vendors and cut into pieces. The purpose of cutting banana peels into pieces is to make sure the banana peels are easy to dry uniformly. The banana peels were dried at 50 °C for 48 hours in an oven to remove water content. Then, the dried banana peels were blended to become powder. After 5 minutes, the banana peel powder (BPP) was mixed with TiO_2 (TDP). Then, polyester and 2% of MEKP as curing catalyst were poured into the compound. The mixture of the compound was stirred manually for 5 minutes to ensure the powders were evenly mixed with the resin. A thin layer of wax was placed onto the metal plate to prevent the composite from sticking to the plate during the hot press moulding process. Then, the mixture was poured into the mould. The mould was pressed using a hot press machine that uses a hydraulic system under standard moulding conditions: temperature, 100 °C, pressing during heating, 5 MPa, heating time, 10 minutes. After being pressed by a hot press, the mould was cooled to room temperature. The method was repeated by using different ratios of fillers. The percentage of composition of the composites is shown in Table 1.

For the characterisation method, weathering trial (ASTM D1435), tensile test (ASTM D3039) and morphological study by scanning electron microscopy (SEM) were conducted. The samples were exposed to natural

eISSN Number: 3036-017X

weathering for 14 days. Upon 14 days of exposure to sunlight and rain, the strength of the samples was observed by a universal testing machine (UTM) and the surface of the samples was examined under SEM.

Table 1: Formulation for fabrication of UPE biocomposites

Samples	Compositions		
	UPE (wt%)	BPP (wt%)	TiO_2 (wt%)
U100	100	0	0
U80B20	80	20	0
U80B18T2	80	18	2
U80B16T4	80	16	4
U80B14T6	80	14	6
U80B12T8	80	12	8

3. Results and Discussion

3.1 Tensile Test

The bar chart for tensile strength from tensile testing of pure UPE and various hybrid fillers of BPP and TiO_2 reinforced UPE biocomposites is shown in Fig. 1. Pure UPE indicates a superior amount of tensile strength, either before natural weathering degradation or after natural weathering degradation. But, the tensile strength drastically declines as the BPP organic reinforcement is incorporated into UPE resin (U100). This is due to the penetration of UV light into the samples, making scissions to the bonds of UPE chains, and this reflects on the reduction of the mechanical behaviour. UV degradation can significantly impact unsaturated polyester (UPE) resin, leading to changes in its mechanical and chemical properties. Exposure to UV radiation can cause photo-oxidation, resulting in chain scission and cross-linking, which may reduce the resin's strength and durability. Studies have shown that UV exposure can lead to discoloration, surface cracking, and embrittlement, affecting the resin's long-term performance [4].

For the early stage, the addition of a low amount of TDP (2 to 4 wt%) into BPP/UPE biocomposites demonstrated a small decrease in tensile strength. Nevertheless, it was interesting to observe that the tensile strength of TDP-filled BPP/UPE biocomposite drastically increased compared to BPP/UPE alone (U80B20), showing that the degradation process resulting from UV radiation was drastically reduced with the addition of titanium dioxide (TDP) as a hybrid filler. According to HosseiniHashemi et al. [5], TDP plays a crucial role in the weathering process of plastics, particularly in enhancing their resistance to UV degradation. It acts as a UV stabiliser, reducing the harmful effects of sunlight exposure, such as colour fading, surface cracking, and embrittlement. UV radiation is the radiation from sunlight in the wavelength range of 100 to 400 nm. TiO_2 particles are used in composite materials because of their high ability to absorb UV radiation. The main advantages of the TiO_2 pigments used in coating applications are excellent hiding power, high chemical stability, high refractive index, and high weather resistance [6,7].

