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MECHANICAL PROPERTIES OF HYBRID GLASS/SUGAR PALM FIBRE REINFORCED UNSATURATED POLYESTER COMPOSITES

S.M. Sapuan[a, d, e*], H.Y. Lok[b], M.R. Ishak[c, e] and S. Misri[a]

[a] *Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

[b] *Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, 75450 Bukit Beruang, Melaka, Malaysia*

[c] *Department of Aerospace Engineering,Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

[d] *Institute of Advanced Technology (ITMA), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

[e] *Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

Abstract A research has been carried out to investigate the mechanical properties of composites made by hybridizing sugar palm fibre (Arenga pinnata) with glass fibre into an unsaturated polyester matrix. Hybrid composites of glass/sugar palm fibre were fabricated in different weight ratios of strand mat glass fibres : sugar palm fibres 4:0, 4:1, 4:2, 4:3, 4:4, and 0:4. The hybrid effects of glass and sugar palm fibre on tensile, flexural and impact properties of the composites were evaluated according to ASTM D5083, ASTM D790 and ASTM D256 respectively. Results have been established that properties of hybrid glass/sugar palm composites such as tensile strength, tensile modulus, elongation at break, toughness, flexural strength, flexural modulus and impact strength are a function of fibre content. The failure mechanism and the adhesion between fibres/matrix were studied by observing the scanning electron micrographs of impact fracture samples. In general, the incorporation of both fibres into unsaturated polyester matrix shows a regular trend of increase in the mechanical properties.

Keywords: Tensile test; Flexural test; Impact test; Hybrid composite; Sugar palm fibre.

INTRODUCTION

Recently there has been a rapid increment of shifting the synthetic fibres such as carbon, glass and aramid to natural fibres in the field of composites. This took place to be in line with the increasing environmental consciousness and awareness for the need for sustainable development[1]. Natural fibres were claimed to offer various advantages such as low density, low price and low abrasive wear of processing machinery that attracted interest of many researchers[2–7]. The natural fibres have the potential to provide a high strength over weight ratio material. These advantages are the reasons why natural fibres have become popular alternatives to synthetic fibres in many industries such as automotive, construction and furniture industries. In building and construction industries for instance, designers have used natural fibre composites in important applications such as panels, ceilings and partition boards. Knowing that the natural fibres suffer from low modulus, low strength properties, low impact strength, poor fire resistance, poor moisture resistance and limited durability, products from these composites were restricted to the components that were not exposed to strong mechanical impacts; in contrast to synthetic fibre composites they were found in a wide range of high performance applications. In the interest of

* Corresponding authors: S.M. Sapuan, E-mail: sapuan@eng.upm.edu.my
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solving these weaknesses, natural fibres can be combined with a stronger and a more corrosion-resistant synthetic fibres such as glass fibre in the same matrix to produce hybrid composites that take full advantage of the best properties of the constituents, and thereby an optimal, superior but economical composites can be obtained. It has been reported that the hybridizing of glass fibre with sisal[8, 9], bamboo[10, 11], coir[12, 13], oil palm[14–16] and banana[17] fibres in thermoplastic and thermoset matrices has drastically improved the mechanical, thermal, moisture absorption and weathering properties of the natural fibre composites. Details study on the effect of hybridization of short and long fibres from different fibres, particles and polymers are reported in many studies[18–23]. The current research is an attempt to investigate the tensile, flexural and impact properties of the sugar palm and glass fibre hybrid reinforced thermosetting matrix; *i.e.* unsaturated polyester composites.

EXPERIMENTAL

Materials

Sugar palm fibre with the density of 1.29 g/cm^3[24, 25] was obtained from Kampung Kuala Jempol, Negeri Sembilan, Malaysia. In this research, the used strand mat E-glass fibre with density of 2.55 g/cm^3[24], unsaturated polyester with density of 1.28 g/cm^3 as resin for reinforced composites and catalyst, MEKP (methyl ethyl ketone peroxide) for curing were supplied by Pultrution Innovative Sdn. Bhd., Seremban, Negeri Sembilan, Malaysia. Table 1 lists the mechanical and physical properties of sugar palm fibre, E-glass fibre and unsaturated polyester.

