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Mechanical Properties of Oil Palm Frond Wood Filled Thermoplastic Polyurethane

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ABSTRACT:

The problem on the biomass waste produced from palm oil plantation is presences today. The biomass waste typically sourced from oil palm trunk (OPT), oil palm frond (OPF) and oil palm fruit bunch. Considering huge amounts OPF wood waste from palm oil plantation, the waste can have other added value if they can be used as in polymer composite materials. This study is subjected to investigate the effect of oil palm frond (OPF) fiber and powder loading to hardness, toughness, tensile and flexural strength of thermoplastic polyurethane (TPU) as wood polymer composite. Frond fiber with size of 2-3 mm and frond powder with size of 60-90 micron were used as filler materials. The TPU/OPF composite samples were fabricated by compressive molding approach. The result shows that hardness of TPU based composite were increased by 48% with addition of 30 wt.% of OPF powder. Ultimate tensile strength of TPU was increased by 26% with addition of 30 wt.% OPF frond powder. The impact strength of TPU was increased about 50 % by addition of 30 wt.% of OPF frond fiber, while the flexural strength of TPU/OPF composites has increased about 86% by addition of 30% OPF frond fiber. The microstructure of TPU/OPF composite samples shows good interfacial bonding between TPU matrix to OPF powder and OPF fiber, which represents the significant improvement of mechanical properties of TPU/OPF composites. It can be concluded that both of OPF powder and fiber addition significantly improved the mechanical properties of TPU. The OPF powder improved hardness and tensile strength, while the OPF fiber improved impact and flexural strength of the TPU.

KEYWORDS: composites, oil palm frond, polyurethane

1. INTRODUCTION

Thermoplastic Polyurethane (TPU) is an important thermoplastic elastomer material typically used in food packaging, medical devices, cable, building, and automotive industry due to its high abrasion and chemical resistance, high mechanical and elastic properties, versatile, and adaptable physical properties [1], [2]. Thermoplastic polyurethanes (TPU) are subcategorized as copolymers called thermoplastic elastomers (TPE) and considered as one of the first segmented copolymers to be made commercially available.

As one of main industry in Malaysia, oil palm plantation industries has its consequences due to large biomass waste produced. Although there is falls on the palm oil price in the past five years that dropped out of oil palm production [3], it is believed that the business will be sustain again in the near future. Therefore, the problem on the biomass waste produced will persist. The main biomass waste from palm oil plantation are typically sourced from oil palm trunk (OPT), oil palm frond (OPF) and oil palm fruit bunch [5]. It was reported that 44.8 Million tonnes of oil palm frond waste were produced in Malaysia on the year of 2009 [6].

Cellulose materials such as wood powder or wood fibers are acknowledged as an interesting filler for thermoplastic polymer. Wood fillers in composites are known to be lightweight, biodegradable, recyclable, nonabrasive, and inexpensive fillers. Owing to the advancements in processing technology, growing environmental awareness, and economic factors, the wood-based thermoplastics (WPC) have gained worldwide attention [7]. Over the past years, the application of biomass fiber as reinforcement as well as wood powder or saw dust as filler in the development of polymer matrix composite has been increases. This because they readily available in the nature, biodegradable, possess acceptable specific strength and modulus, low cost, low density, good thermal insulation properties, absence of associated health hazards, and renewable [8]–[10].

Considering huge amounts OPF wood waste from palm oil plantation, the waste can have other added value if they can be used as in polymer composite materials. Thus, the objective of this work is to investigate the effect of palm oil frond dust and oil palm frond fiber to mechanical properties of thermoplastic polyurethane (TPU) elastomer.

2. MATERIALS AND METHOD

2.1. Materials

Thermoplastic Polyurethane Elastomers of BASF Elastollan B90A was used as matrix. The polymer was received in form of clear pellets without further treatment (Figure 1). The oil Palm Frond (Figure 2) was obtained from local palm oil tree in Malacca, Malaysia. Three samples of three different content of oil palm frond fiber and powder, 10wt%, 20wt.% and 30wt.%, respectively, were prepared as the samples as shown in Table 1. Sodium Hydroxide was obtained from Merck Malaysia Sdn.Bhd.

