Research Article

Talc filled polylactic-acid biobased polymer composites: tensile, thermal and morphological properties

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Abstract
Global warming due to human activities (i.e., burning fossil fuels) has led to many issues, such as extreme weather (storm or drought) and rise in sea level making low land uninhabitable. One of the solutions to mitigate the global warming is to promote the use of biobased material. In this work, various dosage of talc powder ranged from 5, 10, 30 and 40 wt% were added into polylactic acid (PLA) to form biobased polymer composites. The biobased polymer composite has the potential to replace fossil-based polymer for sustainable packaging application. The PLA/talc composites were prepared by using melt blending method and compressed into thin sheet for characterisation test. The effect of talc content on the thermal properties and tensile performance of the PLA composites were investigated. Scanning electron microscope was used to study the fracture surface of the composites and the dispersion of talc powder in the matrix. Results showed that the addition of talc ranged from 5 to 30 wt% can enhance the Young's modulus and thermal stability of the composites but there is no improvement in tensile strength and elongation at break due to poor interfacial adhesion. The addition of talc beyond 30 wt% (i.e., 40 wt%) did not show improvement in thermal stability because at high talc content, the formation of agglomerate and voids allows the oxygen to diffuse into the matrix which lead to decomposition process.

Keywords Polylactic acid · Talc · Biobased polymer composite · Thermal · Tensile · Morphology

1 Introduction

Biobased polymers are defined as polymers that are fully or partially produced from renewable raw materials, and they can be either fully biodegradable or non-biodegradable. A biobased product is defined as commercial or industrial goods (other than feed or food) composed in whole or in significant part of biological products [1]. This research project aimed to produce a sustainable packaging material to replace the fossil-based raw material with renewable resource. Polylactic acid (PLA) is a renowned example of biobased polymer, it is an aliphatic polyester derived from biomass such as corn and sugarcane. PLA is not only a biobased polymer, but it is also a promising biodegradable and compostable polymer which can be processed via conventional machinery [2]. PLA has advantages such as low carbon footprint, good appearance, high mechanical strength and good barrier properties [2, 3]. However, the main drawbacks of PLA are the low thermal stability and inherent brittleness which has restricted its usage in many valued-added applications [4, 5]. In order to overcome these drawbacks, approach such as addition of reinforcing filler to form biobased polymer composite have been adopted to improve these properties [6, 7].

In this study, talc is used as a reinforcing filler to blend with PLA to form biobased polymer composite. A polymer composite can be referred as a multi-phase material made from two or more constituent components. For example,

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talc as reinforcement filler is added and integrated into PLA matrix, to produce a biobased polymer composite with characteristics different from the individual component. The combination of talc and PLA can result in synergistic effect, whereby it is expected to create a material with superior properties that cannot be achieved from either component alone. This biobased polymer composite has great potential to use in packaging industry such as packaging tray. The use of biobased packaging tray can cut down the dependence on fossil fuel by replacing the traditional fossil-based tray, which also contribute to the achievement of sustainable development goal of climate action.

Talc is a type of natural mineral that can be mined from the mother earth. "Talc" came from an Arabic word 'talk' indicating the white color of talc, composed of hydrated magnesium silicate with the chemical formula of $Mg_3Si_4O_{10}(OH)_2$ [6]. Talc is a monoclinic mineral with stacked platelets developed by thousands of elemental sheets, these sheets structure can also increase the stiffness of the product when it is added into polymers [8]. Talc is one of the softest known natural occurring minerals and this characteristic is important as it gives less abrasion on the polymer processing equipment. The colour of the naturally occurring talc is ranged from white, colorless, green or brown. Talc has high thermal stability up to 900 °C, the addition of talc as filler can reduce shrinkage on the product. Moreover, talc is also chemically inert, it is insoluble in water, dilute mineral acids and dilute solutions of alkaline [9].

