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MECHANICAL PROPERTIES STUDY OF *DURIO ZIBETHINUS* SKIN FIBER REINFORCED POLYETHYLENE COMPOSITE

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Abstract: Composite materials have been continuously innovated and developed so that they can be improved in almost any criteria as their characteristics are preferable to single-phase materials. Natural fiber reinforced polymer composites can sustainably reduce inorganic and organic wastes, aside from serving as materials with improved mechanical properties. In this study, fiber extracted from *Durio zibethinus* (durian) skin was examined. *Durio zibethinus* (DZ) fiber was fabricated into fiber paper sheets and underwent hot-press lamination to produce a composite. This study investigates the differences between fibers extracted from DZ skin and husk. Tensile and micro Vickers tests were performed on the fabricated composites. The results show that the tensile behaviour of the composite fabricated from DZ skin fiber had a value of 20.1 MPa compared with the composite fabricated from a mixture of skin and husk which had a value of 19.4 MPa. These findings suggest that using durian skin resulted in better tensile strength with a FVF (fiber volume fraction) of 18%, compared with using a mixture of skin and husk which had a FVF range of between 8% and 23%. The hardness, meanwhile, increased with the FVF for the composite fabricated from a mixture of DZ skin and husk. This natural fiber composite has the potential to be used in households, automotive parts, lightweight furniture and many other composite engineering applications.

Keywords: Natural fiber composite, green fiber, polymer composite, sustainable, tensile.

Introduction

The application of natural fiber polymer composite has gained traction in many engineering fields. The aim of composites is to achieve properties that are unique and cannot be displayed by any individual material. Although the strength and stiffness of composites by area may not be as superior as metals, the specific modulus (modulus per unit weight) of composites can compete with metal (Martin, 2006). New bio-composite materials are constantly being researched and developed. The increased application of newly developed bio-composite materials with customised properties shows that the materials are able to meet the required performance in most engineering fields. Furthermore, their properties are better than certain other materials such as alloys and ceramic. Bio-composites have been applied in the automotive industry and in households (Akintayo *et al.,* 2017). The classification of plant-based natural fiber is shown in Figure 1.

Natural fibers derived from plants are formed through the joining and forming of the strong connections of cell walls. Plant fibers may be considered as natural occurring composites, comprising mainly of cellulose that are embedded in an amorphous lignin matrix (Saba *et al.,* 2014). The fibers from the bast stem, leaf and fruit are naturally organised in bundles while those in seeds are single cells (Mwaikambo, 2006). Three organic compounds, cellulose, hemicellulose and lignin are part of the major composition of cell walls (Chen, 2014). Hence, organic natural fibers are extensively used in environmentally friendly

