

Characteristic of thermoplastics corn starch composite reinforced short pineapple leaf fibre by using laminates method

H.Z. Nazri^{1,2,4*}, Z. Ngali², M.Z. Selamat^{3,4}, F.A. Munir^{3,4} and M.A. Aman¹

¹ Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

Phone: +60122796057; Fax: +6062701068

² Fakulti Kejuruteraan Mekanikal dan Pembuatan, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, Johor, Malaysia

³ Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

⁴ Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

ABSTRACT – In recent years, the increased demand of biodegradable polymers has sparked the research interest in the development of alternatives to conventional polymers. As such, starch considerably one of the best substitutes to the non-degradable polymers owing to its advantages. The main purpose of this study is to investigate the mechanical, physical and environmental characterization of bio-composites, which is in this case the thermoplastic corn starch (TPCS) reinforced with a 2 mm length of pineapple leaf fibre (PALF). The selection of different weight percentages in the range of 20 to 60 weight percentage (wt.%) of PALF contents were applied in this work. The mixtures of TPCS with different wt.% of PALF were made by using a hot compression moulding at 165 °C for 15 minutes. Several testing has been performed to determine the bio-composites characteristics. The results show that by incorporating 40 wt.% loading of PALF, the tensile and modulus strength has increased to the maximum. It is also seen that there is an inverse relationship between the moisture content and the wt.% loading of PALF. However, the water and moisture absorption show a direct relationship with wt.% loading of PALF. Meanwhile, the soil burial decreases when the wt.% loadings of PALF increase while the results for water solubility suggest vice versa. It is also found that the TPCS with 40 wt.% of PALF have a good miscibility between matrix/fibre in the bio-composites.

ARTICLE HISTORY

Revised: 14th Apr 2020

Accepted: 15th Apr 2020

KEYWORDS

Bio-composites;
biodegradable;
thermoplastic corn starch;
pineapple leaf fibre

INTRODUCTION

Plastics product is the commonly used materials in our daily lives and are widely used in industries including packaging, electrical and electronic equipment, automotive and others. The features of plastics such as convenience, light in weight, low cost and stylishly satisfying are making them high needed materials in the product creation. However, the plastics generated from petroleum resources are non-biodegradable products and causing a negative effect to the environments [1–4]. Due to all these negative factors, the development of fully biodegradable composite is one of the best alternatives to the conventional plastics, which can potentially solve polymer waste disposal problems [5, 6].

Nowadays, natural fibre such as flax, banana, sisal, oil palm, kenaf, jute, cotton, pineapple leaf fibre and etc. has been popularly studied to discover its potential as a substitute to synthetic fibre [7]. 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 [8]. Mixing natural fibre with the bio-plastic produces green composite that is easy to be degraded by a particular enzyme or bacteria [9, 10]. Pineapple leaf fibre (PALF) has been seen as a great potential to replace the synthetic fibres. PALF is effectively accessible and has considerably good mechanical properties. PALF shows high tensile strength and Young's modulus due to the high cellulose substance content and low microfibrillar angle [11, 12].

In recent years, the development of bio-polymers are dependent on the renewable resources for examples, cellulose, soya, starch, polyhydroxy alkanooates and polylactic acid have been investigated as exchange materials to supplant conventional polymers (synthetic) [13]. The most suitable source for the production of bio-degradable plastics and their composites is starch. This is because it is sustainable, abundant, natural and biodegradable. In addition, starch is capable to show thermoplastic behavior under high temperature and shear stress [14, 15]. Starch comprises of two major parts, the linear amylose and the highly branched amylopectin [16]. The proportion of amylose chains in native starch is genetically recognized and generally consistent for a specific plant species. In addition, previous studies have suggested that thermoplastics starch (TPS) produced using high amylose starch has better thermal and mechanical properties [17–19]. Therefore, thermoplastics corn starch (TCPS) can be considered as the bio-polymers, which is reinforced with PALF to form bio-composites.

The natural fibre reinforces bio-polymer composites can be developed by employing various methods, such as varying the fibre loadings, fibre ratio, fibre type (short, long), fibre orientation (random, unidirectional, woven), number of ply,

and ply stacking sequence [20]. Previous studies have been performed to investigate the effect of ply on the mechanical properties of hybrid natural fibre composite laminates such as kenaf/Kevlar reinforced epoxy composites [21] and oil palm empty fruit bunch (OPEFB)/jute reinforced epoxy composites [22]. In addition, previous work by Mansor et al. [23] suggested that the final hybrid composite product quality is influenced by the ply stacking sequence due to the interaction between the combined fibres and matrix.

In this work, the main objective is to fabricate fully biodegradable composite using a hand lay-up technique and the effect of TPCS reinforced with PALF on mechanical, physical, environmental and morphological behaviour with respect to the layering (laminated) pattern of fibre/matrix is examined. The various ratios of weight percentage (wt.%) were applied 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, impact test, density, water absorption, moisture content, moisture absorption, soil burial, water solubility and microstructure analysis utilizing the scanning electron microscopes (SEM).

METHODS AND MATERIALS

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 was used in this study from Josapine cultivars were purchased directly from cultivated areas in Kampung Parit Puteri Menangis, Pontian, Johor, Malaysia.

Sample Preparation (Laminates)

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 [24]. Five various fibre layer (laminated) was applied to prepare the laminates of the PALF/TPCS bio-composites as shown in **Figure 1**. **Table 1** shows the compositions (wt.%) of every layer and the total weight of the PALF/TPCS bio-composites were 40 grams. All PALF with 2 mm length were randomly orientated within the layer. All laminates of PALF/TPCS bio-composites were subjected to the compression moulding (Hot Press Machine) at the pressure of 750 kg/cm² and 165 °C of temperature for 15 minutes followed by curing for 30 minutes. The laminates were fabricated based on a mild steel mould with fixed length x width x height of 140 mm x 60 mm x 3 mm.

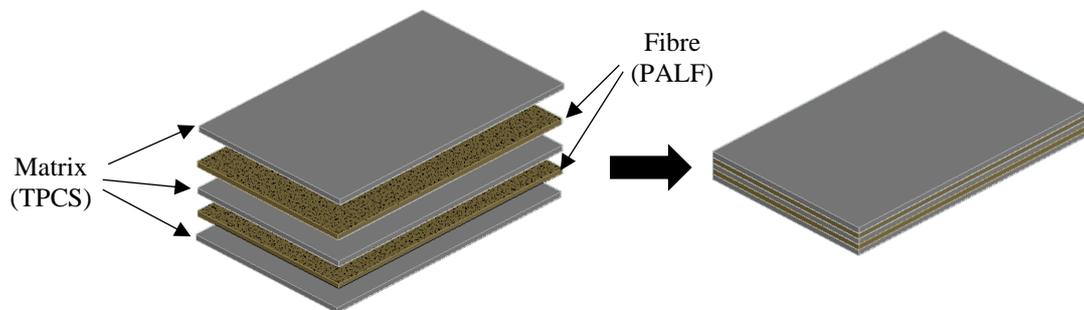


Figure 1. Layer (laminated) of the PALF/TPCS bio-composites materials

Table 1. Compositions of PALF/TPCS bio-composite layer (laminates) at various layers

Loading	PALF (wt.%)		TPCS (wt.%)		
20/80	10	10	27	26	27
30/70	15	15	23	24	23
40/60	20	20	20	20	20
50/50	25	25	17	16	17
60/40	30	30	13	14	13

Tensile Test

The tensile tests were conducted according to ASTM D-638 [59] at the temperature of $23 \pm 1^\circ\text{C}$ and relative humidity of $50 \pm 5\%$. The tests were carried out on five replications sample by using Universal Testing Machine (INSTRON 5969) with a 5 kN load cell; the crosshead speed was maintained at 2 mm/min [25].

