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Thermal and Mechanical Properties of Thermoplastic Cassava Starch/Beeswax Reinforced with Cogon Grass Fiber

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ABSTRACT

The aim of this paper is to investigate the effect of cogon grass fiber (CGF) on the thermal and mechanical properties of thermoplastic cassava starch (TPCS)/beeswax matrix. The alteration of TPCS/beeswax reinforced with cogon grass fiber was performed by incorporating various amount of CGF (0,10,20,30,40 wt.%) into the polymer matrix. The samples were then evaluated using thermogravimetric analysis and tensile test. The findings showed that the thermal properties of the composite were slightly improved as the CGF content increase. The mechanical test showed that the tensile strength and tensile modulus increased with the addition of the CGF. However, the elongation at break showed a decreased pattern following the increasing content of CGF compared to the 0% of fiber content. In general, the findings from this study have shown that the TPCS/beeswax reinforced with the CGF composite has improved the functional properties of the composites compared to the TPCS matrix.

1. Introduction

In recent, the concern about protection of ecological systems is rapidly growing. Non-biodegradable and environmental pollution are the side effects of petroleum based synthetic polymers. These polymers affect wildlife severely, due to its poor disposition [1]. Together with increasing environmental regulations, the depletion of petroleum resources acts synergistically to

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provide the impetus for new materials and products that are environmentally compatible and independent fossil fuel [2]. However, the increased demand for environmentally friendly plastics, such as bio-based plastics produced from renewable resources, and biodegradable plastics that are degrading in the environment to build a more sustainable society and managing global waste and environmental problems [3].

Among bio-based plastic, starch is one of the most promising due to the abundant, low cost, renewable, and totally biodegradable in nature [4,5]. Starch can be converted into thermoplastic material with the presence of heat and shear; hence, it can be processed by using conventional plastic processing technique such as extruder and injection molding [6,7]. However, pure thermoplastic starch has limitation such as poor mechanical properties which limits the potential application of this bioplastic in the industry.

In recent, natural-based reinforcement has gain increasing interest due to the high demand for more sustainable and environmentally friendly manufacturing approach [8-10]. The performance of this material is quite promising as reported in the previous studies [11-13]. On the other hand, cogon grass or Imperata Cylindrica grass are part of the Poacea (Graminae) grass family. This plant also known as jap grass, blady grass, spear grass, and Lalang in Malaysia. This grass is well known because of its troublesome traits which is the rough edges of the mature cogon grass leaves and silica bodies all over the leaves cause the grass is not edible for the animals. Instead, this grass can bring injuries to the animals. This grass also can grow aggressively throughout the tropical and subtropical areas across the world [14]. Nevertheless, cogon grass composed of several elements which are cellulose, hemicelluloses, lignin, pectins and extractives which serve as potential reinforcement source for composite material. In our previous study, cogon grass has shown good reinforcement effect which makes this material as potential reinforcement for polymer composites [15].

Beeswax is natural wax derive from bees which is widely used in food and cosmetic industry. Apart from that, beeswax portrays good properties such as ability to block moisture migration and improve product's shelf life and remain its main application as a product coating [6]. In our previous study, incorporation of beeswax has successfully improved the thermoplastic starch rigidity and reduce its moisture sensitivity [6].

Hence, even though there are previous study reported on using cogon grass fiber as reinforcement, however, none has been found on using this fiber as reinforcement for thermoplastic starch/beeswax composites. Hence, this study investigates the behavior of thermoplastic cassava starch modified by incorporation of beeswax and cogon grass fiber. The thermal and mechanical properties of the composites will be evaluated in this study.

