



ORIGINAL RESEARCH ARTICLE

EFFECTS OF FIBRE LENGTH AND FIBRE LOADING ON TENSILE AND FLEXURAL PROPERTIES OF LUFFA CYLINDRICA REINFORCED POLYLACTIC ACID COMPOSITE

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ABSTRACT

This study examines the effects of fibre length and fibre loading on the tensile and flexural properties of *Luffa cylindrica* reinforced polylactic acid (PLA) composites. *Luffa cylindrica* fibres, a natural and biodegradable reinforcement material, were incorporated into PLA at varying fibre lengths (1 mm, 3 mm, and 5 mm) and fibre loadings (10%, 20%, 30%, 40%, and 50%) to assess their impact on mechanical performance. The results revealed that both tensile and flexural properties were significantly affected by fibre length and loading. Optimal mechanical properties were observed at 30% fibre loading with a 3 mm fibre length, where tensile strength reached 28.52 MPa and flexural strength peaked at 77.81 MPa. However, higher fibre loadings (40% and 50%) led to a reduction in strength due to poor interfacial adhesion and fibre wetting. Shorter fibre lengths (1 mm) contributed to a higher tensile modulus, suggesting that compact fibre arrangements resist deformation more effectively. This study highlights the potential of *Luffa cylindrica* fibres as effective reinforcements in PLA composites, offering valuable insights for sustainable material development.

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1.0 Introduction

The growing environmental concerns associated with synthetic polymer usage have spurred interest in developing sustainable and biodegradable alternatives. In this context, natural fibre-reinforced biopolymer composites have emerged as promising materials, combining the biodegradability of natural fibres with the versatility of biopolymers (Naser et al., 2021). Among these, *Luffa Cylindrica* fibre (LCF) reinforced Polylactic acid (PLA) composites have gained attention due to their potential applications in various industries, including automotive, packaging, and construction (Kumar et al., 2023; Ashok et al., 2024). The shift towards sustainable materials is further driven by stringent environmental regulations and the increasing demand for eco-friendly products, particularly in industries seeking to reduce their carbon footprint (Ahmed and Susmel, 2017).

Polylactic acid (PLA) has proven itself as a good potential polymer material with desirable characteristics for applications in engineering, physical/life sciences and medical sectors. Many developed composites in use presently have provided the edge in material's technology, establishing their advanced applications in aerospace, structures and aeronautic engineering (Nazrin et al., 2020; Karande et al., 2021; Charles et al. 2024). However, composite materials are around for centuries, therefore it is not a completely new idea, but has been there for centuries. Khanam, et al., (2007) reported that early Egyptians produce reinforced mud bricks (composite) from chopped straw and mud, while Mongol warriors produce very durable archery bows using composites made up of Bamboo strips, bullock tendon, pine resin, horn, strips and silk.

*Luffa Cylindrica*, commonly known as sponge gourd or vegetable sponge, is a plant species that produces a fibrous network within its fruit. These fibres are characterized by their lightweight nature, high specific strength, and biodegradability, making them an attractive reinforcement material for biopolymer matrices (Siqueira et al., 2010; Shen et al., 2012). Moreover, *Luffa Cylindrica* fibre is abundant, cost-effective, and renewable, which enhances their appeal as a sustainable alternative to synthetic fibre (Baigh et al., 2023). PLA, on the other hand, is a biodegradable thermoplastic derived from renewable resources such as corn starch or

sugarcane. It offers a promising alternative to petroleum-based plastics due to its biodegradability and comparable mechanical properties (Teixeira et al., 2021). The combination of PLA with natural fibre like *Luffa Cylindrica* not only enhances the mechanical properties of the resulting composites but also aligns with the principles of a circular economy, where waste is minimized, and resources are reused (Ilyas, et al., 2021). In addition, the mechanical properties of natural fibre-reinforced polymer composites are significantly influenced by various factors, including fibre length and fibre loading (Saba et al., 2016). These parameters play crucial roles in determining the interfacial adhesion between the fibre and the matrix, stress transfer efficiency, and overall composite performance (Khan et al., 2023). Earlier studies have investigated the effects of fibre length and loading on various natural fibre-reinforced composites, such as jute/PLA (Ejaz et al., 2020), sisal/PLA (Kittikorn et al., 2018) and many other green/PLA composites (Li et al., 2022; Aji et al. 2011). For instance, Fang et al. (2020) demonstrated that optimal fibre length and loading significantly improved the tensile strength of jute/PLA composites, while Ejaz et al. (2020) highlighted the importance of fibre-matrix compatibility in sisal/PLA composites. These findings underscore the critical role of fibre parameters in tailoring composite properties for specific applications. Review by Aji et al. (2009) expressed the immense benefits of reinforcing polymers with natural or synthetic fibre. However, there is a notable research gap in understanding these effects specifically for *Luffa Cylindrica* fibre reinforced PLA composites.

