

EFFECT OF HYBRID RATIO AND SURFACE-MODIFIER HEMP FIBER/TALC ON PLA HYBRID BIOCOMPOSITES

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Abstract

Polylactic acid (PLA) hybrid biocomposites reinforced with micro-fillers of hemp fiber (Hf) and talc (Tc) were investigated, and estimated the mechanical, thermal properties and water absorption behavior of those biocomposites. The Hf was chemical surface-modified using γ -methacryloxypropyltrimethoxy, and Tc used was modified with silane. Hybridized Hf/Tc was varied in the range of 7/3, 14/6, 20/10, 20/20, 10/20, 6/14, and 3/7 wt% were prepared and compound. The results revealed that silicon dioxide content in Hf and Tc were 34% and 69% by weight, respectively. Biocomposites for modified Hf/Tc micro-fillers loading, the properties in modulus and Shore-D hardness were higher compared to those non-modified fillers. The impact strength significantly increased for modified Hf/Tc content of 14/6 and 6/14 wt%. The results revealed that the crystallinity of biocomposites for non-modified and modified Hf/Tc slightly increased but the melting temperatures were not different to the virgin PLA. The thermal stability of those hybrid biocomposites systems decreased as compared to the virgin PLA. A coupling agent relieved water absorption of biocomposites. PLA hybrid biocomposite could be used as a new alternative green material in non-construction industrial such as a drawer handle.

Keywords: Hemp fiber, talc, polylactic acid, thermal-mechanical properties, water absorption, biocomposites

Introduction

Nowadays, most plastic products are obtained by synthetic polymers from petroleum oil due to those plastics mentioned was non-biodegradable, and become caused plastics waste problem. Government each country is encouraging people to used more green materials and bio-based products which are from renewable resources. Therefore, new environmental-friendly biocomposites materials by using natural fibers have become a new alternative material to investigate and industrial research.

Natural fibers are used to reinforce in polymers matrix, due to those fibers are light-weight, easy to access, cheap, low-density and non-toxicity as compared to artificial fibers. Hemp fiber (Hf) is one of nature-fiber and easily obtainable, inexpensive which is suitable as a reinforcing material for polymer composites, and fabrication the automotive and construction parts with high strength and endurance (Kajaks *et al.*, 2015; Panaitescu *et al.*, 2016; Zegaoui *et al.*, 2018). Hemp fiber treated with

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sodium-hydroxide and add maleic-anhydride-grafted polypropylene (PP) composites was investigated by Sullins *et al.* (2017). They found that the composites with reinforce chemical surface-treated hemp fibers, exhibited obvious higher the tensile and flexural behavior. Sawpan *et al.* (2011) used an alkali-surface-treated short-hemp fibers which leading to significant improvement the tensile and impact properties and also increased of crystallinity up to 27% in polylactide (PLA) biocomposites. Talc is one of an inorganic reinforcing filler that a widely used in commercial for polymer composites, as it is used to improve the toughness, strength, hardness and also saved the cost polymer for producing parts (Huda *et al.*, 2007; Yang *et al.*, 2013). Yousfi *et al.* (2013) studied the synthetic-talc-filled polypropylene composites, and exhibited that the thermal stability of composites samples extremely improved, but Young's modulus of composites slightly increased. In addition, Dias *et al.* (2018) used synthetic talc-berberine chloride as reinforcing fillers to fabricate clay-polyurethane nanocomposites (CPN), and found that the values of stiffness, thermal stability increased, and composites samples were able to quite well fluorescence. Hybrid composites are polymer

matrix reinforced with more than one type of materials, an outstanding properties of one type reinforcement filler able to promote and/or substitute another type of drawback fillers (Beloshenko *et al.*, 2017; Fragassa *et al.*, 2018). A recent study by Aslan *et al.* (2018) used sisal and glass hybrid fibers to reinforce polypropylene composites, results exhibited that excellent coefficient of friction and tensile properties of composites with sisal and glass fiber ratio of 25:75 wt%. Senturk *et al.* (2018) found that polypropylene filled with calcite and short glass fiber (SGF) increased melting and decomposition temperatures, and found that the mechanical properties of hybrid composites significantly increased with increasing calcite particles and SGF content. Das (2017) fabricated a waste- newspaper and jute-fabric reinforced polyester resin composites using hand lay-up technique, results found that pure jute-fabric better reinforcement in composites than newspaper/ jute-fabric.

This research purpose is to develop biodegradable hybrid composite material made from polylactic acid filled with surface-modified hemp fiber and natural talc particles, and investigate its most important mechanical-thermal, and water absorption characteristics.

