Polylactic acid (PLA) based green composites reinforced pineapple leaf fibres: evaluation of processing and tensile performance

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Abstract. This paper reports on a study of the compression moulding and the vacuum forming of unidirectional pineapple leaf fibres/polylactic acid composites and the influence of process variables on the tensile properties of the material. The characterisation of the micro and meso structures of the pineapple leaf fibres is reported. The effect of consolidation temperature on the fibre thermal stability and the tensile properties of the composites is investigated. The results show that vacuum forming was found to be preferable process with high stiffness modulus and UTS of the composites, compared to compression moulding. The insignificant detrimental effect of 165°C high consolidation temperature was observed. Finally, the fibre thermal degradation seems to dominate the composite tensile performance over its interfacial quality between the fibre and the matrix.

1 Introduction

There has been a sustainable agriculture itinerary toward short product life cycle made from renewable or biodegradable materials. For this season, academic research has been shifting from synthetic materials to natural materials, like fibres and bio-plastic composites [1-3]. Furthermore, the natural material offers several advantages i.e., light weighting, eco-friendliness and safety from hazards [4, 5].

Since 2006, environmental legislation in Europe and Japan has increased the pressure to reuse or to use renewable materials in the manufacture of vehicles [6]. For that reason, and the general drive toward sustainability, natural fibre reinforced polymer composite materials are of increasing interest in the automotive industry. They are also attracting interest for many other application areas including tribology, piping and electronic devices [7-9].

Natural fibres, such as pineapple leaf, ramie and hemp, are low density and can be used as the composite reinforcement, especially non-structural applications [6, 7]. Even though their tensile strength is low, compared to the E-glass fibres, it can compete in terms of specific properties [10-12].

Notwithstanding, their thermal stability of hemicellulose consisted of plant fibres limits composite properties after high temperature thermoplastic forming. The various natural constituents of plant fibre result in poor composite performance due to their low thermal degradation [13-15]. It depends on a number of factors namely heat rate, temperature and chemical composition

of materials. Flax retains its strength at 170 °C for 2 hours while that of 200 °C for half an hour, for instance [14, 16]. In addition, polymers (as matrix materials) are limited from low thermal decomposition temperature of the plant fibres at high melted temperature processing. On the other hand, high viscosity melted thermoplastic property leads to low consolidation with high void content of composite, especially short dwelling period. Natural materials could generate a number of volatile products from their chemical constituents during high temperature and trap in the laminates as voidage [17].

2 Materials and experimental Method

2.1. Materials

Polylactic acid (PLA) and pine apple leaf fibrers are used in this investigation. PLA in a pellet form, supplied by Naturework Co., Ltd., is used as the matrix and the reinforcement is a unidirectional (UD) pineapple leaf fibres. Before the moulding studies, the fibres were fully characterised to determine, fibre diameter, fibre apparent density and fibre hydration levels.

2.2 Composite manufacturing

The UD pineapple leaf fibre/PLA composites were processed by isothermal film stacking of 40% fibre volume fraction (V_f) with compression moulding and vacuum forming process.

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2.3 Thermogravimetric analysis

Thermal stability of pineapple leaf fibres was studied by thermogravimetric analysis. The samples were dried at 60 °C for 8 hours and were vacuum packed before performing. The fibres were weighted 10 mg and test using thermogravimetric (TG) technique to obtain a differential thermogravimetric (DTG) curves. The examination was conducted with a thermal analyzer setaram (Labsys evo TG/DTA, TG/DSC), under argon atmosphere. A heating process of room temperature to 600 °C at 10 °C/min of heating rate was used with an argon flow rate of 20 ml/min. Argon does not react with all materials as an inert gas.

2.4 Tensile test

Single fibres were performed tensile properties, according to ISO 11566: 1996. A TA XTplus of Texture Analyzer was used to examine 20 replicated samples with 2.5 mm/min of cross head speed. Each fibre cross-sectional area was calculated from each optical micrograph with image processing (ImageJ open source program).

The composite samples were examined their tensile perform according to ISO527-5:2009 (using an Instron universal testing machine). An extensometer gauge length of 50 mm at a cross head speed of 2 mm/min attached to ten replicated from each plaque test.

3 Results and discussion

3.1. Characterisation of the pineapple leaf fibres

The pineapple leaf fibre bundles were shown in Fig. 1 and single fibres were shown in Fig. 2. Each single fibre is not uniform shape. The mean equivalent diameter is 62.27 micrometres. A fibre apparent density of 1.32 g/cm³ and the average moisture content at the initial condition of 11.24% for arbitrary storage RH were examined. Fig. 3 shows the stress-strain curves of pineapple leaf single fibre.

Fig. 1 The pineapple leaf fibre bundles.

Fig. 2 The pineapple leaf single fibres.

Fig. 3 Stress-strain curves of pineapple leaf single fibre.

3.2 Effect of temperature on the Thermal Stability of Fibres

Fig. 4 shows the differential thermogravimetric (DTG) peak between 30 °C and 600 °C. A small peak (between 45 °C and 120 °C) attributed to the water mass loss of the moist fibres. There is a shoulder peak (between 230 °C and 270 °C) attributed to hemi-cellulose and pectin degradation. A sharp peak at 350 °C attributed to cellulose degradation.

The DTG and the second time derivatives (D²TG) curves were used to evaluate the initial decomposition temperature (T₀) of pineapple leaf fibres as described in Yao, et al.'s article[18]. The results from the thermal stability study reveal that the pineapple leaf fibre are stable until 250°C at a heating rate of 10°C/min. Nevertheless, TGA only shows the dynamic heating results (~40 to 200°C for 18 minutes). The result of quasi-static composite processing (~40 to 200°C for about 300 minutes) could show a much higher thermal degradation effect and the temperature limit of that is therefore likely to be below 250°C, resulting in a likely compromising of the mechanical performance of the fibres.

Fig. 4 The differential thermogravimetric (DTG) curves of the pineapple leaf fibre bundles.

3.4 Effect of processing on the tensile performance of composites

Tensile performance of 40%V_f UD pineapple leaf /PLA composites, are compared in Figs. 5. The materials processed with compression moulding of 50 kPa at 165, 180 and 190°C for 3, 5 and 7 mins were performed. The materials processed with vacuum forming at 165, 180 and 190°C for 30, 60 and 90 mins were examined. Both modulus and UTS of the composites decrease with the dwelling time increase. The UTS of the compression moulding material is lower than that of the vacuum forming material. The weaker performance of the compression moulding material could be attributed to the higher void content level of the composite, caused by low consolidation time. Fig. 6 shows a micrograph of fibre-matrix interfaces.

Voidage presences in Fig. 6 expose their weak interfacial bonding between the fibres and the matrix due to inadequate consolidation time.

4 Conclusions

- Vacuum forming was found be preferable process with high stiffness modulus and UTS of the composites, compared to compression moulding.
- The insignificant detrimental effect of 165°C high consolidation temperature was observed.
- The fibre thermal degradation could dominate the composite tensile performance over their poor interfacial bonding effects.

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Fig. 5 (a) Stiffness modulus (E) of 40%V_f UD pineapple leaf /PLA composites (b) Ultimate tensile strength (UTS) of 40%V_f UD pineapple leaf /PLA composites (c) Percentage of composite elongation at break of 40%V_f UD pineapple leaf /PLA composites

* c165 is compression moulding process of 50 MPa at 165°C of 40%V_f UD pineapple leaf /PLA composites

* v165 is vacuum forming process at 165°C of 40%V_f UD pineapple leaf /PLA composites.

Fig. 6 poor-impregnated laminate with high void content of the pineapple leaf fibre bundles

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