Impact Test

Meanwhile, impact tests were conducted according to ASTM D256 [60] at a temperature of $23 \pm 1^\circ\text{C}$ and relative humidity of $50 \pm 5\%$. The unnotched samples were prepared with dimensions of 13 mm (W) x 70 mm (L) x 3 mm (T). The tests were performed on five replications using a digital Vector pendulum impact tester. The impact strength was calculated based on the impact energy and cross section area of the specimen as shown in Eq. (1).

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

Density Measurement

The purpose of density test is to determine the specific gravity of the composite specimens. The experiment utilizes Electronic Densimeter. The specimens need to be cut into smaller pieces for 10 mm x 10 mm x 3 mm in dimensions. Firstly, the mass of the specimen will be measured by putting the specimen on the Densimeter. After that, the specimen was placed in the water to get the density of the specimen. These steps were then repeated for each specimen to obtain the average values of the density. A density test was carried out according to Selamat et al. [27] and Loh et al. [28].

Water Absorption

A water absorption test was carried out according to Salleh et al. [29]. The water absorption capacity was expressed as grams of water bound per gram of the specimen on a dry basis. The data were collected in triplicate to obtain a mean value. For the composites, five specimen size (10 mm x 10 mm x 3 mm) was dried in an air circulating oven at $105^\circ\text{C} \pm 2$ for 24 hours in order to remove the existing moisture. Then the specimen is immersed in water at a room temperature ($23 \pm 1^\circ\text{C}$) for 0.5 hours and 2 hours. The weight of the specimen before W_i and after the immersion, W_f was calculated to obtain water absorption by using Eq. (2).

$$\text{Water Content (\%)} = [(W_f - W_i) / W_i] \times 100 \quad (2)$$

Moisture Absorption

A moisture absorption test was carried out according to Ridhwan Jumaidin et al. [30]. Prior to investigate the moisture absorption, three specimens (10 mm x 10 mm x 3 mm) for each composition were dried at $105^\circ\text{C} \pm 2$ for 24 hours. The specimen weight after drying, W_i and weight, W_f for a certain period until a constant weight was obtained. The moisture absorption was determined by using Eq. (3).

$$\text{Water Absorption (\%)} = [(W_f - W_i) / W_i] \times 100 \quad (3)$$

Moisture Content

Five specimens were prepared for the moisture content investigation. The specimens of each composition were heated in an oven for 24 hours at 105°C . The weight of the specimens before W_i and after W_f heating was obtained in order to calculate the moisture content. The moisture content was determined by using Eq. (4). A moisture content test was carried out according to Sahari et al. [31].

$$\text{Moisture Content (\%)} = [(W_f - W_i) / W_i] \times 100 \quad (4)$$

Water Solubility

Water solubility of the samples was determined according to the method by Kanmani and Rhim [32]. For this testing, a piece of sample (10 x 10 x 3 mm) was cut and dried at $105^\circ\text{C} \pm 2$ for 24 hours. The initial weight of samples (W_i) was measured before immersing into 30 ml of distilled water with a gentle stirring. After 2 hours of immersion, the remaining piece of the sample was taken from the beaker and filter paper was used to remove the remaining water on the surface. Then, the sample was dried again at $105^\circ\text{C} \pm 2$ for 24 hours to determine the final weight (W_f). The water solubility of the sample was calculated, as follows Eq. (5).

$$\text{Water solubility (\%)} = [(W_i - W_f) / W_i] \times 100 \quad (5)$$

Soil Burial

A soil burial degradation test was carried out according to modify the method by Bootklad & Kaewtatip [33]. Five specimens (10 mm x 10 mm x 3 mm) were buried at 10 cm depth in soil. The physico-chemical properties of the soil were pH: 6.52. Prior to this testing, specimens were dried at 105 °C for 24 hours and weighed to obtain the initial weight, W_i . Two different periods of testing were made for predetermined intervals of 2 and 4 weeks. Afterwards, they were dried at 105 °C for 24 hours again and weighed to obtain the final weight, W_f . The final weight loss was determined by using Eq. (6).

$$\text{Weight loss (\%)} = [(W_i - W_f) / W_i] \times 100 \quad (6)$$

Scanning Electron Microscope

The morphology of samples PALF/TPCS bio-composites were observed under a scanning electron microscope (SEM), model JEOL JSM-6010/PLUS/LV after undergoing platinum coating using autofine coater model JEOL JEC-3000FC.

RESULTS AND DISCUSSION

Tensile Properties

The tensile strength and tensile modulus for the PALF/TPCS bio-composites are demonstrated in Figure 2. The tensile strength of PALF/TPCS bio-composites shows that the load is gradually increased to a maximum point before suddenly dropping, implying that a brittle fracture occurred in the material. It can be seen that both tensile strength and tensile modulus of the composite samples indicate the similar pattern where the increment is up to 40% in the presence of the PALF fibre. However, further adding more in fibre loading (40 to 60%) indicates a reduction in value of tensile strength and modulus. The optimum value is at 40% fibre loading with the corresponding tensile strength of the PALF fibre reinforcing with TPCS is 8.88 MPa. The lowest tensile strength occurs at 60% of the fibre loading. The total reduction of the tensile strength is around 61%, which stands at 3.42 MPa.

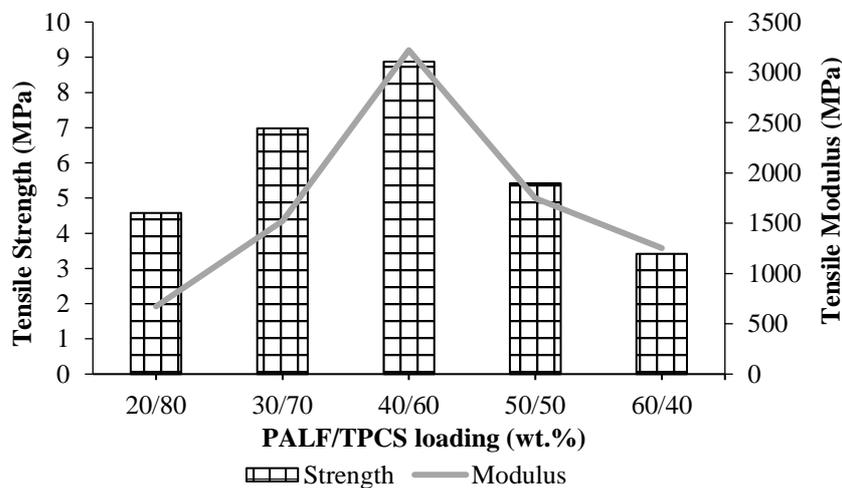


Figure 2. The tensile strength and modulus against PALF/TPCS loading (wt.%)

Generally, the improvement of tensile strength and modulus with the increase of PALF fibre is due to the fibre acts as a load carrier in the matrix (TPCS). Good tensile strength result is depending on the effective and uniform stress distribution between the fibre and matrix. Fibre also acts as the reinforced material which can stop crack propagation [34]. The enhancement of tensile strength and modulus clearly shows that the fibre has higher tensile properties than neat matrix. The optimum tensile strength and modulus from 40% fibre loading is due to the good interfacial bonding between the fibre/matrix and uniform dispersion of the fibre in the matrix. Furthermore, the mechanical interlocking fibre/matrix is good enough at 40% fibre loading to transfer the load from the matrix to the fibre and the reinforcing effect of the predominated cellulose fibre. However, the fall in tensile strength was attributed due to fiber to fiber interface than fiber

to matrix interface in the PALF/TPCS bio-composites. In addition, the distribution of fiber in the polymer may become poor when further amount of fiber is increased as mentioned by Gunti Rajesh et al. [35].