Table 1. Particle size distribution of Hf and Tc

Particle size distribution (μm)	Hf content (%)
<39	50.94
39-47	5.55
47-57	4.88
57-69	4.87
69-84	5.58
84-113	12.69
>113	15.49
Particle size distribution (μm)	Tc content (%)
<2.0	8.51
2.2-3.3	9.81
3.3-5.4	36.95
5.4-8.1	22.44
8.1-11.0	11.73
11.0-16.0	8.68
>16	1.88

Table 2. Chemical composition of Hf and Tc

Investigation of chemical composition by XRF (Hf)	Content (%)
Iron (III) oxide (Fe ₂ O ₃)	55.157
Silicon dioxide (SiO ₂)	34.897
Calcium oxide (CaO)	6.771
Titanium (IV) oxide (TiO ₂)	3.175
Investigation of chemical composition by XRF (Tc)	Content (%)
Silicon dioxide (SiO ₂)	69.237
Magnesium Oxide (MgO)	28.373
Iron (III) oxide (Fe ₂ O ₃)	2.121
Calcium oxide (CaO)	0.198
Vanadium(V) oxide (V ₂ O ₅)	0.049
Manganese (IV) oxide (MnO ₂)	0.022

Materials and Methods

Materials

Polylactic acid (PLA) pellets were biopolymer grade-3251D for injection molding, with a melt flow rate (MFR at 190°C, 2.16 kg) of 35 g 10 min⁻¹ by purchased from NatureWorks LLC, USA. Hemp fibers (Hf) were grown in Chiang Mai, Thailand and harvested in 2018. Hemp fibers were dried at 100°C for 48 h with an oven, then grinded and sieved (Stainless steel sieve, ASTM-E11 No. 325 mesh), and derived an average of particle size of 45 μm. Two types of talc (Tc) (product names: Mistron vapor R with non-modified and Mistron CB with surface-modified by silane) were supplied in powder form by Luzenac America, Inc. of Englewood, Colorado. The average particle size of both talc used were 2.2 μm. The particle size distributions of Hf and Tc were investigated on Mastersizer-S apparatus, Malvern, UK, as shown in Table 1. The characterization of the Hf and Tc as reinforcing fillers were examined with X-ray fluorescence (XRF) analyzer, Horiba-MESA-500W, as shown in Table 2.

Chemical Surface-Modifier of Hf

Since PLA matrix was hydrophobic and Hf fibers was hydrophilic, therefore, in order to

improve the compatibility between the PLA matrix and Hf fibers with a chemical surface-modifier. Thus, a chemical surface-modifier was used should be promote the Hf fillers to more hydrophobic characteristic. The chemical surface-modifier for Hf was γ -methacryloxypropyltrimethoxy (MPS) silane coupling agent solution, which was carried out by addition of 30.0 wt% of MPS in 800 ml/200 ml (ethanol/water mixture: 1,000 ml), and stirred continuously at room temperature for 15 min (Abdelmouleh *et al.*, 2007; Panaitescu *et al.*, 2016). Amount of Hf was 1 kg, immersed in this chemical solution and then slowly stirred at room temperature for 20 min, and then desiccated for 24 h in the open-air.

Preparation of Biocomposites

Hf and Tc particles with non-modified and chemical surface-modified for each compound ratio varied in the range of 0-20 wt% were mixed with polylactic acid pellets using a mixer apparatus for 3 min. After that, mixed using a single-screw extruder (RMUTL-T&D-001, Thailand) (low screw speed of 50 rpm, barrel temperature profiles at 150-180°C). Biocomposites melt strands were pulled through a water bath at 25°C, and cut into pellets using a pelletizer. All the test specimens were done with an injection-molding machine made in Charoen Tut Co., Ltd.-Thailand, used an injection temperature of 185°C.

Mechanical Properties

H50KS-Hounsfield-universal testing instrument was used to evaluate a tensile and flexural for the biocomposites materials. Tensile test for the biocomposites were done on a standard of ASTM D638-2014, with the specimen type I, gauge length of 50 mm, and used a crosshead-movement at speed rate of 50 mm min⁻¹. Flexural test for the biocomposites were tested on a standard of ASTM D790-2007, used a crosshead-movement at speed rate of 1 mm min⁻¹, with a support span as cylindrical surface, and had a span distance of 40 mm. GT-7045 impact test machine was used to assess the impact strength values of the biocomposites using Izod test method type A. The specimens were angle of the notch of 45±1° with facing of the pendulum hammer, a pendulum hits with an energy of 15J at impact speed of 3.46 m sec⁻¹, as according to ASTM D256-2004. Mitutoyo HH-337-11 apparatus was used to estimate the hardness values of the biocomposites using Shore D-Durometer scale, with test specimens of 6 mm in thickness was used to measure, with according to ASTM D2240-2015. The values of all mechanical properties were evaluated and then reported from an average of five samples.