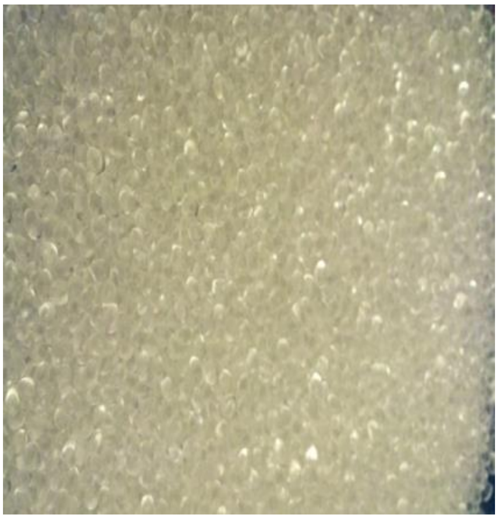


Figure 1. Elastollan B90A Thermoplastic Polyurethane Elastomers

Figure 2. Oil Palm Frond (OPF) Sample

Table 1 Composition of Samples

Composite sample	TPU (wt.%)	OPF Powder (wt.%)	OPF Fiber (wt.%)
Sample 1	100	0	0
Sample 2	90	10	0
Sample 3	80	20	0
Sample 4	70	30	0
Sample 5	90	0	10
Sample 6	80	0	20
Sample 7	70	0	30

2.2. Sample Preparation

Prior to sample fabrication, the oil palm frond was washed with water to remove unwanted dirt, soil and insects then dried under the sun for 3 days. The frond then pressed by using a pressing machine to obtain fibers from the frond.
After the fiber obtained from the frond, alkali treatment was performed on the fiber by soaking the fiber in 2% sodium hydroxide (NaOH) solution at room temperature. The OPF were soaked in the solution for 30 minutes then washed several times with water. To ensure no more moisture content presence in the fiber, the sample was placed into a drum dryer at 100°C for 6 hours to ensure fibers properly dried.
Short OPF fiber was used in this work, which prepared by cut the dried fibers to a size of 2 – 3 mm. To prepare the OPF powder, parts of the dried fibers were crushed to powder by using crusher machine then sieved with a 60-micron mesh filter to separate uncrushed fiber from the powder.
Haake internal mixer was employed to mix the fiber or the powder into the TPU matrix. The process was taken place at 60 rpm for 12 minutes at 190^0C. The extruded polymer composite then crushed into pellet by using a plastic crusher machine. Furthermore, the polymer composite samples were prepared put the pellet into a 200 mm (L) × 200 mm (W) × 3 mm (T) mold. The samples were pre-heated at 190°C for 7 minutes then the mixture was press with pressure of 95 kgf/cm^3 for 3 minutes. The samples then undertake cold press for 5 minutes. Finally, the specimen was cut according the required ASTM standard testing size by using sample cutter

2.3 Morphology characterization

Two type of microscopes were employed to examine the morphology of the samples. The microstructure was examined by a Zeiss SMT EVO 18 Scanning Electron Microscopy (SEM) under secondary electron beam at 100-1000 X magnification and Carl Zeiss Axio Lab Imager Upright Microscope at 5 – 20 X magnification scale.

2.4 Mechanical Properties

Tensile properties of the samples were evaluated in accordance to ASTM D638 by using Instron 5960 Dual Column testing machine with a 5 kN load cell and the crosshead speed was maintained at 5 mm/min. The testing was performed at room temperature and relative humidity of 50 ± 5%. Dog bone specimen of type-V was prepared for the tensile testing as shown in Figure 3.

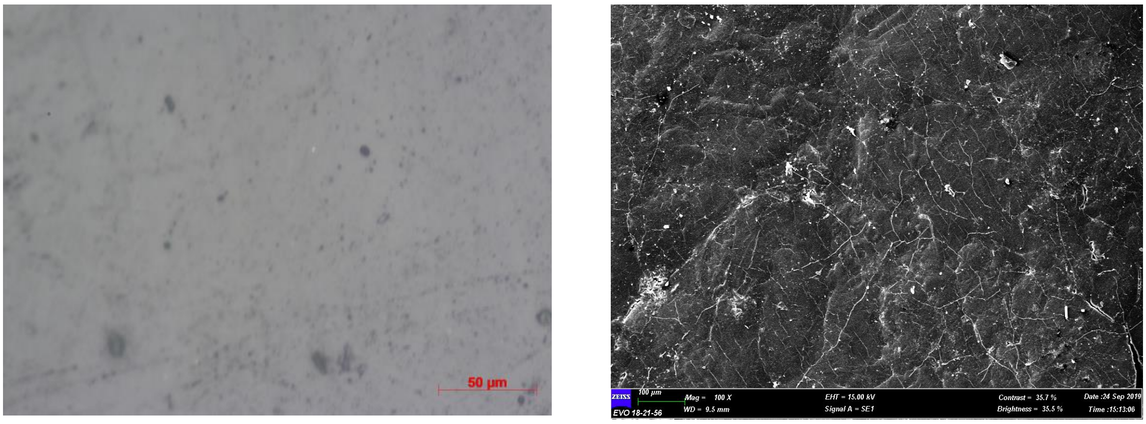
(a) (b)

