Original Article

Physical and mechanical properties of sugar palm/glass fiber reinforced thermoplastic polyurethane hybrid composites

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**Abstract**

This paper studied the physical and mechanical properties of sugar palm and glass fiber reinforced thermoplastic polyurethane hybrid composites with the aim of investigation on the hybrid effects of the composites made of natural and synthetic fibers. The aim of this study is to evaluate the physical properties such as density, thickness swelling, water absorption whereas the tensile, flexural and impact properties of sugar palm, hybrid and glass composites were also investigated. Morphological properties of tensile fracture samples of composites were done by using scanning electron microscopy (SEM). The composites were fabricated at a constant weight fraction of total fiber loading at 40 wt.% using melt compounding method. The result revealed that incorporation of glass fiber 30 wt.% to sugar palm/TPU composites exhibited the higher density, lower thickness swelling and water absorption properties. The tensile and impact properties of the hybrid composites were improved with the increasing of sugar palm fiber content (30/10 SP/G) as compared to glass fiber reinforced composites (0/40 SP/G) due to the excellent hybrid performance of the two fibers. The flexural properties were increased when the higher amount of glass fiber was introduced at 40 wt.% (0/40 SP/G). The fibers cracks, fiber pull out and fiber dislocation of the fractured surfaces are evaluated by using scanning electron microscope (SEM). Overall results indicated that the incorporation of glass fiber to sugar palm fiber composites can improve the physical and mechanical properties and developed hybrid composites can be used as an alternate material for glass fiber reinforced polymer composites for different applications.

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1. Introduction

As a matter of fact, composite is comprised of more than one basic material with constant dissimilar properties. This combination, however, at micro’s level has not merge together and, hence can be identified either as reinforcement or matrix. As to its fibers, natural fibers or synthetic fibers have become significant material as a reinforcement to produce the fiber reinforced polymer (FRP) composite.

In recent development of FRP, natural fibers are dominating the demand and application from industry in which it was before, highly depending on synthetic fibers. This migration from synthetic fibers to natural fibers is began from the view that natural fibers are efficient in term of cost, density, easy-to-get, eco-friendly, non-toxic, flexible, renewable, biodegradable, abrasive less, high strength and modulus, and easy to process. However, be that as it may, there are some identified drawbacks of natural fibers which is low strength in impact part and high water uptake in absorption properties part.

Apart from FRP, thermoplastic composites are equally competitive in dominating the demand and application from industry due to its remarkable properties, amongst, excellent strength and very firm when in load proportion, recyclability, good corrosion resistant and ecological resistant [1]. The efficiency of this thermoplastic is best elected when it can overcome the situation where the intrinsic brittleness of thermosetting matrices happened in certain low temperature’s condition [1,2]. As mentioned, this is the excellent factor in the thermoplastic where it can sustain the lower temperature in the product operation in which the thermosetting has reach its limit, and in the case of thermoplastic polyurethanes (TPUs), for instance, this matrices is able to be combine and process with high elasticity of elastomers and even have glass transition temperature lower than −40°C.

In probing the way out from those weaknesses, hybridization technique is identified as an urgently required invention to improve the mechanical properties. Basically, this hybridization technique is purported to combine a single fiber with additional fibers to strengthen the mechanical properties as opposed to one fiber in the composites. This combination of multiple fibers as mentioned, has equally distributed the loading and stress imposed from matrix to fibers and successively can increase the mechanical properties.

The fact that natural fibers is well-known in lower cost and lighter weight, its mechanical properties is being compromised too when its mechanical properties were tested to be lower as compared to the mechanical properties in glass fibers. At this weak point, the outcome from hybridization to synthetic and natural fibers, called as hybrid synthetic and natural fibers have shown that this low mechanical property can be improved. Studies have been conducted to see the effect from load proportion aspect and it was found that hybrid synthetic and natural fibers’ result are encouraging the mechanical properties to its good loading performance. Hybridization of glass fiber with other viable natural fibers like kenaf [3,4], jute [5,6], banana [7,8], sisal [9,10], flax [11], coir [12,13], basalt [14], oil palm wood flour [15] and sugar palm [16,17]. Numerous researches had joined to endure further this development. The tensile properties unidirectional of flax–glass fiber reinforced phenolics composites is carried out by Yongli et al. [11]. They have stated that rise of glass fiber’s content can eventually enhancing the hybrid composites. Mariam et al. [18] pursued this likely with hybrid glass/date palm wood flour fiber reinforced recycled polypropylene composites to observe its properties as well as its performance.

