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Mechanical Properties of Oil Palm Frond Wood Filled Thermoplastic Polyurethane

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ABSTRACT

The problem of the biomass waste produced from palm oil plantation is present today. The biomass waste typically is sourced from oil palm trunk (OPT), oil palm frond (OPF) and oil palm fruit bunch. Considering the 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 increased by 48% with the addition of 30 wt.% of OPF powder. Ultimate tensile strength of TPU increased by 26% with addition of 30 wt.% OPF frond powder. The impact strength of TPU increased by about 50 % by the addition of 30 wt.% of OPF frond fiber, while the flexural strength of TPU/OPF composites increased by about 86% by the 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 a significant improvement of mechanical properties of TPU/OPF composites. It can be concluded that both, 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 on the 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 the main industries in Malaysia, the oil palm plantation industry has its set back due to the large biomass waste produced. Although there has been a fall in the palm oil prices in the

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past five years that has reduced oil palm production [3], it is believed that the business will revive and be sustained again in the near future. However, the problem on the biomass waste produced will still persist. The main biomass waste from palm oil plantation are typically 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 in 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 reinforcements as well as wood powder or saw dust as filler in the development of polymer matrix composite has increased. This because they are readily available in 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 the huge amounts OPF wood waste from the palm oil plantation, the waste can have other added value if they can be used 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 the form of clear pellets without further treatment (Figure 1). The oil Palm Frond (Figure 2) was obtained from the local palm oil tree in Malacca, Malaysia. Three samples of three different contents of oil palm frond fiber and powder, 10wt%, 20wt.% and 30wt.%, respectively, were prepared as 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 was then pressed by using a pressing machine to obtain the fibers from the frond.

After the fiber was obtained from the frond, alkali treatment was done 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 is present in the fiber, the sample was placed into a drum dryer at 100°C for 6 hours to ensure the fibers were properly dried.

Short OPF fiber was used in this work, which was prepared using the cut 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 a crusher machine then sieved with a 60-micron mesh filter to separate the uncrushed fiber from the powder.

Haake internal mixer was employed to mix the fiber or the powder into the TPU matrix. The process took place at 60 rpm for 12 minutes at 190^0C. The extruded polymer composite was then crushed into pellet by using a plastic crusher machine. Further to this, the polymer composite samples were prepared and put into pellets of 200 mm (L) × 200 mm (W) × 3 mm (T) molds. The samples were pre-heated at 190°C for 7 minutes then the mixture was pressed at a 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 the 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.

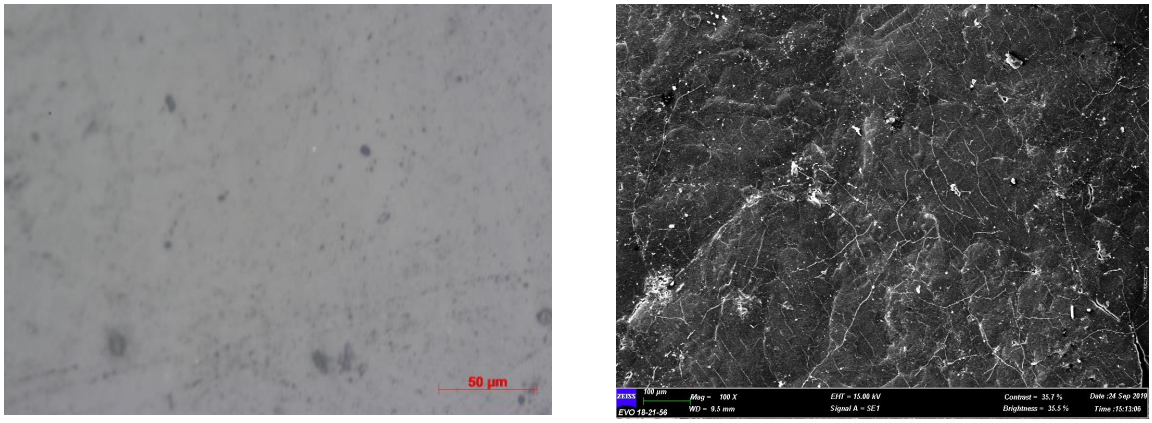
(a) (b)

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 the 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 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 using the powder size of 60 – 90 μm. Figure 6 to Figure 8 shows the 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 possess good bonding with the TPU matrix. Figure 9 to Figure 11 shows the morphology of TPU loaded with the OPF Fiber. The short fiber was 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.

