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Tensile Properties of Luffa Acutangula Reinforced Polymer Composite

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Abstract: In recent years, there has been a growing trend in the popularity of natural fiber-reinforced polymer composites (NFRPC). Numerous researchers have put forward various alternatives to synthetic fibers. Luffa is one of the many natural fibers can be integrated into NFRPCs. Luffa with its unique interconnecting branch (mat/mesh) is suitable for NFRPCs. In this study, luffa reinforced high-density polyethylene (Luffa/HDPE) composite was fabricated using compression molding machine. In the preparation of the fiber, Luffa were cylindrically cut-out and opened into sheets form. The fiber was then laminated with high-density polyethylene (HDPE) film using compression molding method. The proposed fabricated composite consisting of a fiber volume fraction (FVF) of 7%, 14%, 21%, 27% and 30%. Tensile properties of the Luffa/HDPE composite were determined. SEM was used to study the interlamination and delamination of the composite. Tensile test shows that the increase of FVF enhanced the tensile strength of Luffa/HDPE composite. Tensile strength has gradually increased from 7 % to 21 % FVF. Though, tensile strength declines after 21% FVF.

Keywords: Natural fiber, tensile, Luffa, NFRP

1. Introduction

In this study, Luffa was used as fiber reinforcement in the natural fiber reinforced polymer composite (NFRPC). Current trends in the composite industry suggest the replacement of synthetic fibers for natural fiber as it is safer for human health and environment. The cost to produce NFRPC is far economical compared to synthetic fibers. A study carried out in 2013 shows that when synthetic cotton was manufactured, the synthetic fiber cause irritations and in the long term induce lungs and skin cancer to the workers [1]. Plastic waste is a problem to the environment. Since 2018, 3,300 metric tons were dumped on daily basis in this country. The waste consists of 45 % organic and food waste, while plastic took up 13 % of the statistics. Despite the recycling awareness, only 17.5 % of citizens recycled their waste [2].

Luffa acutangula or *Luffa cylindrica* has been known to be a type of vegetable, it has been more of a remedy for gastric and diabetes for some cases [3]. It can be grown in all-warm weather countries and mostly found in Asia. Some other warm weather countries have been commercializing luffa and mostly used for replacing dish washing sponge, bath scrub and shoe insole. Currently, studies have made on chemical constituents, aging and, structural and mechanical properties [4-6]. A tensile test study was done on luffa fiber itself ranges between 10 MPa to 50 MPa. Due to the high specific strength of luffa, it can be used as a good fiber reinforcement material [7,8]. The aim of this study is to investigate the tensile properties of Luffa/HDPE composite.

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2. Materials and Method

2.1 Materials

Luffa was used as the fiber reinforcement material in this study. Luffa was obtained from the rural area in Sarawak where it is widely planted by local farmers. The physical and chemical composition of luffa in this experiment were pre-determined by other researchers [8,9]. Luffa density ranges between 0.87-0.97 gcm^{-3}. The average luffa density is 0.92 gcm^{-3} [11]. Bulk densities were used to determine the approximate density of the luffa fiber used in this study. The outer ring was used as the fiber reinforcement material as in Fig. 1. High-density polyethylene (HDPE) is used as matrix in the composite fabrication. HDPE was purchased from the local plastic industry.

2.2 Fiber Extraction

Luffa fibers were cut open cylindrically. The outer ring of the luffa was taken as the fiber reinforcement [8] as shown in Fig. 1. Luffa used in this experiment was not chemically treated. The dimension of the fiber was cut to a dimension of 250 mm × 250 mm. The outer ring was flattened to ease the fitting in the mold for fabrication.

(a) (b) (c)

Fig. 1 - (a) Extracted raw luffa fiber; (b) the outer ring of luffa was disected to spread the into flat sheets; (c) the inner core was removed and outer ring is ready for fabrication

2.3 Fabrication of Composites

Fabrication of luffa reinforced HDPE (Luffa/HDPE) polymer composite include polymer and fiber preparation followed by compression molding process. HDPE films with approximate thickness of 0.022 mm were trimmed into the mold dimension of 250 mm × 250 mm. A total of 150 ply of HDPE films were used in the fabrication making of samples to at least 3 mm in thickness. Luffa fibers were prepared in the dimension of 250 mm × 250 mm. The compression molding fabrication temperature was set to be 160 ºC at 3 MPa. The stacking sequence of Luffa/HDPE composite were prepared according to as shown in Table 1.