Scanning Electron Microscopy (SEM) Investigations

The images of Hf/Tc fillers and biocomposites samples were investigated on JEOL, JSM-5910LV, scanning electron microscope (SEM), an operated with an accelerating voltage of electron was 15 kV. At the top surface of the fillers and biocomposites were coated gold using a sputter coater apparatus.

Thermo-Gravimetric Analyzer (TGA)

The thermal behavior for the biocomposites samples were tested on a thermogravimeter 209F1 Libra®-Netzsch instrument. The samples were performed in the range of 30 to 550°C in condition of continuous flow of nitrogen-gas, with the rate of heating at 20°C min⁻¹.

Differential Scanning Calorimetry Analyzer (DSC)

The melting temperatures (T_m), melting energies (ΔH_m), glass transition temperatures (T_g), cold crystallization temperatures (T_{cc}), and crystallinity (C_s) for the biocomposites were scanned on DSC-200F3 Maia®-Netzsch apparatus. Biocomposites samples were scanned in the range of 30 to 200°C under an inert-nitrogen-gas with flow continuously throughout the samples, with the rate of heating at 10°C min⁻¹. The C_s of biocomposites was reported as the percentage of crystallinity (% C_s), by using an Equation (1) (Battezzato *et al.*, 2011).

$$\%C_s = \frac{\Delta H_m}{\Delta H_0} \times \frac{1}{(1-W_f)} \times 100\% \quad (1)$$

where ΔH_m is the melting energy of biocomposites (derived: DSC curve, J/g), ΔH_0 is the melting energy of 100% crystalline polylactic acid (93 J/g), and W_f is the percentage of weight fraction of Hf/Tc fillers (%Hf/Tc) at hybrid ratio for the biocomposites.

Water Absorption (W_a) Testing

ISO-62-2008 (a modified standard method) was used to the water absorption (W_a) properties test of the PLA hybrid biocomposites. Five samples in each compound of biocomposites were submerged in a water container at room temperature for 336 h, and then those biocomposites was weighed. The percentage of water absorption (% W_a) was calculated as follows Equation (2) (Saenghirunwattana *et al.*, 2014).

$$\%W_a = \frac{W_1 - W_0}{W_0} \times 100\% \quad (2)$$

where W_0 and W_1 are weight of samples before immersion, and weight of samples after immersion in water, respectively.

Results and Discussion

Characterization of Hf and Tc Fillers

The particle size distribution of Hf and Tc were evaluated by using Mastersizer-S analyzer, as shown in Table 1. It is affirmed that the average particle size of Hf was divided into two size which it was smaller than $39.0\ \mu\text{m}$ and bigger than $84\ \mu\text{m}$, and Tc had particle size in the range of $3.3\text{--}11.0\ \mu\text{m}$, as displayed in Figure 1. XRF analyzer was used an investigates the characterization of the Hf and Tc, and it is obviously that the majority of chemical composition of Hf was 55.157% of Fe_2O_3 and 34.897% of SiO_2 , whereas the majority of chemical composition of Tc was 69.237% of SiO_2 and 28.373% of MgO , as given in Table 2. The images of Hf and Tc by SEM are displayed in Figure 2. The images of the Hf (Figure 2(a)) was long bar shape,