Figure 3. Tensile testing sample, a. OPF-Fiber composite and (b) OPF Powder composite

The Flexural strength was also evaluated by using Instron 5960 Dual Column tester by using Three-point method according to ASTM D790 standard method. Specimen of size 130 mm (L) x 13 mm (W) x 3 mm (T) was employed for this testing. Charpy impact test was performed according to ASTM D256 at a temperature of room temperature °C and relative humidity of 50 ± 5% by using a digital INSTRON CEAST 9050 pendulum impact tester. The samples were cut to the dimensions of 60 mm (L) x 13 mm (W) x 3mm (T), in which unnotched samples were used.

3. RESULTS AND DISCUSSION

Figure 4 shows the morphology of the sample 1 with no OPF fiber or powder loaded into the TPU. A light white color sample was seen from sample 1 with clear boundary between the polymer grain boundary observed from the micrograph. Figure 5 shows the OPF powder observed under the microscope which powder with size of 60 – 90 μm were observed under the microscope. Figure 6 to Figure 8 shows morphology of the TPU loaded with the OPF powder. The color change of the TPU matrix from light white to dark brown color was observed. It is observed that the OPF powder has good bonding with the TPU matrix. Figure 9 to Figure 11 shows the morphology of TPU loaded with OPF Fiber. The short fiber typically visible on the sample with good bonding between the fiber and the TPU matrix.



a. Upright microscope (20 X) b. SEM micrograph (100X)

Figure 4. Morphology of sample 1

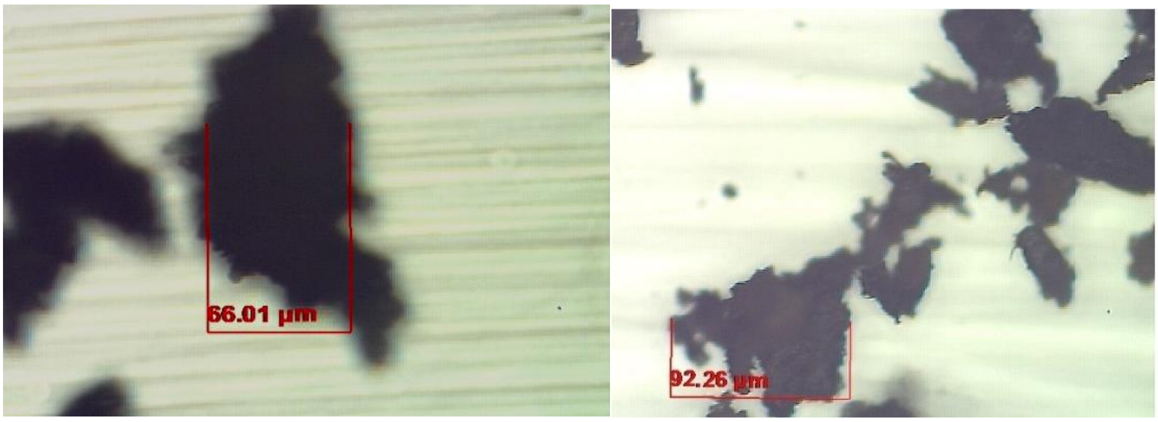
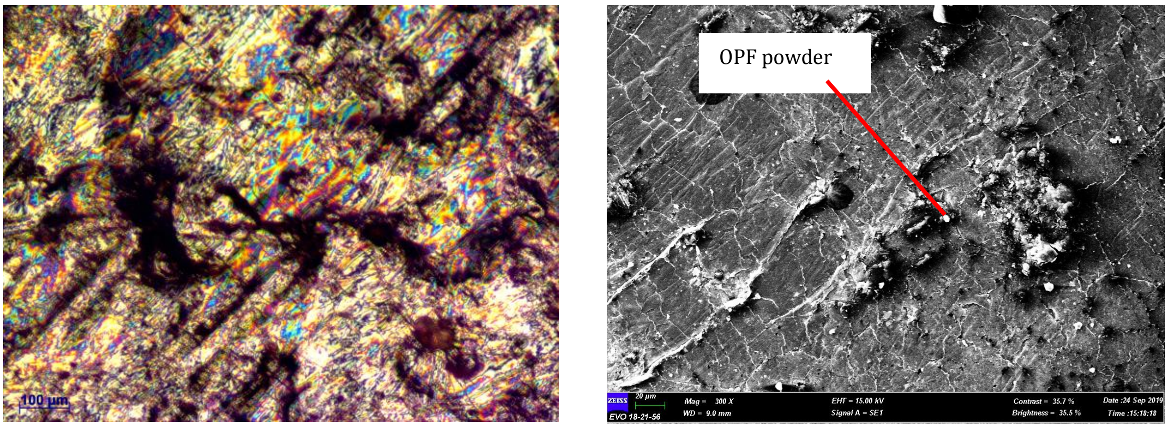
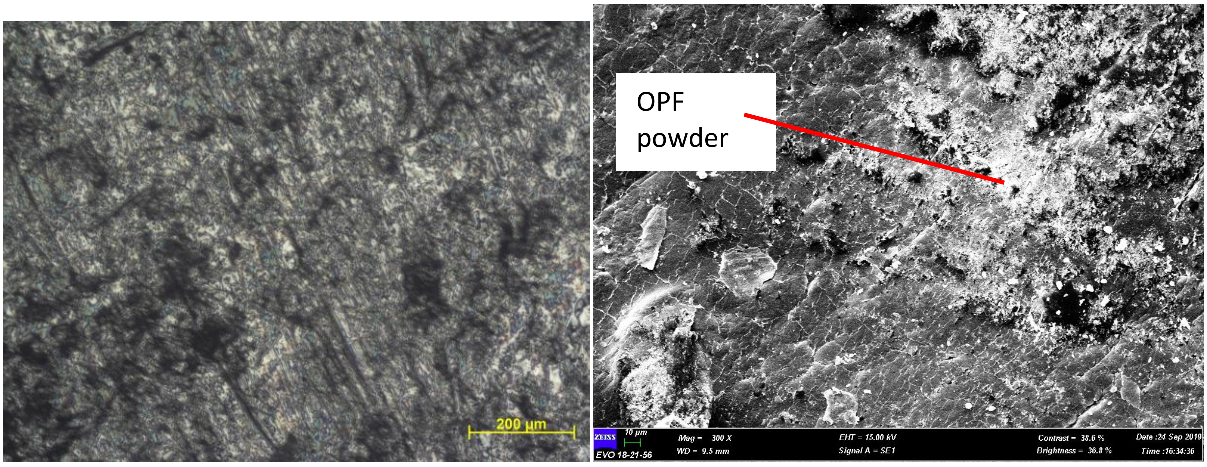