Table 1 - Luffa reinforced HDPE composites

Sample	Matrix volume fraction (vol%)	Fiber volume fraction (vol%)	Stacking sequence of Luffa (L) and HDPE (#)*
C0	100	0	150
C1	93	7	75/L/75
C2	86	14	50/L/50/L/50
C3	79	21	38/L/37/L/37/L/38
C4	73	27	30/L/30/L/30/L/30/L/30
C5	70	30	25/L/25/L/25/L/25/L/25/L/25

**** L – Luffa, # ply of HDPE***

2.4 Tensile Testing

Tensile samples were cut into a dimension of 250 mm × 25 mm. Tensile test were performed according to ASTM 3039/3039D using Shimadzu universal testing machine Model AG-50kN IS MS at a crosshead displacement rate of 10 mm/min. Five (5) samples from each type of laminated composite were tested to attain an average value for the respective composite. From the results, tensile strength, tensile modulus, specific tensile strength, specific tensile modulus was determined.

3. Results and Discussion

Fig. 2 (a) shows the graph of tensile strength (MPa), (b) tensile modulus, (c) specific tensile strength and (d) specific tensile modulus with respect to fiber volume fraction (FVF%). The tensile strength of neat HDPE was approximately 19.78 MPa. Luffa/HDPE with 7% and 14% FVF having tensile strength of 19.54 MPa (- 1.20 %) and 19.16 MPa (- 4.90 %), a slight decline from neat HDPE value. However, tensile strength at 21% shows the peak tensile strength at 21.30 MPa (+ 7.70 %). Tensile strength of Luffa/HDPE with 27 % and 30% FVF drop to a value of 20.27 MPa (+ 2.48 %) and 20.09 MPa (+ 1.57 %). From the data, the highest tensile modulus for Luffa/HDPE composite was at 30% FVF with a tensile modulus of 912 MPa and the lowest was 230 MPa at 7 % FVF. The result of the tensile test shows that the higher the FVF, the higher the tensile strength of the composite and thus a higher force needed to break the composite [12]. Tensile modulus for 14 %, 21 % and 27% reached up to 362 MPa, 759 MPa and 842 MPa respectively. The trend for specific tensile strength and specific tensile modulus follows the tensile strength and tensile modulus due to density of the composite from 7 % up to 30 % is at 1047 to 1065 kgm^{-3}.

In a study done on Luffa reinforced thermoplastic composite, fiber loading does increase the tensile strength due to the strength interaction between fiber and matrix bonding [5, 10]. This is due to the fiber preparation and orientation proved to have a great influence on the tensile modulus [4]. When the matrix – fiber ratio is optimized, the optimum tensile strength is achieved. Beyond the optimum FVF, HDPE matrix will not be able to bond the fiber reinforcement sufficiently. However, thermoplastic matrix can achieve a good bonding with FVF Luffa less than 40 %, exceeding that and reaching 50 % FVF the tensile strength will decrease drastically as the matrix is insufficient to bond with the fiber [11, 12].

