Mechanical and water absorption behaviour of palm seed particles based hybrid bio-composites

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Abstract: In the recent decades, many scholars and researchers are interested in natural fibres today because they are inexpensive, widely available, and easy to process compared to conventional fibres. Due to environmental awareness and growing concern over the greenhouse effect, the construction, automotive, and packaging industries are also looking for eco-friendly materials that can replace conventional synthetic polymeric fibres. Alpaca fiber (AF), palm seed filler (PSF), and polypropylene (PP) were combined in this investigation to create composites that outperformed traditional polymer composites in terms of properties. Polypropylene (PP)/Alpaca fibre/palm seed composites with a filler content of 20 wt. % were found to be more promising than PP/Alpaca fibre composites.

Keywords: Hardness, flexural strength, alpaca fiber, Natural fiber, Water Absorption.

1. Introduction
Growing demands of environmental awareness in the recent era promoted the use of renewable resource in numerous application of lightweight materials gained the attention of researchers in the industries. Natural fibres is considered as alternative for the current material research possessing beneficial to the selected structural application in automotive and other material processing industries. However, the natural fibres shows lower rate of mechanical performance than the synthetic fibre composites. Current demerits of the natural fibre composite restricts the application of structural components to a minor mechanical loading. Hybridization is the next step of the development stage with combining the one fibre composite to the another to develop a new individual fibre composite possessing better mechanical properties under varying environmental condition [1-3]. Protein-based waste materials (such as fibres, feathers, horns, and nails) amount to more than 5 million tonnes annually. Most of the waste protein-based materials come from the poultry industry and the protein
fiber-based textile industry. Waste from these industries is also not properly disposed of, and is instead disposed of in landfills or burned [4]. In addition to softness and warmth, these animal protein fibres are biodegradable, fire resistant and have a higher strength and moisture absorption rating [5-7]. These waste protein materials can be used, therefore, to produce green bio-composite fibres for their sustainable application. When it comes to the creation of biobased composite fibres, natural cellulosic materials are widely used, but proteinaceous fibres have been largely overlooked. The use of protein fibres in composite films for biomedical and other applications has been studied in the literature, but composite fibres based on protein materials have been reported very rarely [8]. Polyvinyl alcohol (PVA) and polyethylene oxide (PEO) were used to blend keratin, the biopolymer found in protein fibres, to create composite fibres (PEO). In comparison to their synthetic counterparts, keratin was found to have a higher capacity for absorbing heavy metal ions [9-11]. In recent years, biodegradable polyester and polypropylene (PP) have been used to make composite fibres with a maximum loading of wool fibres (60 percent) [12]. Fibers made from poly (lactic acid) were created from feathers from chickens, another source of keratin [13]. Toxic and hazardous organic and inorganic chemical solvents are used in all of these processes to extract keratin from the fibres, which is harmful to the environment. As the alpaca content increased, this decrease in mechanical properties grew even more pronounced. Compared to fibres made with 10 and 20 per cent of alpaca, composite fibres with 30 per cent alpaca had lower mechanical properties [14-20]. Palm seed fillers were added to alpaca/polypropylene composite fibres to improve their mechanical properties.

2. Materials and Methods

2.1 Composite preparation

Prior to mixing, alpaca fibre and palm seed fillers (less than 100 m in size) had to be dried for 10 hours. To compare the effects of compounding techniques on mechanical properties, alpaca fibres of 35, 30, 25, 20, 15, and 10 weight percent and palm seed fillers of 0, 5, 10, 15, and 20 weight percent were used. Two techniques were used for compounding the materials: an internal mixer and a twin-screw extruder. After loading all components into the internal mixer, they were mixed for 15 minutes at 80 rpm at a temperature of 190°C. This was done at a screw speed of 80 revolutions per minute for the twin screw extruder. There were four zones of extruder temperatures set at 180°C (first), 185°C (second zone) and 190°C (third zone) (at die). Figure 1 depicts the twin screw extrusion and hot injection moulding processes schematically.

![Figure 1. Twin screw extruder schematic arrangement](image)

2.2 Mechanical Testing

The fabricated composite samples were cut to the desired shapes for different test specimens using a saw cutter. A UTM was used to perform flexural tests at room temperature. According to ASTM D790-10 standard, the flexural test was performed using a three-point bending method with a 400-kN
capacity and a 3 mm/min crosshead speed for all specimens that were 130 mm long, 13 mm wide and 5 mm thick. Vickers Micro Hardness tester was also used to measure hardness in accordance with ASTM 2583 standard.

2.3 Water Absorption Behaviour
Bio-composites produced in accordance with ASTM D570-99 standard were evaluated for water absorption. To begin, the specimens were dried in a 90°C oven until they reached a uniform weight. In normal water for 72 hours, five replicas of each specimen were immersed in the solution. A known weight of each specimen was immersed in water for 48 hours one after the other. Water on the specimen surface was removed with absorbent paper. The specimen's weight was determined immediately. The weight difference between dry specimens and specimens immersed in water was used to calculate the water absorption percentage using equation 1.

\[
\text{Percentage of Water Absorption} = \left( \frac{W_A - W_B}{W_B} \right) \times 100
\]

In this case, \( W_A \) is defined as the specimen's weight after testing, and \( W_B \) as the specimen's weight before testing.

3. Results and Discussions

3.1 Flexural Properties
Figure 2 shows bending test results obtained on variations in the flexural characteristics obtained for the palm seed/Alpaca fiber/Polypropylene (PP) composites, with the effect of fiber/filler loadings.