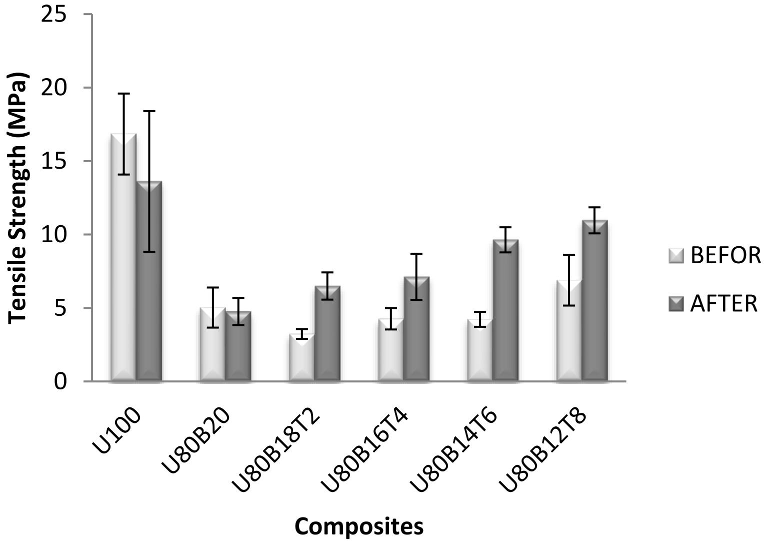


Fig. 1: Tensile strength of UPE biocomposites before and after natural weathering

Fig. 2 shows the elongation at break of pure UPE and various hybrid fillers of BPP and TiO_2 (TDP) reinforced UPE biocomposites. Before weathering degradation, the graph exhibits an ascending rate, but in the sample that has 12% of BPP and 8% of TDP, the elongation breaks suddenly decline. After weathering degradation, elongation at break is slowly increasing, but the amount of elongation at break after weathering degradation is low compared to before weathering degradation. Generally, the incorporation of inorganic fillers into polymer composites enhances their mechanical properties, such as tensile strength, elastic modulus, but decreases impact strength and elongation at break. It has been physically explained that the decline in elongation break of composite after weathering is mainly due to the breakdown of the molecular chain tie and entanglements, which is particularly detrimental to the ductility of the polymer [8].

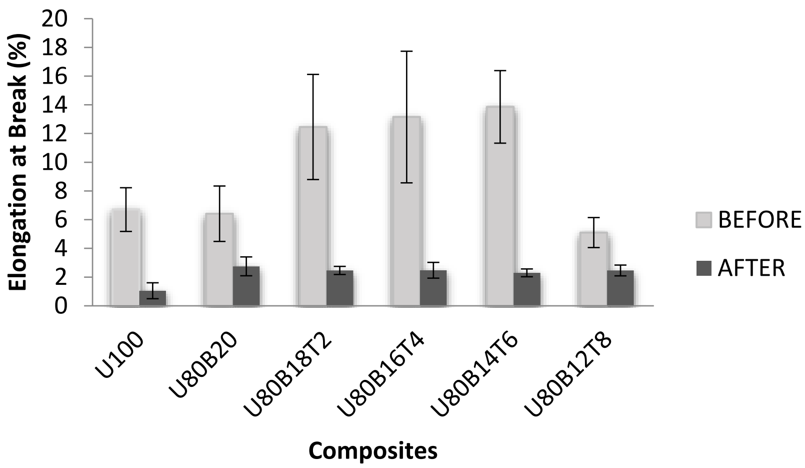
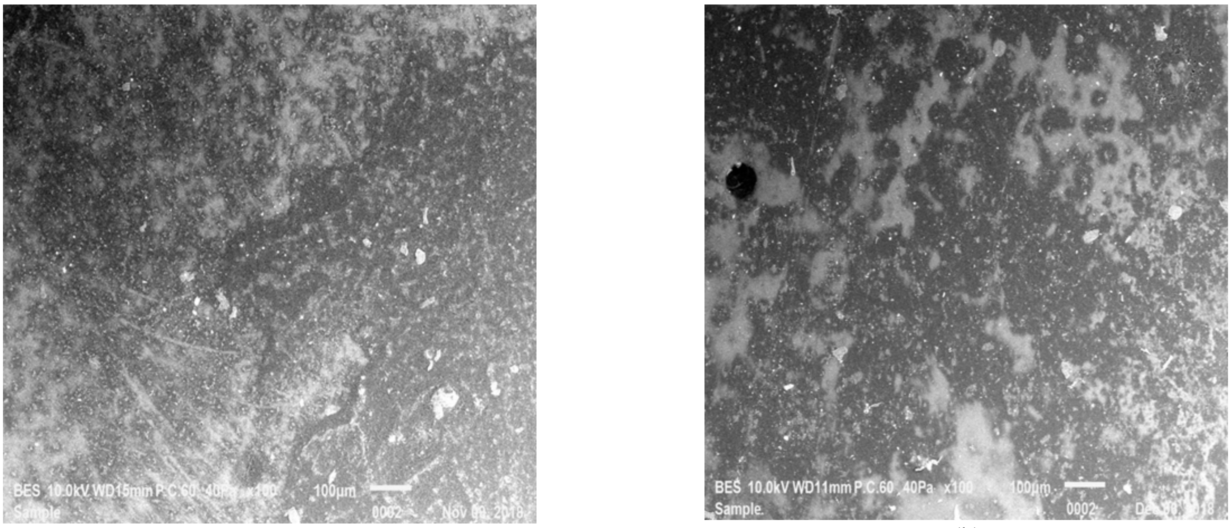