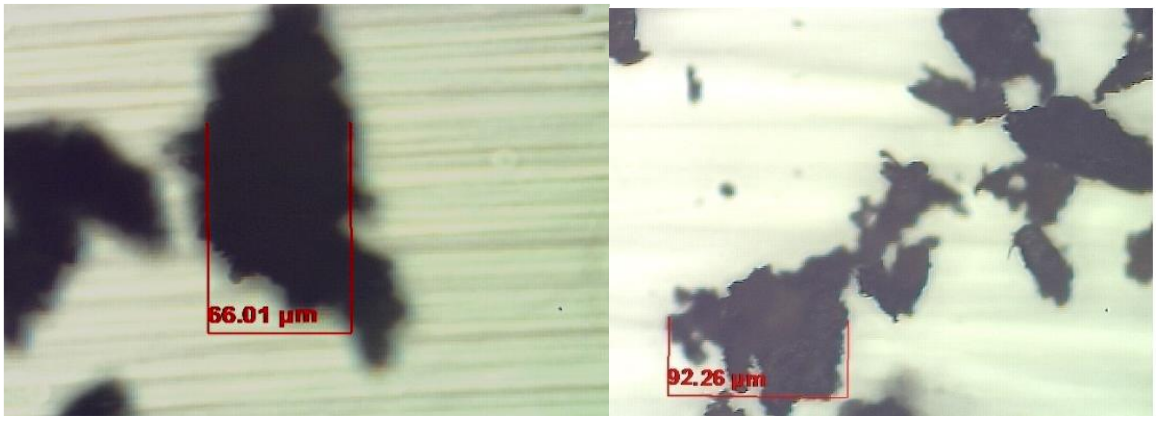
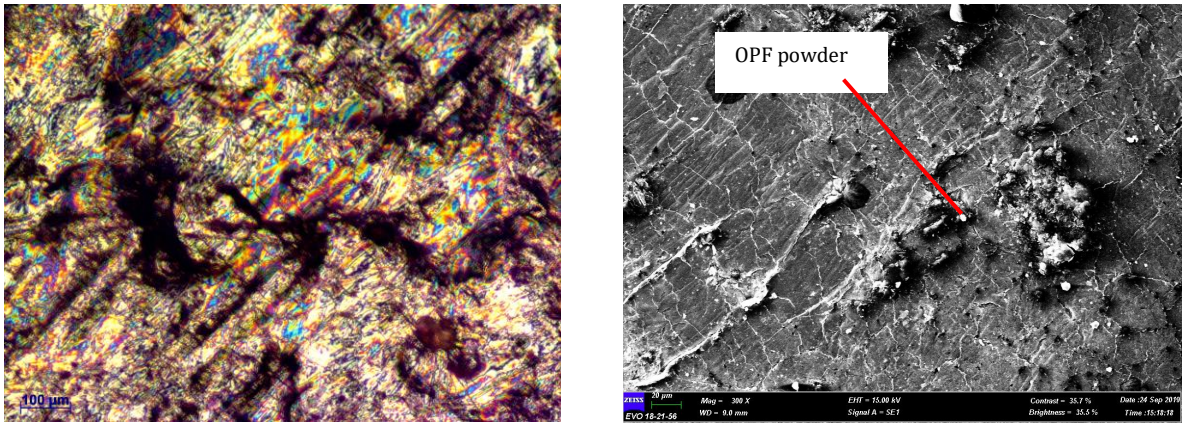
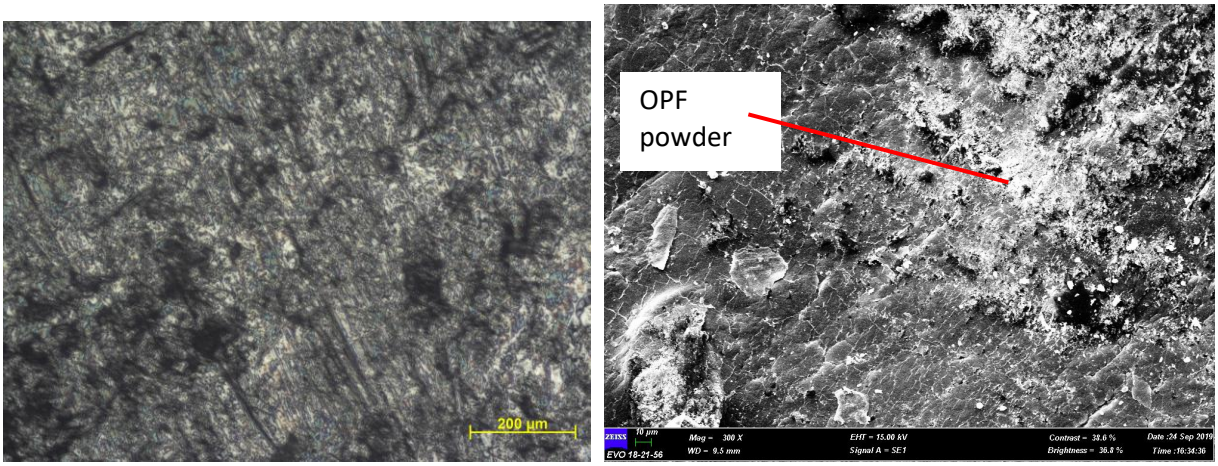


