OPEN ACCESS
International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-4, November 2019

Thermal Degradation and Mechanical Behavior of Banana Pseudo-Stem Reinforced Composites

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Abstract*: Banana fiber has potential to be utilized in bio-based composite structures due to its low price, abundantly available and biodegradability. However, the performance of this fiber is still not comparable to the synthetic polymeric system. In this work, the thermal stability analysis and tensile test of optimized banana fiber that was initially evaluated using response surface method were conducted. The thermal analysis and the tensile test were conducted using thermogravimetric analyzer and universal testing machine respectively. It was shown that the banana fiber content offered an outstanding performance in thermal stability. The highest thermal stability however, was found in neat epoxy resin system. The TG and DTG results showed the lowest amount of residue occurred in banana/epoxy composite. The tensile data properties revealed that banana composite is comparable to synthetic samples.

Index Terms*: Thermal analysis, tensile strength, banana, epoxy, synthetic fiber.

I. INTRODUCTION

Fiber reinforced composite that constructs relatively light weight structure as corresponds to its high load over weight ratio, is configured from synthetic fibers and polymer matrices [1-3]. The commonly utilized fibers in aerospace, marine and automotive industries are Kevlar, carbon and glass. Due to the emerging concept of green technology, the promotion of natural fibers in reinforcements of composite has increased steadily. Recently, kenaf [4], palm oil [5], jute [6], bamboo [7] and ramie [8] fibers are the mostly utilized in composite applications. These fibers are widely used in composite structures due to its recyclable, high thermal resistance, acoustic insulation and good abrasiveness. However, the presence of hydroxyl group in nature imposes a great drawback on the natural fibre durability including high moisture absorption resulting in fiber swelling and delamination [9]. In addition, limited processing temperature, low fire resistant, variation in quality are other disadvantages of natural fibers.

Banana fibers, extracted from their pseudo-stem, is abundant, cost-effective and biodegradable. In previous study, Van-Pham et al. [10] mentioned that mechanical properties of unidirectional banana fiber-reinforced composites were generally affected by several processing parameters during fabrication. Ahmed et al. [11] stated that mechanical properties of banana reinforced acrylonitrile butadiene styrene (ABS) were influenced by fiber loading and chemical treatment. In addition, the effect of banana fiber surface treatment and matrix modification using compatibilizer on the mechanical properties of the low-density polyethylene (LDPE)/banana fiber composites was evaluated by Prasad et al. [12]. They proved that the addition of compatibilizer to the acid treated banana fiber composites provided the improvement in the impact and flexural strength. Here, it has to be noted that without the modification of physical and enzymatic treatment, those banana fiber composites have relatively poor mechanical properties.

With these results however, the performance of the natural fiber reinforced composite is still not comparable with the synthetic composites. Therefore, optimization in the compounding parameters of the natural fiber has been suggested. Govindaraju and Jagannathan [13] proposed the compression molding process parameters for the manufacturing of silk fiber-reinforced polypropylene composites using Box–Behnken Design (BBD). The compression molding process parameters such as temperature, time and pressure were optimized with respect to the mechanical properties. The optimized parameters have offered a good response to the predicted model. A surface response method using BBD for hybrid bamboo/wood fiber composite was evaluated by Song et al. [14]. Initially, three preparation variables such as volume fraction, process parameters and hot processing parameter were determined. The composites were examined for water uptake, thickness swelling and bending properties. A predicted model proved that all variables have significantly influenced the composite properties. Roslan et al. [15] optimized the alkaline treatment variables including sodium hydroxide (NaOH) concentration, soaking and drying time that affected the strength of bamboo strip. The Mode I interlaminar fracture toughness (GIC) of bamboo, in longitudinal direction was evaluated. They found that the proposed parameter significantly affected the fracture toughness. The effect of temperature, pressure, and time on the tensile strength of jute fiber composite has been evaluated by Kannappan et al. [16] using response surface method. The tensile strength values were in good agreement with predicted values and were found to have a R2 of 96%.