![Image of flexural properties graph](image)

**Figure 2.** Effect of fiber/filler loading on Flexural Strength PP/AF/PSF composites

Its flexural strength and flexural modulus were 92 MPa and 5.9 GPA, respectively. Figure 3 shows all composites' flexural modulus variations. With filler loadings of 5, 10, 15 and 20 wt, the composites' flexural strength increased. This is a significant improvement over pure Polypropylene (PP)/Alpaca fibre specimens by more than 100 percent. The flexural modulus also followed the same trend and it increased with an increased palm seed filler content. The flexural strength of the palm seed/Alpaca fiber/Polypropylene (PP) composites increased as the filler content increased compared to the pure Polypropylene (PP)/Alpaca fibre composite specimen. It was evident that 15 wt. % and 20 wt. % of palm seed/Alpaca fiber loaded composites produced an increased flexural strength of 39 and
59 % higher than pure Polypropylene (PP)/Alpaca fiber composite specimen respectively. Then, a decreased trend was evident from the test results obtained beyond the 20 wt. % filler loadings. A severe increase in flexural strength was observed in 20 wt. % of the palm seed loading. The flexural strength was 40 % higher than the pure Polypropylene (PP)/Alpaca fiber reinforced composites for the filler loading of 0 wt %.

![Figure 3. Effect of fiber/filler loading on flexural modulus PP/AF/PSF composites](image)

The optimum flexural strength of 20 wt.% palm seed/Alpaca fiber reinforced composite was 149 MPa, and it was about 40 % higher than that of Polypropylene (PP)/Alpaca fiber reinforced composites. Admittedly, the flexural modulus was observed to be highest for 20 wt.% filler loading. There was a sinusoidal decrease in flexural strength with filler loadings higher than 20 wt.%, due to the agglomeration and incompatibility between higher quantity of palm seed filler and Polypropylene (PP). Furthermore, it can be significantly observed that the trend of flexural strength of palm seed/Alpaca fiber reinforced composites was similar to the tensile strength for various filler loadings. Figure 4 shows flexural stress-strain curves of the palm seed/Alpaca fiber /Polypropylene (PP) composites with different filler loadings.
Figure 4. Flexural strain vs flexural stress curves for PP/AF/PSF composites

3.2 Vickers Micro Hardness
Figure 5 depicts the Vickers micro hardness values of the palm seed/Alpaca fiber /Polypropylene (PP) composites with respect to different filler loadings. It was inferred that the palm seed filler was well dispersed all over the matrix and produced an excellent surface roughness. With an increase in filler loading of up to 20 wt. percent, the hardness of the material increased accordingly. The hardness was 33 for the Alpaca fiber/Polypropylene (PP) composites. In particular, the hardness for 20 wt.% addition of palm seed increased by 43 percentage than that of the Alpaca fiber/Polypropylene (PP) composites. A similar trend of results was followed by many researchers, as reported on rice husk reinforced with polyester and epoxy.

Figure 5. Effect of fiber/filler loading on Vickers Micro Hardness for PP/AF/PSF composites

Admittedly, an increasing values of hardness property was produced by increasing the filler loadings, especially between 0% (neat Polypropylene (PP) with no filler) and 20 wt.% (Figure 5).

3.3 Water Absorption Behaviour
Figure 6 shows the percentage of water absorption curves for the palm seed/Alpaca fiber /Polypropylene (PP) composites; with average data of three specimens of different filler loadings after immersing the composite specimens in normal water. On the basis of Figure 6, it is clear that an increase of the filler loading in composites leads to an increase of the water absorption percentage. A
similar trend was observed in different natural filler/fibre reinforced composites. There was no water absorption for the pure Polypropylene (PP) at aforementioned four different environments, due to the hydrophobic nature of the Polypropylene (PP).

![Figure 6. Variation of water absorption properties for PP/AF/PSF composites](image)

Due to the presence of micro voids in composites, palm seed/Alpaca fiber/Polypropylene (PP) composites absorbed more water than the other five fiber/filler combinations. At filler loading of 20 wt.% and above, the palm seed/Alpaca fiber /Polypropylene (PP) composites contained a lesser amount of matrix, and this led to an increase in the formation of voids. However, lowest water absorption was recorded with pure Polypropylene (PP)/Alpaca fiber when compared with other five combinations, because of the absence of palm seed molecules in the particular composite specimens. The slow penetration of large molecules into the composites produced a smallest moisture absorption percentage.

4. Conclusions
The effects of filler loading on flexural, hardness and water absorption properties of polypropylene (PP)/Alpaca fibre composites were successfully investigated in an experimental study. From this analysis, the following conclusions can be drawn.

- The Vickers micro hardness of the Polypropylene (PP)/Alpaca fiber composites was 56 and addition of palm seed loading of 20 wt.% increased it by 40 % than that of the Polypropylene (PP)/Alpaca fiber composites.
- Furthermore, the water absorption test showed that the lowest and highest percentages of water absorptions were recorded in 0 wt.% and 25 wt.% of palm seed filler weight percentage respectively. In addition, the percentages of water absorption increased as the filler loadings were increased.
- The flexural strength and hardness of the Polypropylene (PP)/Alpaca fiber/palm seed composites increased by 40 and 43 %, respectively. Polypropylene (PP)/Alpaca fiber/palm seed composites with a filler content of 20 wt.% were found to be more promising than PP/Alpaca fibre composites.

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