The incorporation of talc into PLA to form biobased polymer composite can be potentially used as a sustainable packaging material, and this material can be reused and recycled besides dispose in composting facility. Moreover, talc powder price is relatively cheap as compare to the PLA resin, the addition of talc as filler is expected to produce a packaging material with competitive price. There is also limited research works or publications on the study of high dose talc (> 30 wt%) filled PLA composite. Previous studies [10–13] were utilising talc at low content (< 30 wt%) to improve the properties of PLA. According to Shakoor and Thomas [14], at low talc content, it acts as a nucleating agent for crystallisation of PLA, meanwhile significant reinforcing effect on Young's modulus was observed with talc content up to 30% in PLA matrix. Therefore, the aim of the study is to fill the knowledge gap by examine how the addition of talc, particularly the high talc content (> 30 wt%) can affect the properties of the composites. The dispersion of the high talc content in the PLA matrix was also examined via the scanning electron microscope. As mentioned earlier, there is very limited studies on high talc content filled PLA and lacking comparative study on the effects of low to high talc content on the PLA composites. Hence, in this work, various dosage of talc, ranged from low to high (5, 10, 30 and 40 wt%) were added into PLA via melt blending method and their properties in term of thermal, tensile and morphology were reported.

2 Methodology

This section discussed the experimental works that were carried out in this research in order to accomplish the objectives mentioned above.

2.1 Materials

The PLA resin (grade 3051D) was purchased from Nature Work LLC, with density of 1.25 g/cm^3, glass transition temperature of 55–65 °C and melting temperature of 150–165 °C. Talc powder (KM10TC) is obtained from Kaolin (M) SDN BHD with average particle size of 2–6 µm.

2.2 Sample preparation

The talc filled PLA biobased polymer composites were prepared via melt blending method (using Haake Polylab System E93 at 180 °C, rotor speed of 100 rpm and retention time of 10 min) according to the formulation listed in Table 1. The amount of talc was added at the range of 0, 5, 10, 30 to 40 wt% and designated as PLA, 5 wt% talc, 10 wt% talc, 30 wt% talc and 40 wt% talc. Compression moulding machine (model: Moore E53) was used to mould the compound into a thin sheet with 1 mm thickness. The moulding steps included pre-heating at 180 °C for 5 min, followed by full compression process for 5 min at pressure of 150 bar and last, cooled the thin sheet for 8 min before it can be used for characterisation tests.

2.3 Tensile test

Tensile test was carried out according to ASTM D638 by using Instron Tensile Test Machine (model: Instron 3366). The crosshead speed of the testing was 5 mm/min with a load cell of 50kN, and the tests were conducted at room temperature. Properties such as tensile strength (σ),

Table 1 Formulation list

Sample	PLA (wt%)	Talc (wt%)
PLA	100	0
5 wt% talc	95	5
10 wt% talc	90	10
30 wt% talc	70	30
40 wt% talc	60	40

elongation at break (ε_b) and Young's modulus (E) were calculated as shown in Eqs (1) to (3). All the reported values of the tensile tests are the average of 5 dumbbell–shaped tensile specimens.

$$\sigma = \frac{\text{Force}}{\text{Area}} \tag{1}$$

$$\varepsilon_b = \frac{elongated\ length}{original\ length} \times 100\% \tag{2}$$

$$\text{E} = \frac{\text{tensile stress}}{\text{tensile strain}} \tag{3}$$

2.4 Thermogravimetry analysis (TGA)

TGA testing was performed by using Perkin Elmer TGA 8000 Analyser (USA). The sample weight of approximately 7–8 mg was heated from 30 to 600 °C with heating rate of 10 °C/min under nitrogen atmosphere. The nitrogen gas flow rate was 50 ml/min. The onset degradation temperature and the residual wt% of PLA and the PLA/talc composites were measured.

2.5 Morphology

The fracture surface of the PLA/talc specimens were examined by using FEI Quanta 400F field emission scanning electron microscope (FESEM), USA. The specimens were coated with thin layer of gold (approximately 20 nm) using vacuum sputter-coater to prevent electrical charging while examination was being processed. The talc dispersion was observed at an accelerating voltage of 10 kV.

