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Mechanical Properties of Thermoplastics Corn Starch (TPCS) Reinforced Pineapple Leaf Fibre (PALF) Composite

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Abstract*: *The aim of this study is to investigate the mechanical characterization of bio-composites on thermoplastic corn starch (TPCS) reinforced with 2 mm length of pineapple leaf fibre (PALF). The selection of different weight percentage of fibres (20, 30, 40, 50 and 60) weight percentage (wt.%) of PALF contents were applied in this study. The mixtures of TPCS with different wt.% of PALF were made by using a hot compression moulding at 165 °C for 15 minutes. The mechanical testing that has been performed are tensile, flexural and impact testing to determine the effect of fibre loading on bio-composites characteristics. The results show that by incorporating 40 wt.% loading of PALF, the tensile strength and tensile modulus has increased to the maximum. However, the flexural testing result shows that 50 wt.% loading of PALF show the highest strength and modulus. Meanwhile, the impact testing result shows decrement when the loadings of PALF increases. Scanning electron microscopy (SEM) show that the TPCS with 40 wt.% of PALF have a good miscibility between matrix/fibre in the bio-composites. Overall, the TPCS/PALF composites enhance the properties of the bio-composites for short-life application: that is, plate, container, disposable tray, packaging etc.

Keywords*: *bio-composites, thermoplastic corn starch, pineapple leaf fibre.

I. INTRODUCTION

Plastics product are a common material in our daily life and are widely used in various industries including packaging, electrical and electronic equipment, automotive and other. Plastics properties such as convenience, lightweight, low cost and stylish style make them an indispensable material in products creation. However, plastics generated from petroleum cannot be degraded and cause negative effect on the environments [1]–[3]. Due to all these negative factors, green composite are one of the best alternatives to conventional plastics, which could potentially solve the problem of polymer waste disposal [4,5].

In recent years, the development of bio-polymers has relied on renewable sources for examples, cellulose, soy, starch, polyhydroxy alkanoates and polylactic acid have been investigated as substitutes materials for replacing conventional (synthetic) polymers [6]. The most suitable source for the production of biodegradable plastics and their composites is starch. This is because it is sustainable, abundant, natural and biodegradable. In addition, starch can exhibit thermoplastic behavior under high temperature and shear stress [7,8]. The starch consists of two main parts, linear amylose and highly branching amylopectin [9]. Amylose chains rates in native starch are genetically recognized and are generally consistent for certain plant species. In addition, previous studies have suggested that thermoplastics starch (TPS) produced using high amylose starch has better thermal and mechanical properties [10]–[13]. Therefore, thermoplastics corn starch (TCPS) can be considered a bio-polymers, which is reinforced with PALF to form a bio-composites materials.

Nowadays, natural fibre such as flax, banana, sisal, oil palm, kenaf, jute, cotton, pineapple leaf fibre and etc. have been extensively studied to discover their potential as synthetic fibre substitutes [14]. The main advantages of natural fibre over the conventional plastics are lower in cost, sustainable, less emission and abrasive damage, lower density and higher specific strength and stiffness [15]. Mixing natural fibre with bio-plastics produces green composite that are easily degraded by certain enzymes or bacteria [16,17]. Pineapple leaf fibre (PALF) has been seen as a great potential for replacing synthetic fibres. PALF is very accessible and has excellent mechanical properties. PALF exhibits high tensile strength and Young's modulus due to its high cellulose substance content and low microfibrillar angle [18,19].

In this work, the main objective is to fabricate bio-composite material from thermoplastic corn starch (TPCS) with pineapple leaf fibre (PALF).

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The effect of fibre loading on mechanical testing and morphological behaviour were examined to investigate the impact on the properties of TPCS mixtures with PALF. A number of experimental approaches were utilized to describe the properties of the TPCS/PALF bio-composites including tensile test, flexural test, impact test and microstructure analysis utilizing the Scanning Electron Microscopes (SEM).