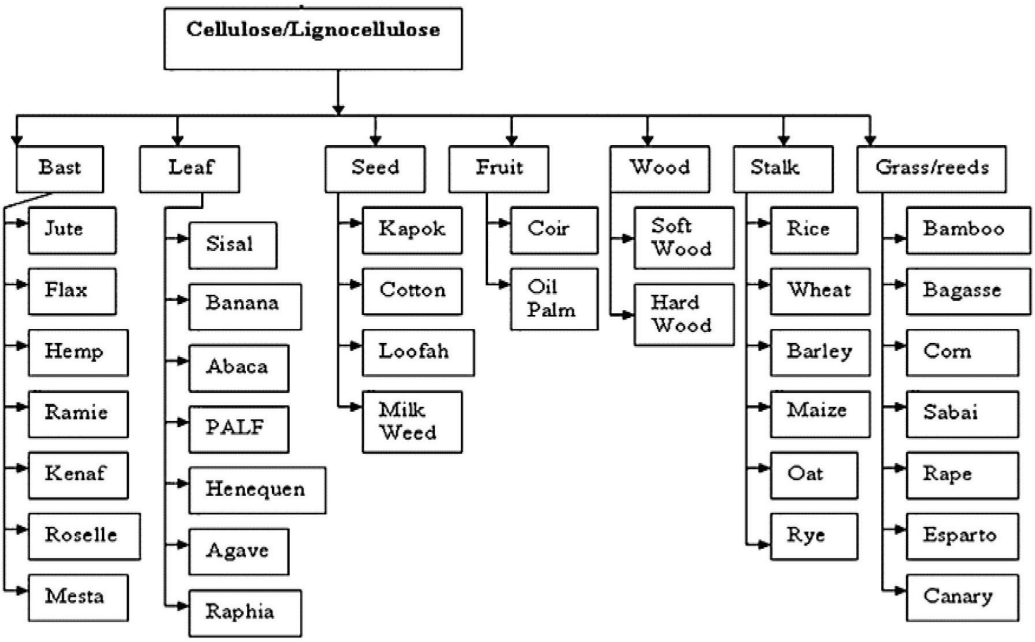


Figure 1: The classification of natural fibers as reinforcement materials (Jawaid *et al.,* 2011)

composite applications and they are also the subject of material innovation researches due to their sustainable, light weight, eco-friendly and superior characteristics (Kuan *et al.,* 2021). Durian peels fiber reinforced high density polyethylene (HDPE) composites by extrusion showed improvements in elasticity modulus compared with neat HDPE (Charoenvai, 2014). Durian husk fiber in poly(lactic acid) biocomposites shows that materials higher fiber content have the strength and modulus that are suitable for non-structural application (Lee *et al.,* 2020).

Malaysia is the second largest exporter of *Durio zibethinus* (DZ) or commonly known as durian, exporting 20,000 tonnes of durian in 2015 and the country produced approximately 350,000 tonnes of durians per year between 2012 and 2015 (Suntharalingam *et al.,* 2018). The actual amount of durian pulp in a fruit is approximately 30%wt, with the other 60% to 70% being the durian skins and seeds which are normally treated as waste. These durian wastes contain a high amount of fiber that might act as excellent filler. Therefore, there are many opportunities with durian skin fiber (DSF) in using it as reinforcements in composites, even though its properties, behaviour and feasibility have yet to be understood. Furthermore, plastic waste has emerged as a major problem to the environment. Therefore, using DZ fiber as filler can significantly reduce the usage of polymer. In this study, the mechanical properties of DZ fiber reinforced high density polyethylene (HDPE) composites were studied. Results were compared with neat HDPE and the relationship between skin and husk fiber composites were also investigated.

DSF may act as a superior and eco-friendly bio-filler in composite fabrication. DSF extracted from durian waste can be reused, regenerated and manufactured as filler materials. It has the optimum potential to be used as reinforcement with a polymer matrix to form bio-composites to replace other synthetic materials that are not sustainable and not biodegradable.

Materials and Methods

Durian skins and husks were collected from a local supplier and were prepared with the pulping method. The durian husks and skins were washed with water thoroughly to remove dirt and fruit residue and they were subsequently boiled in an approximately 2:1 water-fiber ratio for approximately two hours until they soften. They were then cut into thin strips of 1 cm to 2 cm and rinsed thoroughly. The durian rinds were blended at a speed of 1,500 rpm and this was gradually increased to 10,000 rpm and they were then immersed in water for the thin sheet-screening process. Finally, the wet random fibers were pressed with a load that weighs approximately 5 kg between cloths to be dried. All the fiber sheets were prepared to achieve a thickness of approximately 1-2 mm as seen in Figure 2.

Figure 2: A *Durio zibethinus* fiber sheet

The study was performed by preparing the fibers with different proportions from the durian husks, using equal portion of the outer skin (green husk skin) and the inner skin (white flesh skin) fibers. Commercial polyethylene (PE) film with a thickness of 0.2 mm was used as the polymer matrix. A total of six different types of laminates were fabricated and details of the stacking sequences of the laminates are provided in Table 1 with 150 plies of PE film laminated as neat PE reference. DZ_{1-4} and DZS_1 were pressed by laminating 150 plies of PE between DZ or DZS (*Durio zibethinus* skin) fiber sheets. All the samples were laminated to achieve a thickness of approximately 3 mm. The composites were fabricated with different DZ fiber volume fraction (FVF) using hot-press lamination at 180°C before being cooling to room temperature. Tensile samples were cut to a length of 250 mm and a width of 25 mm. Tensile tests were performed in accordance with ASTM D3039 tensile testing at a crosshead displacement rate of 5 mm/minute for all the laminates. The Vickers hardness test was performed to study the effect of fiber loading on the composites. It is known that the greater the hardness, the better the ability of the composite to resist localised plastic deformation. The tests were performed using Shimadzu HMV-G21D Micro Vickers Hardness Tester according to ASTM E384 standards.