Impact Properties

Santhosh et al. [36] mentioned that the impact property of a material indicates its capacity to absorb and dissipate energies under impact or shock loading. The composite impact energy level depends on several parameters, such as the construction and geometry of the composites, fibre/matrix adhesion, fibre arrangement, test conditions and the nature of the components. The types of failures due to impact loading applied on fibre composites are the matrix fracture, fibre/matrix debonding, fibre breakage and fibre pullout. Debonding may occur if the applied load exceeds the fibre/matrix interfacial bond where this load is normally transferred by shear force directly to the fibres. The frictional force along the interface may transfer the stress to the debonded fibre. Fibres may break if the fibre stress level exceeds the fibre strength. Ultimately, energy is dissipated when the broken fibres are pulled out of the matrix [37].

Figure 3 shows the impact strength of the PALF/TPCS bio-composites with various fibre loading start from 20 wt. % to 60 wt. %. In general, by increasing PALF in the composite results in consistently decreasing the value of the impact strength of composites up to 60 wt.% fibre loading. Fibre loading at 20 wt.% yields the highest impact strength, which stands at 5.5 kJ/m² while the lowest impact strength was shown at 60 wt.% fibre loading. Similar findings were reported by Threepopnatkul et al. [7] where incorporation of PALF with polycarbonate (PC/PALF) has revealed that the impact strength tends to dramatically drop when the PALF content increased. Specifically, at low PALF loading (e.g., 20 wt.%), impact strength of composites depends on polymer matrix (TPCS) to absorb the energy. A previous study by Srinivasa & Bharath [38] revealed that the addition of natural fibres increases the stress concentration, thereby initiating crack growth. Therefore, broken cracked growth in the fibres and matrices, resulting in reduced composite impact strength when the fibre load increases. Based on the observation, the matrix (TPCS) has the higher tendency to withstand the energy compare to the fibre (PALF).

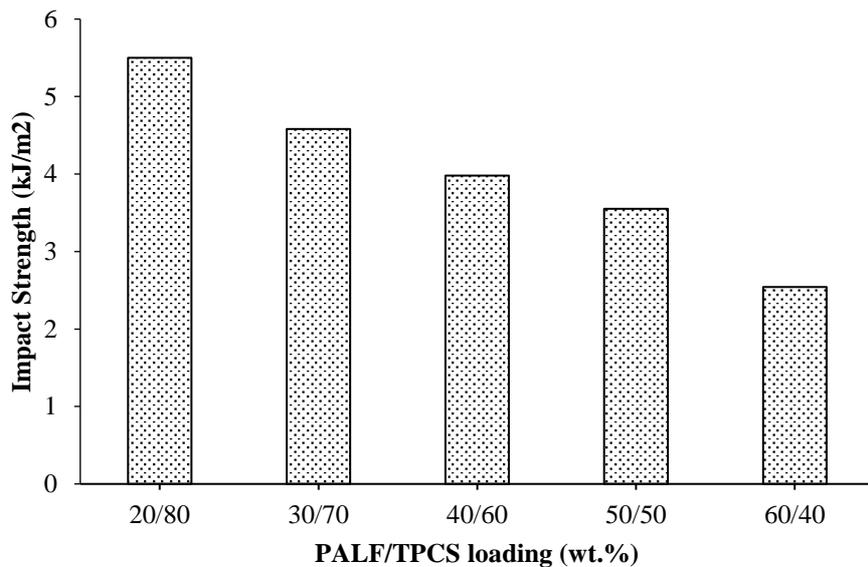


Figure 3. The impact testing of PALF/TPCS bio-composite

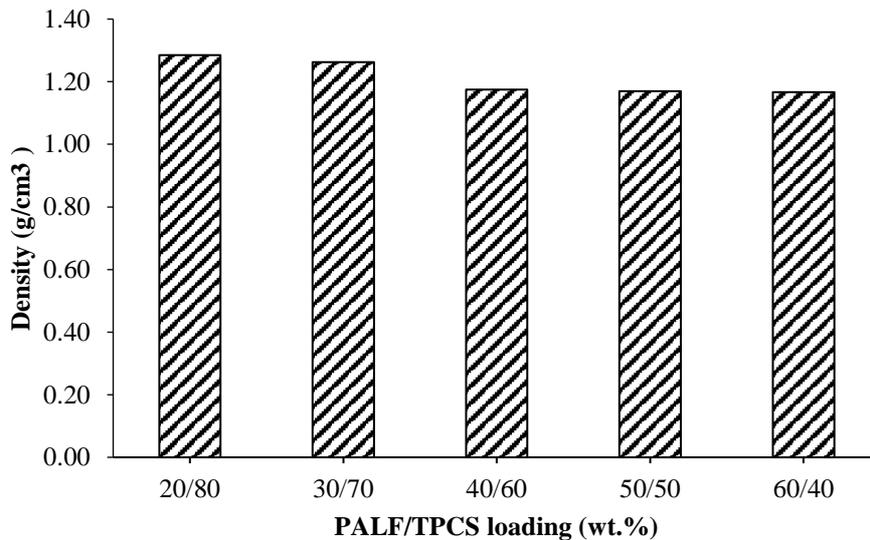


Figure 4. The density testing for PALF/TPCS bio-composite

Density

According to Jumaidin et al. [39], the weight of the material is one of the most important aspects in the material selection process, since it may affect the performance of the end products. The density of the material is the main criterion that directly correlates to this property. **Figure 4** shows the density results of PALF/TPCS bio-composites for various fibre loading. Generally, the density result is constantly decreasing with the increasing the PALF load. The reduction in density of composites due to the incorporation of natural fibre was also reported in previous work by Ramanaiah et al. [40]. Ramanaiah et al. [40] conducted a study on the effect of Borassus seed shoot fibre on the properties of polyester composites where increasing the fibre content is shown to result in reducing the density of the composites.

From this figure, the highest density occurs at 20 wt.% fibre loading which is about 1.32 g/cm³ while the lowest value of density is 1.23 g/cm³ with 50 and 60 wt.% of fibre loading, respectively. The difference in reduction of the density results between higher and lower is around 7.32%. This might be attributed to the formation of voids following the incorporation of fibre into the matrix [41]. Ibrahim et al. [42] reported a decline in the density of composites following the addition of date palm fibre into thermoplastic starch (TPS) matrix, which was attributed to the formation of voids in the composites. This is consistent with previous research on the physical properties of coir and pineapple leaf fibre reinforced polylactic acid hybrid composites that stated that the density of the composites decrease due to void space inside the composites. This phenomenon occurred due to the manufacturing process and fibre ratio or loading [43]. From the observations, it can conclude that the density of PALF/TPCS bio-composites are significantly higher in the matrix (TPCS) than in fiber (PALF).