Fig. 2: Elongation at break of UPE biocomposites

3.2 Surface Morphological Characterisation

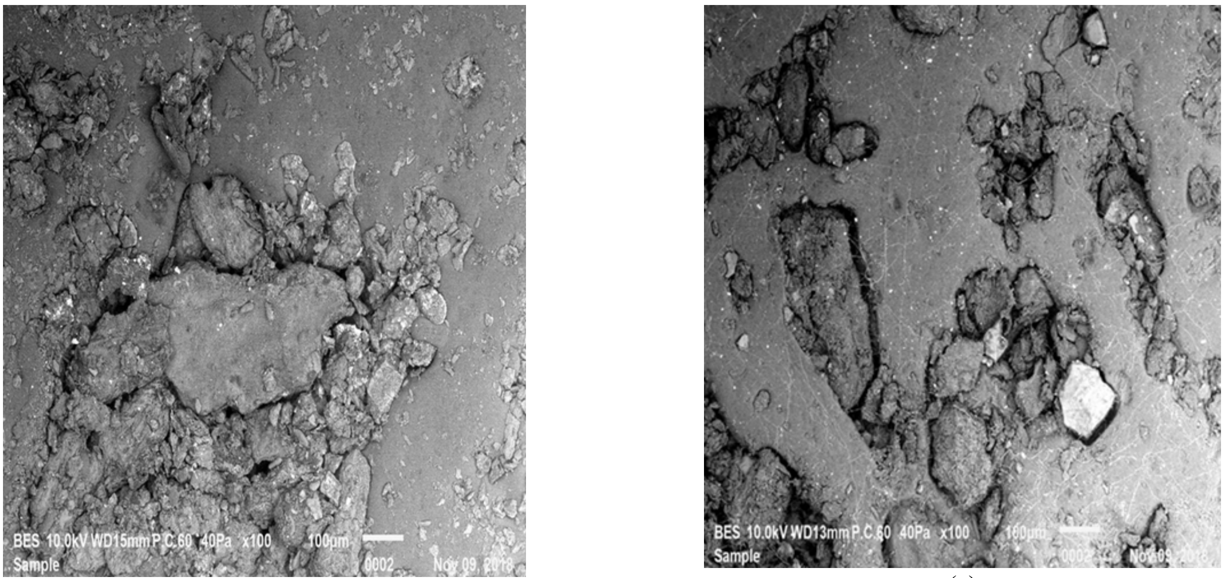
Fig. 3 presents the surface morphology of pure UPE before and after natural weathering degradation. As seen, there are not many changes between these two polymers. The sample before weathering illustrates smooth surface morphology, while after weathering degradation, the sample shows fewer cracks, is no longer smooth and forms holes.



(a) (b)

Fig. 3: (a) Pure UPE before weathering, and (b) pure UPE after weathering.