Table 1: Composites and design of the stacking sequence

No.	Fiber Source	Composite	Fiber Volume Fraction (FVF), $\%v_f$	Stacking Sequence (Number of PE Film and Fiber Sheet)
1	-	Neat PE	0	[150 PE]
2	Mixture of DZ husk (green) and skin (white)	DZ_1	8	[75 PE – DZ – 75 PE]
3		DZ_2	14	[50 PE – DZ – 50 PE – DZ – 50 PE]
4		DZ_3	20	[40 PE – DZ – 35 PE – DZ – 35 PE – DZ – 40 PE]
5		DZ_4	23	[30 PE – DZ – 30 PE – DZ – 30 PE – DZ – 30 PE – DZ – 30 PE]
6	DZ skin (white flesh only)	DZS_1	18	[75 PE – DZS – 75 PE]

Results and Discussion

The tensile strength for composites with different FVF is shown in Figure 3. The tensile strength of neat polyethylene is measured to be 18.17 MPa while laminates with DZ_{1-4} reinforced fiber at 8%, 14%, 20% and 23% FVF are 19.43 MPa, 19.13 MPa, 17.85 MPa and 18.01 MPa, respectively. The use of skin and husk mixture fiber increases the tensile strength of composites with 8% FVF then gradually decreased from 14% to 20% FVF composites while 23% FVF composites experienced a slight increase in tensile strength.

The tensile strength for composites using 8% and 14% FVF are better compared with neat PE while the 20% and 23% FVF composites exhibited almost similar tensile strength compared with the neat PE. The possible factors could be insufficient or uneven bonding between the fiber and the matrix in the composites when mixing the husk and skin of DZ. The composites were prepared using DZ fiber sheets as reference. The sheets were prepared using approximately 8 g to 12 g of random fibers. For example, the 8% FVF used one fiber sheet, 14% FVF used two fiber sheets and so on. The fabrication of composites involved the stacking of fiber sheets and PE film layers. The stacking of fiber sheets in 20% and 23% FVF involved three and four fiber sheets, respectively. A higher ratio of FVF caused insufficient bonding between the PE and DZ fiber. Furthermore, the void ratio in 20% and 23% FVF composites will be higher due to the fiber sheets acting as a barrier in between the PE film layer.

Although theoretically the mechanical properties of natural fiber composites are directly proportional to the volume fraction of the fibers, the reduction of the tensile strength can still happen due to the presence of non-cellulosic compounds in untreated fiber polymer composites. Non-cellulosic compounds such as lignin, pectin and hemicellulose hinder the interfacial bonding between natural fibers and the polymer matrix (Goriparthi *et al.,* 2012; Chai *et al.,* 2016) due to poor wettability and the smooth surface of the fibers (Latif *et al.,* 2019).

The tensile strength of the composites reduced when the 20% and 23% FVF composites were compared with the 8% and 14% FVF composites. Therefore, the tensile strength results showed that DZ fibers with a FVF of less than 20% be used in composite fabrication to ensure a good bonding between the fibers and the matrix for better tensile strength when compared with the neat PE. The use of DZ skin fiber only reinforced polyethylene composites with 18% FVF (laminate DZS1) which exhibited the highest tensile strength at 20.05 MPa with a specific tensile strength of 0.0202 $MPa.m^3/kg$

