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EFFECT OF HUMIDITY ON THE MECHANICAL PROPERTIES OF KENAF YARN FIBRE/POLYLACTIC ACID BIOCOMPOSITES

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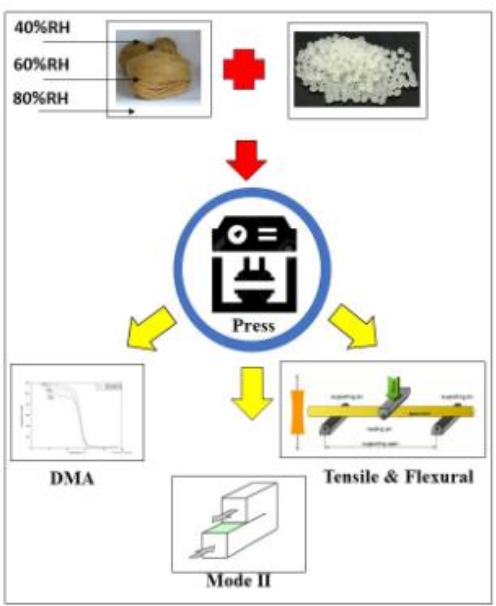
Graphical abstract



Abstract

Humidity during the fabrication of natural fibre reinforced composites can harm their mechanical performance. This study examines the effect of humidity during the fabrication of unidirectional kenaf/polylactic acid (PLA) biocomposites on their dynamic and static mechanical properties. Kenaf fibres were conditioned at different relative humidity (RH) levels (40% RH, 60% RH and 80% RH) before being pressed with PLA to form biocomposites. Kenaf/PLA biocomposites were analysed using dynamic mechanical analysis, fracture toughness in mode II, tensile and flexural. Results indicated that the value of G_{IIC} and storage modulus decreased when the relative humidity increased. Reduced tensile and flexural modulus were observed when kenaf was exposed to high relative humidity of 80% RH. However, the form of unidirectional kenaf affected the properties and reduced the drop value in the tensile modulus. The optimum relative humidity to produce kenaf/PLA biocomposites is 40% RH.

Keywords: Biocomposite, Kenaf fibre, polylactic acid, fracture toughness, humidity

Abstrak

Kelembapan semasa pembuatan komposit bertetulang gentian asli boleh menjejaskan prestasi mekanikal komposit tersebut. Kajian ini mengkaji berkaitan kesan kelembapan semasa proses pembuatan biokomposit kenaf searah/asid polilaktik (PLA) pada sifat mekanik dinamik dan statik. Gentian kenaf dikenakan pada taha kelembapan relatif (RH) yang berbeza (40% RH, 60% RH dan 80% RH) sebelum ditekan dengan PLA untuk membentuk biokomposit. Kenaf/PLA biokomposit dianalisa dengan menggunakan analisa mekanikal dinamik, keliatan patah pada mod II, tegangan dan lenturan. Keputusan menunjukkan bahawa nilai G_{IIC} dan modulus storan menurun apabila kelembapan relatif meningkat. Modulus tegangan dan lentur diperhatikan menurun apabila kenaf terdedah kepada kelembapan yang tinggi iaitu 80% RH. Walau bagaimanapun, bentuk kenaf dsatu arah mempengaruhi sifat dan mengurangkan nilai penurunan dalam modulus tegangan. Kelembapan relatif optimum untuk menghasilak biokomposit kenaf/PLA adalah 40% RH

Kata kunci: Biokomposit, gentian Kenaf, asid polilaktik, keliatan patah, kelembapan

1.0 INTRODUCTION

Due to their sustainability and biodegradable properties, biocomposite materials have gained attention from researchers worldwide. A biocomposite is a composite with at least one component obtained from natural resources and generates a positive impact to the surrounding environment [1]. Current global environment issues have increased the demand for the application of sustainable and environmentally friendly materials. Factors such as reduced fossil fuel use, minimised environmental pollution and high availability make biocomposite materials suitable replacements for synthetic fibre reinforced polymer [2]. This desirability can also be attributed to the excellent properties and superior advantages of natural over synthetic fibres in terms of the relatively low specific weight ratio, low cost and good thermal and acoustic insulating properties of the former. Studies reveal that biocomposites have wide applications in the automotive and construction industries. However, their low strength, poor fire resistance, high moisture absorption and notable deficits in properties limit their usage.