Table 1. The mechanical and physical properties of sugar palm, E-glass fibre and unsaturated polyester[18]

Properties	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation at break (%)	Diameter (μm)
Sugar palm	190.29	3.69	19.6	99–311
E-glass	1800–3000	72.83	3	8–14
Unsaturated polyester	40–90	2–4.5	2	–

Fabrication of Composites

This fabrication of composites involved six samples with different weight ratios of glass/sugar palm fibres; 4:0, 4:1, 4:2, 4:3, 4:4, and 0:4. The strand mat glass fibre was cut into a dimension of 300 mm × 300 mm to fit the mould. The collected sugar palm fibre was air dried for 24 h and cut into 50.8 mm (2 in) long. These sugar palm fibres were arranged into a mat with random orientation according to weight shown in Table 2.

Table 2. Fibre content of glass/sugar palm fibre composites

Weight ratio of glass/sugar palm fibre	0:4	4:0	4:1	4:2	4:3	4:4
Fibre loading (%)	12.2	19.7	21.14	26.5	31.6	36.5
Weight of glass/sugar palm fibre (g)	0/80	80/0	80/10	80/20	80/30	80/40

Hand lay-up method was used for composite preparation of glass fibre-reinforced composites. While glass/sugar palm fibre hybrid composite and sugar palm fibre composite were prepared by using hand lay-up method followed by compression moulding. The purpose of the compression process for these samples is to obtain constant pressure distribution on the composite. Compression process was done by using the mechanical hydraulic press with the pressure of 0.08 MPa.

Method of Result Analysis

Standard error was used to show the significant difference between the variables (Table 3). It is obtained by dividing the standard deviation of set of sample to the size (n) (number of observations) of the sample.

Mechanical Testing

Tensile test was performed according to ASTM D5083 using UTM type Instron 3366 with load capacity of 10 kN. A minimum of five samples was tested and an average value was taken for investigation. The data such as tensile strength, tensile modulus and elongation at break were obtained from the raw data of the test.

Table 3. Standard error analysis for tensile, flexural and impact properties

G/SP ratio	Standard error					
	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (GPa)	Impact strength (kJ/m^2)
0.4	3.72	0.79	0.09	1.71	0.17	0.10
4.0	9.02	0.68	0.079	4.35	0.18	0.19
4.1	1.04	0.28	0.06	2.71	0.19	0.14
4.2	1.23	0.20	0.07	7.70	0.19	0.19
4.3	2.14	0.49	0.08	3.63	0.18	0.15
4.4	0.58	0.51	0.85	2.12	1.07	0.21

Flexural testing was conducted based on ASTM D790 using UTM type Instron 3365 with load capacity of 5 kN. Based on the information shown in the standard test, the span length of the specimen is 16 times of its thickness. A minimum of five samples was tested and an average value was recorded.

Impact test was performed according to ASTM D256 by using the TMI Impact Tester. Impact energy was obtained by then and the impact strength was calculated by dividing the recorded impact energy by the cross sectional area of the particular specimen. A minimum of five samples was tested and an average value was taken.

Morphological Observation

For morphological study, scanning electron microscope (SEM) was used to observe the shapes of fibres, fracture surfaces as well as some information concerning the bonding between the fibres and matrix.

RESULTS AND DISCUSSION

Tensile Properties

Tensile test measures the force required to break a reinforced thermoset plastic specimen and the extent to which the specimen stretches or elongates to its breaking point. Tensile strength, tensile modulus, and elongation at break were recorded and calculated from the raw data obtained from the test result. These data are often used to specify a material, to design parts to withstand application force and as a quality control check of materials. Typical stress-strain curves of glass/sugar palm fibre composites at varying weight ratios are shown in Fig. 1.