2. Materials and Methodology

2.1 Materials

Food grade cassava starch was procured from Antik Sempurna Sdn Bhd, Malaysia. Glycerol used as a plasticizer was purchased from QReC Chemical. Beeswax was purchased from Sigma Aldrich chemical. Cogon grass was obtained from Ayer Keroh, Melaka, Malaysia. The extraction process of Cogon grass fiber was carried out using water retting method. Minimum time required for the water retting is 2 weeks depends on the Cogon grass texture itself. When the leaves of Cogon grass become soft enough, the leaves need to be tear to smaller parts to ease the following grinding process. After tearing the leaves to smaller parts, the leaves need to be dried under the sunshine for few hours. The dried leaves of Cogon grass need to be cut more into smaller pieces before underwent the grinding process that will produce fine Cogon grass fiber.

2.2 Sample Fabrication

The modification of TPCS/Beeswax reinforced with Cogon grass fiber was performed by mixing different amount of Cogon grass fiber (0, 10, 20, 30, 40 wt.%) into the polymer matrix using high speed mixer (Table 1). The mixture was pressed at 145 °C for 1 hour into 3 mm thickness plate using GoTech hot press machine. The prepared samples were stored in close desiccator until further testing.

Table 1
Amount of cogon grass fiber as reinforcement

Composites	TPCS/Beeswax (%)	Fiber loading (%)
0	100	0
10%	90	10
20%	80	20
30%	70	30
40%	60	40

2.3 Thermal Testing: Thermo-gravimetric Analysis (TGA)

Thermogravimetric analysis was carried out to identify the thermal degradation behaviour of the material with respect to weight loss due to temperature increment. TGA was conducted with a Mettler-Toledo AG, Analytical from Schwerzenbach, Switzerland. The specimen weighs around 10±2 mg. The analysis was performed in an aluminium pan under a dynamic nitrogen atmosphere in the temperature range 25 to 900°C at heating rate of 10°C min^{-1}.

2.4 Mechanical Testing: Tensile

The specimens for tensile tests were prepared according to the ASTM D638. The test was carried using a Universal Testing Machine (INSTRON 5969) with a 5 kN load cell; the crosshead speed is maintained at 5 mm/min. The testing needs to be set at room temperature of 23 ± 1 °C and relative humidity of 50 ± 5%.

3. Result and Discussion

3.1 Thermo-gravimetric Analysis

The decomposition and thermal stability of TPCS/beeswax reinforced with CGF were presented in thermogravimetric analysis (TGA) and derivative thermogravimetric (DTG) curves in Figure 1 and Figure 2. Figure 1 shows the TGA curves obtained from the TPCS/Beeswax reinforced with the CGF composite. The first phase of degradation in temperature range of 0°C to 200°C was attributed to the evaporation of water and glycerol. After that, the change of the weight loss for TPCS/Beeswax reinforced with CGF composite in temperature range between 150°C to 180°C was mainly attributed to decomposition of three major chemical components of the natural fibers; hemicellulose, cellulose and lignin) [16]. Besides that, another study by Sarifuddin *et al.,* [17], stated that decomposition process that take place at temperature in range up to 300°C where the thermal degradation of starch carbon chains occurred.

After completion of hemicellulose decomposition, the cellulose decomposes approximately at temperature of 320°C and followed up by the hardest component to 68 decompose which is the lignin that started as early of 160°C and degrade slowly up to 900°C for complete decomposition [16].

Degradation above 500˚C may possibly related to the decomposition of carbonate fiber leading to the formation of char. In the final decomposition stage of the composites, the remaining char were oxidated [18]. can be observed that the composite with the highest fiber content which is 40% have higher thermal stability compared to the 0% of fiber content. The justification is mainly due to the fiber loading in the composite.

Meanwhile, Figure 2 shows the DTG curves obtained from the TPCS/Beeswax reinforced with the CGF composites. It is clearly visible that the first peak of the composites (maximum decomposition) after integration with CGF was slightly deviated into the lower temperature which is compliance with the result shown in TGA curve, implying enhanced the thermal stability. The weight loss at the maximum decomposition phase was decreased following the increase of CGF content. According to Lomelí-Ramírez *et al.,* [19], addition of the fiber with the starch matrix enhances the thermal stability when the fiber and the matrix adhere properly, reducing mass loss in the sample.