Figure 5. Micrograph of typical OPF dust in the samples obtained by Upright Microscope (20 ×).



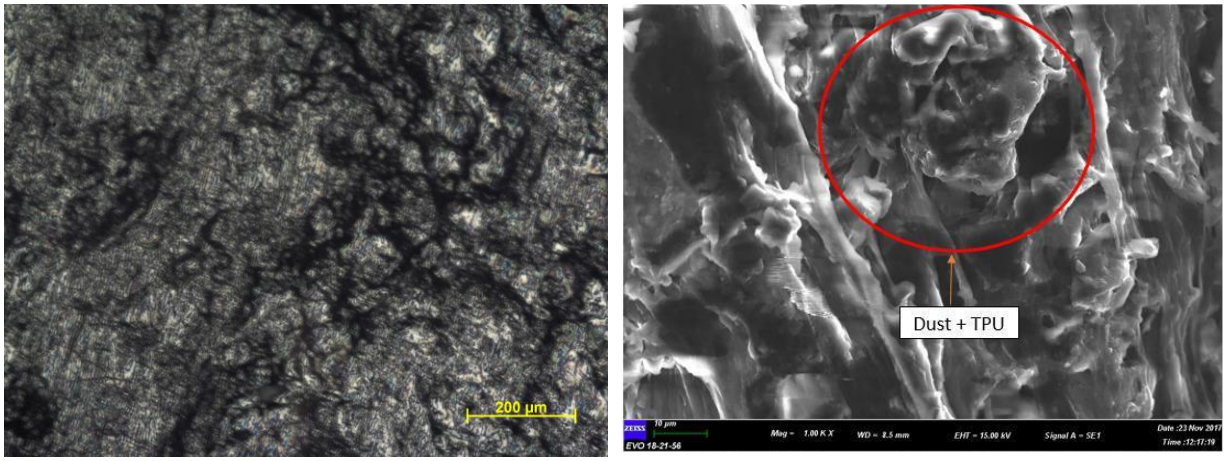
a. Upright microscope (10 X) b. SEM micrograph (300X)

Figure 6. Morphology of Sample 2.