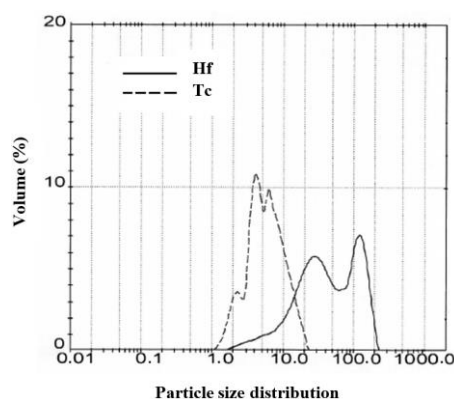


Figure 1. Particle size distribution of Hf and Tc

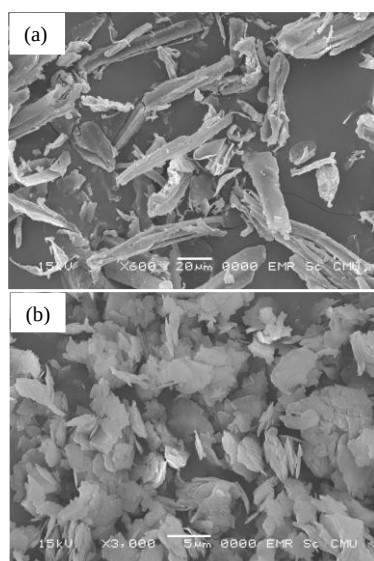


Figure 2. SEM images of reinforcement fillers: (a) Hf (mag. x600), and (b) Tc (mag. x3,000)

whereas those the Tc (Figure 2(b)) was a relatively small lamina and thin in the shape.

Mechanical Properties Of Biocomposites

The results of Young's modulus and tensile strength of PLA hybrid biocomposites for different Hf/Tc hybrid ratio are shown in Figure 3. The Young's modulus of biocomposites at Hf/Tc of 20/20 wt% was increased the highest 40% for non-modified and 60% for chemical surface-modified Hf/Tc compared to the virgin PLA. Obviously, the stiffness behavior of their biocomposites increased due to both volume of concentration of reinforcing fillers and chemical surface-modified Hf/Tc. It can be seen that when adding both Hf/Tc fillers into the polylactic acid matrix, the Young's modulus of biocomposites significantly enhanced due to strong of both fillers which was inserted throughout the matrix in a random-stacking formed, can be illustrated as a model in Figure 4. It was found that the tensile strength behavior of biocomposites samples were an inverse with the modulus behavior; namely its reduced. The low-strength behavior of polymer composites is typical which has been

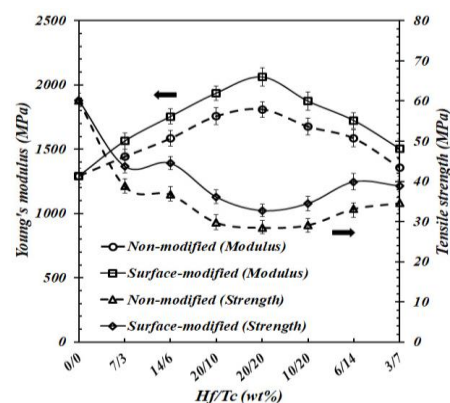


Figure 3. Young's modulus and tensile strength of PLA hybrid biocomposites for different Hf/Tc hybrid ratio

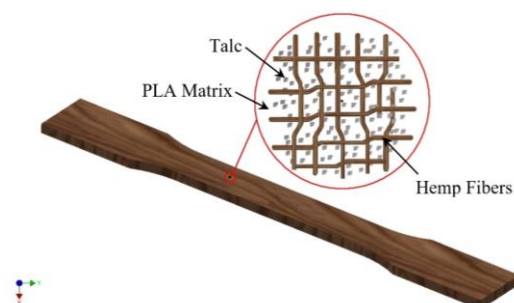


Figure 4. Sketch of PLA hybrid biocomposites structure formed

reported by a number of works (Spiridon *et al.*, 2016; Beloshenko *et al.*, 2017; Sitticharoen *et al.*, 2018). This may be associated an agglomeration of the fillers when compound the polymer matrix with high concentration fillers. The tensile strength value of the samples with Hf/Tc of 20/20 wt% for non-modified and modified Hf/Tc reduced 53% and 46%, respectively as comparing with the virgin PLA. Flexural modulus and flexural strength values of PLA hybrid biocomposites for different Hf/Tc hybrid ratio are depicted in Figure 5. It is observed that the flexural modulus has increased continuously in a similar style with tensile modulus until arrived a maximum at 20/20 wt% for non-modified and modified Hf/Tc. The results reported that the flexural modulus of the samples a significantly improved of 58% for non-modified and 78% for modified at Hf/Tc of 20/20 wt% compared to the virgin PLA. On the other hand, flexural strength values of the biocomposites slightly reduced. This may attribute to the increase in both Hf-Tc fillers, the increased tendency of agglomeration and reduction of interfacial bonding between fillers and matrix.