Moisture Content

Moisture content is an important characteristic that should be taken into account before considering a new potential natural material for polymer bio-composites [39]. High moisture content may undermine the stability of the bio-composite in terms of strength, dimensions, and porosity formation [37]. Therefore, the low moisture content value in composite is desirable for further investigation. The results of moisture content of the PALF/TPCS bio-composites for various ratios are shown in **Figure 5**. In general, there is a slight decrement in the moisture content from 20 wt.% to 60 wt.% fibre loading. The high moisture content result was contributed at lower fibre content (20 wt.%) around 15.46%. Moreover, the low moisture content result was revealed at higher fibre content (60 wt.%) almost 12.2%. The total reduction of moisture content result was about 27%.

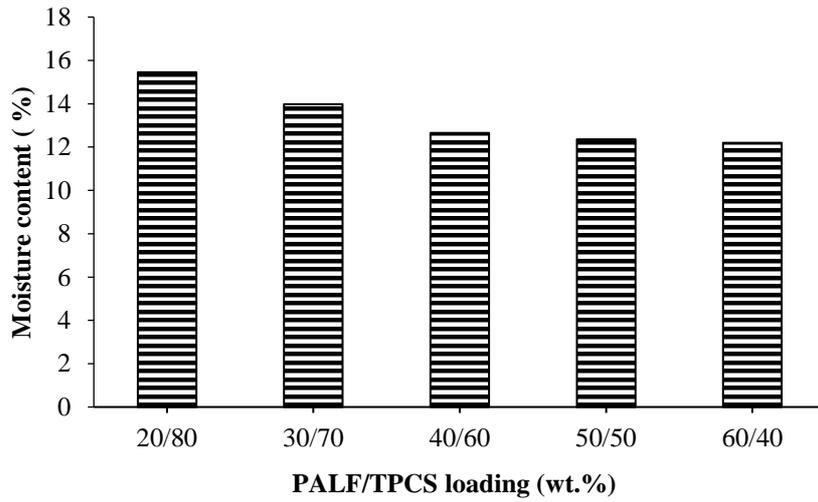


Figure 5. The moisture content in PALF/TPCS bio-composite

On the other hand, the high content of matrix (TPCS) contributed the higher content of moisture content result as compared to the higher content of fibre in PALF/TPCS bio-composite. This might as well be attributed to the hydrophilic behaviour of corn starch in the composites [44]. Moreover, the addition of glycerol in the native corn starch resulted in a mixture (TPCS) resulting in high hydrophilic behavior [45]. In addition, this is consistent with previous research by Sahari et al. [31] where in their finding also reported a significant drop in the moisture content of sugar palm fibre (SPF) reinforced plasticized sugar palm starch (SPF/SPS) bio-composites.

Moisture Absorption

The moisture absorption behaviour of PALF/TPCS bio-composites are shown in **Figure 6** for difference loading of fibre. In general, all PALF/TPCS bio-composites showed similar increasing trend for moisture content with increased storage time and this is a similar trend was revealed by Jumaidin et al. [41] that’s investigating the effect of seaweed on physical properties of thermoplastic sugar palm starch/agar composites. Based on the observation, the moisture absorption change was more rapid at the initial stages from the 1st day until 11th day. Starting from 11th day onwards, lower amounts of moisture were absorbed and become more stable. This is because after 11 days, the moisture content of the composites began to achieve equilibrium with the surrounding. This result is in agreement with previous studies of moisture absorption behaviour of sugar palm fibre reinforced epoxy composites performed by Leman et al. [46]. Moreover, incorporation of PALF with TPCS was observed to increase moisture absorption of PALF/TPCS bio-composites. The low PALF content contributes to the lowest moisture absorption, which is around 6.3%, while the high content of PALF of 60 wt. % exposes the moisture absorbs about 9.1%. Both value of moisture absorption was considered in the stability period on the 11th day and above. Again, this effect can be attributed to the more hydrophilic nature of PALF than the matrix [47].

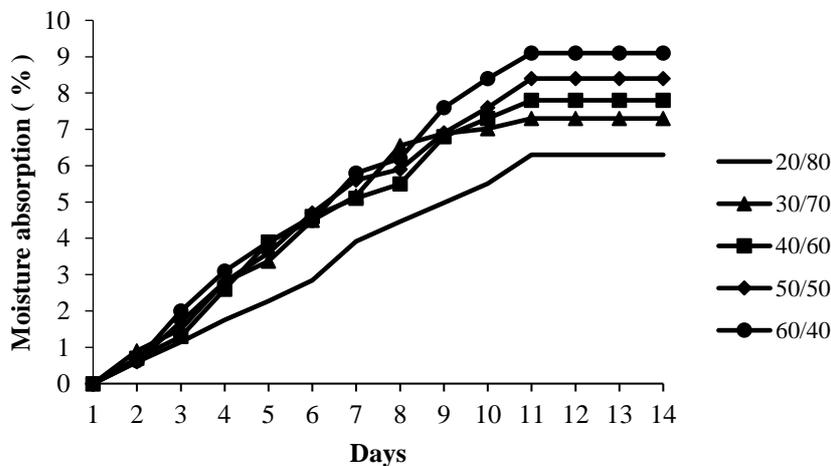


Figure 6. The moisture absorption of PALF/TPCS bio-composite

Water Absorption

Jumaidin et al. [30] reported that the bio-based material is known to be more sensitive to the water. As such, it is important to consider the water absorption behaviour of the fully bio-based material in this study. **Figure 7** illustrates the water absorption result in two different periods. From the figure, it is clearly the water absorption for both periods increase by increasing the PALF content. The low result water absorption at 20 wt.% fibre content about 126% and the high water absorption at 60% fibre content around 291%. As expected, the 0.5 hour period shows the lower water absorption rate compare with 2 hours. This finding is in agreement with previous studies of water absorption behaviour of PALF as they reinforce fibre in their composite [48]. The higher water absorption at higher fibre loading is due to the increase in cellulose content in the high fibre content as mention by Uma Devi et al. [11] which study an ageing study of pineapple leaf fibre reinforced polyester composites. Moreover, the increasing of water absorption is might be due to the hydrophilic behaviour for both TPCS and PALF. In addition, the presence of the void between the PALF and TPCS in the bio-composites contributed to higher water uptake as mentioned by Lee et al. [49].

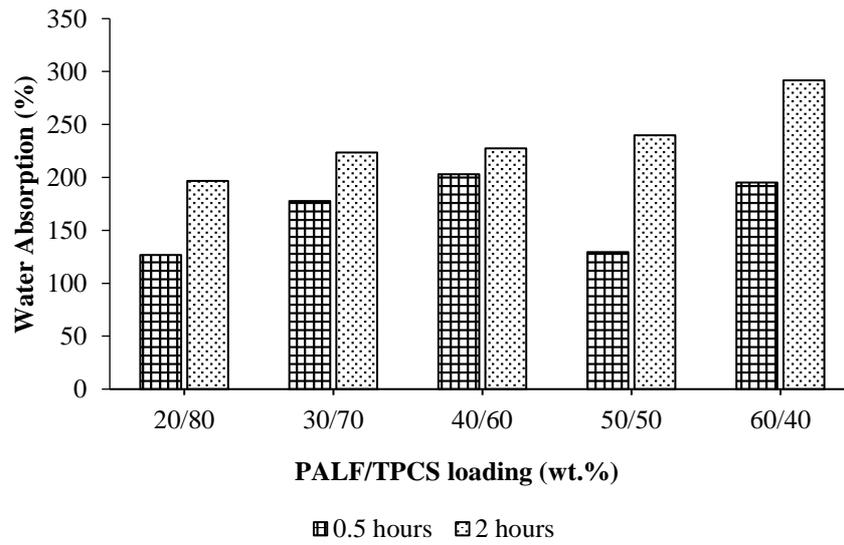


Figure 7. The water absorption for PALF/TPCS bio-composite in 0.5 hours and 2 hours