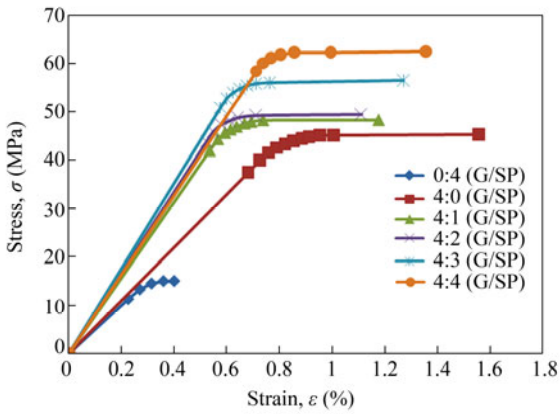

Fig. 1 Stress strain curves of glass/sugar palm fibre composites at different weight ratios

Generally, the stress strain behavior of these samples is non-linear. It is found that the stress strain curve of sugar palm fibre composite (weight ratio of glass/sugar palm fibre, 0:4) is similar to that of brittle material where the specimen fails at low strain. This is possible due to the weak interfacial shear strength of sugar palm fibre with the unsaturated polyester matrix which results in the easy pull out of sugar palm fibre from the unsaturated polyester resin. The glass fibre reinforced composite (weight ratio of glass/sugar palm, 4:0) indicates a better adhesion between the glass fibres and polyester matrix. However, it is interesting to note that the incorporation of glass fibre into the sugar palm fibre composites makes the composite ductile. This is evident from the high elongation at break value of hybrid composites (weight ratio of glass/sugar palm fibre; 4:1, 4:2, 4:3, 4:4) as compared to sugar palm fibre composite.

Figure 2 shows the tensile strength of glass/sugar palm hybrid composites as a function of weight ratios. As observed from the graph, the tensile strength of the sugar palm fibre composite, which is 14.80 MPa, is very much inferior as compared to the glass fibre reinforced composite which carry the tensile strength of 44.81 MPa. This is possibly due to the nature of sugar palm fibres, which are irregular in diameter[26] as shown in Fig. 3.

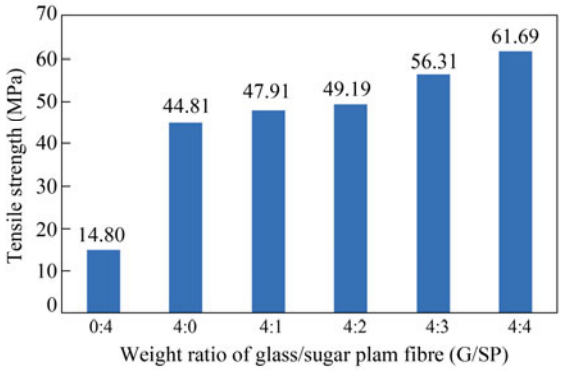

Fig. 2 Tensile strength of glass/sugar palm fibre composites at different weight ratios

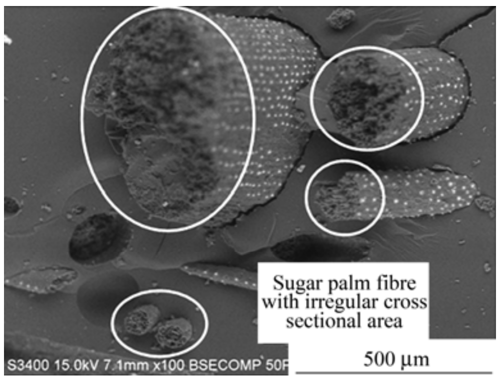

Fig. 3 SEM micrograph of sugar palm fibre composite

Besides, sugar palm fibres also exist in the form of fibre bundles. Oksman *et al*.[27] stated that the individual fibres are not loaded uniformly as some individual fibres are even not loaded at all due to the non-homogenous load distribution in fibre bundles. Furthermore, sugar palm fibres happen to be in different orientation whereby the orientation of fibres are not uniformly in only one direction. Therefore, the sugar palm fibres are not able to support the stress transferred from the polyester matrix successfully resulting in the failure of sugar palm fibre composites at a lower load as compared to the glass fibre reinforced composite. However, the tensile strength increased significantly as seen from the graph in Fig. 2 with the incorporation of glass fibres into the sugar palm fibre composite. A similar trend was reported by Kalaprasad *et al*.[9, 28], Mishra[13], and Pavithran *et al*.[8] with the addition of glass fibre into a natural fibre composite. In general, an increase in the tensile strength of hybrid composites was observed with an increase in weight of glass/sugar palm fibre in hybrid composite. In this case, the increase in the strength of the hybrid composites is mainly governed by the additional content of sugar palm fibre into the fixed weight of glass fibre. Furthermore, the fibre loading in these hybrid composites plays an important role in the increment of tensile strength. In the current research, the fibre weight loading is varied from

19.7% to 33.5%. Note that there must be an increment on the fibre loading to achieve the maximum strength in the hybrid composite. These factors were supported by the previous researches which stated that the properties of hybrid composites were mainly dependent on the fibre content, fibre length, fibre orientation, arrangement of individual fibres, extent of intermingling of the fibres and also the fibre matrix adhesion[8, 29]. Similar behavior is observed in Fig. 4, the variation of tensile modulus with different weight ratios of fibres.