Misi et al. [16] on the other hand, had used the woven glass/sugar palm fibers reinforced unsaturated polyester hybrid composites to observe its mechanical properties by considering different layer of fibers namely strand mat, natural and hand woven of sugar palm fibers. They have reported the hybridization to woven glass/sugar palm fibers reinforced unsaturated polyester hybrid composites by compression molding increasing the mechanical properties. The overall tensile and impact properties of woven glass/sugar palm fibers reinforced unsaturated polyester hybrid composites were higher than the natural woven sugar palm fibers used.

Moreover, it has already proved that hybridization of oil palm empty fruit bunches (EFB) with synthetic fiber or natural fiber will improve the mechanical properties of hybrid composite. Jawaid et al. [19] investigated that flexural and impact strength of oil palm EFB with jute fibers reinforced epoxy composites were fabricated by hand lay-up method. Result indicated that the flexural properties of jute fiber and oil palm EFB with the ratio (1:4) hybrid composite have good mechanical properties than those of pure EFB/epoxy composites. In this study, it also observed that impact strength of pure EFB composites is higher than hybrid composites is proved that this composites is mainly dependent on the characteristics of natural fibers.

Mohammed et al. [20] have developed the sugar palm reinforced thermoplastic polyurethane composites and have tested its fracture’s toughness. An excellent result has been achieved in mechanical performance for sugar palm fiber composites at 250 μm size. Moreover, previous studies done by other research who are working with glass with sugar palm with variation of polymer matrices such as thermoset unsaturated polyester [16], no other works shows that combination between sugar palm and glass fiber reinforced thermoplastic polyurethane has been reported. In this work, sugar palm and glass fibers were chosen to layer the hybrid composite by melt compounding shows remarkable effect from this hybridization. Hence, a number of essentials testing methods from tensile, flexural and impact properties were studied in this hybrid composite. The influence of hybrid ratio and post tensile testing were investigated and the hybrid mechanisms were revealed with the aid of the scanning electronic microscopy (SEM) observations.

2. Experimental

2.1. Materials

Estane® 58311 TPU was supplied in pellet form with density of 1.13 g/cm3 by Pultrusion Sdn. Bhd. and was used as the polymer matrix. The sugar palm fiber (SPF) was collected from sugar palm tree at Jempol, Negeri Sembilan, Malaysia. The properties of sugar palm and glass fiber are shown in Table 1.
2.2. Preparation of sugar palm

Firstly, sugar palm fiber was first washed with tap water for several times to get rid of any impurities and unnecessary things that attached to the SPF. The SPF was kept in an open air for 24 h and dried in an air circulating oven at 60 °C for 48 h. The dry SPF ground to get size of 10–15 mm using plastic crusher machine then followed by using pulverize machine then the particle SPF were sieved to obtain 125–250 μm.

2.3. Fabrication of hybrid SP/G reinforced TPU composites

The SP/G composite hybrids were prepared using melt compounding technique followed by hot pressing molding process. Sugar palm particles size 125–250 μm, chopped E-glass fiber size 12.5 mm and thermoplastic polyurethanes in pellet form were dried in an electric oven at 80 °C for 48 h. Five sets of SP/G/TPU composites (30/10, 20/20, 10/30 and 0/40) wt.% of sugar palm particles reinforced thermoplastic polyurethane were fabricated as seen in Table 2. The SP/G hybrid composites were prepared using blending, followed by hot pressing molding process to achieve uniform distribution. Haake polydrive R600 was used in the mixing process at the optimum processing parameters 190 °C, 11 min and 40 rpm, temperature, time and rotating speed; respectively [21]. Vechno Vation 40 ton compression molding machine was used in the compression molding. The samples were pre-heated for 7 min at 190 °C. Then they were full pressed for 10 min at 190 °C. Finally, they were cold-pressed for 5 min at 25 °C.