Water Solubility

Recently, the main problem to the ecosystem is due to non-biodegradable materials cannot be disposed in the water. Therefore, bio-based materials are solution because of their readiness to decompose when disposed in the water [41]. **Figure 8** shows the water solubility of the PALF/TPCS bio-composites, which indicates the water resistance of the composites when subjected to immersion and continuous stirring in water. On the other hand, water solubility also shows the degradation behaviour of composite when disposed in water. Generally, it was observed that the water solubility of PALF/TPCS bio-composites dramatically increased from 25.08% to 36.83% with the addition of PALF (20 to 60 wt.%) of fibre content. From these findings, low fibre content contributes to the lower of water solubility while at higher fibre content, water solubility reveals vice versa. This result suggests that PALF has the ability to increase the solubility of PALF/TPCS bio-composites. This phenomenon was attributed to more hydrophilic behaviour of PALF and TPCS in this bio-composite [10, 44]. Apart from that, this finding also shows that PALF has radically improved the degradability of PALF/TPCS bio-composites in water which is favourable for sustainable waste disposal. Similar findings on water solubility were reported by previous studies on thermoplastic cassava starch following the incorporation of carrageenan in the matrix [50]. However, it should be noted that higher water solubility also indicates a weak bio-composites resistance when exposed to water. Hence, increasing PALF amount may also be associated with weakening of the bio-composites structure when in contact with water [41].

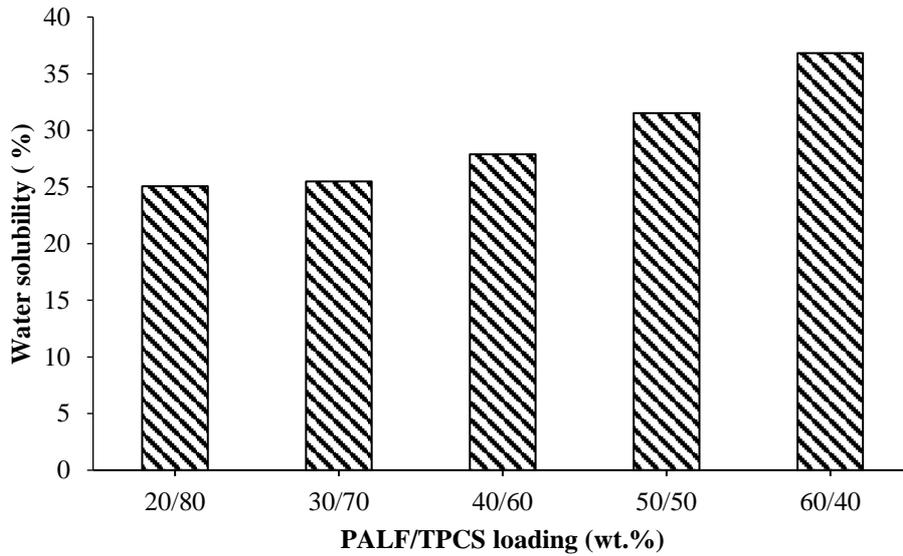


Figure 8. The water solubility for PALF/TPCS bio-composite

Soil Burial

According to Bootklad and Kaewtatip [33], the weight loss of material can be taken as the main indicator for the biodegradation process by moisture and microorganism during soil burial period. Figure 9 represents the weight loss of PALF/TPCS bio-composites after soil burial process in two different periods of two (2) and four (4) weeks. As expected, higher weight losses of soil burial were shown in all bio-composites for 4 weeks as compared with the burial of 2 weeks. This phenomenon is due to the higher amount of microorganism activity occurred at a longer soil burial time, which led to the increase in the weight loss of the composites [51]. Incorporation of PALF from 20 wt.% to 60 wt.% has decreased the weight loss of bio-composites from 26.74% to 16.66% and 32.49% to 18.34% after soil burial for 2 and 4 weeks, respectively. This is in agreement with the results of Prachayawarakorn et al. [52] where the lower fibre content was associated with greater reduction in the weight. Therefore, it was concluded that the extent of degradation was inversely proportional to the fiber content implying that the composites were completely degradable. Many factors associated with soil influence the degradation of the polymer composites. Some of these important factors are the texture and soil structure, temperature, soil composition (mineral and organic), water activity, pH, and the oxygen and carbon dioxide content [53]. In addition, the biodegradation in the composites occurred due to the microorganism attack such as bacteria and fungi [54].

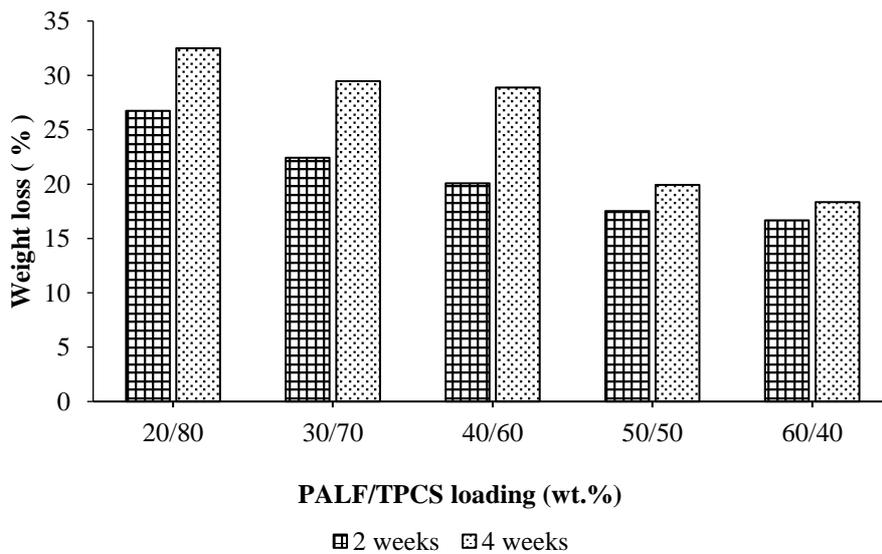


Figure 9. The soil burial for PALF/TPCS bio-composite in 2 weeks and 4 weeks

Morphological Properties

Surface morphology was investigated under scanning electron microscopy. **Figure 10** 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 (TPCS rich) at the top and bottom of composite and low content of fibre as shown in **Figure 10a**. This figure reveals the less existence of a matrix between the fibres and this phenomenon will result in weak interfacial bonding between the fibres and the matrix [55]. These findings suggest that the transfer of stress is directed more to the matrix (TPCS) than to the fibre itself [56]. Moreover, the existence of voids between the fiber and the matrix contributed to the low tensile result. Furthermore, the increased tensile strength is an indicator that the PALF/TPCS bio-composites promoted good wettability and better fiber–matrix adhesion, allowing efficient stress transfer between the matrix and the fibers [57]. TPCS/PALF bio-composites show good adhesion between the matrix and the fibers at present in **Figure 10b**, which can be attributed to good miscibility during the processing. Due to this bondability, the stress transference between the 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 [44, 45, 47]. This finding is in good agreement with the tensile results where the higher fibre content helped the composite to withstand slightly higher loads [58]. At high fibre content, the tensile result shown lower result and this might be due to the fibre-to-fibre (fibre rich) contact is greater, which is evident from the SEM photograph (**Figure 10c**). This observation is similar to previous studies by Nadlene Razali et al. [34] on mechanical and thermal properties of roselle fibre reinforced vinyl ester composites where the higher fibre loading developed more fibre to fibre contact, compared with the fibre and matrix. The composites failed at a small load, which indicated a low tensile strength due to the weak interfacial bonding between fibre and matrix [34].