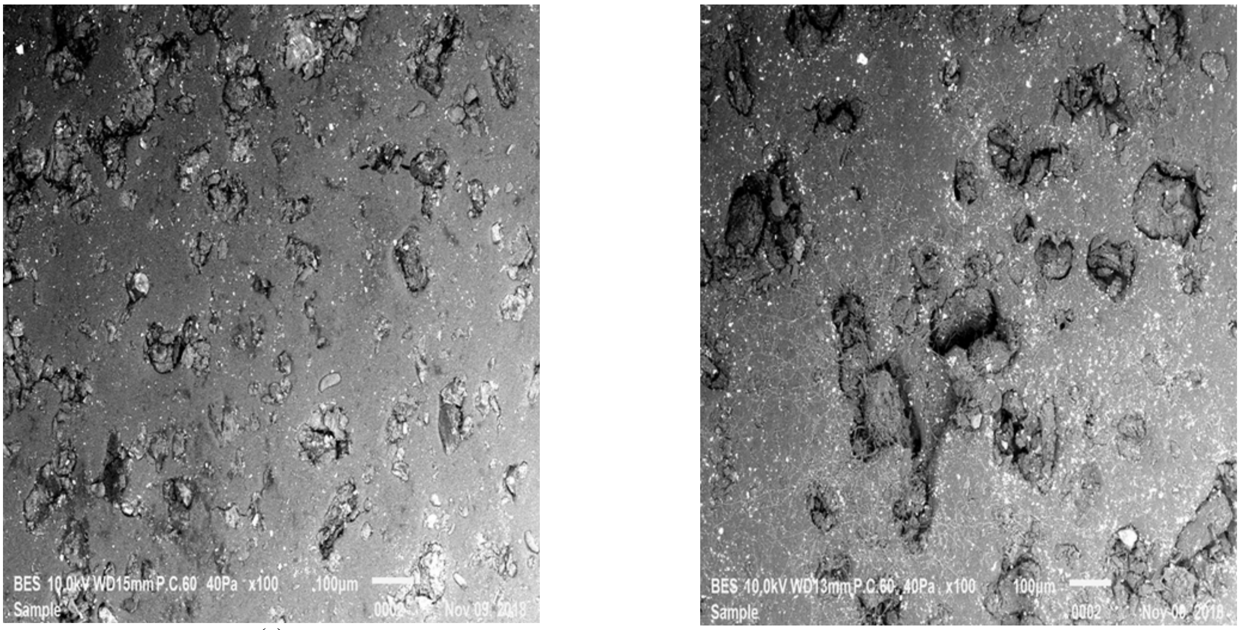
Fig. 4 shows the effect of BPP reinforced UPE biocomposite before and after natural weathering degradation. Surface morphology of the composite after weathering degradation, the surface shows that there were crack formations on the surface. As the result also showed that the banana peel powder shrinks after weathering degradation, this may be due to the absorption of moisture during exposure to natural weathering. This reaction could result in voids at the composite surface.



(a) (a)

Fig. 4: (a) BPP/UPE biocomposite before weathering, and (b) BPP/UPE biocomposite after weathering degradation