Kenaf reinforced polylactic acid (PLA) is a potential biocomposite material. Kenaf fibre is also a well-known natural fibre that can replace synthetic counterparts. In addition to its application in thermoset resin, kenaf can be reinforced for composite thermoplastics due to its properties over other natural fibres [3–6]. For the matrix, PLA presents a good selection of bio-resins, as proven by several mechanical tests, to evaluate the fibre/matrix adhesion properties of bio-resin [7]. This research compares PLA, MAPP and PP that have been examined using the pull-out, microbond and single fibre fragmentation tests, in which PLA revealed higher results than other matrixes. This finding is supported by another comparative study between PLA and PP composites by Mamun *et al*. [6] in which PLA exhibited better properties after reinforcement with oil palm fibre. Huda *et al*. [9] also demonstrated that PLA resin has good adhesion properties with kenaf fibre and is suitable as a matrix for kenaf biocomposites.

The main failure of laminated composite is delamination due to crack initiated, weak matrix–fibre bonding and impurity. This failure can be measured using fracture toughness, which is indicated by the strain energy release rate of the crack propagation to be investigated. Many factors affect the mechanical properties of this natural fibre, for which light exposure, temperature and humidity are amongst the most prominent factors influencing the capability of the fibre in natural composites [10–12]. Note that fracture toughness decreases as humidity and temperature increase. The reduction of mechanical properties with the presence of elevated temperature has also been reported [13]. A study on the degradation of PLA also indicates that water absorption affects the adhesion of the matrix [14]. The factors that tend to affect interlaminar fracture toughness for mode II crack propagation include the nature of the environment, temperature, loading conditions, molecular weight and the effect of the processing technique. Research on the temperature effect in relation to the fracture toughness for unidirectional and woven composites is scarce [15]. Hence, major emphasis is given on the first two factors of humidity and temperature [12].

In this study, fracture toughness in mode II was investigated to analyse the effect of humidity during the manufacturing of biocomposites and temperature during the fracture toughness test. Thermal analysis through DSC on PLA was performed to select the low melting temperature for fabrication usage, following Nur Adilah *et al.* [16]. Mechanical properties were found positively affected when using low temperature. Moreover, the mechanical responses to the frequencies and temperatures of kenaf/PLA composites were characterised by using dynamic mechanical analysis (DMA). Tensile behaviour was also monitored. The suitable humidity during the manufacturing of biocomposites and the correct temperature during application were also identified. The humidity levels varied from 40%–80% RH, whereas the temperatures ranged from ambient to 100 °C. Furthermore, an optimisation parameter was used to prevent strength reduction due to thermal degradation [17–19].

2.0 METHODOLOGY

2.1 Material

2.1.1 Reinforcement

Kenaf fibre was supplied by Innovative Pultrusion Sdn. Bhd. in the form of a yarn. The fibre was treated with 5% NaOH solution where it was immersed in for 24 hours and was then washed by water before being dried in an oven. The fibre was loomed manually to form a unidirectional mat sized 20 mm x 20 mm matched with a hot press mold. Figure 1 shows the kenaf yarn fibre used as a reinforcement.

Figure 1 Kenaf yarn fibre

2.1.2 Matrix

The matrix used PLA supplied by Nature Works with grade Ingeo biopolymer 2003D in the form of granules. PLA was changed from granules to sheets for the fabrication of the composite by using a hot press machine (Figure 2). A total of 50 grams of PLA were used to form a sheet of 1 mm thickness.

Figure 2 PLA bio-resin

2.1.3 Process Conditioning

Unidirectional kenaf fibre was conditioned in a humidity chamber for 24 hours before fabricating the composite panel. Humidity varied from 40%, 60% and 80% RH at 23 °C.

2.2 Composite Fabrication

Kenaf/PLA composite was fabricated using the compression method with 30%wt of the kenaf fibre [17] and two layers of laminated construction. A 25 mm wide PTFE sheet was placed in the middle of the 3 mm composite panel to initiate cracking at the edge of the kenaf/PLA sample for the fracture toughness test (Figure 3). Compression was used with the optimisation parameter pressure of 3 MPa at 160 °C temperature for 3 minutes.