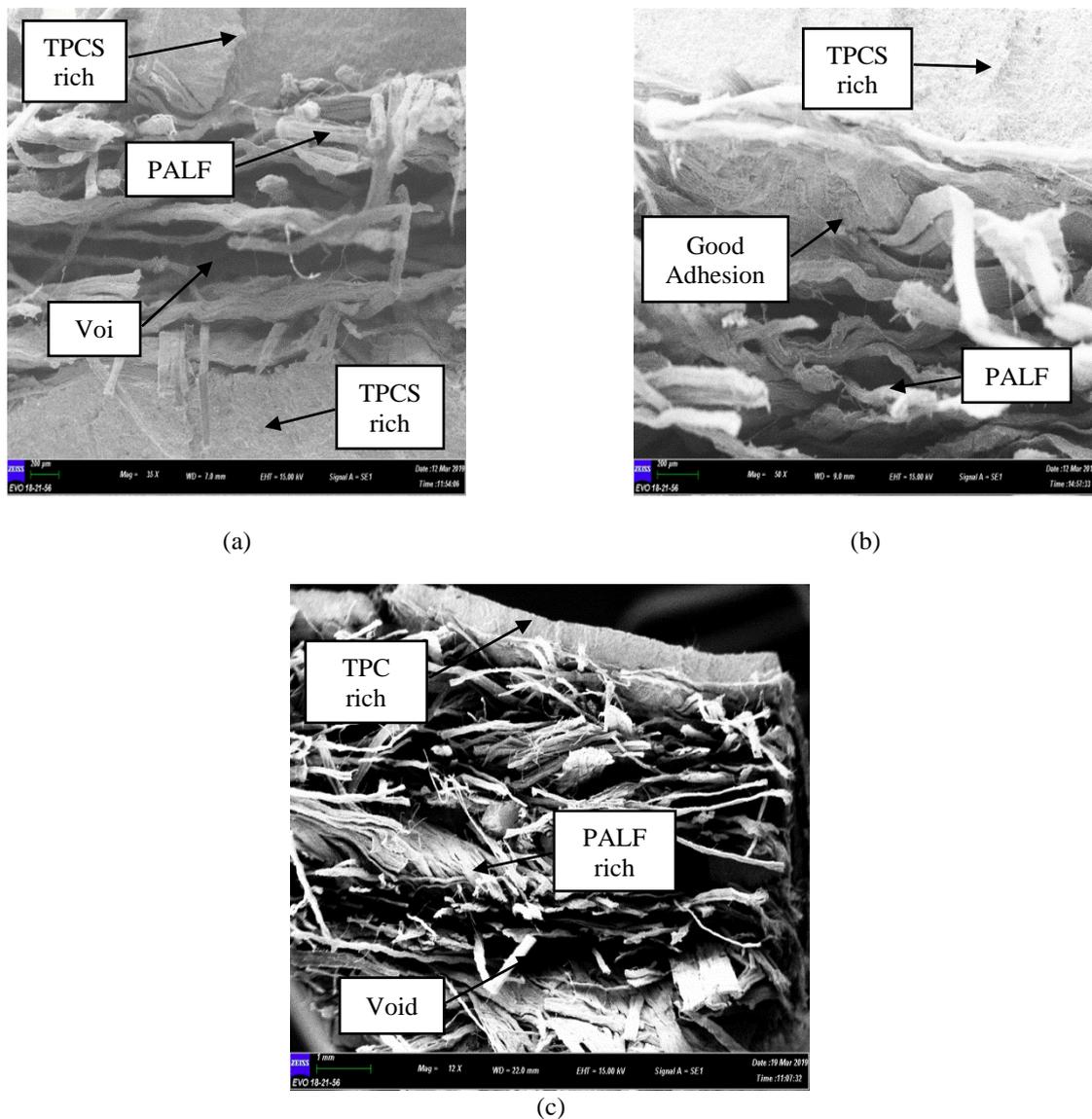


Figure 10. SEM of the tensile failure surface of TPCS blended with different fibre content of PALF (a) 20 wt.% (b) 40 wt.% (c) 60 wt.%

CONCLUSIONS

Bio-polymer composite from TPCS reinforced short PALF was successfully prepared via laminating method in five various plies by using hot press machine. From the results, it can be deduced that the 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 other compositions. On the other hand, TPCS reinforced with 60 wt.% PALF shows the lowest result on tensile properties. The impact properties of TPCS/PALF bio-composite 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. The physical test results for moisture content represent a decreasing pattern when the fibre content of PALF is increased. However, the water and moisture absorption show otherwise whereby adding in the fibre content causes the water and moisture content to increase. The density value for all fibre content of PALF does not significantly change. Last but not least, the environmental result of soil burial decreases when the fibre content is increased. 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 adhesion of fibre/matrix at 40 wt.% fibre content has huge potential to be a better bio-composite.

ACKNOWLEDGEMENTS

The authors would like to thank Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia and Advance Materials Research Group (A-Mat), Faculty of Mechanical and Manufacturing Engineering Technology, Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka for financial sustenance and the utilisation of their facilities and besides the Ministry of Higher Education Malaysia for providing the scholarship award to complete this study.