3. Characterizations

3.1. Physical property of sugar palm reinforced TPU hybrid composites

Density, thickness swelling (TS) and water absorption (WA) of the composites were evaluated according to ASTM D4018, ASTM D570, respectively. The developed hybrid composites of SP/G were weighed in air using digital weighing scale and in water using densimeter, MD-200S Mirage.

The thickness and weight of the composite specimens were recorded for tests. 10 replicates of composite specimens with the dimension of 20 mm × 20 mm × 3 mm were immersed in distilled water with the room temperature 25 °C. The data of TS and WA were recorded after 72 h, 120 h and 168 h of water immersion period.

3.2. Tensile test

The tensile test was performed on flat dog-bone shaped sample as per ASTM D618 [22] test standards using a universal testing machine, LLYOLD Instruments. The specimen was tested by a calibrated universal testing machine with a speed of 50 mm/min. All the tests were performed for six samples and average of six samples was taken as a final result.

3.3. Flexural test

Flexural properties of developed SP-G/TPU hybrid composites were performed according to ASTM D790-03 [22] (3 point bending) standard. The testing was executed using LLYOLD (AMETEC) universal testing machine with 60 mm span length and 12 mm/min crosshead speed.

3.4. Impact test

Standard notched Izod impact test specimens were cut out from the developed SPF/TPU hybrid composites plates using abrasive water-jet machine (Excel WJ 4080) according to ASTM D256 [22]. Averages of the five samples were taken to present the final impact strength on SP-G/TPU hybrid composites.

3.5. Scanning electron microscopy (SEM)

Morphological investigations were performed on the SP-G/TPU hybrid composites with SEM machine Model (HITACHI S-3400N). SEM instrument was used at an emission current of 58 μA and acceleration voltage of 5.0 kV, and the working distance was set to 6.2 mm. Before the SEM analysis, samples were coated with gold.

4. Results and discussion

4.1. Density

The value of density measurements of sugar palm/glass fiber reinforced thermoplastic polyurethane hybrid composites is shown in Fig. 1, subjected to different fiber loading of (30/10, 20/20, 10/30 and 40/0) SP/G by weight fractions. The results for density showed that with the addition of glass fiber to SP/TPU composites, the density increased. In this case, the glass/TPU (0/40 SP/G) composites exhibited the highest density as compared to other formulation of SP/G hybrid composites. Similar work done on natural fiber/glass hybrid composites increases with an increase in glass fiber loading to jute composites [23]. This result is mainly attributed to a higher density of glass fiber to sugar palm fibers.
Fig. 1 – Density of SP/G reinforced TPU hybrid composites.

4.2. Thickness swelling

Fig. 2 shows TS values obtained after 72, 120 and 168 h after immersion tests. For the long term immersion, the 30/10 SP/G hybrid composites had the highest TS value of 7.5% as compared to other composites. Though, 0/40 SP/G composites exhibited the lowest TS value of 4.8% after 168 h respectively. It was clearly shown that the lower TS value is belongs to higher content of glass fiber reinforced TPU composites. In the case of hybridization of SP/G, the 10/30 SP/G showing the lower TS followed by 20/20 SP/G and 30/10 SP/G composites. It is apparent proposed that by substituting more glass fiber thus will reduce the swelling properties, though it might be reduced the content of sugar palm fiber in the hybrid formulation.

4.3. Water absorption

The values of WA of SP/G reinforced TPU hybrid composites as depicted in Fig. 3 show that the higher content of sugar palm fiber (30/10 SP/G) yielding the higher WA values. Among the sugar palm/glass fiber hybrid composites, 10/30 SP/G composites had the lowest WA values of 5.03%, which demonstrates 8% reduction in WA compared to 20/10 SP/G composites. However the glass reinforced TPU composites (0/40 SP/G) exhibited the lowest WA than other SP/G/TPU composites. The addition of glass fiber to the SP/TPU composites yields a positive effect on reducing the water uptake of the specimens. It can be assumed that the higher fiber loading of natural fibers, the higher water uptake, while the higher fiber loading of glass fiber resulting the lower moisture and water absorbed by the hybrid composites. This finding was also in line from previous work done by Kushwaha and Kumar [24] who figured out the water resistance properties increased when addition of glass fiber by the epoxy and polyester/bamboo composites.

Fig. 2 – Thickness swelling of SP/G reinforced TPU hybrid composites.