This was led to formation of micro-crack in polymeric biocomposites, resulting in flexural strength deterioration. The flexural strength value of the samples at Hf/Tc of 20/20 wt% for non-modified was decreased 22% and 6% for modified Hf/Tc with comparing to the virgin PLA. Figure 6 displays images by SEM of PLA hybrid biocomposites at

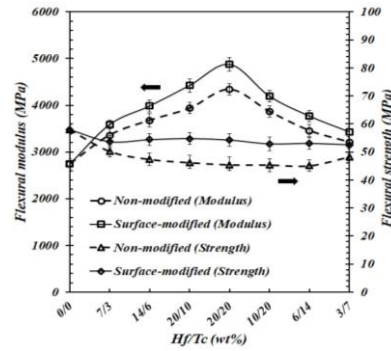


Figure 5. Flexural modulus and flexural strength of PLA hybrid biocomposites for different Hf/Tc hybrid ratio

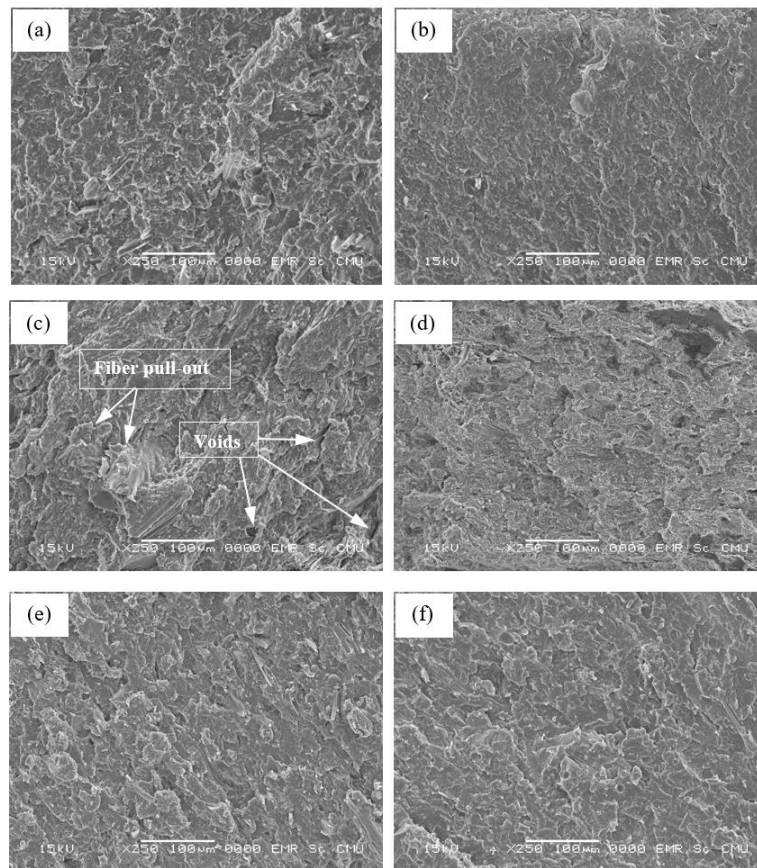


Figure 6. SEM images of PLA hybrid biocomposites at different Hf/Tc hybrid ratio: (a) 7/3 wt% (c) 20/20 wt% (e) 3/7 wt% non-modified, and (b) 7/3 wt% (d) 20/20 wt% (f) 3/7 wt% chemical surface-modified Hf/Tc

different Hf/Tc content. Figures 6(a), 6(c), and 6(e) show images by SEM for biocomposites with non-modified Hf/Tc, an incompatibility between the non-modified Hf/Tc and the polylactic acid matrix which obviously exhibited the voids occurs and the pull-out of fibers in the case at Hf/Tc of 20/20 wt% of biocomposites (Yang *et al.*, 2013; Shih *et al.*, 2014). Figures 6(b), 6(d), and 6(f) show the biocomposites with chemical surface-modified Hf/Tc, it is clearly seen that the modified Hf/Tc an enhanced their compatibility between Hf-Tc fillers and matrix, no fibers pull-out apparently seen, and both filler particles were well dispersed in the PLA biocomposites. Impact strength values of PLA hybrid biocomposites samples are shown in Figure 7. PLA has a ductility value of 4.05 kJ m^{-2} on its own. The impact strength value of the samples at 14/6 wt% and 6/14 wt% for modified Hf/Tc were 4.27 kJ m^{-2} and 4.20 kJ m^{-2} , respectively. An increase in impact strength may be due to the dispersed uniformly of Hf/Tc fillers which to sustain the ductility of the biocomposites. The impact strength value of the samples at Hf/Tc of 20/20 wt%

for non-modified and modified Hf/Tc decreased 23% and 11%, respectively as comparing with the virgin the PLA. The reduction of impact strength when increasing of both filler particles loading led to the brittle fracture of the samples, when cracks occurred and its able to propagate through weak points (micro-voids and pores) within matrix. Figure 8 shows the Shore-D hardness values of the biocomposites samples. At Hf/Tc of 20/20 wt% for non-modified and chemical surface-modified Hf/Tc, the Shore-D value of the samples an improved 6% and 9%, respectively compared to the virgin PLA. This was due to a rigidity of Hf/Tc fillers.