REFERENCES

- [1] R. Jumaidin, S. M. Sapuan, M. S. Firdaus, A. F. Ab Ghani, M. Y. Yaakob, H. Z. Nazri, F. A. Munir, A. A. Zakaria, N. Jenal, "Effect of agar on dynamic mechanical properties of thermoplastic sugar palm starch: Thermal behavior," *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 47, no. 1, pp. 89–96, 2018.
- [2] M. Drzal, L. T., Mohanty, A. K., & Misra, "Bio-Composite Materials As Alternatives To Petroleum-Based Composites for Automotive Applications," *Magnesium*, vol. 40, no. 60, pp. 1–3, 2001.
- [3] M. L. Sanyang, S. M. Sapuan, M. Jawaid, M. R. Ishak, and J. Sahari, "Effect of Plasticizer Type and Concentration on Dynamic Mechanical Properties of Sugar Palm Starch-Based Films," *Int. J. Polym. Anal. Character.*, vol. 20, no. 7, pp. 627–636, 2015.
- [4] A. Jiménez, M. J. Fabra, P. Talens, and A. Chiralt, "Edible and Biodegradable Starch Films: A Review," *Food Bioprocess Technol.*, vol. 5, no. 6, pp. 2058–2076, 2012.
- [5] J. Sahari, S. M. Sapuan, E. S. Zainudin, and M. A. Maleque, "Thermo-mechanical behaviors of thermoplastic starch derived from sugar palm tree (*Arenga pinnata*)," *Carbohydr. Polym.*, vol. 92, no. 2, pp. 1711–1716, 2013.
- [6] F. Xie, E. Pollet, P. J. Halley, and L. Avérous, "Starch-based nano-biocomposites," *Prog. Polym. Sci.*, vol. 38, no. 10–11, pp. 1590–1628, 2013.
- [7] P. Threepopnatkul, N. Kaerkitcha, and N. Athipongarporn, "Effect of surface treatment on performance of pineapple leaf fiber-polycarbonate composites," *Compos. Part B Eng.*, vol. 40, no. 7, pp. 628–632, 2009.
- [8] K. L. Pickering, M. G. A. Efendy, and T. M. Le, "A review of recent developments in natural fibre composites and their mechanical performance," *Composites Part A: Applied Science and Manufacturing*, pp. 98–112, 2016.
- [9] A. O'Donnell, M. . Dweib, and R. . Wool, "Natural fiber composites with plant oil-based resin," *Compos. Sci. Technol.*, vol. 103, no. 3, pp. 1135–1145, 2004.
- [10] M. Asim, K. Abdan, M. Jawaid, M. Nasir, Z. Dashtizadeh, M. R. Ishak, M. E. Hoque, "A Review on Pineapple Leaves Fibre and Its Composites," *Int. J. Polym. Sci.*, vol. 2015, pp. 1–16, 2015.
- [11] L. U. Devi, K. Joseph, K. C. M. Nair, and S. Thomas, "Ageing studies of pineapple leaf fiber-reinforced polyester composites," *J. Appl. Polym. Sci.*, vol. 94, no. 2, pp. 503–510, 2004.
- [12] M. S. Alwani, A. Khalil, N. Islam, W. O. W. Nadirah, and R. Dungani, "Fundamental approaches for the application of pineapple leaf fiber in high performance reinforced composites," no. 11, pp. 38–44, 2014.
- [13] X. Ma, J. Yu, and J. F. Kennedy, "Studies on the properties of natural fibers-reinforced thermoplastic starch composites," *Carbohydr. Polym.*, vol. 62, no. 1, pp. 19–24, 2005.
- [14] X. Z. Mo, Y. X. Zhong, C. Q. Liang, and S. J. Yu, "Studies on the Properties of Banana Fibers-Reinforced Thermoplastic Cassava Starch Composites: Preliminary Results," *Adv. Mater. Res.*, vol. 87–88, pp. 439–444, 2009.
- [15] R. Manríquez-González, S. Iwakiri, T. S. Flores-Sahagun, G. B. de Muniz, S. G. Kestur, and M. G. Lomelí-Ramírez, "Bio-composites of cassava starch-green coconut fiber: Part II—Structure and properties," *Carbohydr. Polym.*, vol. 102, pp. 576–583, 2013.
- [16] G. Moad, "Chemical modification of starch by reactive extrusion," *Prog. Polym. Sci.*, vol. 36, no. 2, pp. 218–237, 2011.

- [17] L. Yu and G. Christie, "Microstructure and mechanical properties of orientated thermoplastic starches," *J. Mater. Sci.*, vol. 40, no. 1, pp. 111–116, 2005.
- [18] J. Li, X. Luo, X. Lin, and Y. Zhou, "Comparative study on the blends of PBS/thermoplastic starch prepared from waxy and normal corn starches," *Starch/Staerke*, vol. 65, no. 9–10, pp. 831–839, 2013.
- [19] J. Sahari, S. M. Sapuan, E. S. Zainudin, and M. A. Maleque, "Physico-chemical and thermal properties of starch derived from sugar palm tree (*Arenga pinnata*)," *Asian J. Chem.*, vol. 26, no. 4, pp. 955–959, 2014.
- [20] N. A. Hamid, N. H. N. Abdullah, M. R. Mansor, M. A. M. Rosli, and M. Z. Akop, "An Experimental Study of The Influence of Fiber Architecture on The Strength of Polymer Composite Material," *J. Mech. Eng. Technol.*, vol. 2, no. 2, 2009.
- [21] R. Yahaya, S. M. Sapuan, M. Jawaid, Z. Leman, and E. S. Zainudin, "Effect of layering sequence and chemical treatment on the mechanical properties of woven kenaf-aramid hybrid laminated composites," *Mater. Des.*, vol. 67, pp. 173–179, 2015.
- [22] M. Jawaid and H. P. S. Abdul Khalil, "Effect of layering pattern on the dynamics mechanical properties and thermal degradation of oil palm-jute fibres reinforced epoxy hybrid composite," *bioresources.com*, vol. 6, no. 3, pp. 2309–2322, 2011.
- [23] M. R. Mansor, M. A. A. Hadi, M. J. Taufiq, M. A. Salim, and A. Saad, "Fabrication of hybrid oil palm empty fruit bunch and kenaf reinforced epoxy composite panels at varying fiber layering sequence," *1st Colloq. Pap. Adv. Mater. Mech. Eng. Res.*, vol. 1, pp. 42, 2018.
- [24] N. H. Zakaria, Z. Ngali, and M. Z. Selamat, "Preliminary Investigation to Determine the Suitable Mixture Composition for Corn Starch Matrix," *IOP Conf. Ser. Mater. Sci. Eng.*, pp. 1-8, 2016.
- [25] R. Punyamurthy, D. Sampathkumar, R. P. G. Ranganagowda, B. Bennehalli, and C. V. Srinivasa, "Mechanical properties of abaca fiber reinforced polypropylene composites: Effect of chemical treatment by benzenediazonium chloride," *J. King Saud Univ. - Eng. Sci.*, vol. 29, no. 3, pp. 289–294, 2017.
- [26] M. Z. Selamat, M. Razi, A. N. Kasim, S. Dharmalingam, and A. Putra, "Mechanical Properties of Starch Composite Reinforced by Pineapple Leaf Fiber (PLF) from Josapine Cultivar," vol. 11, no. 16, pp. 9783–9788, 2016.
- [27] A. N. Kasim, M. Z. Selamat, M. A. M. Daud, M. Y. Yaakob, A. Putra, and D. Sivakumar, "Mechanical properties of polypropylene composites reinforced with alkaline treated pineapple leaf fibre from josapine cultivar," *Int. J. Automot. Mech. Eng.*, vol. 13, no. 1, pp. 3157–3167, 2016.
- [28] X. H. Loh, M. A. Mohd Daud, and M. Z. Selamat, "Mechanical properties of kenaf/polypropylene composite: An investigation," *J. Mech. Eng. Sci.*, vol. 10, no. 2, pp. 2098–2110, 2016.
- [29] Z. Salleh, Y. M. Taib, K. M. Hyie, M. Mihat, M. N. Berhan, and M. A. A. Ghani, "Fracture toughness investigation on long kenaf/woven glass hybrid composite due to water absorption effect," in *Procedia Engineering*, 2012.
- [30] R. Jumaidin, S. M. Sapuan, M. Jawaid, M. R. Ishak, and J. Sahari, "Thermal, mechanical, and physical properties of seaweed/sugar palm fibre reinforced thermoplastic sugar palm Starch/Agar hybrid composites," *Int. J. Biol. Macromol.*, vol. 97, pp. 606–615, 2017.
- [31] J. Sahari, S. M. Sapuan, E. S. Zainudin, and M. A. Maleque, "Mechanical and thermal properties of environmentally friendly composites derived from sugar palm tree," *Mater. Des.*, vol. 49, pp. 285–289, 2013.
- [32] P. Kanmani and J. Rhim, "Antimicrobial and physical-mechanical properties of agar-based films incorporated with grapefruit seed extract," vol. 102, pp. 708–716, 2014.
- [33] M. Bootklad and K. Kaewtatip, "Biodegradation of thermoplastic starch/eggshell powder composites," *Carbohydr. Polym.*, vol. 97, no. 2, pp. 315–320, 2013.
- [34] N. Razali, S. M. Sapuan, M. Jawaid, M. R. Ishak, and Y. Lazim, "Mechanical and Thermal Properties of Roselle Fibre Reinforced Vinyl Ester Composites," *BioResources*, vol. 11, no. 4, pp. 9325–9339, 2016.
- [35] G. Rajesh, G. Siripurapu, and A. Lella, "Evaluating Tensile Properties of Successive Alkali Treated Continuous Pineapple Leaf Fiber Reinforced Polyester Composites," *Mater. Today Proc.*, vol. 5, no. 5, pp. 13146–13151, 2018.
- [36] J. Santhosh, N. Balanarasimman, R. Chandrasekar, and S. Raja, "Study of Properties of Banana Fiber Reinforced Composites," *Int. J. Res. Eng. Technol.*, vol. 03, no. 11, pp. 144–150, 2015.
- [37] R. Nadlene, S. M. Sapuan, M. Jawaid, M. R. Ishak, and L. Yusriah, "A Study on Chemical Composition, Physical, Tensile, Morphological, and Thermal Properties of Roselle Fibre: Effect of Fibre Maturity," *BioResources*, vol. 10, no. 1, pp. 1803–1823, 2015.
- [38] C. V. Srinivasa and K. N. Bharath, "Effect of Alkali Treatment on Impact Behavior of Areca Fibers Reinforced Polymer Composites Effect of Alkali Treatment on Impact Behavior of Areca Fibers Reinforced Polymer Composites," vol. 7, no. 4, pp. 875–879, 2015.
- [39] R. Jumaidin, S. M. Sapuan, M. Jawaid, M. R. Ishak, and J. Sahari, "Characteristics of *Eucommia cottonii* waste from East Malaysia: physical, thermal and chemical composition," *Eur. J. Phycol.*, vol. 52, no. 2, pp. 200–207, 2017.
- [40] K. Ramanaiah, A. V. Ratna Prasad, and K. Hema Chandra Reddy, "Effect of fiber loading on mechanical properties of borassus seed shoot fiber reinforced polyester composites," *J. Mater. Environ. Sci.*, vol. 3, no. 2, pp. 374–378, 2012.
- [41] R. Jumaidin, S. M. Sapuan, M. Jawaid, M. R. Ishak, and J. Sahari, "Effect of seaweed on physical properties of thermoplastic sugar palm starch/agar composites," *J. Mech. Eng. Sci.*, vol. 10, no. 3, pp. 2214–2225, 2016.
- [42] H. Ibrahim, M. Farag, H. Megahed, and S. Mehanny, "Characteristics of starch-based biodegradable composites reinforced with date palm and flax fibers," *Carbohydr. Polym.*, vol. 101, no. 1, pp. 11–19, 2014.
- [43] R. Siakeng, M. Jawaid, H. Ariffin, and S. M. Sapuan, "Physical properties of coir and pineapple leaf fibre reinforced polylactic acid hybrid composites," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 290, no. 1, 2018.