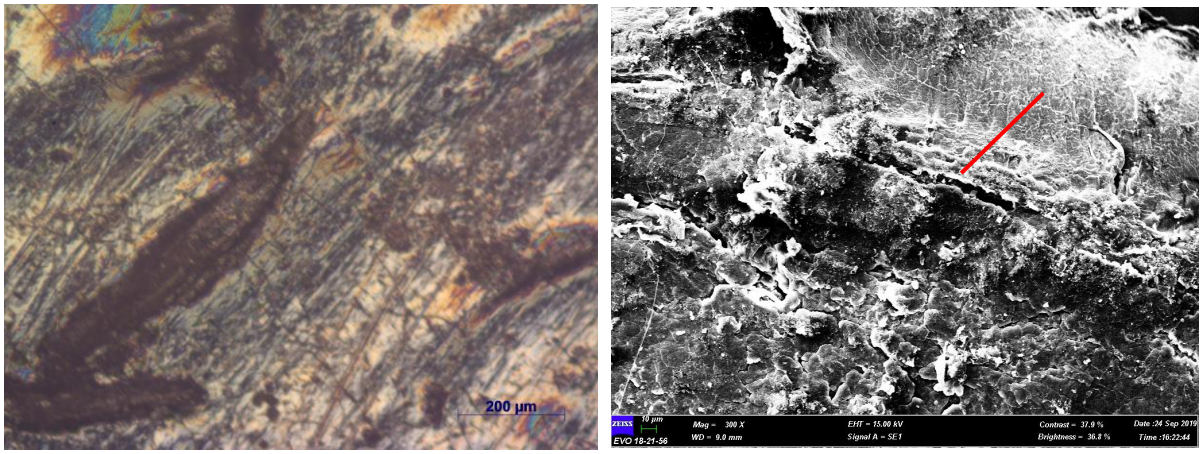
a. Upright microscope (10 X) b. SEM micrograph (300X)

Figure 7. Morphology of Sample 3.



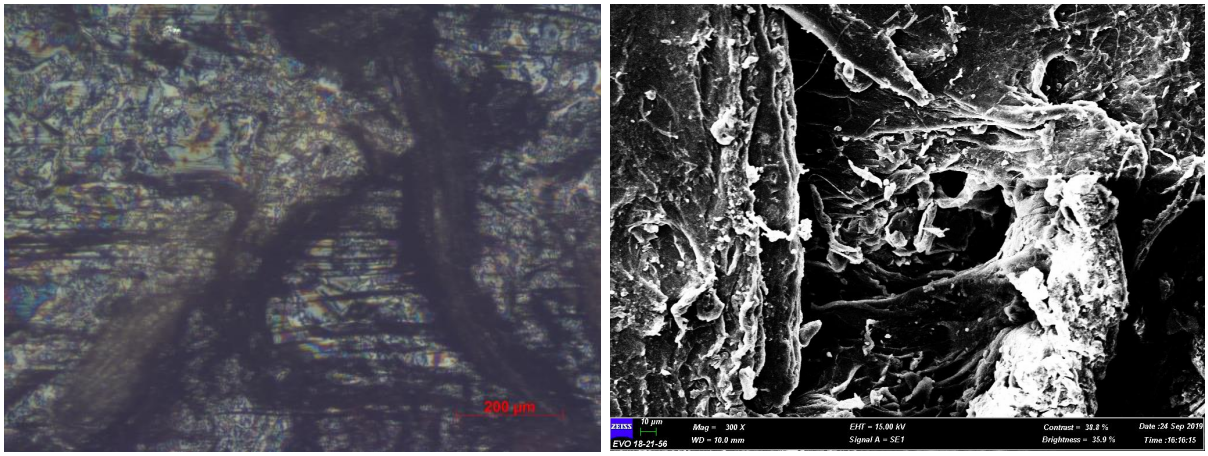
a. Upright microscope (10 X) b. SEM micrograph (1000X)

Figure 8. Morphology of Sample 4.