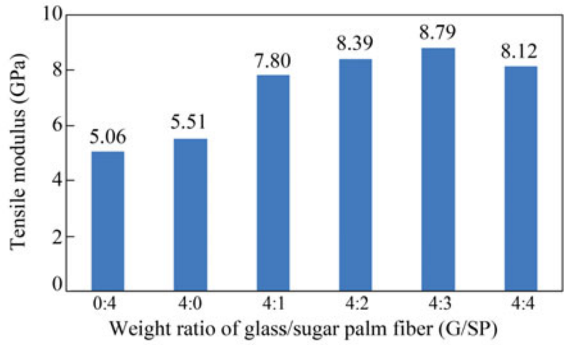

Fig. 4 Tensile modulus of glass/sugar palm fibre composites at different weight ratios

This figure clearly shows that the tensile modulus of hybrid composites is significantly improved with the increment of the fibre loading and sugar palm fibre in a fixed amount of glass fibre. The enhancement in the stiffness of these composites is attributed to the higher modulus of glass fibre (72.83 GPa) than that of the sugar palm fibre (3.69 GPa). However, a further increase in fibre content up to 80/80 of glass/sugar palm fibre by weight gives a slightly decrement in the tensile modulus. This result might be caused by the increment of interaction between the fibre bundles of sugar palm resulting in the failure of uniform stress transferred.

Figure 5 shows the variation of elongation at break of the focused hybrid composites. It is observed that the elongation at break of sugar palm fibre composite is drastically lower than that of the glass fibre-reinforced composite. As the sugar palm fibres owned a higher value of elongation at break (19.6%)[18] than the glass fibres (3%)[18], one would expect the sugar palm fibre composite to have a higher elongation at break than the glass fibre reinforced composite. However, owing to the low strength nature of the sugar palm fibre and its low adhesion with the matrix, the sugar palm fibres are not able to withstand the load transferred from the polyester matrix. Therefore, the sugar palm fibre composite (matrix rupture) fails even before reaching its actual extensible strain. Referring to the graph, the composites exhibited a higher value of elongation at break with the hybridization of glass into sugar palm fibres as compared to the composite reinforced by sugar palm fibre alone. Many studies have proven that the hybridization of natural fibres with synthetic fibres may post a positive effect of elongation at break[14, 29–32]. Zweden[29] then concluded that the incorporation of lower elongation fibres with high elongation fibres in a hybrid composite often increased the elongation at break of the composite than the composite made from low elongation fibres. Since these hybrid composites were made of glass-sugar palm-glass, 3 layers hybrid composite, therefore, a load sharing mechanism is expected in between the glass fibre plies and the sugar palm fibre ply. This is due to the ability of the failed glass fibre plies to continue to carry the load while re-distributing the remaining load to the sugar palm fibre ply. Thus, the composite does not fail at low strain and are able to reach its actual extensible strain successfully with the additional glass fibres. As the percentage weight of the sugar palm fibre increase, they are able to withstand a higher applied load. However, the hybrid composite with weight ratio of glass/sugar palm fibre of 4:2 has a slightly lower elongation at break value as compared to the ratio of 4:1. The elongation at break values for the rest of the hybrid composites increase with the increment of the fibre loading. The load sharing mechanism between sugar palm fibres and glass fibres as well as the synergistic effect between both fibres enhance the elongation at break of the hybrid composites.