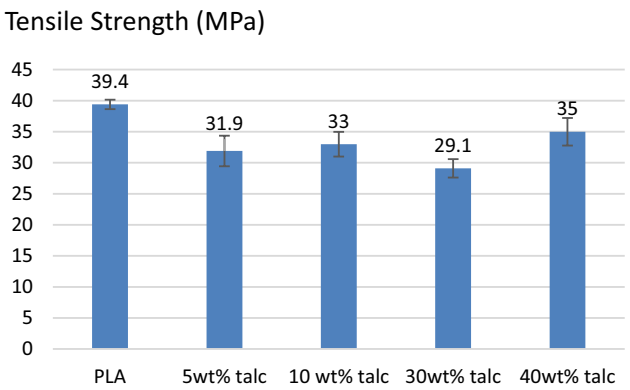

Fig. 1 Tensile strength

3 Results and discussions

3.1 Tensile test

Figures 1, 2 and 3 show the tensile strength, elongation at break and Young's modulus of the tested specimens, respectively. As shown in Fig. 1, it is observed that the PLA/talc composites show an inconsistent trend of change in tensile strength. The tensile strength fluctuated between 29.1 and 35 MPa for the talc addition between 5 and 40 wt%. The highest tensile strength was recorded for 40 wt% talc content; however, it was still lower as compared to neat PLA at 39.4 MPa. The reduction in tensile strength may attribute to the poor interfacial adhesion between the talc to the PLA matrix. Similar result was reported by Huang et al. [15], where the tensile strength decreased for PLA/talc composite as compared to neat PLA. According to Petchwattana et al. [11], the addition of talc increased the crystallinity of PLA. The higher crystallinity tends to increase the tensile strength as molecular chains are closely packed. However, in this study, due to poor interfacial adhesion between the talc and matrix, there is no improvement shown in the tensile strength.

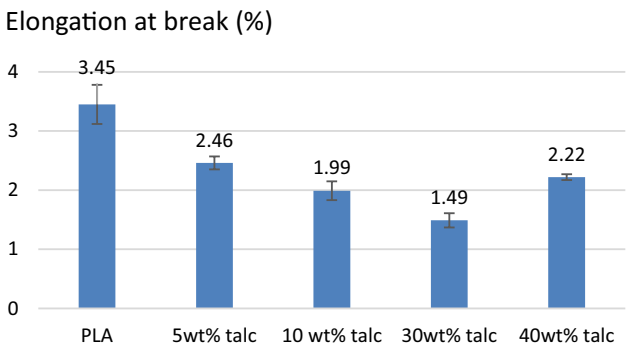

Fig. 2 Elongation at break

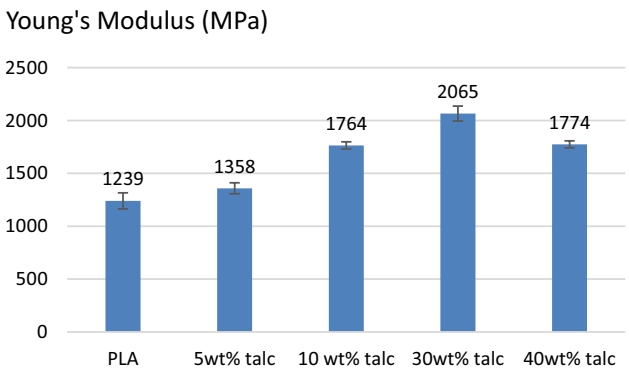

Fig. 3 Young's modulus

Refer to Fig. 2, the addition of the talc filler in PLA reduced the elongation at break from 3.45% for neat PLA to 1.49% for 30 wt% talc filled PLA. However, when the talc content increased to 40 wt%, the elongation at break increased slightly to 2.22%. Among the PLA/talc composites, 5 wt% talc addition recorded the highest elongation at break of 2.46%. The deterioration in the elongation at break suggested that PLA/talc became more brittle with the addition of talc powder, where the talc filler acts as stress concentrator and initial cracks, therefore resulted in easier breakage of the specimen. Previous study by Khuenkeao et al. [16] reported the similar finding where PLA/talc became more brittle with increasing talc content. The incorporation of talc as rigid filler not just hindered the PLA molecular chain movement during stretching, it also acted as stress concentrator, embrittling the matrix and causing reduction in elongation at break.