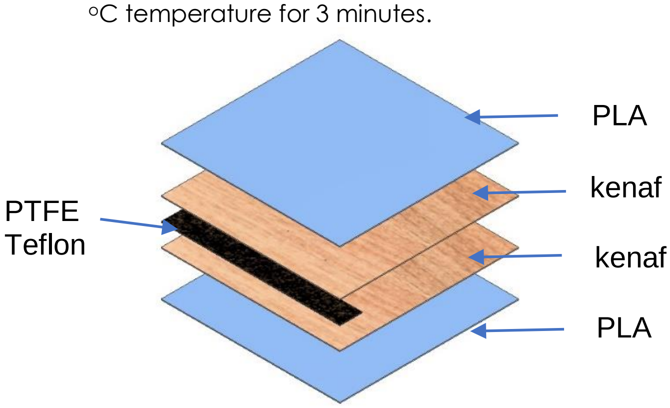


Figure 3 Sequence of laminated kenaf/PLA biocomposites

2.3 Mode II Fracture Toughness Test

The end-notched flexure (ENF) test was used to determine the mode II interlaminar fracture toughness G_{IIC} of unidirectional kenaf/PLA. ENF test was conducted following the ASTM D7905 standard by using a 10 kN Instron Universal Testing Machine (UTM) (Figure 4). The test was performed with a 50 kN Instron UTM. The kenaf/PLA sample was loaded in a 3-point bending fixture with 1 mm/min of loading rate at ambient temperature. After the test, the strain energy release rate was calculated from direct beam theory, where G_{IIC} was expressed as follows:

$$G_{IIC} = \frac{9P_c\delta_c a^2}{2b(2L^3 + 3a^3)},$$

with *L*: half-span length, *a*: starting defect length, *b*: width of the ENF specimen, *P*: force and *δ*: displacement recorded during the testing.

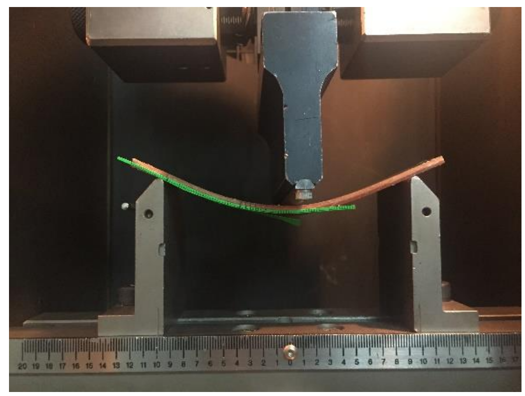


Figure 4 ENF test for fracture toughness test, mode II

2.4 Dynamic Mechanical Analysis

The dynamic mechanical properties of kenaf/PLA biocomposites were determined using a 3-point cantilever beam on a TA Instrument Q800 Dynamic Mechanical Analyser (Figure 5).

(a)

(b)

Figure 5 (a) TA Instrument Q800 for Dynamic Mechanical Analysis. (b) 3-point cantilever beam mode test

Analyses of the storage modulus, loss modulus and tan delta (δ) as a function of temperature were conducted in the range of 20 °C–100 °C at a frequency of 1 Hz and a heating rate at 5 °C/min. This test was performed in accordance with ASTM D7028 [9].

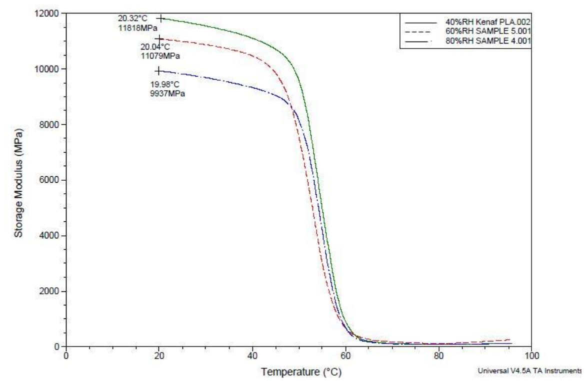
2.5 Tensile Test

Tensile test was conducted according to ASTM D3039 by using an Instron UTM. The dimension of the Kenaf/PLA biocomposite sample was 25 mm in width, 175 mm in total length, with 25 mm of tab length. The speed of the loading rate was fixed at 2 mm/min at ambient temperature with a 10 kN load cell. All results were taken as the average value of the five replications.