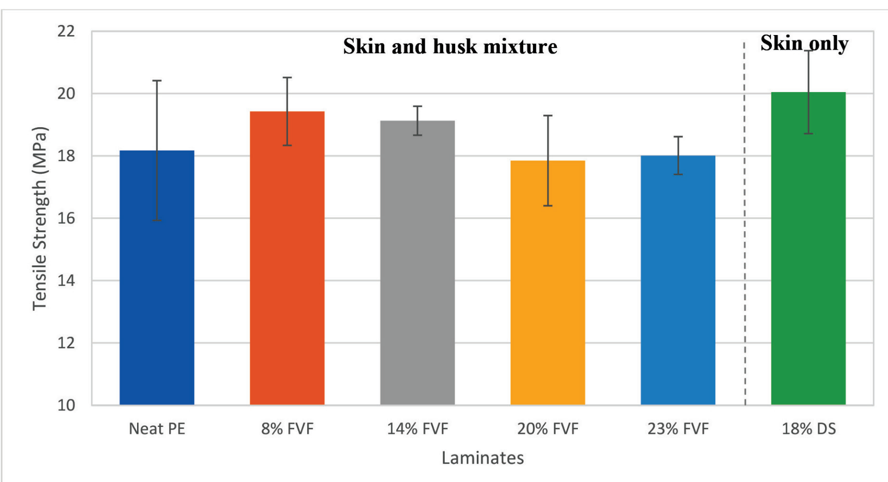


Figure 3: Tensile strength of the laminates with different FVF of DZ husk and skin

and specific tensile modulus of 0.5295 MPa. m^3/kg. This suggests that the durian skin fiber exhibited a better tensile strength than the husk.

The results for the micro Vickers hardness test are sorted according to the FVF in Figure 4. It is observed that the hardness of the composites was improved to a mean hardness of 7.3 HV at 23% FVF DZ. The hardness of the composites increased gradually from neat PE at 6.06 HV to 8% FVF and peaked at 23% FVF. The 18% FVF DZ skin fiber only achieved a hardness of 6.07 HV. It significantly indicated that the use of husk in the composite increased its. Lastly, hardness of the 8%, 14%, 20% FVF composites are 6.11 HV, 6.25 HV and 6.49 HV, respectively. A similar trend was found by Srinivasa and Bharath (2011) where the hardness is increased as the fiber loading is increased. The increased hardness is contributed by the fiber sheets which reduced the mobility of PE molecules. As the fiber content increased, the free volume that allows the mobility of fibers or polymer molecules will decrease (Mahshuri & Amalina, 2014). It slightly improved the properties of the surface of the composites and thus exhibiting a good potential to reduce dents or scratches. The hardness increased with the increase of DZ fiber. Hence, the hardness of the composites increases in such a trend.

Figures 3 and 4 clearly reveal that as the FVF increased, the tensile strength decreased and the hardness increased. This result contradicts with Tabor's relationship. According to Tabor's relation, for homogeneous materials, the hardness value is about three times larger than the yield stress of the materials (Tabor, 1951). Since fiber reinforced polymer composites are a non-homogeneous material, this discrepancy may be due to the greater complex deformation process in polymer matrix composites compared with metal (Zhang *et al.,* 2011). The presence of voids and poor fiber-matrix adhesion as shown in Figure 5 also contributed to the decrement of tensile strength as the fiber volume increased.

Figure 5 shows the SEM images depicting the tensile fracture surfaces of composite laminate DZ4 at different magnification levels. Fiber breakages, matrix fractures, fiber debonding and fiber pullouts can be observed in the micrographs. The images clearly show the fiber contents of the composites. From the figure, some delamination of the matrix and the fibers can be seen in the circled area in the images. It is due to the hydrophilic nature of natural fiber and hydrophobic nature of polyethylene. The weak bonding between polyethylene and DZ fiber can be due to the excessive fiber used for the 23%