Fig. 3 – Water absorption of SP/G reinforced TPU hybrid composites.
4.4. Tensile properties

Different types of hybrid composites were prepared as sugar palm/glass fiber reinforced thermoplastic polyurethanes. Different weight percentages of sugar palm/glass fiber were used in hybrid composites. The total fiber content (sugar palm and glass) of the composites was fixed at 40 wt.% while TPU matrix at 60 wt.%. The tensile properties are displayed in Fig. 4. It was shown that tensile strength of SP/G reinforced TPU hybrid composites is enhanced by the addition of sugar palm. Nevertheless, by adding of 10 wt.% glass fiber to sugar palm TPU composites increase the tensile modulus by about 20% as compared to the single glass fiber (0/40 SP/G) reinforced TPU composites. The attributes of hybrid composites are dependent on the properties of reinforcement. The tensile strength of glass fiber is higher than sugar palm fiber as in Table 1 leads to the extensibility of glass fiber than those of sugar palm fiber. According to Phillips [25], at normal strain, the lower tensile strength of pineapple fibers fails first although they are strongly adherence to and bounded to glass fiber reinforced matrix. Even though, the both fiber are short and discontinuous, they remain to carry on the same load and contribute to stiffness. The enhancement in tensile strength at lower fiber loading of glass fiber (10/30 SP/G) can be correlated due to fact that these fiber content of glass fiber can efficiently transfer load from the pineapple leaf fiber. AlMaadeed et al. [18] demonstrated the mechanical properties of date palm wood flour reinforced recycled polypropylene and analyzed that tensile strength was improved by substituting chopped E-glass fiber. The findings of Akil et al. [26] investigated that tensile strength of the polyester/jute fiber composites increased with increasing glass fiber content. Jayabal et al. [12] carried out the study of mechanical properties woven coir/glass fiber reinforced polyester composites improves by adding of glass fibers.

The tensile modulus of hybrid sugar palm/glass fiber reinforced TPU composites, as shown in Fig. 4 proportionally increased with glass fiber loading until 40 wt.%. As can be seen, the tensile modulus is affected by sugar palm and glass fiber content. The tensile modulus of hybrid SP/G reinforced TPU composites increased with increase of glass fiber content at the different content of sugar palm fiber. When comparing tensile strength and modulus of SP/G reinforced TPU, the tensile modulus is more increased by adding of glass fiber. The reason why glass fiber in the hybrid SP/G/TPU composites (Fig. 4) might be that the adhesion between sugar palm and TPU is well attached to improve the modulus which is evaluated at low fiber content in the linear elastic region but tends to break at higher fiber content approximate to ultimate tensile strength of the TPU matrix. The results show that the ratio of sugar palm/glass fibers in the hybrid composites with the addition of glass fiber content has a negligible effect on tensile strength due to a limited interaction between TPU and glass fibers. This finding agrees with Ghasemzadeh-Barvarz et al. [27] who found that by adding only 10 vol.% of glass fiber leads to 27% increase in tensile properties of flax–glass reinforced polypropylene composites.

Fig. 4 gives the tensile stress–strain curves for 30/10, 20/20, 10/30, 0/40 wt.% SP/G during tensile test. The figure pointed out that the higher content of sugar palm fiber at 30 wt.% and lowest content at 10 wt.% of glass fiber resulted in improvement in the tensile stress and strain as compared with 20/20, 10/30 and 0/40 wt.%. This is evident from the micro-graph of a fractured specimen in Fig. 9(a) which shows a large size sugar palm particle in the TPU matrix. The more sugar palm fiber cracking act as barrier is presumed to have occurred during tensile fracture. This process of improving tensile strength with higher sugar palm content is true particularly at lower glass fiber loading. The average tensile stress of five replicates specimens of 30/10 SP/G reinforced TPU composites was found to be 21.15 MPa with tensile strain 18.31 mm/min. Tensile properties of 30/10 SP/G results in an improvement of 13% stress and 123% strain as compared with to the tune of respectively as compared the single glass fiber reinforced TPU (0/40 SP/G). It was found that adding of sugar palm in glass fiber composites resulted in an improvement in strain for 12.73 mm/min (20/20 SP/G) and 11.13 mm/min (10/30 SP/G) as compared to 8.21 mm/min (0/40 SP/G). It was noticed in this study that the by adding 30 wt.% of sugar palm fiber the higher tensile strength, modulus and the elongation break of the hybrid composite was observed. Previous studies reported the same trend [28].