As shown in Fig. 3, the Young's modulus improved with increasing talc wt% from 1239 MPa for neat PLA to 2065 MPa for 30 wt% talc content. The Young's modulus slightly decreased to 1774 MPa when the talc content reached 40 wt%. The improvement in Young's modulus is attributed to the ability of stress transfer from the matrix to the filler as reported by Whaling et al. [17]. Moreover, talc itself is a rigid particle, it can restrict the polymer chain movement and increase the stiffness of the composite. Similar result was reported by Huang et al. [15], where there was a linear relationship between the increase in talc content and the increase in Young's modulus of the composites. The incorporation of rigid platelet inorganic filler such as talc into the PLA matrix has successfully transferred the stress from the matrix to filler and provides improvement in the stiffness of the material. Among the PLA/talc composites, 30 wt% talc exhibited the highest Young's modulus at 2065 MPa in comparison to other talc loading. It is observed that the Young's modulus of 40 wt% talc is lower than 30 wt% talc, this might occur because of agglomeration and poor dispersion of talc powder in the matrix containing a high talc content and subsequently reduce the ability of the stress transfer from the matrix to the filler. Overall, the lack of interfacial adhesion between talc and PLA limited the tensile strength and elongation properties of PLA/talc composites.

3.2 Thermogravimetry analysis (TGA)

Table 2 shows the onset degradation temperature and the residual wt% at 600 °C for the neat PLA and the PLA/talc composites. It is observed that 5 wt% talc exhibited the highest onset degradation temperature as compared to other talc loading PLA composites. The onset degradation temperature representing the point where the material will start to break down or disintegrate. The higher the onset degradation temperature indicates the better the thermal stability. As shown in Table 2, neat PLA onset degradation temperature was recorded at 293.9 °C and the addition of 5 wt% of talc improved the onset degradation temperature by 15 °C to 309.2 °C. The 5 wt% talc has the potential to use at a higher use temperature application as compared to neat PLA. The improvement in the thermal stability could be attributed to the present of talc as an inorganic filler that hinder the out-diffusion of the volatile decomposition products as a result of the decrease in permeability [18]. The improvement in thermal stability can be observed up to 30 wt% talc where the onset degradation temperature was recorded at 301.5 °C as compared to neat PLA at 293.9 °C. Once the talc content increased to 40 wt%, the onset degradation was reported to be lower than the neat PLA. The reason could be due to the poor dispersion of the high content of talc in the PLA matrix, coupled with the voids formation between the big agglomerate of talc and the PLA matrix that allows the permeability/diffusivity of oxygen to the composite which lead to the decomposition process. It is noted that the residual wt% increased with the increment of talc content. The residual weight is an indication for the fraction of non-volatile material such as talc. Talc is thermally stable and will only decompose at temperature above 900 °C by losing its hydroxyl groups to form enstatite (anhydrous magnesium silicate) [19].

Table 2 Thermal properties

Sample	Onset degradation temperature (°C)	Residual weight % at 600 °C
PLA	293.9	0.45
5 wt% talc	309.2	3.07
10 wt% talc	296.1	15.05
30 wt% talc	301.5	26.37
40 wt% talc	279.9	28.52

3.3 Morphology

Figure 4 shows the SEM micrographs of neat PLA and the PLA/talc composites. Refer to Fig. 4a, neat PLA micrograph shows clear and smooth surface corresponding to the brittle fracture in PLA. Once the talc content increases in the matrices, the micrographs show more compact surface. The distribution of talc was considered homogenous as indicated in Fig. 4b, c. However, it is shown that tiny voids adjacent to talc particles (indicated by arrows) suggested that the interfacial adhesion between the filler and matrix needs to be further improved. The poor interfacial adhesion is the root cause for the poor tensile performance of the PLA/talc composites, particularly for high content of