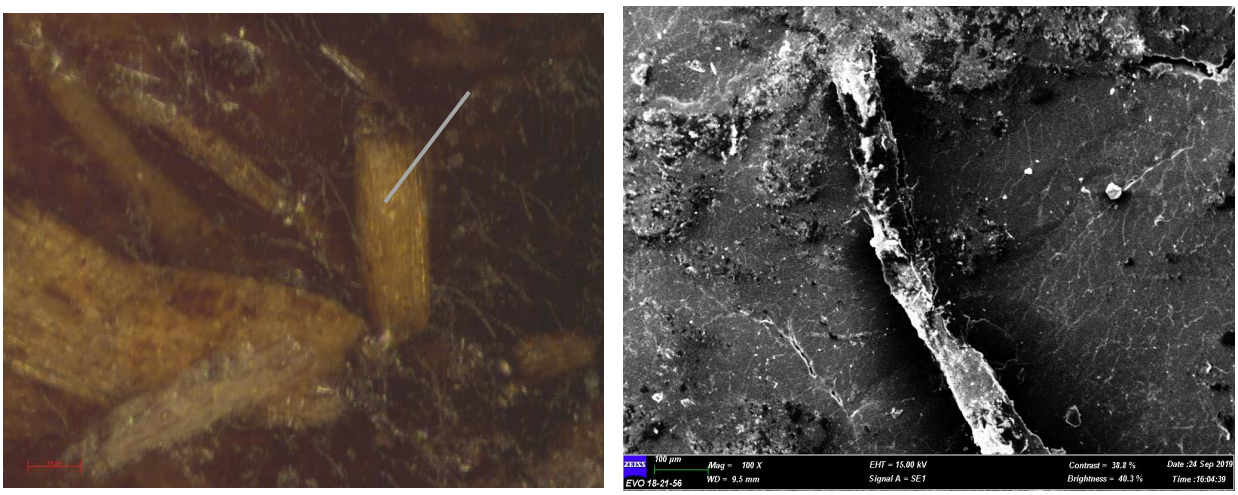
a. Upright microscope (10 X) b. SEM micrograph (300X)

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

Figure 13 shows the effect of OPF fiber and powder to impact properties of TPU measured at room temperature. The absorbed impact energy increased with fiber content as well as OPF powder. However, the addition of OPF fiber gives more impact

energy absorption improvement compared to the OPF powder. Initially, the TPU matrix possessed 4.1 J/m^3 impact absorbed energy. It is observed that the addition of 30 wt.% frond fiber significantly improved the TPU impact strength (50 % improved). In the case of OPF powder, the impact strength slightly increases by 10 wt.% and 20 wt.% of powder loading and significantly increased when 30 wt.% of OPF powder was added into the TPU matrix (29% increased).

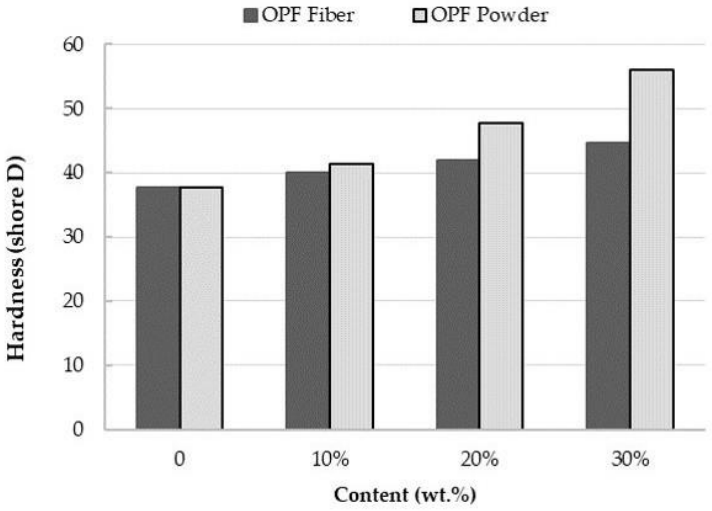


Figure 12. The effect of palm oil frond fiber and powder to hardness.