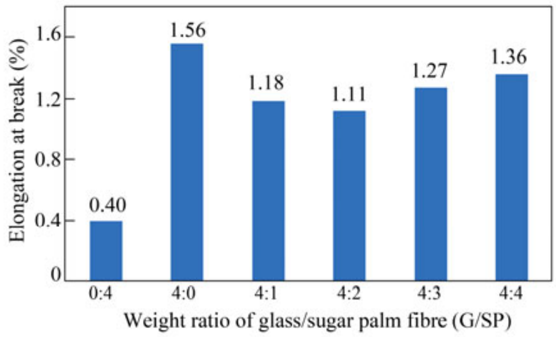

Fig. 5 Elongation at break of glass/sugar palm fibre composites at different weight ratios

The toughness of the tested composites was calculated from the area under the graph of stress strain curves, and the results are shown in Fig. 6. Figure 6 shows that the sugar palm fibre composite has the lowest toughness which is of 0.037 MJ/m^3 as compared to the toughness of glass fibre reinforced composite of 0.515 MJ/m^3. Sugar palm fibre composite itself is very low in the value of toughness while glass fibre reinforced composite is tough. The hybridization of sugar palm and glass fibres makes the composites have the higher value of toughness as compared to sugar palm fibre composite itself. The toughness of these hybrid composites are lower than the toughness of glass fibre reinforced composite until the sugar palm/glass fibre ratio reaches 4:3 and 4:4. The graph shows the similar pattern as the graph of elongation at break (Fig. 5). The toughness of hybrid composites increase with the increment of fibre loading. However, toughness values of hybrid composites at glass/sugar palm ratio of 4:1 and 4:2 have slight difference. It is believed that the value of toughness is highly influenced by the interfacial bonding strength, the matrix and also fibre properties. As the fibre loading increases, the increasing population of fibre is able to adhere with the matrix and gives a tougher strength to the composite before it break.

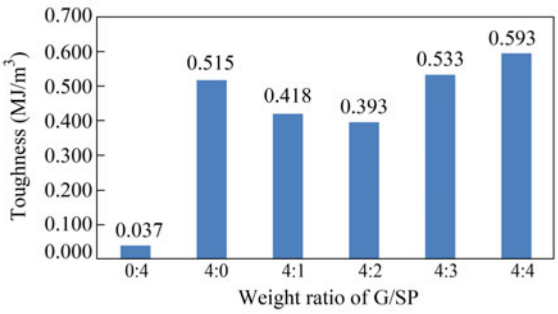

Fig. 6 Toughness of glass/sugar palm fibre composites at different weight ratios

Flexural Properties

The flexural test measures the force required to bend a beam under three point loading conditions. The specimen fails when bending or shear stress reaches the corresponding critical value. Flexural strength and modulus were indicated from the raw data of the experiment. These data are often used to select materials for parts that will support without flexing, and the flexural modulus is used as indication of a material's stiffness under flexing. Flexural strength and modulus of the glass/sugar palm hybrid composites are given in Figs. 7 and 8.

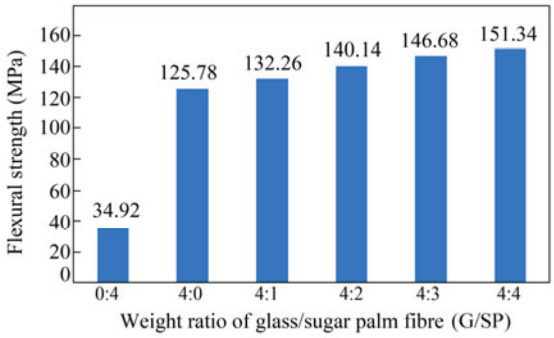

Fig. 7 Flexural strength of glass/sugar palm fibre composites at different weight ratios

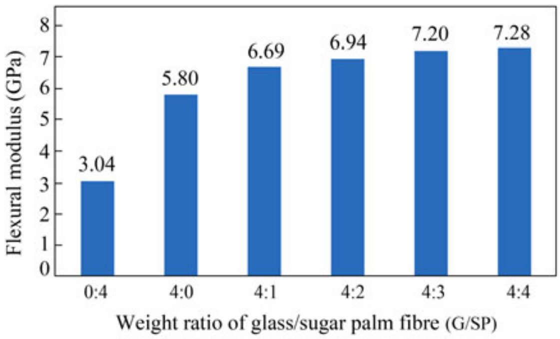

Fig. 8 Flexural modulus of glass/sugar palm fibre composites at different weight ratios

As observed from the graph, the flexural strength of the sugar palm fibre composite, which is about 34.92 MPa, is very much inferior than the glass fibre reinforced composite which has the flexural strength of about 125.78 MPa. This is mainly due to the low mechanical properties of sugar palm fibre as fibre reinforcement. Therefore, the sugar palm fibres are not able to support the stress transferred from the polyester matrix successfully. With this, the sugar palm fibre composite fails at a lower load as compared to the glass fibre reinforced composite. Whereas the high flexural strength of glass fibre reinforced composite is due to the inherent property of glass fibre itself.