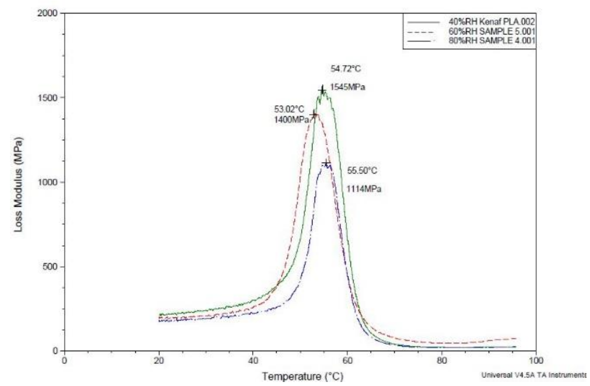
3.0 RESULTS AND DISCUSSION

3.1 Dynamic Mechanical Analysis

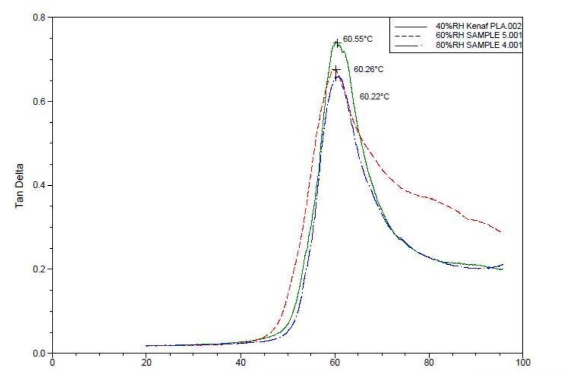
Figure 6 illustrates the result of the temperature dependence of the dynamic storage modulus (E'), loss modulus (E'') and tan δ of the Kenaf/PLA biocomposite sample at different fabrication humidity levels. Humidity during fabrication affects the interfacial bonding between the kenaf fibre and PLA matrix. The E' and E'' plots indicate that the values decreased as the relative humidity during fabrication increased. The highest modulus achieved was for fabrication at 40% RH, followed by 60% RH, and the lowest value was at 80% RH. This variant result showed that the presence of humidity does affect the dynamic properties of the composite lamination with an adhesion problem between the matrix and reinforcement. These results are in line with those of Li *et al*. [20], who found that increased relative humidity causes decrease in the dynamic performance of other natural composites. However, a sudden drop was observed starting at 50 °C for all samples. This decline is related to the glass transition temperature (Tg) of PLA and the loss of composite stiffness.



(a)



(b)



(c)

Figure 6 Temperature dependence of (a) storage modulus, (b) loss modulus and (c) tan δ of kenaf/PLA composites

Figure 6(c) shows the T_g derived from the plot of the tan δ curves. All humidity levels during manufacturing did not affect the values of T_g that showed an average of 60 °C. Moreover, a slight decrease occured in the values of T_g at 30 °C compared with the T_g of a single PLA when tested through DSC analysis (Figure 7). Given such a small variance in value, the humidity during manufacturing did not improve the T_g of the biocomposite.

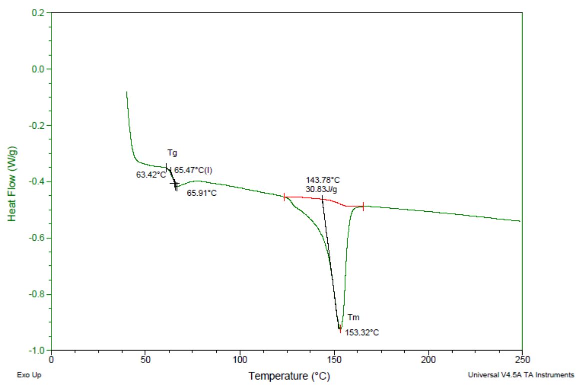


Figure 7 DSC results of PLA

3.2 Fracture Toughness

ENF test determines the fracture toughness G_{IIC} for mode II. The test was completed after a sudden drop occurred for load displacement. The G_{IIC} value in Table 1 was obtained using the calculation formula after the completion of the test. The result was compared with different humidity levels during manufacturing. The highest value of G_{IIC} was 40% RH at 75.21 J/m^2, and this value decreased as humidity increased. The average decrease of the energy release rate was approximately 10% for each humidity level, which gives 66.90 J/m^2 for 60% RH and 60.10 J/m^2 for 80% RH (Figure 8). Thus, the performance of the fracture toughness of unidirectional kenaf/PLA biocomposite is affected by the presence of humidity.

As a natural fibre, kenaf demonstrates hydrophilic behaviour and can absorb considerable water during high humidity. These characteristics cause high failure probability during delamination if the manufacturing process is performed in a wet environment. This notion is supported by the research of Zhang *et al*. [11] who indicated that the lack of resin adhesion to flax fibre shows weak interaction between fibre and resin in wet conditions.