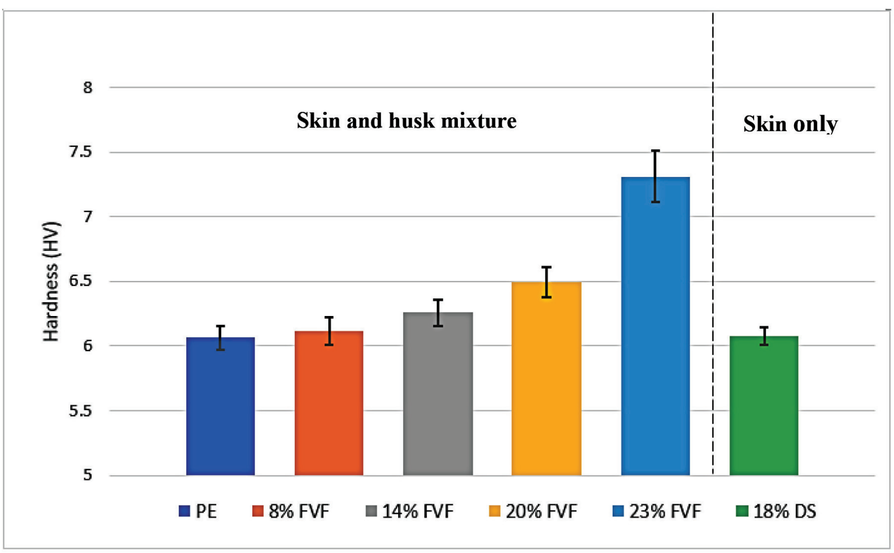
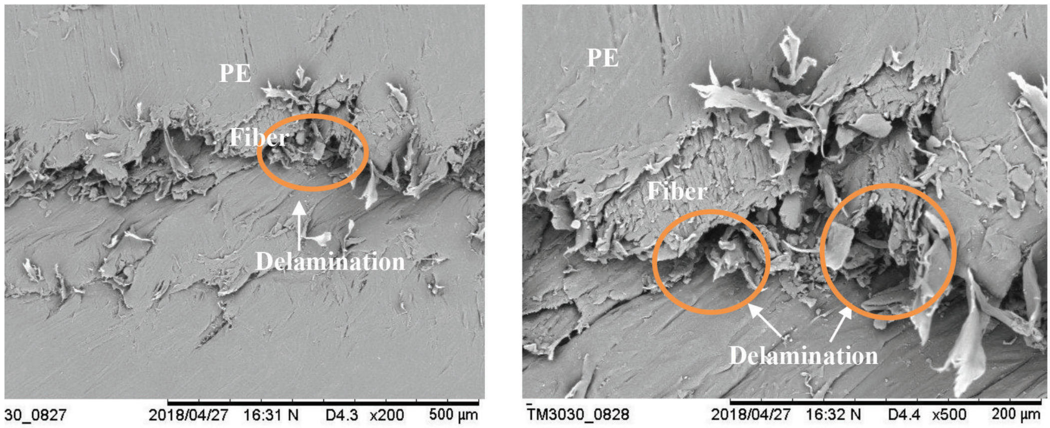


Figure 4: The variation of hardness test results for different FVF laminates



(a) (b)

Figure 5: SEM images of tensile breaking surface of composites type DZ_4 with an FVF 23% at magnifications of (a) ×200 and (b) ×500. The circles in the images highlight the gaps between the durian skin and husk/PE composites with poor adhesion

FVF composite and thus, causing a weak tensile strength and poor adhesion.

Conclusion

The mechanical properties of the composites were characterised with tensile and micro Vickers hardness tests. From the tensile test results, the skin and husk mixture composites exhibited a better tensile strength at FVF values of 8% and 14%. The tensile strength reduced with the increase of FVF at 20% and 23% due to the excessive fibers used in the polyethylene lamination, causing poor adhesion. Too much fiber may cause weak interlamination bonding between the matrix and the fibers. For the skin and husk mixture, laminate DZ_1 exhibited the highest tensile strength at 19.43 MPa. The use of DZ skin fiber only reinforced polyethylene composites at 18% FVF (laminate DZS1) which exhibited the highest tensile strength for all laminates at 20.05 MPa. Therefore, it can be concluded that DZ skin only exhibited better tensile strength as fiber reinforcement in PE. On the other hand, DZ skin and husk mixture with a FVF value of 23% fiber reinforced composite exhibited the highest hardness at 7.3 HV. The results show that the higher the FVF, the higher the hardness of the composite and DZ skin fiber reinforced PE exhibited a better tensile strength than the DZ skin and husk mixture.

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