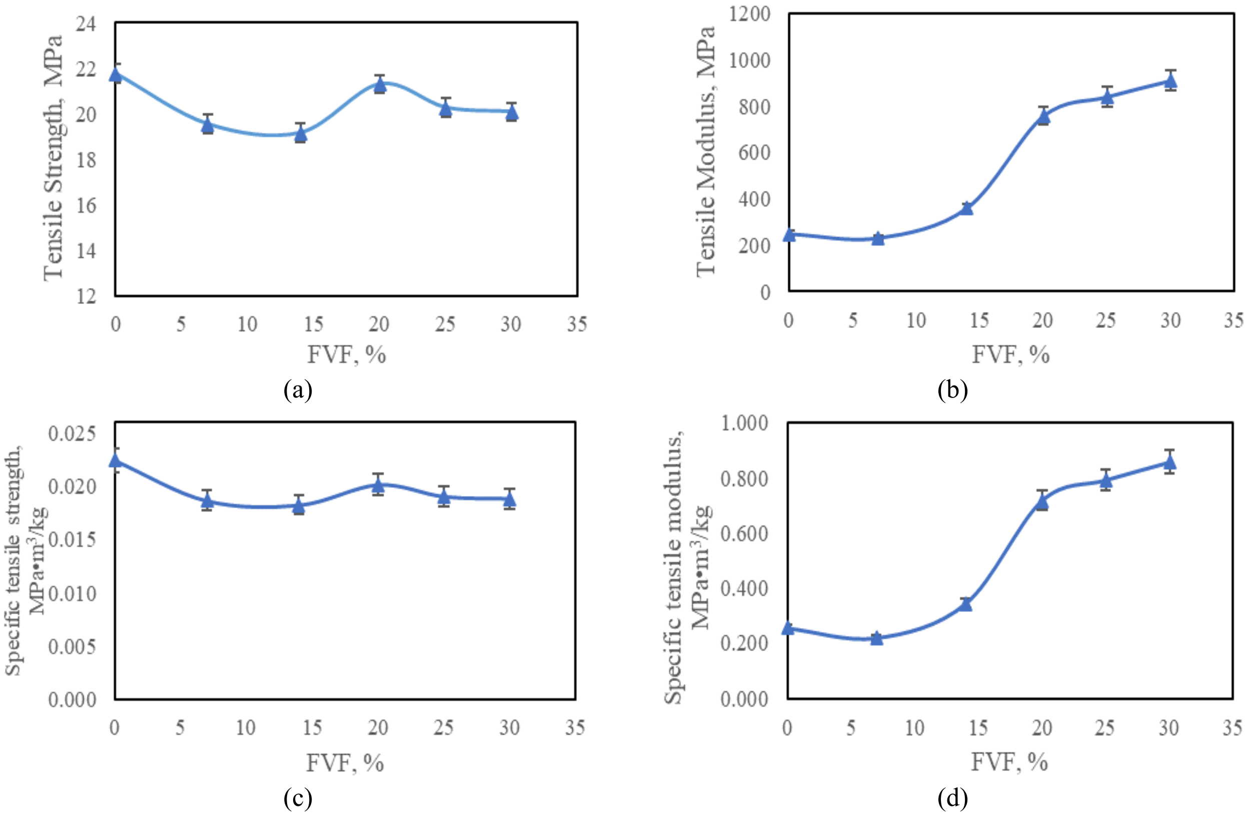

Fig. 2 - (a) Tensile strength (MPa); (b) tensile modulus; (c) specific tensile strength and; (d) specific tensile modulus with respect to fiber volume fraction (FVF, %)

Fig. 2(c) shows the specific tensile modulus also known as strength to weight ratio. All Luffa/HDPE composites shows quite similar in term of value. Neat HDPE having 0.022 MPa•m^3/kg and a slightly lower value for 21 % FVF at 0.020 MPa•m^3/kg. This proves that the composite having a consistent strength to weight ratio despite an increase in FVF. The trend for specific tensile modulus follows tensile modulus as the composite densities were quite similar as shown in Fig. 2(d). Fig. 3 shows stress-strain graph following tensile stress at a crosshead displacement rate of 10 mm/min. From the curve, increasing FVF cause the Luffa/HDPE composites to be more rigid. As can be seen that neat HDPE shows ductile properties, exhibiting a non-linear response with the stiffness decreasing with increasing strain. For Luffa/HDPE composite, localized plasticity takes place between the fibers and the loading direction, thus leading to a knee in the stress-strain curve. The stiffness trend of the composites remains similar upon reaching the peak, then drastically drops to breaking point [12, 13].

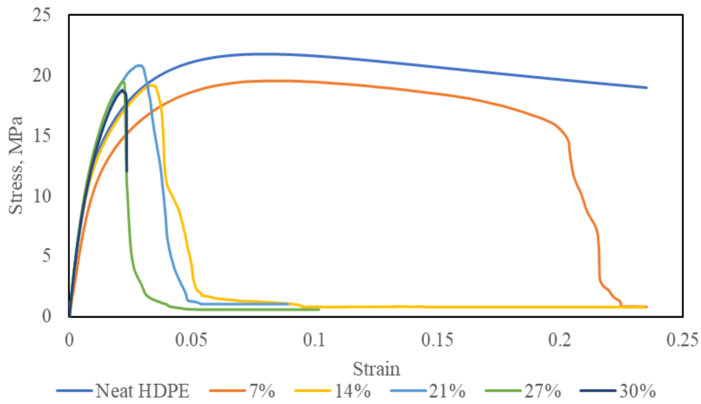

Fig. 3 - Stress-strain graph following tensile stress at a crosshead displacement rate of 10 mm/min for Luffa /HDPE composites (neat HDPE is included for comparison)

