NATURAL FIBER LOADING EFFECTS ON TENSILE AND ELONGATION PROPERTIES OF THERMOPLASTIC POLYURETHANE (TPU) COMPOSITES

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ABSTRACT

Natural fibers of trees, fruit skins and so on are considered as recyclable and are used as filler materials in polymer composites. For decades, natural fibers have become the attention of researchers as an alternative to commercial, synthetic and costly fibers. Therefore, this study has used 10 types of natural fibers from local fruit waste parts in Malaysia, as fillers in TPU. This composite was produced via melt mixing technique, with different filler loading from 5wt% to 20wt%. Different types of natural fiber and its loading showed different mechanical properties results through tensile strength and elongation at break. Also, it is found that each of these natural fibers gives maximum tensile strength to the optimum loading between 5wt% and 10wt%. The composite with pineapple fiber is the composite with the highest tensile strength value at 5wt% filler load, as well as the most elastic composite with the highest elongation at break percentages.

Keywords: Tensile properties, Thermoplastic polyurethane, Natural fibers

1. INTRODUCTION

Over the past 20 years, natural fibers have received attention as filler in polymeric material to be a substitute for synthetic fiber, for the cheaper source. Natural fibers are usually selected as filler because it is readily available and environmentally friendly, inexpensive because they are waste, non toxic biodegradable and still have good characteristics for a variety uses. Due to this advantages, some of the natural fibers based polymer composites have already found applications in furniture manufacture, non-structural building applications and as interior parts in automobile industry [Emmanuel 2013].However, they also stated that the natural fibers are inherently incompatible and poor interfacial adhesion in such matrices due to poor wetting, hydrophilic nature of natural fiber and difficulty in mixing with the matrices. Most of the previous studies on natural fiber filled polymer composites have demonstrated that the increasing of fiber content the tensile properties are compromised and reduced. Also proved from a review by previous researchers [Taneli 2016, 2017], the drawbacks that reduce the potential for natural fiber as filler are the incompatibility between natural fibers and the polymer, their poor dispersion may compromise the strength and also the aggregates may form during processing.
Natural fiber can be combined with other material and for this study, the material chosen is thermoplastic polyurethane (TPU) to form a new composites. The formation of composites structure is dependent on the fiber and the TPU. The fibers are responsible for the strength and stiffness while the matrix provides the orientation that bonds the fibers. The main characteristics of the most important natural fibers however, are described in terms of their mechanical properties such as tensile strength, hardness [Nilza 2008] and the chemical composition of natural fibers vary between the distinct fiber types, but the most abundant chemical constituents are typically cellulose, hemicelluloses and lignin [Taneli 2016, Ahad 2017a, Ahad 2017b].

Each type of natural fiber will show different mechanical properties, as well as its loading as filler in the matrix. Composite industries have therefore looked for natural fiber such as flax, hemp jute, sisal and kenaf as alternative material [Amir 2017]. Non-wood fibers from agricultural and plant can be classified into trunk/stem/frond, bast, straw., leaf, seed/fruit and grass [Manshor 2014, Amir 2017]. Table 1 listed all the natural fibers used in this study. This study is an effort to survey on mechanical properties of various natural fibers from agricultural sources, in TPU. As a matrix material, TPU is used because of it is one of the polymer which very useful and commercially used widely in industry and daily life. Also, TPU is described as “bridging gap between rubber and plastic” [Ahad 2015].

The authors continued our previous research in studying regarding the potential of all ten types of natural fibers to replace standard materials in use today and also the cost saving thus achieved. In this work, we intend to explore the potential of natural fibers as filler in TPU composites through their mechanical properties, the fiber type and its loading.

2. MATERIALS AND METHODS

Thermoplastic polyurethane (TPU) in pellet form was supplied from Duplas Marketing Sdn. Bhd. The local fruits and its waste were listed in Table 1, as they are coconut (shell, husk and residue from flesh), pineapple (leaf), mangoesteen (rind), banana (peel), corn (cob), rambutan (rind), sugarcane bagasse (stem) and durian (skin) were collected from market, stall and village. The wastes were washed, dried under the sun and grinded using grinding machine to produce fibers in the small size between the ranges of 50 to 125 μm.