Thermogravimetric Analysis (TGA)

The results of the TGA for the biocomposites samples for non-modified and chemical surface-modified Hf/Tc at different hybrid ratio are displayed in Figure 9. The results clearly shown that when the temperature increases continuously the weight loss of the biocomposites systems for non-modified and chemical modified Hf/Tc were slowly decreased, until in the range of 300-400°C the weight loss occurred a maximum. The biocomposites for non-modified and modified

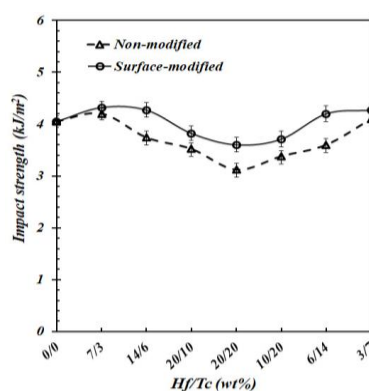


Figure 7. Impact strength of PLA hybrid biocomposites for different Hf/Tc hybrid ratio

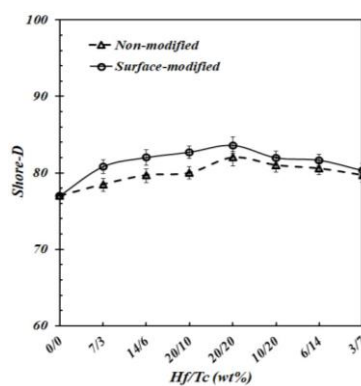


Figure 8. Hardness of PLA hybrid biocomposites for different Hf/Tc hybrid ratio

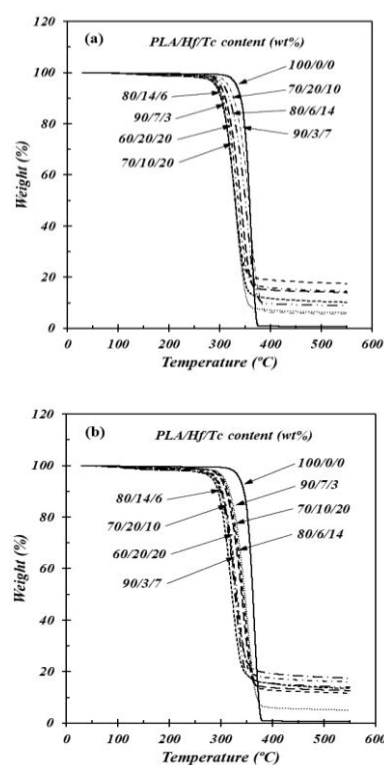


Figure 9. TGA curves of PLA hybrid biocomposites: (a) non-modified, and (b) chemical surface-modified Hf/Tc

Hf/Tc had the thermal stability less than the virgin PLA. This was due to some portions of those PLA matrix obtained replacing by the Hf-Tc filler particles which was less thermal stable, leading to a reduced thermal stability of biocomposite systems. This view could be supported by the works (Huda *et al.*, 2007; Oza *et al.*, 2014; Tawakkal *et al.*, 2014) who stated that the thermal stability of composites decreased when addition with the filler particles that low thermal stable. The thermal stabilities at Hf/Tc of 20/20 wt% for non-modified was greater than that of modified composites. It was found that the virgin PLA showed one single decomposition step (T_d) at 363.2°C, without a char residual occurs (Tawakkal *et al.*, 2014). The PLA hybrid biocomposites samples for non-modified and modified Hf/Tc displays three thermal decomposition steps. The first step (T_{d1}) of the biocomposites systems for non-modified and modified Hf/Tc were appeared in the range of 100-130°C, which their mass loss because of the vaporization of moisture out of the Hf. The next step (T_{d2}) was occurred in the range of 200-350°C, can be defined as the decomposition of hemicellulose and cellulose. The last step (T_{d3}) was decomposition temperature completed which in the range of 350-550°C (Huda *et al.*, 2007; Mulinari *et al.*, 2009; Oza *et al.*, 2014). It is clearly visible that the percentage of weight for the hybrid biocomposites samples were not changed after the temperature of 380°C and also found that all biocomposites samples had massed of a char residual between 2.82 and 14.11% (Tawakkal *et al.*, 2014; Jumaidin *et al.*, 2017).