II. METHODS AND MATERIALS

A. Raw Materials

Corn starch (CS) used in this study is in powder form and for manufacturing usage. CS powder and glycerol were procured from Polyscientific Enterprise Sdn. Bhd. Melaka. The brand of glycerol was used is Qrec G4018-1-2500. The PALF type utilized in this study is from Josapine cultivars. The procurement of the PALF type was obtained from cultivated areas in Kampung Parit Puteri Menangis, Pontian, Johor, Malaysia.

B. Sample Preparation

Thermoplastics corn starch was prepared from blended 70 wt.% of native corn starch powder and 30 wt.% of glycerol via hand-mixed and high speed mixer [20,21]. All PALF with 2 mm length were randomly orientated within the sample. All sample of PALF/TPCS bio-composites were subjected to the compression moulding (Hot Press Machine) at the pressure of 750 kg/cm^2 and 165 °C of temperature for 15 minutes followed by curing for 30 minutes. The sample were fabricated based on a mild steel mold with fixed length x width x height of 140 mm x 60 mm x 3 mm.

C. Tensile Test

The standard of ASTM D-368 is adhered in performing the tensile tests at room temperature. Five replication samples were utilized in the test. Universal Testing Machine (INSTRON 5969) with 5 kN load cell was used for the tensile test. The crosshead speed was maintained at 2 mm/min while the samples were prepared with dimensions of 140 mm (L) x 13 mm (W) x 3 mm (T).

D. Flexural test

Meanwhile, Flexural tests were performed based on ASTM D-790 at the room temperature. The samples dimensions of which 140 mm (L) x 13 mm (W) x 3 mm (T) were prepared by using a circular saw. Universal Testing Machine (INSTRON 5556) was utilized to conduct testing with a 5 kN load cell while the crosshead speed was maintained at 2 mm/min.

E. Impact test

Impact tests were performed based on the standard from ASTM D256 at the room temperature. The dimensions of the unnotched samples are of 70 mm (L) x 13 mm (W) x 3 mm (T). A digital Vector Pendulum Impact Tester was used to perform the impact tests on five replications. The impact strength was calculated based on the impact energy and cross sectional area of the specimen as shown in Eq. (1).

$$\text{Impact strength} = \text{Impact energy (J)} / \text{area (mm}^2\text{)} \quad (1)$$

F. Scanning electron microscope

A scanning electron microscope (SEM) (Model: JEOL JSM-6010/PLUS/LV) was utilized to observe the morphology of samples PALF/TPCS bio-composites These samples were coated with platinum using autofine coater (Mode: JEOL JEC-3000FC).

III. RESULTS AND DISCUSSION

A. Tensile testing

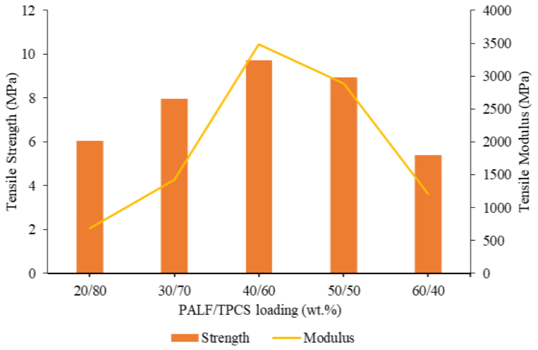


Fig. 1. The tensile strength and modulus against PALF/TPCS loading

The tensile properties of PALF/TPCS composites is depicted in Fig. 1. The properties demonstrated is tensile strength and tensile modulus respectively. The tensile strength of PALF/TPCS composites suggests that the load has initially increased to a maximum value and followed by a sudden drop. This behavior shows that a brittle fracture occurred on the composite samples. From these results, it clearly indicates that both tensile strength and tensile modulus of the composite samples increases up to 40% with the existence of PALF fibre. Nevertheless, any further increase in fibre loading (between 40 to 60%) causes a drop in the value of tensile strength and tensile modulus. Based on this testing, the optimum value was observed at 40% fibre loading where the tensile strength of the PALF fibre reinforces TPCS about 9.72 MPa and the tensile modulus was around 3483 MPa. However, the lowest tensile strength result was clearly visible at 60% of the fibre loading where the total reduction from the optimum were around 45%, which was 5.39 MPa and the tensile modulus values was 1205 MPa.