- [44] J. Guan and M. A. Hanna, "Extruding foams from corn starch acetate and native corn starch," *Biomacromolecules*, vol. 5, no. 6, pp. 2329–2339, 2004.
- [45] N. F. Magalhães and C. T. Andrade, "Thermoplastic corn starch/clay hybrids: Effect of clay type and content on physical properties," *Carbohydr. Polym.*, vol. 75, no. 4, pp. 712–718, 2009.
- [46] Z. Leman, S. M. Sapuan, A. M. Saifol, M. A. Maleque, and M. M. H. M. Ahmad, "Materials & Design Moisture absorption behavior of sugar palm fiber reinforced epoxy composites," vol. 29, pp. 1666–1670, 2008.
- [47] D. Mathivanan, H. Norfazilah, J. P. Siregar, M. R. M. Rejab, D. Bachtiar, and T. Cionita, "The study of mechanical properties of pineapple leaf fibre reinforced tapioca based bioplastic resin composite," *MATEC Web Conf.*, vol. 74, pp. 1-4, 2016.
- [48] A. Danladi and J. Shu'aib, "Fabrication and Properties of Pineapple Fibre / High Density Polyethylene Composites," *Am. J. Mater. Sci.*, vol. 4, no. 3, pp. 139–143, 2014.
- [49] C. H. Lee, S. M. Sapuan, J. H. Lee, and M. R. Hassan, "Mechanical properties of kenaf fibre reinforced floreon biocomposites with magnesium hydroxide filler," *J. Mech. Eng. Sci.*, vol. 10, no. 3, pp. 2234–2248, 2016.
- [50] A. C. Flores, E. R. Punzalan, and N. G. Ambangan, "Effects of Kappa-Carrageenan on the Physico-Chemical Properties of Thermoplastic Starch," *Kimika*, vol. 26, no. 1, pp. 11–17, 2015.
- [51] R. Jumaidin, S. M. Sapuan, M. Jawaid, M. R. Ishak, and J. Sahari, "Effect of seaweed on mechanical, thermal, and biodegradation properties of thermoplastic sugar palm starch/agar composites," *Int. J. Biol. Macromol.*, vol. 99, pp. 265–273, 2017.
- [52] J. Prachayawarakorn, N. Limsiriwong, R. Kongjindamunee, and S. Surakit, "Effect of Agar and Cotton Fiber on Properties of Thermoplastic Waxy Rice Starch Composites," *J. Polym. Environ.*, vol. 20, no. 1, pp. 88–95, 2012.
- [53] A. Kalambettu, A. Damodaran, S. Dharmalingam, and M. T. Vallam, "Evaluation of Biodegradation of Pineapple Leaf Fiber Reinforced PVA Composites," *J. Nat. Fibers*, vol. 12, no. 1, pp. 39–51, 2015.
- [54] Z. J. A. Amer and A. Q. Saeed, "Soil Burial Degradation of Polypropylene/Starch Blend," *Int. J. of Technical Research and Applications*, vol 3, no 1, pp. 91-96, 2015.
- [55] S. Öztürk, "Effect of fiber loading on the mechanical properties of kenaf and fiberfrax fiber-reinforced phenol-formaldehyde composites," *J. Compos. Mater.*, vol. 44, no. 19, pp. 2265–2288, 2010.
- [56] R. Nadlene, S. M. Sapuan, M. Jawaid, M. R. Ishak, and L. Yusriah, "The Effects of Chemical Treatment on the Structural and Thermal, Physical, and Mechanical and Morphological Properties of Roselle Fiber-Reinforced Vinyl Ester Composites," *Polym. Compos.*, no. 36, pp. 1230–1241, 2016.
- [57] M. F. Rosa, B. Chiou, E. S. Medeiros, D. F. Wood, T. G. Williams, L. H. C. Mattaso, W. J. Orts, S. H. Imam, "Effect of fiber treatments on tensile and thermal properties of starch/ethylene vinyl alcohol copolymers/coir biocomposites," *Bioresour. Technol.*, vol. 100, no. 21, pp. 5196–5202, 2009.
- [58] K. Senthilkumar, N. Rajini, N. Saba, M. Chandrasekar, M. Jawaid, and S. Siengchin, "Effect of Alkali Treatment on Mechanical and Morphological Properties of Pineapple Leaf Fibre/Polyester Composites," *J. Polym. Environ.*, pp. 1-11, 2019.
- [59] ASTM D638-00 2001. Standard Test Method for Tensile Properties of Plastics. American Society for Testing Materials.
- [60] ASTM D256-02 2002. Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics. American Society for Testing Materials.