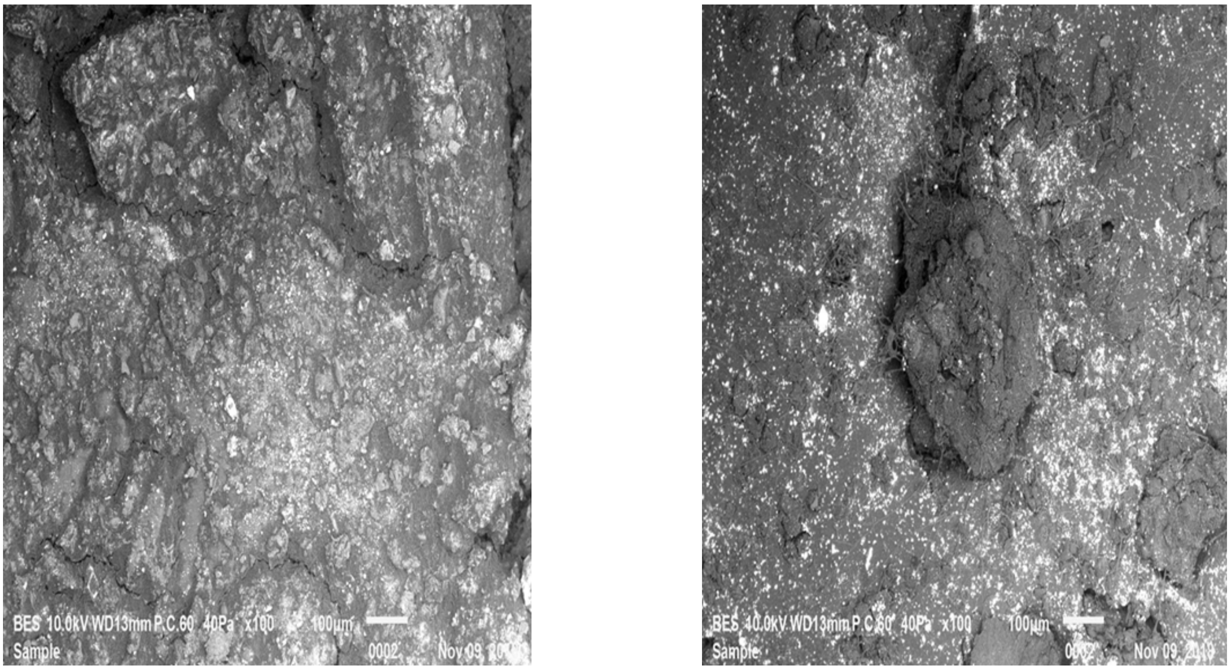
Fig. 5 shows the effect of surface morphology on BPP with TDP reinforced polyester hybrid composite before natural weathering degradation and after natural weathering degradation. The presence of the filler TiO_2 is not quite visible since the percentage of the filler is only 2% over 20% of the reinforcement. The cracks can also be seen on the surface after natural weathering degradation, and the particles of agglomeration are bigger compared to the agglomeration on the surface before weathering. The presence of agglomeration normally may create stress concentration points, which lead to the reduction of the strength of the samples.



(a) (b)

Fig. 5: (a) 18% BPP/2% TDP/UPE before weathering and (b) 18% BPP/2% TDP/UPE after weathering degradation

Fig. 6 shows the effect of surface morphology on BPP with TDP reinforced UPE hybrid composite before and after natural weathering degradation. The major problem that can be seen on the surface after degradation is the big particle agglomerate. The agglomerated compounds can act as stress-concentrating points in the matrix and affect the mechanical properties of the composite. Preventing agglomeration is one of the major problems in composite production. The white particles on the surface show that the dispersion of TiO_2 is not homogeneous. The agglomeration of TiO_2 probably gives rise to some micro-pores and micro-cracks as structural defects, but from all the samples, this hybrid composite shows low degradation, which is almost no voids and cracks on the surface morphology.



(a) (b)

Fig. 6: (a) 12% BPP/8% TDP/UPE before weathering, and (b) 12% BPP/8% TDP/UPE after weathering degradation

4. Conclusion

In this study, various BPP and TDP hybrid fillers reinforced UPE biocomposites were successfully fabricated and subjected to the natural weathering test. The tensile strength of the biocomposites samples indicates an improvement in both before and after weathering as a result of TDP incorporation as a hybrid filler. A hybrid composite with 12% of BPP incorporated with 8% of TDP reinforced 80% of UPE demonstrated the highest tensile strength compared to the other composite formulations. This proved that TDP can be utilised in order to increase the mechanical properties of hybrid composites. Morphological study by SEM showed that most of the surface before weathering degradation demonstrates no voids and cracks. After natural weathering, the specimen's surface shows the presence of voids and cracks since exposure to UV radiation can cause photo-oxidation, resulting in chain scission and cross-linking, which may reduce the resin's strength and durability. Composite with 20% BPP reinforced 80% UPE (U80B20) presented the highest degradation with high cracking of banana peels inside the UPE matrix. This causes a big gap between the fibre-matrix interfacial adhesion, which contributes to low mechanical properties.

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