In the previous study, the Box–Behnken design (BBD) was initially adopted to evaluate the optimal condition for achieving the better mechanical properties of banana pseudo stem epoxy composites [17]. Here, the parametric factors including the fiber length, fiber loading and chemical treatment concentration were determined.

Manuscript published on November 30, 2019.
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This study focused on the thermal and mechanical behavior of the banana fiber composite as compared to the synthetic polymer.

II. MATERIAL AND METHODS

The material preparation of the banana epoxy composite and the procedures for the thermogravimetric analysis and tensile test conducted in this study are given.

A. Materials

The pseudo-stem banana fibers originated from Musa acuminate species was purchased from Innovative Pultrusion Sdn Bhd, Seremban Negeri Sembilan, Malaysia. The EpoxyAmite 100 epoxy resin and EpoxyAmite 102 medium hardener was obtained from Kird Enterprise, Nilai Negeri Sembilan, Malaysia. Sodium hydroxide (NaOH) was purchased from Orioner Hightech Sdn Bhd, Cyberjaya Selangor. The carbon, glass and Kevlar fiber tows were purchased from EasyComposite Ltd, Stoke-on Trent, England

B. Preparation of banana pseudo-stem epoxy composite

Initially, the pseudo-stem banana fibers were washed with deionized water and then was soaked in 5.45 wt.% NaOH for 5 hours. These fibers were placed in circulation oven at 80° C for 12 hours before grounded to 0.1-15 mm using a Cheso Model N3 crusher machine. These short banana fibers were sieved using rotational shaker and strainer BS410/1986 (Endecots Ltd.) model to obtain 3.3 mm of fiber length. Epoxy-resin with fiber was gradually blended to 29.86 wt% fiber loading according to the optimum condition suggested by Box-Behnken design [17]. The tensile specimen composites were placed in the mold cavity and cured overnight as illustrated in Figure 1. For comparison purpose, Kevlar, carbon and glass epoxy composite were also fabricated.

Fig. 1 Photo of molding fabrication of tensile specimens

C. Thermogravimetric Analysis

The thermal gravimetric analysis was conducted to analyze the thermal stability using TGA 55 (TA Instrument). Initially, composite samples ranging between 30-75 mg were placed in the platinum crucible pan before they were passed through the nitrogen atmosphere. Then, samples were scanned in temperature ranging from 30 to 600°C at a heating rate of 10°C/min.

D. Tensile Test

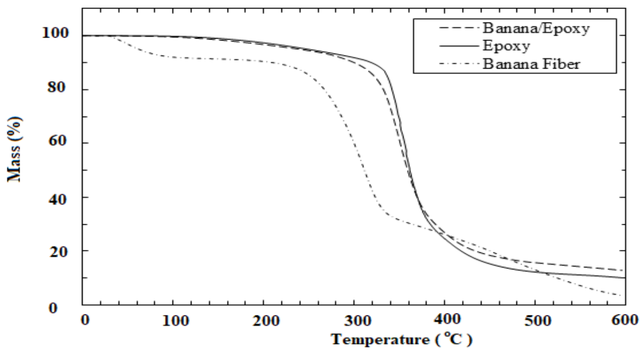
The tensile test of the dog bone specimen was conducted following ASTM 638 (18). The quasi-static measurements were investigated at crosshead displacement rate of 1 mm/min using 10 kN load cell. At least three specimens of each type of materials were tested and their average value was undertaken as a final result. The tensile tests were conducted on a Shimadzu AGX-S Universal Testing Machine at room temperature.