<table>
<thead>
<tr>
<th>Natural fiber</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane</td>
<td>Baggase-Stem</td>
</tr>
<tr>
<td>Coconut husk</td>
<td>Husk-Fruit</td>
</tr>
<tr>
<td>Coconut shell</td>
<td>Shell-Fruit</td>
</tr>
<tr>
<td>Coconut residue</td>
<td>Flesh-Fruit</td>
</tr>
<tr>
<td>Durian</td>
<td>Skin-Fruit</td>
</tr>
<tr>
<td>Banana</td>
<td>Peel-Fruit</td>
</tr>
<tr>
<td>Mangoesteen</td>
<td>Rind-Fruit</td>
</tr>
<tr>
<td>Rambutan</td>
<td>Rind-Fruit</td>
</tr>
<tr>
<td>Pineapple</td>
<td>Leaf</td>
</tr>
<tr>
<td>Corncob</td>
<td>Cob-Fruit</td>
</tr>
</tbody>
</table>

Table 1: Ten types of natural fiber as filler in TPU
The composites were prepared by melt mixing technique using internal mixer. The composition of TPU and natural fibers are 100/0, 95/5 90/10, 85/15 and 80/20. The melt mixing were carried out at temperature 180°C with mixing speed of 60 rpm for 10 min [Ahad 2017]. The composites sheet then cut into dumbbell shape for tensile testing according to ASTM D638. The purpose of this test is to measure tensile strength and elongation at break because the mechanical characteristics of a polymer composite filled with natural fiber are mainly result of the quantity and fibers type, besides the interfacial strength between the filler and matrix [Otto 2017].

3. RESULTS AND DISCUSSION

The variation of tensile strength and elongation at break with varying fiber type and fiber loading are presented in Figure 1 and Figure 2. It was clearly evidence that with increasing the fiber loading in TPU, the tensile strength is decreasing, for all the natural fiber types. However, it is interesting to note that, each type of natural fiber we can identify at which load is the optimum in the TPU matrix. As we can be seen from the plot in Figure 1, it is clear that there are two categories of natural fiber groups. Groups with high tensile strength are pineapple, coconut shell, coconut husk and corn cob. Tensile strength of them is around 16MPa to 35 MPa. The other group was sugarcane, banana, mango, rambutan, coconut residue and durian, with the range of tensile strength between 2 MPa to 7 MPa.

Then, most natural fiber provides the highest tensile strength reading on fiber loading between 5wt% and 10wt%. Sugarcane, durian pineapple, mango, rambutan showed highest tensile strength at 5wt% loading of its fibers, and coconut husk, coconut shell, coconut residue and banana reached highest tensile strength at 10wt% fiber loading. The superior mechanical properties of those natural fibers are associated with its high cellulose and lignocelluloses [Ahad 2017]. Among various natural fibers, pineapples exhibit excellent mechanical properties and this also proved by Indra [2018]. The coconut shell particle size and shape are vary and they can sorted into three main groups- prismatic spherical and fibrous [Sarki 2011]. Mechanical properties of the natural fillers composites depend on several factors such as the stress-strain behavior of fillers and matrix phases, the phase volume fractions, the fillers concentration, the distribution and orientation of the fillers relative to one another [Sarki 2011]. According to Kuburi [2017], the coconut fibers have high lignin content. Lignin not only holds the materials together but also acts as a stiffening agent for the cellulose molecules within the material cell wall. Lignin and cellulose content of coconut coir have increased the tensile strength of the composites.