Table 1 Value of fracture toughness for mode II at different processing humidity levels

Humidity	Fracture Toughness J/m^2
40% RH	75.21
60% RH	66.90
80% RH	60.10

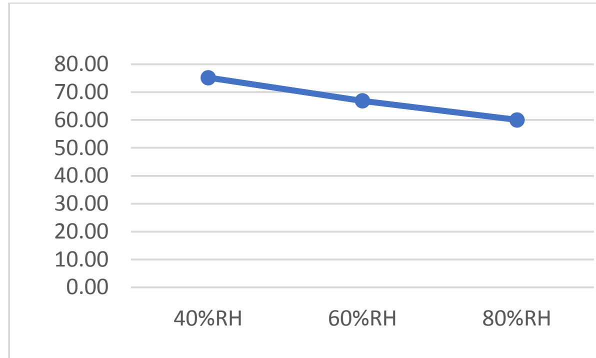


Figure 8 Fracture toughness G_{IIC} for mode II mechanical characterisation

3.3 Tensile and Flexural

Table 2 and Figures 9 and 10 show the tensile and flexural modulus for kenaf/PLA. The three values of relative humidity were tested to evaluate their effects on the tensile properties of kenaf/PLA. The tensile and flexural modulus decreased when the biocomposite sample was exposed to high humidity. For both properties, 40% RH is the suitable manufacturing humidity to ensure a good performance of the biocomposite. The result is in line with the summary by Yahaya *et al*. [21] who revealed that dried kenaf has good tensile properties.

However, the tensile modulus showed smaller differences for each humidity level than flexural modulus. For each drop in humidity level, the tensile modulus exhibited approximately 100 MPa relative to the approximately 700 MPa drop in the flexural modulus. The reason for this outcome is because the tensile test of a unidirectional kenaf is obtained from the fibre direction. Thus, the fibre direction of reinforcement can improve the tensile properties of the composite.

Table 2 Young's modulus of kenaf reinforced PLA biocomposites

Humidity	Tensile Modulus, MPa	Flexural Modulus, MPa
40% RH	6210	7279.6
60% RH	6150	6378.1
80% RH	6040	5874.6

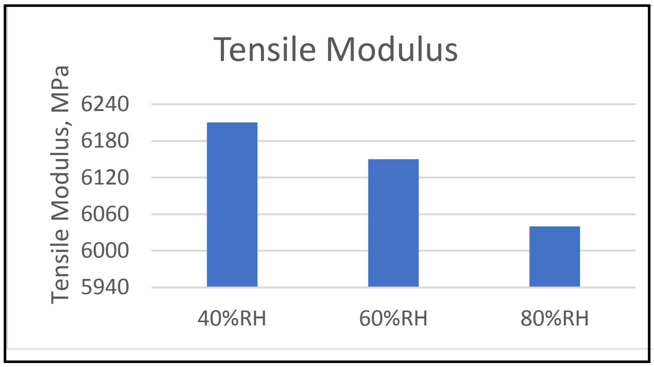


Figure 9 Tensile modulus of kenaf reinforced PLA biocomposite

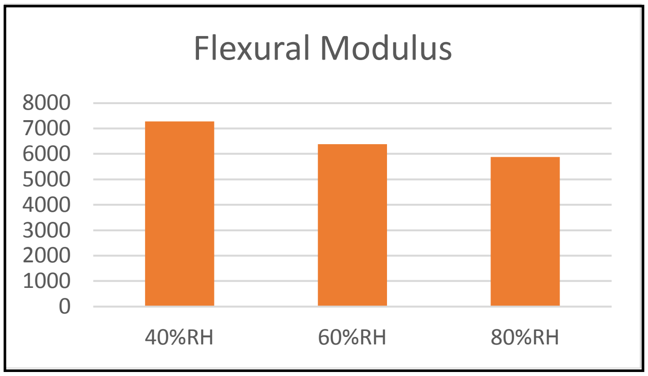


Figure 10 Flexural modulus of kenaf reinforced PLA biocomposite

4.0 CONCLUSION

DMA revealed that the conditioned kenaf fibre creates a high storage modulus in the biocomposite during manufacturing. Moreover, such an analysis presents the ideal relationship by using a dual cantilever beam to determine fracture toughness in mode II, G_{IIC} where both tests are in the bending direction. The ENF experiment confirms that dry humidity during manufacturing provides good properties to the composite itself. The change in humidity during manufacturing causes a decrease in energy release rate by an average of 10%.

Thus, the selection of humidity during manufacturing affects the fracture toughness in mode II of kenaf reinforced PLA biocomposite. Humidity also affects the dynamic and static mechanical properties of the biocomposite. All experiments reveal parallel results in which humidity causes moisture to be trapped in the laminated composite and causes the bond between kenaf and PLA to deteriorate. From this experiment, 40% RH is confirmed to be the optimum humidity to process natural kenaf into a biocomposite.

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