Figure 5. Micrograph of typical OPF dust in the samples obtained by Upright Microscope (20 ×)



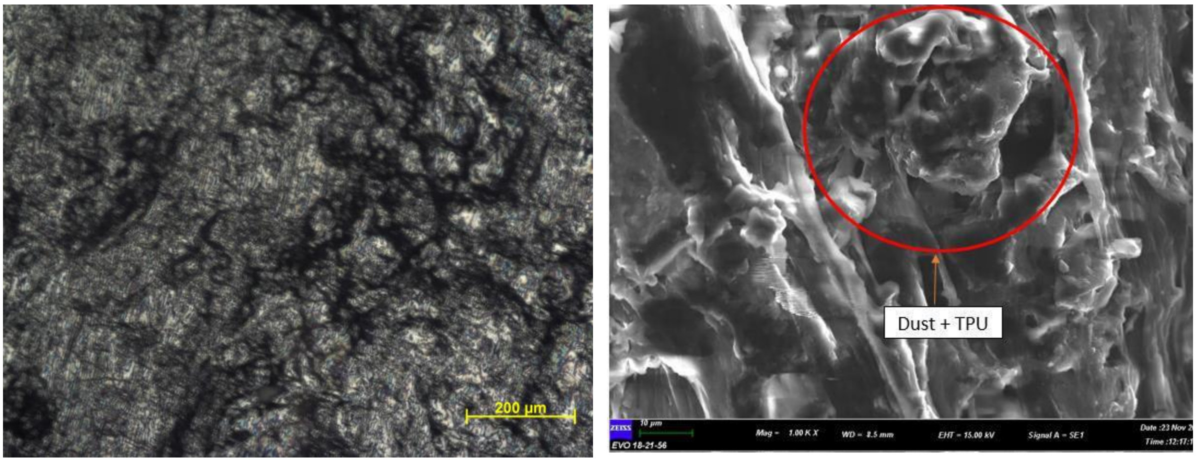
a. Upright microscope (10 X) b. SEM micrograph (300X)