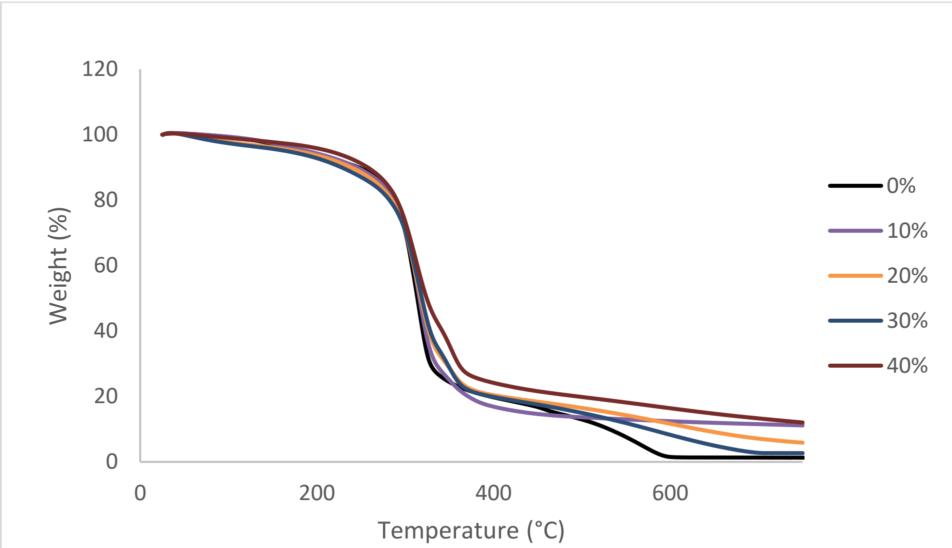

Fig. 1. TGA curve of TPCS/Beeswax + CGF composite

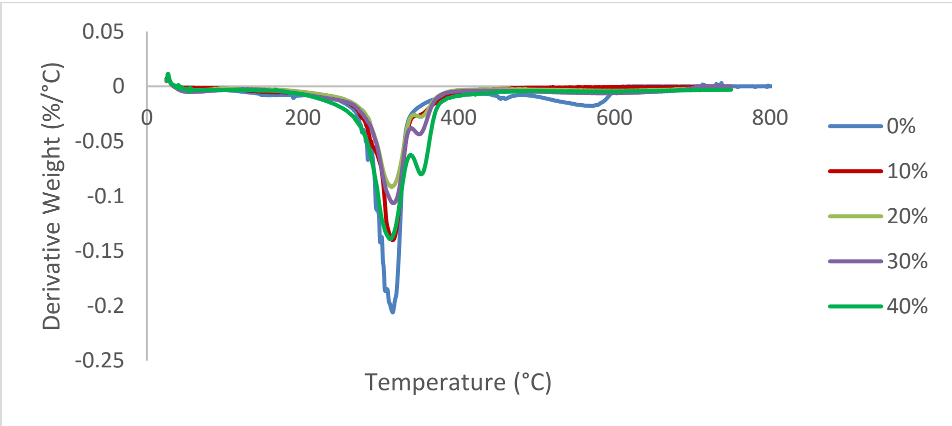

Fig. 2. DTG curve of TPCS/Beeswax reinforced with CGF composite

3.2 Tensile Properties

The alteration of the composition of thermoplastic cassava starch has affected the mechanical characteristics of the thermoplastic cassava starch. The effect of CGF addition on the TPCS/Beeswax composites were shown in the Figure 4 until Figure 6, which is the tensile strength, tensile modulus and elongation at break. Based on Figure 4, the tensile strength of TPCS/Beeswax reinforced with CGF showed a significant increment with an increase fiber content from 0% until 30%. This can be associated with the reinforcing effect of the CGF initiated by the interactions between the TPCS matrix and the cogon grass reinforcement and by the good surface wetting morphology as observed from SEM micrographs in Figure 11. However, there was a slight reduction at 40% of CGF. The reduction of strength at this point might be attributed to larger/higher content of fiber [20].