Differential Scanning Calorimetry (DSC)

The DSC thermograms results for the biocomposites samples for non-modified and modified Hf/Tc at different hybrid ratio are

presented in Figure 10, whereas the melting temperatures, melting energies, glass transition temperatures, cold crystallization temperatures, and crystallinity of the biocomposites are reported in Table 3. The C_s of PLA hybrid biocomposites systems for non-modified and modified Hf/Tc a trend of increased continuously when increasing the Hf/Tc. At the biocomposites samples with Hf/Tc

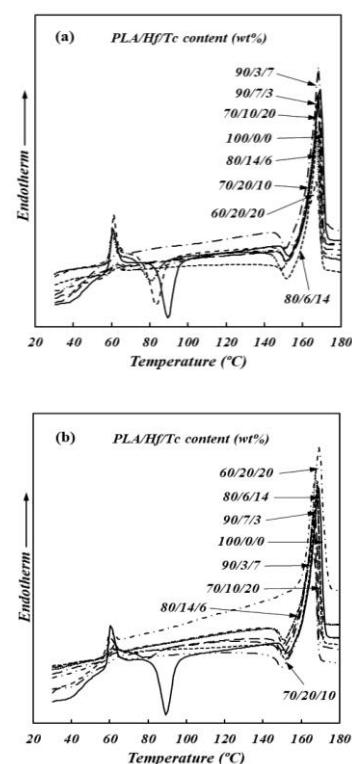


Figure 10. DSC thermograms of PLA hybrid biocomposites: (a) non-modified, and (b) chemical surface-modified Hf/Tc

Table 3. DSC analysis for PLA hybrid biocomposites

Hf/Tc content (wt%)	Thermal properties				
	T_g (°C)	T_{cc} (°C)	T_m (°C)	ΔH_m (J/g)	C_s (%)
Non-modified fillers					
0/0	60.1	89.4	169.1	41.8	44.9
7/3	60.9	83.7	168.2	37.8	45.2
14/6	60.0	80.6	167.3	35.4	47.6
20/10	60.5	none	168.7	33.9	52.1
20/20	60.7	none	167.1	28.1	50.4
10/20	60.9	none	167.9	34.8	53.5
6/14	63.1	none	168.2	38.0	51.1
3/7	63.3	none	168.3	40.4	48.3
Surface-modified fillers					
7/3	61.7	none	167.8	40.1	47.9
14/6	60.0	none	167.2	37.8	50.8
20/10	63.0	none	166.7	34.4	52.8
20/20	60.0	none	168.8	29.7	53.2
10/20	60.0	79.1	166.8	35.6	54.7
6/14	61.3	none	168.1	40.0	53.8
3/7	60.5	none	166.8	39.8	47.6

of 20/20 wt% for non-modified, the C_s of the biocomposites was increased 12% and 18% for modified Hf/Tc compared to the virgin PLA (Battezzore *et al.*, 2011; Sawpan *et al.*, 2011; Yang *et al.*, 2013; Yepes *et al.*, 2017). It was observed that the virgin PLA sample obviously exhibited the glass transition temperature and cold crystallization temperature at 60.1°C and 89.4°C, respectively. The biocomposites systems for non-modified and modified Hf/Tc had T_g in the range of 60.0-63.3°C. The results found that when added the amount of Hf/Tc, the T_m of their biocomposites systems were not different to the virgin PLA.

Water Absorption (W_a) of Biocomposites

When fabricated the PLA-hybrid biocomposite material, the water absorption (W_a) behavior of this material is one property that necessary to know, and as reported in Figure 11. Biocomposites were more absorbs water absorption than the virgin PLA due to water could be penetrated into the biocomposites through micro-voids and pores at the interface bonding area between the Hf-Tc and PLA matrix. It can be seen that increased of both filler particles loading led to increases the W_a in the biocomposites because of hydrophilic properties of Hf which to promote the penetration of water or moisture into the biocomposite samples easier. At the biocomposite samples with Hf/Tc of 20/20 wt%, the W_a was 3.1% for non-modified, versus 2.6% for modified Hf/Tc. Obviously, the biocomposites samples with chemical surface-modified Hf and Tc using a silane coupling agent led to significantly reduce the W_a . The low water absorption phenomenon of the PLA-hybrid biocomposites with surface-modified which had two possible explanations as follows: (a) dispersed uniformly and good compatibility