Figure 6. Morphology of Sample 2



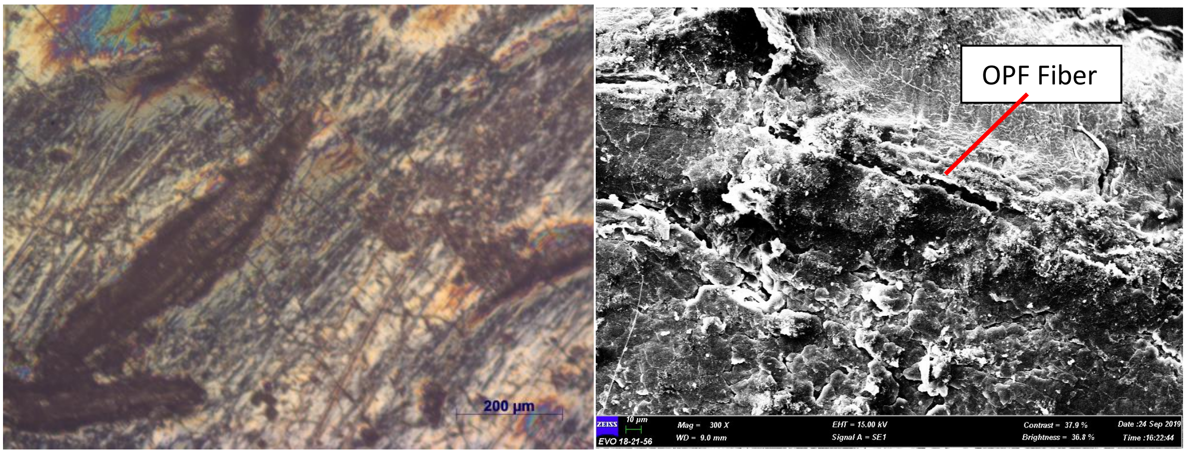
a. Upright microscope (10 X) b. SEM micrograph (300X)

Figure 7. Morphology of Sample 3



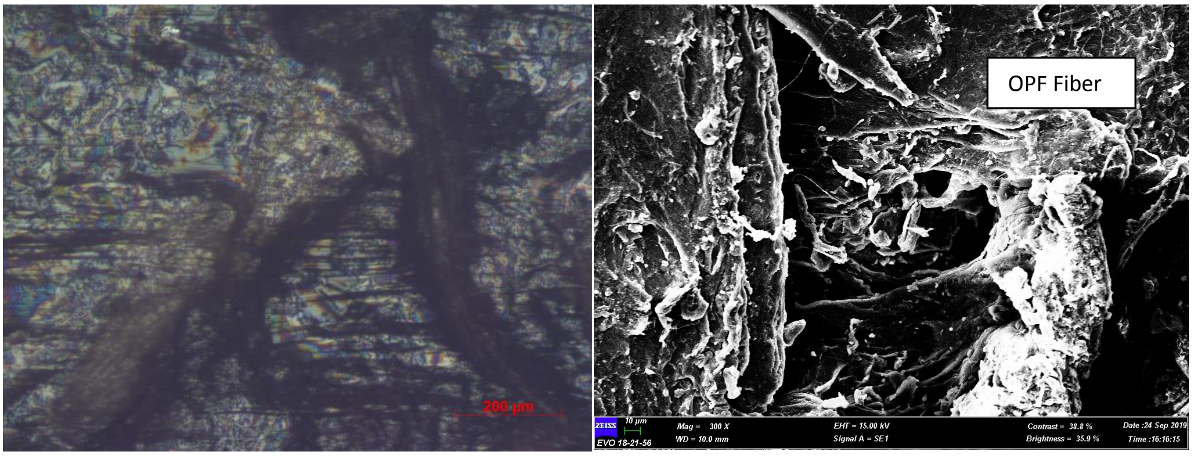
a. Upright microscope (10 X) b. SEM micrograph (1000X)

Figure 8. Morphology of Sample 4



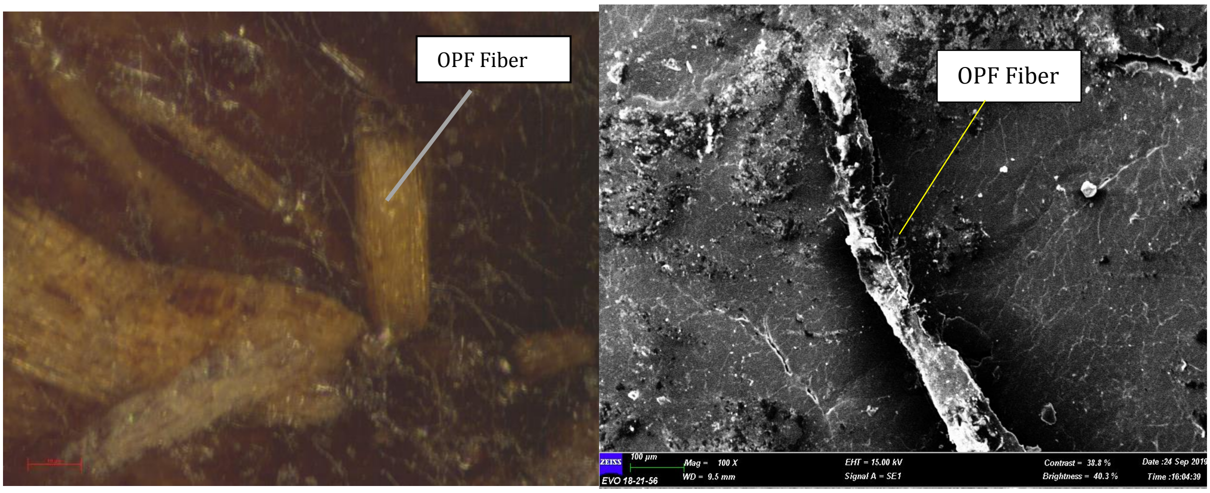
a. Upright microscope (10 X) b. SEM micrograph (300X)