In hybrid composites, the tensile properties of the composites are mostly dependent on the percentage of elongation at break and modulus of the single fibers [29]. The variation of elongation at break with both sugar palm and glass fiber loading are given in Fig. 6.
The result of elongation breaks displays an improvement with higher content of sugar palm fiber in hybrid composites while an inverse trend is noticed as the glass fiber content increased in the composites. In substituting of sugar palm fiber loading, the hybrid composites show a decreasing trend in elongation at break of composites. The incorporation of 30 wt.% of sugar palm reveals the highest value of elongation at break of composites is 3.90 mm, while composites with 40 wt.% of glass fiber (0/40 SP/G) are discovered to have the lowest value which is 1.00 mm of these properties. The reason is due to the fact that glass fiber has a low elongation fiber compared to the sugar palm fiber [30]. Thus, incorporation the sugar palm fiber with glass fiber has a high strain to failure properties compared to the low extensibility of glass fiber as seen in Fig. 6. In this case, glass fiber has low elongation will fail first while the sugar palm fiber is able to withstand the applied stress by load [29].

4.5. Flexural properties

Fig. 7 shows the variation of fiber loading of (0/40, 10/30, 20/20 and 30/10) by wt.% SP/G for the flexural strength and modulus of the composites. From the curve, it is evident that flexural strength and flexural modulus of hybrid composites increased with increase in glass fiber weight percentage. According to Mishra et al. [31] in flexural testing, various mechanisms such as compression, tension, and shearing happen promptly, by adding of glass fiber content the shearing resistance of hybrid
The flexural strength of the GF reinforced TPU is found to be 31.09 MPa whereas the maximum flexural strength of hybrid 10/30 SP/G is found to be and 24.48 MPa followed by 20/20 SP/G (17.67 MPa) and 30/10 SP/G (17.24 MPa). This finding is in agreement with Velmurugan and Manikandan [32] that of which attributed the increase in the flexural strength of palm/myra/glass composites to the great fiber-matrix adhesion between palm/myra/glass fiber to the resin matrix.

The variation of flexural modulus of various SP/G fiber loading is shown in Fig. 7. The flexural modulus of the single glass fiber reinforced TPU composites is found to be the optimum at 509.70 MPa (0/40 SP/G), followed by 394.01 MPa (10/30 SP/G), 279.03 MPa (20/20 SP/G) and 266.69 MPa (30/10 SP/G). Bachtiar et al. [33] suggested similar results that flexural properties jute–glass fiber reinforced epoxy resin composites showed an increased flexural strength and modulus from 0 to 40 wt.% of glass fiber loading as compared with the glass/epoxy composites.

In literature only a few examples of comparable hybrid sugar palm/glass by using melt compounding can be tracked down. For instance, sugar palm/glass hybrid reinforced unsaturated polyester composites studied by Sapuan et al. [17], manufactured by compression molding technique from strand mat glass and sugar palm fiber, did show, in spite of the slightly higher amount of glass fibers, a flexural performance higher than sugar palm/unsaturated polyester comparing flexural properties of kenaf/unsaturated polyester and glass/unsaturated polyester produced by sheet molding compound indicated a much lower difference being the region of 18% flexural modulus as compared the glass/unsaturated polyester composite [3].

4.6. Impact properties

Impact resistance of composites is to determine the total energy dissipated in the material before final failure occurs [34]. The variation of the impact strength versus sugar palm–glass fiber content in TPU composites is shown in Fig. 8.

Regarding the curve graph, the impact strength was affected by sugar palm and glass fiber content. Incorporation of glass fiber in the SP/TPU composites gives the variation in impact strength of the hybrid composites. The higher impact energy is with the single fiber content of TPU composites show lower than 20/20 wt.% SP/G. As sugar palm increase from 10 to 30 wt.%, the impact strength starts to increase. Similarly, Mridha et al. [15] found that the impact strength of oil palm wood flour (OPWT) particles with less than 250 μm sizes have been used as filler materials in the woven-glass-fiber reinforced epoxy composites increased with increasing oil palm hybrid volume fraction.
Fig. 8 – Impact properties of SP/G fiber reinforced TPU hybrid composites.