As expected, adding more fibre in the composite can improve the mechanical properties of the composites. However, adding more than 40% of the fiber has resulted to significant decrease of the tensile and modulus strength. This reduction of strength is due to increase of particle concentration, which lead to the agglomeration of the fibre [22]. It was found out by previous researchers that the agglomeration of the fibre make the composites turns into brittle behaviour. Aprilia [23] has pointed out that the agglomeration of fibre reduces the tensile strength of the composites due to low compatibility of the fibre in the matrix. The capability of the stress to be transmitted from the matrix is relatively poor for low compatibility fibre [23]. Meanwhile, Huda [24] also mentioned that the tensile strength decreases when the fibre loading increases, which is due to less adequate adhesion between the cellulose fibres and the matrix.

B. Flexural testing

Fig. 2 shows the flexural strength and modulus of PALF/TPCS composites.

Generally, a similar trend is observed between tensile and flexural properties of the PALF/TPCS composites. From the results, it is seen that flexural strength and modulus of PALF/TPCS composites has a direct relationship with PALF loading in the PALF/TPCS composites. It also can be observed that the highest flexural strength and flexural modulus was shown by 50 wt.% fibre loading. However, the lowest flexural strength and flexural modulus were clearly displayed by 20 wt.% of fibre loading. The enhancement in the flexural properties of the PALF/TPCS composites might be attributed to similar reasons for the tensile results. Higher strength and modulus was shown by flexural test than the tensile test and this finding is inconsistent with the literature [25]. A study on utilizing Pineapple Leaf Fibre (PALF) as fibre for polypropylene composite reported a similar finding where the increase of flexural strength and modulus can be attained by adding the fibre content. The results suggest that the addition of 30 wt.% PALF yields the highest strength [26].

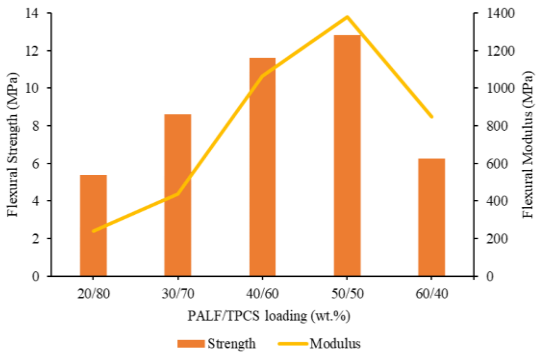


Fig. 2. The flexural strength and modulus against PALF/TPCS loading

C. Impact testing

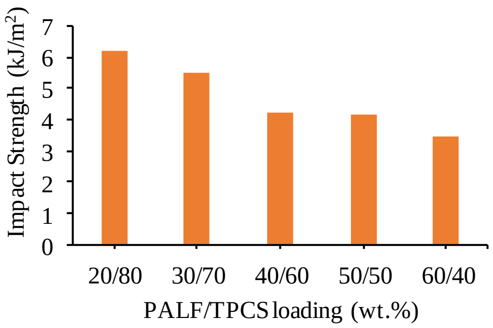
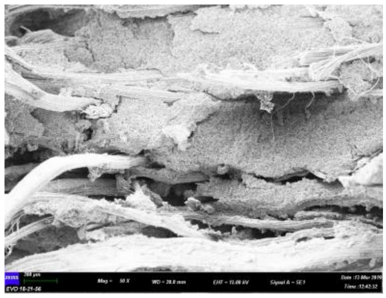


Fig. 3. The impact strength against PALF/TPCS loading

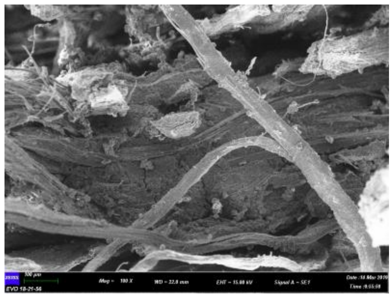
The impact strength of the composites with various fibre loading were presented in Fig. 3. Overall, by growing of PALF content in the composite will constantly decrease the value of the impact strength of PALF/TPCS composites up to 60 wt.% fibre loading. Based on this finding, it's obviously shown that the fibre loading at 20 wt.% give the highest impact strength by 5.5 kJ/m^2. On the other hand, the fibre loading at 60 wt.% bring out the lowest impact strength compared with others fibre loading.