Figure 9. Morphology of Sample 5



(a) upright microscope (5×) (b) SEM micrograph (500×)

Figure 10. Morphology of sample 6



(a) upright microscope (5×) (b) SEM micrograph (100×)

Figure 11. Morphology of sample 7

Reinforcing fiber and filler loading in polymer matrix commonly expected to improve the mechanical properties of polymer matrix. Figure 12 show the effect of OPF fiber and powder to hardness of TPU (shore D). It is observed that addition of OPF short fiber and OPF powder able to enhance hardness of TPU. However, the OPF powder gives more effect to hardness improvement than the OFP fiber. Significant hardness enhancement observed when 30 wt.% OPF powder loaded into the TPU. Hardness of TPU were increases by 48% (from 37.8 Shore D) due to addition of 30 wt.% of OPF powder. When the OPF fiber was loaded, the hardness of TPU was slightly increased with fiber loading where 18.2 % of hardness was improved by 30% of OPF fiber loading. This finding is possibly related to ability of the OPF powder to well dispersed into the TPU [11].

Figure 13 show the effect of OPF fiber and powder to impact properties of TPU measured at room temperature. The absorbed impact energy was increased with fiber content as well as OPF powder. However, the addition of OPF fiber gives more impact energy absorption improvement compared to OPF powder. Initially, the TPU matrix possess 4.1 J/m^3 impact absorbed energy. It is observed that addition of 30 wt.% frond fiber significantly improved the TPU impact strength (50 % improved). In case of OPF powder, the impact strength was slightly increase by 10 wt.% and 20 wt.% of powder loading and significantly increased when 30 wt.% of OPF powder loaded into the TPU matrix (29% increased).