III. RESULTS AND DISCUSSION

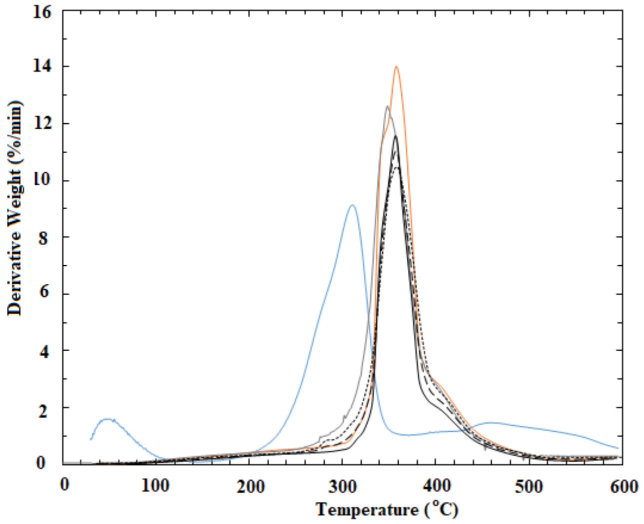
Here, the results from the thermal analysis and the tensile tests are discussed.

A. Thermal Analysis of Composites

Figure 2(a) illustrates the TGA curves of optimal banana epoxy composite, pure epoxy and banana fiber following thermogravimetric test. The banana fiber exhibits two mass loss steps with the initial mass loss of below 100°C is due to the gradual evaporation of absorbed moisture. The first stage mass loss of approximately at 220 and 320°C is adequate to the thermal decomposition of the hemicellulose and pectin, followed by the degradation of cellulose between 320 to 500°C. This is an agreement with the values of many plant natural fibers as reported by the researchers [19]. Kim et. al. [20] reported that lignocellulose materials are thermochemically acted and decomposed between 150 and 500°C, which hemicellulose decomposed mainly in between 150 and 350°C, cellulose from 275 to 350°C and lignin between 250 and 500°C. The mass loss steps of neat epoxy and optimal banana epoxy composite obtained slowly under 285°C; however, at above 500°C this process occurs very rapidly. The mass loss of both neat and composite began at 294 and 290°C, and was completed at 508 and 502°C, respectively. It can be noted that the thermal stability of banana fiber is lower than those of epoxy and optimal composite. As can be seen from the **Figure 2(b)**, the effect of adding of epoxy-resin with fiber has improved the thermal stability of the composites, however it is still lower than the neat specimen. It was apparent that the thermal stability of all the epoxy-resin composites decreased compared to those of the neat sample. In the case of binary optimum banana composites, T_{max} was decreased by approximately 3%, compared to neat epoxy, indicating that banana fiber degraded the thermal stability of the epoxy-resin system to an extent. The thermal degradation of epoxy-resin is dominated through main volatile products, acrolein, acetone, allyl alcohol and cross-linked chain mechanism [21] however, the primary source of thermal depolymerization in banana fiber is the constituents of the natural fillers. Guimarães et. al. [22] also confirmed that banana fibers have a lower ratio of holocellulose/lignin when compared to the other fibers, which resulted in lowering the value of decomposition temperature.



(a)



(b)

Fig. 2 Thermogravimetric plot of (a) thermogravimetric analysis (TGA) and (b) differential thermal analysis (DTA) of banana fiber, epoxy and optimal banana-epoxy composites under air atmosphere 10 °C/min.

As can be observed from Table 2, decomposition temperature T (5%) of banana fiber is taking place at around 61.9 °C. This finding is in close agreement with the value recorded by Arcaro et. al. [23], Pereira et. al. [24] and Zainudin et. al [25]. The epoxy polymer matrix revealed the highest thermal stability with T(5%) and T(50%) are 3.9% and 0.5% higher than the optimum banana-epoxy composite respectively. On the other hand, the table pointed out that the value of T(85%) for pure epoxy is 15% lower as compared to banana composite counterpart. This finding agrees with Chee et. al. [26]. The combination of banana fibers into the epoxy-resin matrix has lowered the thermal stability of the composites, suggesting natural fiber possesses a much lower thermal stability as compared to the synthetic polymer. The thermal stability of natural fiber composite is not depending on the chemical composition of the fibers itself, however some effects may exist on the removal on the thermal's cellulosic component through chemical modification [27]. Further, the initial degradation for all the synthetic composites is in the range of 200°C to 300°C, suggesting the occurrence of the evaporation of physically weak water molecules on the surface of the composites as well as dehydration induced by the secondary alcoholic groups [28].