However, with the addition of glass fibres into the sugar palm fibre composite, the flexural strength increased significantly as seen in Fig. 7. A similar trend was reported by Kalaprasad *et al*.[9, 28], Mishra[13] and Pavithran *et al*.[8] with the addition of glass fibre into a natural fibre composite. Showing in this research, an increase in the fibre loading produces a corresponding increase in the flexural strength and modulus values of the hybrid composites. The flexural properties show good enhancement with increasing fibre loading due to the fact that the composites are able to withstand more loads when the population of the fibres in composites increased. As depicted in Figs. 7 and 8, it is also observed that the flexural strength and modulus of the hybrid composites have similar trends as the tensile properties where the flexural behavior increases with the weight ratio of glass/sugar palm fibres. The highest flexural properties are observed in hybrid composites with weight ratio of glass/sugar palm fibre of 4:4 and fibre loading of 33.5%. This might due to the fibres which are present in optimum amount that can provide the effective stress transfer between the fibre and the matrix and also due to the inherent property of glass fibre. These flexural strength and modulus of glass/sugar palm hybrid composites are comparable to glass fibre reinforced composite.

Impact Property

Impact properties are used to describe the general toughness of materials. Impact energy can overall be dissociated into three pools of energy, the stored energy, the absorbed energy and the dissipated energy. Figure 9 shows the effect of fibre loading on the impact strength of the hybrid composites.

The impact properties of composite materials are directly related to its overall toughness which is highly influenced by the interfacial bond strength, the matrix and also fibre properties[33–35]. Based on the graph in Fig. 9, it is noted that the sugar palm fibre composite has the lowest impact strength, 0.63 kJ/m^2, and the impact strength of glass fibre reinforced composite is 3.82 kJ/m^2. Fibre pullout would be expected in the composite as the interfacial bonding between the sugar palm fibres and the polyester matrix is weak. However, the fracture of the sugar palm fibres at the crack plane without fibre pullout in this case is due to the fact that the sudden stress transferred from the matrix to the fibre exceeds the fibre strength as the sugar palm fibres were impacted at high speed. This was supported by the previous studies which concluded that the impact properties of a fibre reinforced composite were affected by the nature of the constituent materials, interface properties, construction and geometry of the composite as well as the test conditions[36]. Whereas the glass fibres are capable of absorbing high impact energy and are also resistant to propagation of micro cracks[12, 36]. As a result, the glass fibre composite exhibited higher impact strength than the sugar palm fibre composite.

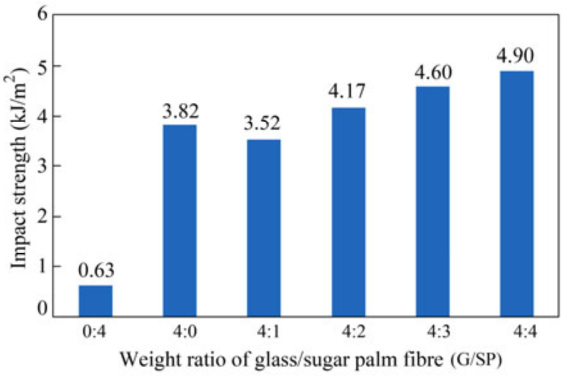

Fig. 9 Impact strength of glass/sugar palm fibre composites at different weight ratios

In general, the hybridization of glass/sugar palm fibre composite increased the impact strength of the hybrid composites significantly as shown in the graph in Fig. 9. The impact energy is dissipated by debonding, fibre fracture, fibre pull out and matrix fracture as shown in Fig. 10. Fibres pull out plays an important role in the energy dissipation mechanism in fibre-reinforced composites. In the case of hybridization of glass/sugar palm fibres, the sudden stress transferred from the matrix to the fibre exceeds the fibre strength when the composite is subjected to an impact at high speed. Debonding might occurs when the shear transferred to fibres may exceed the interfacial bond strength between fibre and matrix.