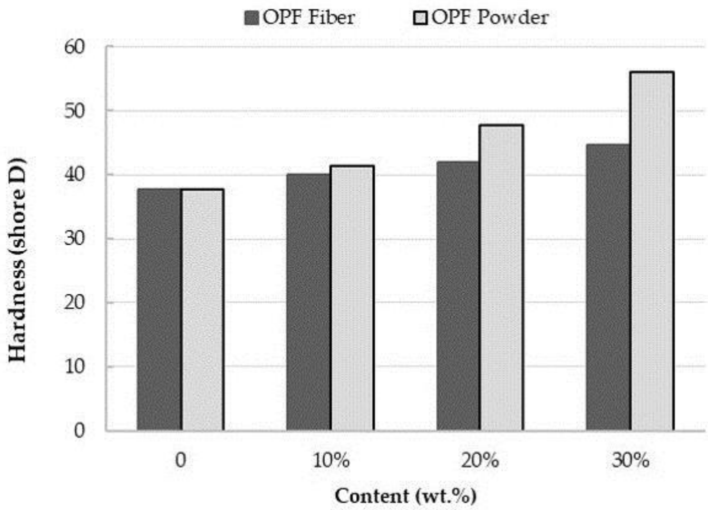


Figure 12. The effect of palm oil frond fiber and powder to hardness

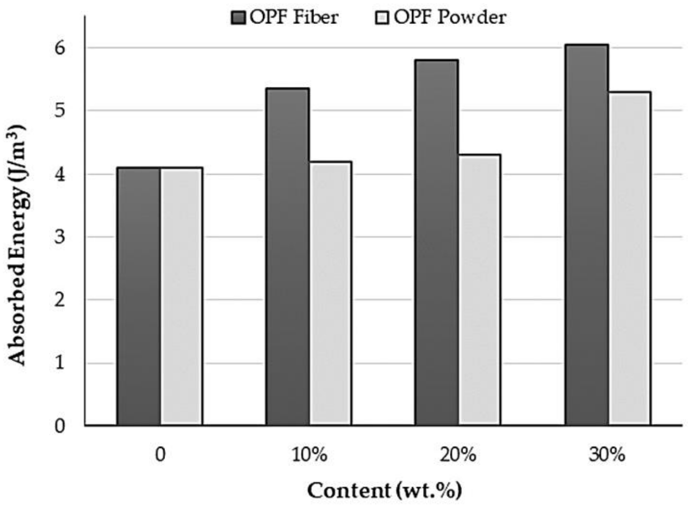


Figure 13. The effect palm oil trunk fiber and powder to absorbed impact energy

The effect of OPF fiber and OPF powder to flexural strength of TPU is shown in Figure 14. Both of OPF fiber and powder increases flexural strength of TPU. The flexural strength of TPU increases if the content of OPF fiber and powder increased. Initially, the TPU matrix has flexural strength of 2.93 MPa and it is observed that OPF fiber provide a better flexural strength improvement for TPU compared to OPF powder. The OPF fiber was significantly improve the flexural strength of TPU at 30 wt.% of fiber loading. The flexural strength was improved by 86% due to 30 wt.% of OPF fiber loading. In case of OPF powder loading, significant flexural strength improvement only observed when the TPU loaded with 30 wt.% OPF powder (74% improvement). Similar tendency of improvement of TPU flexural strength due to natural fiber addition also observed by Haghighatnia et.al [12] whom study the effect of hemp fiber to mechanical properties of TPU. They found that flexural strength of TPU able to increase up to 274.3% due to 40 %.vol hemp fiber with size of 15 mm addition to TPU.

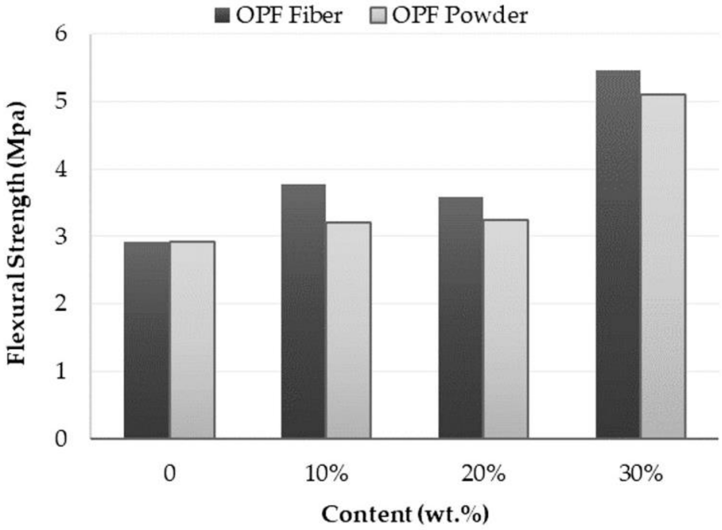


Figure 14. The effect palm oil trunk fiber and powder to flexural strength

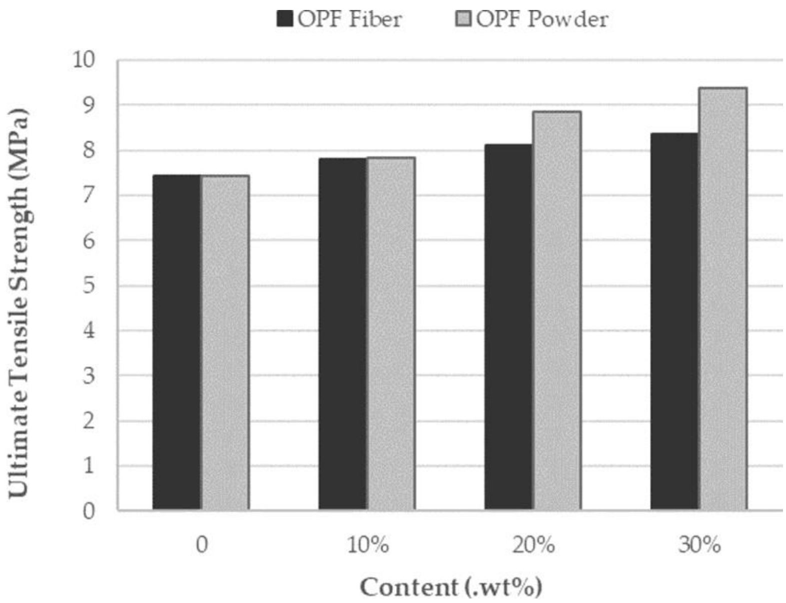


Figure 15. The effect palm oil trunk fiber and powder to ultimate tensile strength