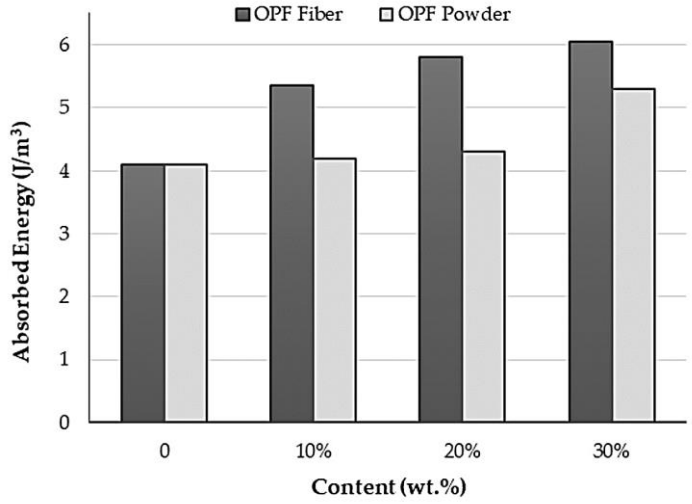


Figure 13. The effect palm oil trunk fiber and powder to absorbed impact energy.

The effect of OPF fiber and OPF powder to flexural strength of TPU is shown in Figure 14. Both, 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 provides a better flexural strength improvement for TPU compared to OPF powder. The OPF fiber significantly improved the flexural strength of TPU at 30 wt.% of fiber loading. The flexural strength improved by 86% due to 30 wt.% of OPF fiber loading. In the case of OPF powder loading, significant flexural strength improvement was only observed when the TPU was loaded with 30 wt.% OPF powder (74% improvement). Similar the tendency of improvement of the TPU flexural strength due to natural fiber addition, was also observed by Haghighatnia *et.al* [12] who studied the effect of hemp fiber to mechanical

properties of the TPU. They found that flexural strength of TPU was able to increase up to 274.3% due to the 40 %.vol hemp fiber with size of 15 mm addition to TPU.

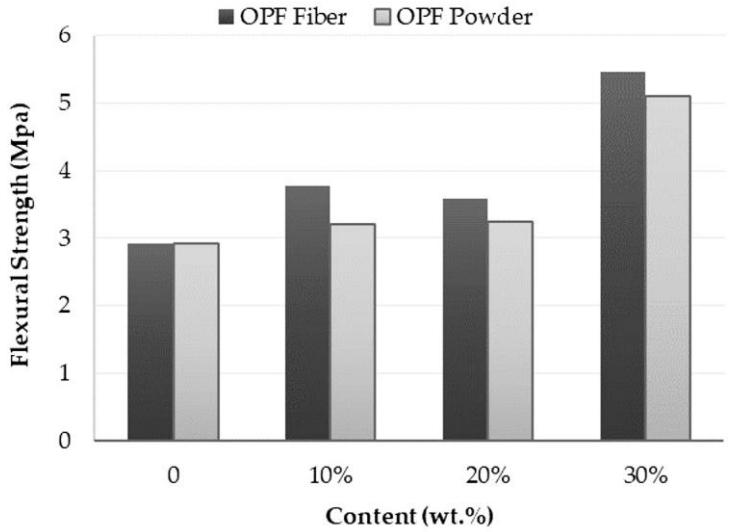


Figure 14. The effect palm oil trunk fiber and powder to flexural strength.