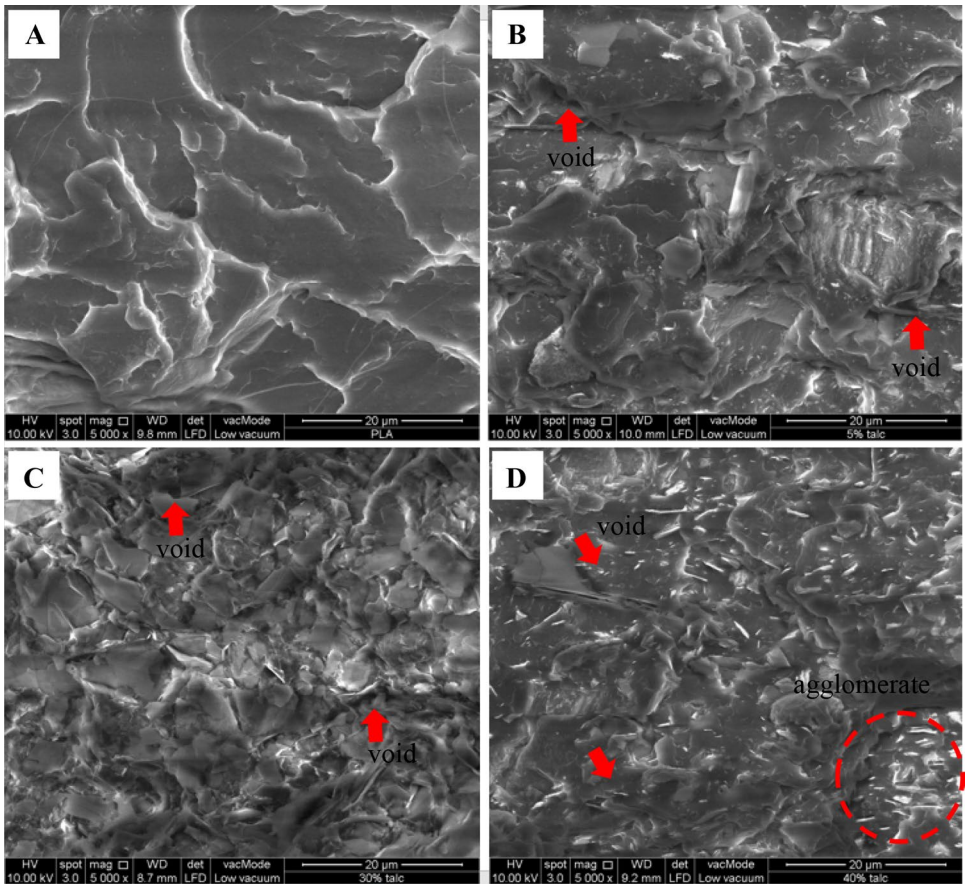

Fig. 4 SEM images of fracture surface of **a** neat PLA, **b** 5 wt% talc, **c** 30 wt% talc and **d** 40 wt% talc

talc as discussed earlier. The SEM micrograph Fig. 4d for 40 wt% talc shows the formation of talc agglomerate (indicated by circle) and tiny voids. The multiple voids can lead to early failure of the composite, coupled with poor dispersion of high talc content which increase in diffusion of oxygen within the PLA matrix and this explain the poor thermal stability among all.

4 Conclusion

In this study, the addition of talc into PLA can form a biobased polymer composite which could potentially be used for sustainable packaging. The tensile test revealed that the talc has significantly increase the Young's modulus by 10–66% due to the reinforcing ability of the talc particles. However, there was no improvement in the tensile strength and elongation at break for the PLA/talc composites due to the poor interfacial adhesion between the talc filler and PLA matrix. The incorporation of talc at 30 wt% has recorded the highest Young's modulus and successfully improved the thermal stability of the neat PLA by 7.6 °C, but at the cost of lower tensile strength and elongation at break. SEM micrographs showed the formation of voids and agglomerate at high talc content. It is concluded that from overall tensile and thermal properties results, the optimum formulation for talc filled PLA biobased polymer composite is 5 wt% talc with an improvement in Young's modulus of 1358 MPa and highest onset degradation temperature at 309 °C. The tensile strength and elongation at break properties for the 5 wt% talc was slightly lower than neat PLA, however, it was statistically insignificant ($p > 0.05$). The addition of 5 wt% talc could eventually reduce the material cost and potentially used as a sustainable packaging material that required good thermal stability.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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