Figure 15 show the effect of OPF fiber and powder to ultimate tensile strength (UTS). Both of OPF fiber and OPF powder can improve tensile strength of the TPU. The higher content of OPF powder (20 wt.% and 30 wt.%) give observable improvement to the tensile strength of TPU. Initially, the TPU matrix has ultimate tensile strength of 7.45 MPa then the tensile strength of TPU was increased by 17% due to 20 wt.% OPF powder and increased by 26% due to 30 wt.% OPF powder loading. This result was in accordance to results obtained by Yaakob et.al [13] whom study the effect of oil palm trunk powder in TPU. They found that the tensile strength of polyurethane increased with the increment of the OPT powder content up to 20%. The OPF fiber were slightly increase the UTS of TPU. The ultimate tensile strength of TPU was increased by 12.5 % at higher content of OPF fiber (30 wt.%). This evidently indicates that natural fiber will improve the TPU strength. A study by El-Shekeil et.al [14] found that 30 wt.% kenaf fiber significantly improve TPU matrix. In addition, they conclude that fiber length, time and temperature of sample preparation

as well as mixing speed are several factors that affects tensile strength of TPU.
In development of composite materials using fibers either organic or non-organic, as reinforcement, bonding interaction between the matrix and the fiber play important role. Similar factor also important when organic or non-organic powder fillers are used. Therefore, the interfacial bonding between the TPU matrix-fiber and TPU matrix-powder is also considered as main factor that affected the hardness, flexural, and tensile and impact properties of the TPU. In Figure 9 to Figure 11, the matrix has good interfacial bonding to the OPF fiber and better interfacial bonding between the TPU matrix and the OPT powder observed too as shown in Figure 6 to Figure 8.

In case of hardness, the OPF powder gives better improvement to TPU since the powder has a better dispersion to fill void between TPU cells to gives a compact structure of the filler – TPU matrix. Thus, the hardness indentation was well distributed on the surface of the TPU-OPF powder samples. This factor also thought as the factors that responsible for the higher ultimate tensile strength of the TPU loaded with OPF powder compared to OPF fiber. The OPF powder may have well engaged with the flexible TPU matrix which compact the structure of the matrix creating some reinforcing effect and possibly increased the hardness tensile strength. The more OPF powder mixed with the TPU gives better hardness and UTS improvement to the TPU. So, it can be concluded that the better dispersion of OPF filler compared to OPF fiber increase filler – matrix interaction is responsible to better hardness and UTS. Similar finding also stated by Onuegbu & Igwe on their study on effects of snail shell powder in the polypropylene [15]. In addition, a study by Pandey et.al indicates that addition the non-organic filler to TPU significantly improved tensile properties of TPU [16]. They found that the nanoclay filler loading show improvement in elastic moduli of TPU that consistent with increasing of filler content due to reinforcing effect of the filler.

In case of TPU - OPF fiber composites, the lower tensile strength compared to TPU - OPF powder composites observed can be because of crack initiation was more dominant compared to the effect of crack inhibition when tensile load applied. This possibly related to random fiber orientation used in this works which does not suffice to withstand the tensile load applied that leading to weak stress transfer from the matrix to fiber when load applied. Low values of tensile strength can be attributed to the lack of the fibers ability to transfer the load to one another [17], [18]. In case of impact strength, lower impact energy absorption shown by TPU loaded with low content of OPF powder possibly due to low resistivity of the TPU matrix and OPF powder composite against the crack propagation, while the OPF fiber can provide good resistivity to crack propagation [19]. Similar effect to flexural strength improvement due to low content OPF powder also observed. Although high content OPF powder (30 wt.%) give good flexural strength improvement, but generally the OPF powder show lower flexural strength improvement compared to OPF fiber. This is possibly affected by the fiber – matrix interactions provide a great pressure resistance during bending [20].

4. CONCLUSION

Both of oil palm frond powder and oil palm frond fiber improved the mechanical properties of TPU. The loading of OPF powder to TPU show improvement towards hardness and tensile strength of the TPU compared to OPF fiber. Hardness of TPU were increases by 48% due to addition of 30 wt.% of OPF powder to TPU and the tensile strength of TPU was increased by 26% due to 30 wt.% OPF powder loading. However, the loading of the OPF fiber into TPU improve the impact and flexural strength of TPU compared to OPF powder filler. The addition of 30 wt.% frond fiber significantly improved the TPU impact strength (50 % improved) and the flexural strength were improved by 86% due to 30 wt.% of OPF fiber loading. These experimental results are believed much affected by the interfacial bonding action between TPU matrix with OPF powder and fiber as well as the dispersion of OPF powder and fiber loaded within the TPU matrix.

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