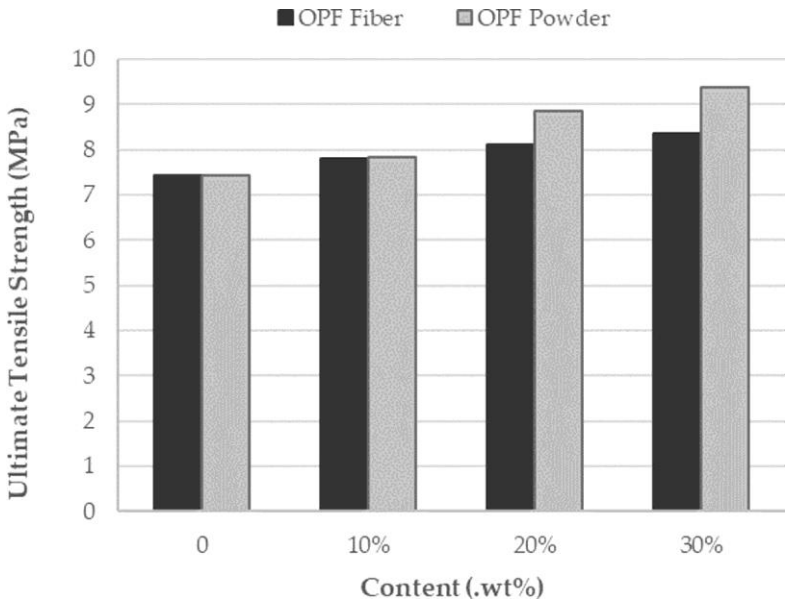


Figure 15. The effect of palm oil trunk fiber and powder to the ultimate tensile strength.

Figure 15 shows the effect of the OPF fiber and powder to the ultimate tensile strength (UTS). Both OPF fiber and OPF powder can improve tensile strength of the TPU. The higher content of OPF powder (20 wt.% and 30 wt.%) gives observable improvement to the tensile strength of TPU. Initially, the TPU matrix had its ultimate tensile strength of 7.45 MPa then the tensile strength of TPU 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] who studied the effect of oil palm trunk powder in TPU. They found that the tensile strength of polyurethane increased with the increase of the OPT powder content up to 20%. The OPF fiber slightly increased the UTS of TPU. The ultimate tensile strength of TPU increased by 12.5 % at a 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 improved TPU matrix. In addition, they concluded that fiber length, time and temperature of sample preparation as well as mixing speed are several factors that affect the tensile strength of TPU.

In the development of composite materials using fibers either organic or non-organic, as reinforcement, bonding interaction between the matrix and the fiber play an important role. Similar factors are 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 factors that affect 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 a better impact to TPU ~~since~~ as the powder has ~~a~~ better dispersion to fill the void between TPU cells to give a more 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 is also thought of as one of the factors that is responsible for the higher tensile strength of the TPU loaded with OPF powder compared to OPF fiber. The OPF powder may have been well engaged with the flexible TPU matrix which compact the structure of the matrix creating some reinforcing effect and possibly increased the hardness of the 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 the OPF filler compared to OPF fiber increase filler – matrix interaction and is responsible for improved hardness and UTS. Similar findings was also stated by Onuegbu & Igwe on their study on the effects of snail shell powder in the polypropylene [15]. In addition, a study by Pandey *et.al* indicates that the addition of the non-organic filler to TPU significantly improved tensile properties of TPU [16]. They found that the nanoclay filler loading show improvement in the elastic moduli of TPU that is consistent with increasing of filler content to reinforce the 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 the crack initiation that was more dominant compared to the effect of crack inhibition when tensile load was applied. This possibly relates to random fiber orientation used in this work which does not suffice to withstand the tensile load applied that leads to weak stress transfer from the matrix to fiber when load is 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 the case of impact strength, lower impact energy absorption shown by TPU loaded with low content of OPF powder is 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 the OPF powder was also observed. Although the high content OPF powder (30 wt.%) gives good flexural strength improvement, generally the OPF powder shows lower flexural strength improvement compared to OPF fiber. This is possibly fiber – matrix interaction that provides a great pressure resistance during bending [20].

4. CONCLUSION

Both, oil palm frond powder and oil palm frond fiber improved the mechanical properties of TPU. The loading of OPF powder to TPU show an improvement towards hardness and tensile strength of the TPU compared to OPF fiber. Hardness of TPU increases by 48% due to the addition of 30 wt.% of OPF powder to TPU and the tensile strength of TPU increased by 26% due to 30 wt.% OPF powder loading. However, the loading of the OPF fiber into TPU improved the impact and flexural strength of TPU compared to the OPF powder filler. The addition of 30

wt.% frond fiber significantly improved the TPU impact strength (50 % improved) and the flexural strength improved by 86% due to 30 wt.% of OPF fiber loading. These experimental results are believed to have been 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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