The pattern of impact strength result achieved is contrasted with the tensile and flexural results were in tensile and flexural by increasing the PALF content will cause the strength increase. The decrement in this finding might be attributable due to the fibre pull-out mechanism absorbed a substantial amount of energy as friction during impact; hence, a good interlocking surface between fibre and matrix is likely to show lower impact resistance due to the tendency to avoid fibre pull-out [27]. In this condition, fibre breakage is more likely to occur with a slight change in the cracking plane, instead of a fibre pull-out [28].

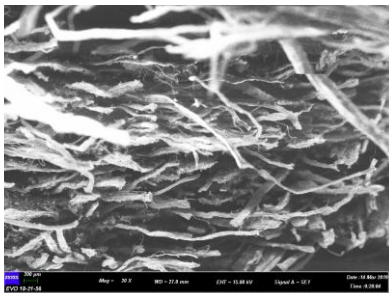
D. Morphological testing



(a)



(b)



(c)

Fig. 4. SEM of the tensile failure surface of TPCS blended with different fibre content of PALF (a) 20 wt.% (b) 40 wt.% (c) 60 wt.%

Surface morphology was investigated under scanning electron microscopy. Fig. 4 present an overview of the tensile fractured surfaces of the TPCS mixture with different fibre content of PALF. The tensile strength result for 20 wt.% fibre content present a lower and this case might be due to the higher content of the matrix and low content of fibre as shown in Fig. 4a. These findings suggest that the transfer of stress is directed more to the matrix than to the fibre itself. However, the presence of TPCS on the fibre surface indicates a better interaction between the fibre and the matrix. TPCS/PALF bio-composites show homogenous structure at present in Fig. 4b, which can be attributed to good miscibility during the processing. Due to the good bonding, the stress transfer between fibres and the matrix is better, resulting in composites with higher tensile strength.

Similarly, this might be attributed to the similar hydrophilic character between TPCS and PALF which led to good adhesion between them. This finding is in good agreement with the tensile results. At high fibre content, the tensile result shown lower result and this might be due to the fibre-to-fibre contact is greater, which is evident from the SEM photograph (Fig. 4c). In this composition, the merging of the matrix with fibres shows worse aggravation in the bio-composites.

IV. CONCLUSIONS

Bio-polymer composite from TPCS reinforced with 2 mm length PALF was successfully prepared via hand-mixed and randomly orientated within the sample. From the results, it can be deduced that the mechanical properties of the TPCS reinforced PALF bio-composites are significantly influenced by the fibre content. The addition of PALF (up to 40 wt.%) is able to improve the tensile strength and modulus of the bio-composites. Meanwhile, TPCS reinforced with 40 wt.% PALF produces the highest value of tensile strength and modulus as compared to others compositions. On the other hand TPCS reinforced with 60 wt.% PALF shows the lowest result on tensile properties. Moreover, the flexural test results represent a pattern similar to the tensile test in which the increase in PALF fibre content will cause the flexural strength increase up to 50 wt.% of fibre content and at 60 wt.% of fibre content, the result of flexural strength dramatically drop. Equally, this pattern is followed by the flexural modulus. However, the impact properties of TPCS/PALF bio-composite shows different pattern compare to tensile and flexural result where the result reveals that the constantly decreases with the increase in the fibre content up to 60 wt.% of fibre content. Therefore, the minimal fibre content is found to be 20 wt.% for better impact properties. Last but not least, from this study, it is also found that the TPCS with 40 wt.% of PALF have a good interaction between each other under the SEM analysis. It can be concluded that the combination of fibre/matrix at 40 wt.% fibre content has huge potential to be a better bio-composite product in the future.

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