Youssef [2015] found that the tensile strength increased with increasing corn cob content up to 10% and then slightly decreases. The decreasing of tensile strength with high fiber content may due to inability to matrix TPU holds fiber content that exceeds its optimum value [Shah 2012]. Sarocha 2014 stated that the optimized durian fiber content in HDPE is 10% and the tensile strength of their composites is poor. This is due to difficulty in proper dispersion of durian fiber and random fiber alignment in the matrix. The agglomeration of durian fibers that caused by inefficient durian fibers dispersion inside matrix was responsible by decrease of the tensile strength. Mahir 2016 has studied rambutan peel fiber filled natural rubber. They reported that, tensile strength of the composite decreased with the increasing of rambutan fiber loading. NR has high strength and with the addition of filler into the compound, the natural tendency of regular arrangement in rubber was disrupted. The decrement in tensile strength with more addition of filler may also due to poor rubber-filler loading bonding
caused by the hydrophobic rubber and hydrophilic natural filler nature and the tendency of fillers to agglomerates, consequently limit stress transfer from rubber matrix to fillers.

According to the study by Ibrahim [2010], the strength of composites contain banana fiber increased was the fiber content increases until 40% of loading. Mention also, the mechanical properties of particulate-polymer composites depend strongly in the particle size, particle-matrix interface adhesion and particle loading. On the other hand, the strength of a material is defined as the maximum stress that the material can sustain under uniaxial tensile loading, the agglomerated filler due to uneven distribution can attributed to lower mechanical properties. For mangoesteen and coconut residue, no studies can be used as evidence to prove that with the increasing fiber loading, the mechanical properties of the composites are reduced. However, it can be concluded that the cause is about the agglomeration, poor dispersion of fibers and weak filler-matrix interaction.

Generally we can conclude that, the natural fibers present some drawbacks such as incompatibility between fibers and matrices, the tendency to form aggregates during the processing and the poor resistance to moisture [Cerqueira 2011]. Despite the attractiveness of natural fibers in polymer matrix they suffer from lower strength [Indra 2018]. The increment in tensile strength is due to the better-increased surface area of filler in matrix but up to optimum loading only. Further than that the increasing of interfacial area, there was poor interfacial bonding between the hydrophilic fiber and the hydrophobic matrix polymer, which lead to decreased in tensile strength [Sarki 2011]. The mechanical characteristics of a polymer composite filled with natural fiber are mainly result of the quantity and fibers type, besides the interfacial strength between the filler and matrix [Otto 2017].

**Figure 1: Tensile strength of the various natural fiber filled TPU composites**

It is generally known that composites materials depend more on matrix to absorb the impact energy. In reinforced composites, the presence of fiber is also expected to absorb the energy through mechanical friction, fiber pull-out and debonding of the fiber from the matrix. The utilization of short fibers tends to reduce the elongation at break thus reduce the impact...
absorbing energy. The finding is also reported on the decrement of tensile strength with filler content. This can be attributed to the poor interfacial bonding which induces micro spaces between filler and matrix thus causing micro crack [Manshor 2014].

**Figure 2: Elongation at break of the various natural fiber filled TPU composites**

In Figure 2, it is observed that almost all composites have decreased the elongation at break as the fiber loading is increased. Elongation at break also known as fracture strain is the ratio between changed length and initial length after breakage of the composite. It expresses the capability of the composites to resist changes of shape without crack formation. Here we can see that, the addition of natural fiber reduced the elasticity of the composites. Somehow, the filler might behave not as reinforcement but defects in the matrix.

Albeit it is good performance of natural fiber due to it’s low cost, low density, biodegradable and environmentally friendly, there is known challenge with the low tensile strength as filler in polymer matrix. Also, the restrictions in presence as filler in composite for a certain percentage only, beside somehow the researcher need to consider the other factor such as agglomeration, filler-matrix interaction, the dispersion of filler and the compatibility between the nature of natural fibers and the nature of polymer matrix.

**CONCLUSION**

The natural fiber filled polymer composite has attracted the attention of researchers and it has many advantages in terms of environment (biodegradable and recycle principle of waste) and low cost. Among the 10 types of natural fiber used in this study, pineapple is a natural fiber that is considered most suitable as filler in TPU as it provides the highest tensile strength value even in low filler content of 5wt% only. It can also be concluded, every type of natural fiber as filler in TPU composites will show different mechanical properties. It actually depends on the type of fiber, fiber shape, fiber size, besides the effects of blending process which caused poor or good dispersion of filler, agglomeration that may occurred, weak or strong bond between the filler and the matrix.

**REFERENCES**