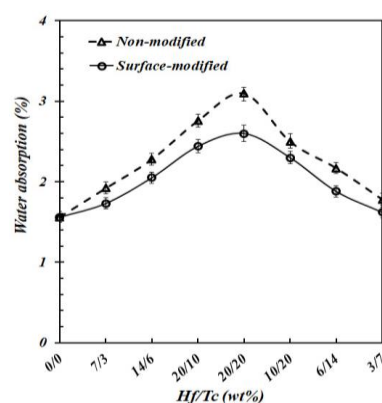


Figure 11. Water absorption of PLA hybrid biocomposites for different Hf/Tc hybrid ratio

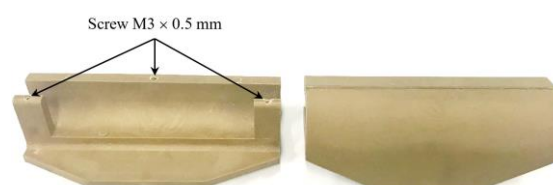


Figure 12. Drawer handle sample made from PLA hybrid biocomposites

between the surface-modified Hf/Tc hybrid ratio and the PLA matrix, which led to a smooth surface in the PLA biocomposites, (b) The Hf-Tc was surface-modified by a chemical coupling agent which led to the hydrophobic of its hybrid biocomposites (Saenghirunwattana *et al.*, 2014). In summary, a comparison between virgin PLA and surface-modified Hf/Tc at 20/20 wt% for hybrid biocomposites, as shown in Table 4.

Table 4. Summary, comparison between virgin PLA and surface-modified Hf/Tc at 20/20 wt.% for hybrid biocomposites

Mechanical properties	Virgin PLA	Surface-modified Hf/Tc biocomposites
Young's modulus (MPa)	1,292.10	2,062.50
Tensile strength (MPa)	60.17	32.75
Flexural modulus (MPa)	2741.74	4875.53
Flexural strength (MPa)	57.97	54.26
Impact strength (kJ/m ²)	4.05	3.60
Shore-D hardness	77.0	83.6
Water absorption (%)	1.56	2.6
DSC analysis	$T_g = 60.1\text{ }^{\circ}\text{C}$ $T_{cc} = 89.4\text{ }^{\circ}\text{C}$ $T_m = 169.1\text{ }^{\circ}\text{C}$ $\Delta H_m = 41.8\text{ J/g}$ $C_s = 44.9\text{ }%$	$T_g = 60.0\text{ }^{\circ}\text{C}$ $T_{cc} = \text{none}$ $T_m = 168.8\text{ }^{\circ}\text{C}$ $\Delta H_m = 29.7\text{ J/g}$ $C_s = 53.2\text{ }%$
TGA analysis	$T_d = 363.2\text{ }^{\circ}\text{C}$ Residuel = 0 %	$T_{d1} = 120.0\text{ }^{\circ}\text{C}$ $T_{dII} = 250.0\text{ }^{\circ}\text{C}$ $T_{dIII} = 357.0\text{ }^{\circ}\text{C}$ Residuel = 12.45 %

Application of Biocomposites

Nowadays, woods (such as teak and red woods) was rather rare and more expensive than that of the plastics, due to those the plastics mentions was non-biodegradable, and become plastic waste problem. In this work was aim to fabricate a new alternative green-PLA hybrid biocomposite material which was light-weight, low-density, easy to access, non-toxicity, and environmental-friendly which the potential for the non-construction materials such as wardrobe, cupboard and drawer handle. Figure 12 shows the photograph of a drawer handle sample (dimensions 29×115×44 mm) of biocomposites with surface-modified Hf/Tc at 20/10 wt%, which was produced using injection-mold at 185°C.

Conclusions

Biodegradable hybrid composites obtained by compound the Hf-Tc surface-modified by a chemical silane coupling agent and PLA matrix was investigated. The results indicated that silicon dioxide content in Hf and Tc were 34% and 69% by weight, respectively. The biocomposites with surface-modified Hf/Tc showed that the modulus and Shore-D hardness were higher as compared to those non-modified, but on the other hand the tensile, flexural strength behavior were decreased. At the surface-modified Hf/Tc content of 14/6 and 6/14 wt%, the impact strength of biocomposites increased significantly. The crystallinity of biocomposites for non-modified and modified Hf/Tc a slightly elevated but the melting temperatures were not changed. The thermal stability of the virgin PLA was higher compared to those of the biocomposites systems. A coupling agent could be reduced significantly water absorption. Hybrid biocomposite is a new alternative green material that potential to be used to as a drawer handle/wardrobe.

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