Table 2: Thermal degradation data of banana fiber, epoxy and optimal banana-epoxy composite

	Decomposition temperature			Residual
	T(5%)	T(50%)	T(85%)	at 600°C (%)
Banana Fibre	61.9	311.32	453.39	3.54
Epoxy	248.65	360.26	453.84	10.14
Glass/Epoxy	249.32	369.25	495.02	38.52
Kevlar/Epoxy	265.25	373.21	665.23	28.63
Carbon/epoxy	268.25	375.58	623.45	25.25
Banana/epoxy	239.09	358.90	524.37	12.91

B. Tensile Properties

Figure 3 shows the stress-strain curves for virgin epoxy, pseudo-stem banana, Kevlar, glass and carbon reinforced epoxy composites. The tensile test results depict for less than 3 % strain, the composites closely obeyed Hooke's law, where the engineering strain, ε, is directly proportional to the applied stress, σ. The peak stress of banana fiber reinforced epoxy composite increased by 90% as compared to the unreinforced epoxy, highlighting that the epoxy matrix transmits the applied stress to the banana fiber resulting in higher strength [29]. Interestingly, all the synthetic composites unfolded good tensile strength and modulus values. For instance, the tensile modulus of the composites containing carbon and glass was recorded to be 126 MPa and 149 MPa respectively, which were evidently higher than that of the reference banana epoxy composite with 110 MPa.

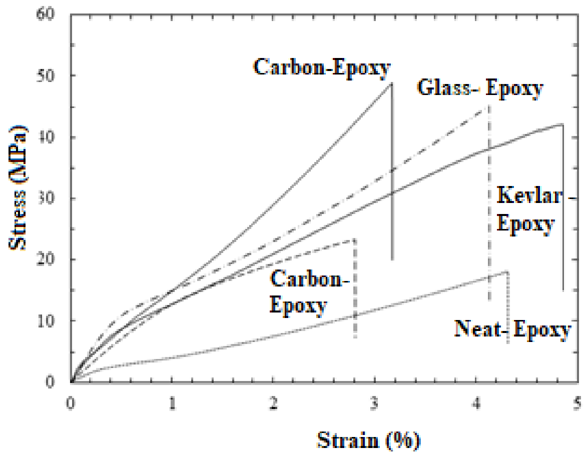


Fig.3: Stress-strain curves of neat epoxy-resin and optimum banana-epoxy following tensile strength

This improvement was expected since it is known that loading high mechanical performance fibers with such a good adhesion dispersion can raise the mechanical properties of the polymer composites. In the meanwhile, adding appropriate masses of carbon, Kevlar and glass reinforced epoxy increased the tensile strength and modulus up to 237 MPa and 7.8 GPa, respectively. It is evident that the tensile modulus of banana fiber has comparable mechanical modulus properties concerning glass and Kevlar epoxy composites.

IV. CONCLUSIONS

The thermal degradation and tensile behaviors of optimization effect of blending parameters on banana fiber reinforced thermoset was examined. TG and DTA curves revealed that the thermal stability of banana-epoxy composite was higher than those of the neat and synthetic samples. It was found that that constituents of the natural fillers in banana fiber improves thermal de-polymerization. In addition, banana fiber composite recorded a lower tensile strength even though it is still significantly comparable to those of synthetic fibers.

ACKNOWLEDGMENT

Appreciation is given to Universiti Teknologi Malaysia under "Geran PRGS-ICC Scheme, Q.K.130000.7756.4J381 for financial support provided to this research. The authors are thankful to Ministry of Education Malaysia and Universiti Putra Malaysia for supporting this work through the Visiting Scholar (Post-Doctoral) scholarship.

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