Meanwhile for the tensile modulus showed a major improvement until 40% even though the tensile strength was slightly decreased. According to Sarifuddin *et al.,* [17], it was anticipated that the fiber additions would improve the modulus due to inclusion in the soft matrix of rigid filler particles. Therefore, this finding suggests that the fiber inside the composites existed to have the stiffening effect.

Besides that, the elongation of the composites was already high initially before addition of Cogon grass fiber. Refer to the Figure 6, the elongation begun to decline when 10% of cogon grass fiber is added into the TPCS/Beeswax matrix. The declination continues until 40% of cogon grass fiber content. The lower concentration of starch that leads to the decrease in elongation in breaks can be related to these phenomena. Therefore, lower content of fiber have improved elongation values, whereas higher content of fiber has provided a decreasing elongation.

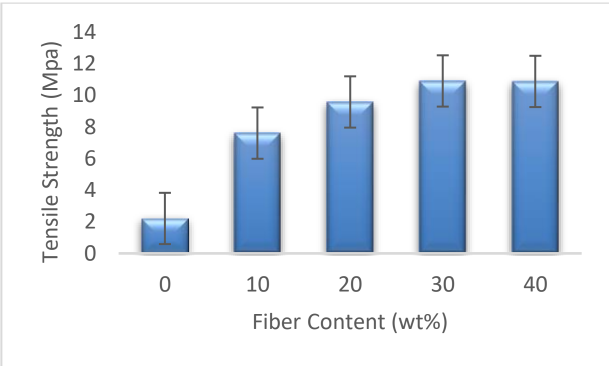

Fig. 4. Tensile strength of TPCS/Beeswax reinforced with CGF

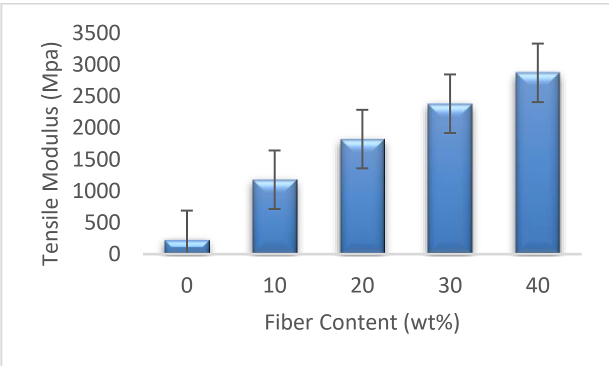

Fig. 5. Tensile modulus of TPCS/Beeswax reinforced with CGF

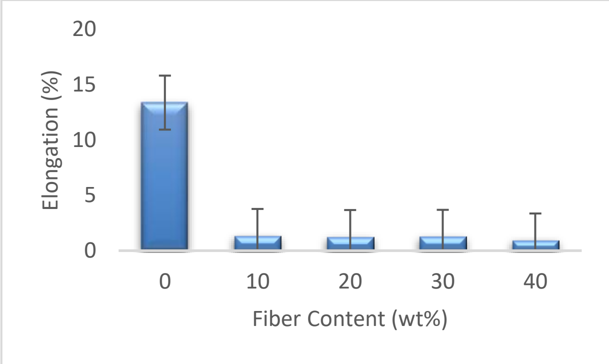

Fig. 6. Elongation at break of TPCS/Beeswax reinforced with CGF

4. Conclusion

The biopolymer composite derived from cassava starch and incorporation of cogon grass fiber were successfully prepared via high speed mixing and hot pressing in this study. The thermal properties of TPCS/beeswax reinforced with CGF composite were successfully evaluated. TGA test indicates that the incorporation of CGF significantly improved the thermal stability of the composite. The mechanical properties of TPCS/beeswax reinforced with CGF composite were successfully evaluated. The incorporation of CGF essentially enhanced the tensile strength and tensile modulus but decrease the elongation at break of the composite. Overall, this finding shows that addition of cogon grass fiber has improve the functional properties of this material.

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