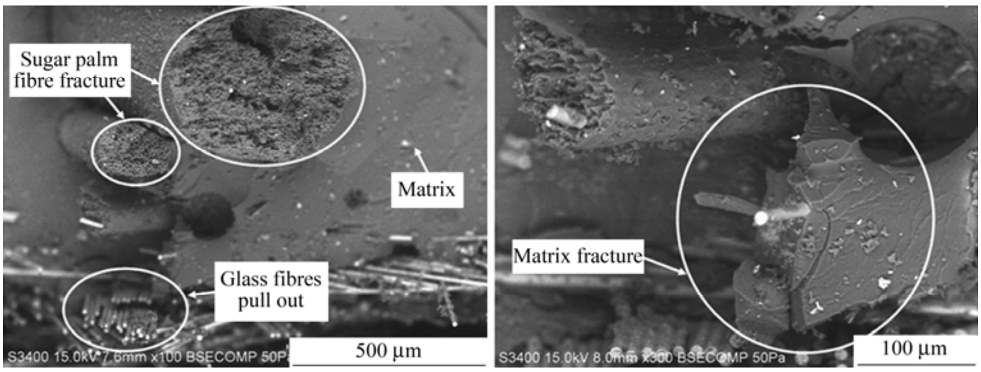

Fig. 10 SEM micrographs of impact fracture surface of hybrid composites

The impact strength of the hybrid composites increases with an increase in the fibre weight fraction as shown in Fig. 9. When this fraction is increased, more energy will have to be used up to break the coupling between the interlaced fibre. In addition, the superior damage tolerance capability and efficient crack resisting characteristics of the glass fibres compared to the sugar palm fibres give significant effect to this result. Besides, additional impact absorption energy occurs between the fibres with the increasing of weight of glass/sugar palm fibres in the hybrid composites, hence increasing the impact resistance of the hybrid composites. Furthermore, when the hybrid composites were impacted, the glass fibres were able to resist the high impact load and were also able to absorb a significant amount of impact energy through delamination of fibres. Thus, the energy needed to initiate and propagate the crack increases. In fibre reinforced composites, fibres play an important role in the impact resistance of the composites as they interact with the crack formation in the matrix and act as a stress transferring medium. The high bonding quality between the glass fibre and matrix creates a good interfacial region. This phenomenon results in an improvement in the ability of the composite system to absorb energy during fracture propagation and enhances the impact resistance of hybrid composites.

CONCLUSIONS

This paper reports on the incorporation of sugar palm and glass fibre as reinforcement in unsaturated polyester composites. Based on the results obtained from this research, the following can be concluded:

The mechanical properties of sugar palm fibre composite are found to be much lower than those of the glass fibre reinforced composite. This may be a result of the poor compatibility in the interfacial region between sugar palm fibre and the unsaturated polyester matrix. Furthermore, the irregularity in the diameter of sugar palm fibres does give a negative effect on the mentioned properties. It is believed that these factors affect the efficiency of the stress transfer mechanism in the matrix.

The tensile stress strain curve of sugar palm fibre composite carries the same behavior as a brittle material, the composite does not experience an plastic region before its fracture resulting in low strain values. However, hybridization of glass and sugar palm fibres makes the composite more ductile.

The incorporation of both sugar palm and glass fibres into the unsaturated polyester matrix has resulted in superior enhancement in the mechanical properties of the composites. All these improvements in the hybrid composite properties are mainly due to the high strength and modulus of glass fibre than the inferior properties of sugar palm fibre itself. The improvement of tensile, flexural and impact properties of the composites are found to be dependent on the fibre content as well as the weight ratio of glass/sugar palm fibres. Glass/sugar palm composites are found to have an increase in tensile, flexural, and impact properties with increasing fibre content and weight ratio of glass/sugar palm fibres.

Overall, the glass/sugar palm hybrid composite with weight ratio of 4:4 owned the highest properties among all samples in this study. This is because the high fibre loading effect gives an excellent dispersion of fibres and excellent load transference occurring at this composition.

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