Fig. 9 – SEM micrograph of cracks developed in the (a) 30/10 SP/G, (b) 20/20 SP/G, (c) 10/30 SP/G and (d) 0/40 SP/G (300× magnification).

The evidence presented in impact properties as in Fig. 8 suggests that the higher impact strength in sugar palm fiber containing over 10 wt.% may be that the fiber content is effective above this range to influence the impact property of the hybrid natural-synthetic fiber composites. Furthermore, it is to be noted that 30/10 SP/G have higher amount of sugar palm fiber loading have larger particles in size which mostly appear in the hybrid composites. The sugar palm particles assumed to acts as barrier in the thermoplastic polyurethane and that enhances the deformability especially at higher content.
Uma Devi et al. [34] have found that hybridization of short pineapple leaf fiber with glass fibers resulted in polyester composites having higher impact resistance than the neat glass/polyester composites. Moreover, Uawongsuwan et al. [28] have found that hybridization of long jute fiber/glass fiber-reinforced polypropylene composite with small amount of 10 wt.% of glass fiber at the impact strength has increased by more than 948%. The value is higher than jute fiber/PP composites. The increase in impact strength can be related to an improved stress capability and thus to a limited contribution of fiber-related mechanism such as fiber pull out.

4.7. Scanning electron microscopy (SEM)

The scanning of electron microscopy of fractures surfaces of the tensile specimen of 30/10, 20/20, 10/30 and 40/0 wt.% of SP/G reinforced TPU composites is shown in Fig. 9. High sample fiber loading of sugar palm is observed in Fig. 9(a) showing a quite strong adhesion between the sugar palm and glass fiber to TPU Matrix. This might be due to strong bonding between TPU matrix and glass fibers are the reasons for enhanced in tensile strength (Fig. 4).

The figure also indicates more fiber fracture and pull out from the specimen and also the dislocation of fibers. Moreover, the SEM morphology of the hybrid SP/G consists of two types behavior are observed in Fig. 9(a), (b) and (c) is the surface of hybrid composites due to tensile load. From Fig. 9(b) and (c) more glass fiber stretching and another sugar palm fiber breakage and pull out at the middle by any stretching.

Fig. 9(d) shows 40 wt.% of GF loading (0/40 SP/G) reinforced TPU composites. For brittle nature of glass fiber is noticed from the fractured mode in Fig. 9(d). An increase of tensile strength (Fig. 4) of the hybrid composite with 10–30 wt.% of SP/G compared with the individual composite (0/40 SP/G) is due to the good dispersion and increase in physical adhesion between the SP/G fiber and the TPU matrix in the hybrid composite. This similar observation was same with Gujijala, Ojha, Acharya and Pal [35] who studied the woven jute-glass fiber reinforced polyester using hand lay-up technique.

5. Conclusions

The physical and mechanical properties of hybrid SP/G reinforced TPU composites have been investigated. It was found that, the density, thickness swelling and water absorption increased as the fiber loading of natural fiber increased. The higher content of sugar palm in hybrid composite was 30/10 SP/G resulted the increased density, TS and WA values of respectively. The substitution of glass fiber with 30 wt.% (10/30 SP/G) decreased the density, TS and WA. It was observed that the incorporation of both sugar palm and glass fiber into TPU matrix has resulted in an increase of tensile and impact strength with increase in sugar palm fiber loading. The maximum tensile strength and modulus is observed for the hybrid composite is 30/10 SP/G. The higher content of sugar palm in hybrid SP/G reinforced TPU improved in tensile stress and strain and has higher elongation at break as compared to 0/40 SP/G reinforced TPU composites. Nevertheless, incorporation of 10 wt.% (10/30 SP/G) showed the maximum value of flexural and strength after glass fiber composites (0/40 SP/G). The hybrid composites (0/40 SP/G) have higher impact strength than the composites based on glass fiber composites. Thus, it is important to combine sugar palm and glass fiber to produce hybrid thermoplastic composites of outstanding mechanical performance.

Conflicts of interest

The author declares no conflicts of interest.

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