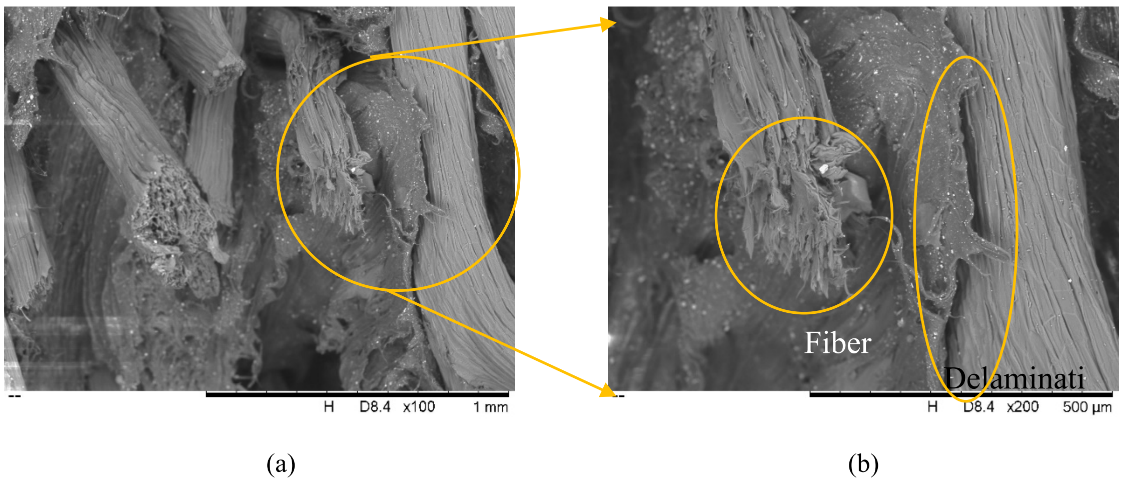

Fig. 4 - (a) SEM micrograph of delamination of Luffa/HDPE at ×100 magnification (21% FVF); (b) the delamination and fiber fracture of Luffa/HDPE composite at ×200 magnification (21% FVF)

Fig. 4(a) SEM micrograph of delamination of Luffa/HDPE (21% FVF). Luffa consists of lignin and hemicellulose other than the major part cellulose make up naturally hydrophobic properties. The strong bonding between the fiber and matrix is attributed to the low wax content in luffa. Conversely, if the wax content is high, it can reduce the reactive functional groups of the fiber and weaken the interlocking between the fiber and matrix [11]. Young's modulus for 21 % FVF is high due to fiber-matrix interfacial strength is established for this study. Mechanical interlocking occurs between fiber and matrix as Luffa surface is rough and thus increasing the interfacial strength [16]. Fig. 4(b) shows the delamination and fiber fracture of Luffa/HDPE composite for 21 % FVF upon reaching fracture point. It shows that the breaking of fiber and matrix at a rigid dislocation condition. The nucleation at some point appears between fiber and matrix as reaching the ultimate tensile strength [17]. Nucleation voids are initiated around inclusions and precipitates by particle cracking or decohesion of the interface between the particle and adjacent matrix [18].

The application of NFRP proves to be challenging compared to synthetic fibers, but it can save cost for a short period of time. Some application worth replacing in short-term including aerospace, automotive and automotive engineering industries. With more studies to be done in the future, Luffa can be made more suitable to be adapted in fiber-reinforced thermoplastic composite.

4. Conclusion and Recommendations

This research offers a good deal to the environment as well to mankind. The composites samples show that even as low as 7% FVF, the tensile strength is near to neat HDPE with only reduction of 1.20 %. The optimum tensile strength is at 21 % FVF, with a value of 21.30 MPa. However, the highest tensile modulus is at 30 % with a value 842 MPa. Luffa increased the tensile strength overall for the Luffa/HDPE composite but making it more rigid. The behavior of Luffa/HDPE composite is influenced by a limited number of factors, including the interlocking and interfacial properties of the fiber-matrix, the natural roughness, and the hydrophobic properties. In industrial application, luffa shows a great potential to be integrated into polymer composites as it has a consistent strength to weight ratio. With a few studies to back-up the findings, it can be a great deal in term if cost effective and environmentally friendly for the industry.

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