While some researchers have explored the potential of *Luffa Cylindrica* as a reinforcement in polymer composites (Saw et al., 2013; Sabarinathan et al., 2016; Sahayaraj et al., 2022), the systematic investigation of how fibre length and loading affect the mechanical properties of LCF/PLA composites remains limited. This gap in knowledge hinders the optimization of these composites for specific applications and limits their potential industrial adoption. This study aims to investigate the effects of fibre length and fibre loading on the tensile and flexural properties of *Luffa Cylindrica* reinforced Polylactic acid composites. By systematically varying the fibre length (1 mm, 2 mm, and 3 mm) and fibre loading (10% to 50% by weight), the study seeks to establish relationships between these parameters and the resulting mechanical properties of the composites. The findings of this research are expected to provide valuable insights into the optimization of LCF/PLA composites, enabling their broader adoption in industries such as automotive, packaging, and construction. Additionally, this study contributes to the growing body of knowledge on sustainable materials, supporting global efforts to reduce reliance on non-renewable resources and mitigate environmental degradation.

## 2. Materials and Methods

### 2.1 Materials

*Luffa cylindrica* was collected from Maiduguri Metropolis. It was sorted, washed, sun dried, shredded into smaller pieces and cut into short fibre form of 1 mm, 2 mm and 3 mm using a Laboratory Milling Machine at the Quality Control Laboratory, Nilest, Zaria, Kaduna State. The polylactic acid was obtained from Abams Chemicals Plc, Ojota Lagos State, Nigeria. Sodium hydroxide and distilled water were obtained from Chemistry Laboratory, Nigerian Institute of Leather and Science Technology, Zaria, Kaduna State.

### 2.2 Methods

#### 2.2.1 Treatment of *Luffa Cylindrica*

The fibre was treated using 5%w/v NaOH solution for one hour at 50 °C temperature. 5%w/v NaOH solution was prepared by dissolving 5 g of Sodium hydroxide (NaOH) pellet in 100 ml of distilled water in accordance with (Bichang et al., 2022). The solution was produced in large volume that was enough for the filler treatment. The treated fibre was rinsed severally with distilled water until the rinsing water becomes neutral to pH paper.

Thereafter, the treated *luffa cylindrica* fibre was dried using hot air oven and was evenly spread on aluminium foil sheet laid on the oven tray. The tray was placed in the oven at temperature of 70 °C allowed to dry for six hours. The weight of the dried fibre was taken and recorded at interval of 30 minutes and then returned to the oven until a constant weight was achieved.

#### 2.2.2 Melt-mixing of Composite

The formulation shown in Table 1 was followed in the melt-mixing process. Sample A, B, C, D and E were replicated for fibre length 1 mm, 2 mm and 3 mm.

**Table I:** Composite formulation

Material	Neat (PLA)	Sample	Sample A	Sample B	Sample C	Sample D	Sample E
LCF (wt %)	0		10	20	30	40	50
PLA (wt %)	100		90	80	70	60	50

The composite obtained from the mixing process was placed into a metal mould of dimensions 120 mm x 100 mm x 3.2 mm and was placed on the hydraulic hot press (Compression Moulding Machine) for shaping at temperature of 150 °C and pressure of 2.5 MPa for five minutes. It was cooled, removed from the mould and labelled accordingly. This process was repeated for all the composites produced.

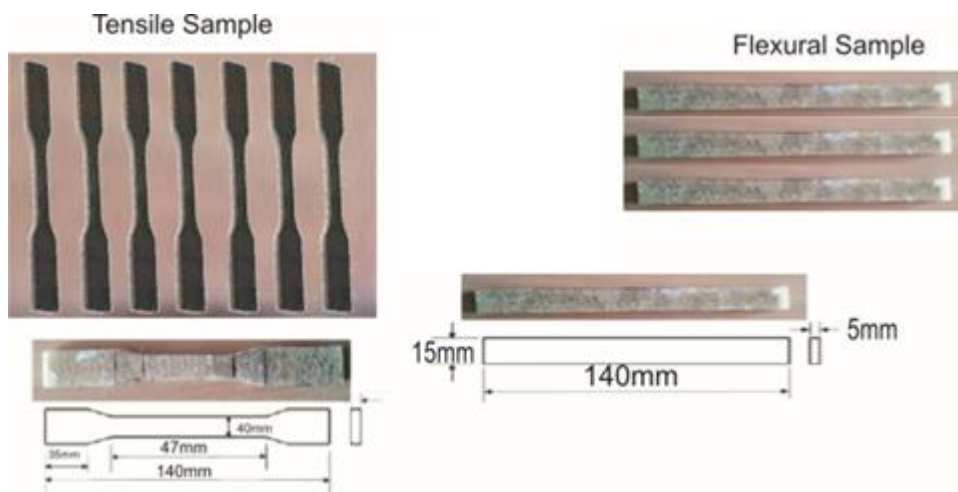
### 2.3 Characterization of the Composites

#### 2.3.1 Tensile Strength

The tensile strength was carried out in accordance with ASTM D-638. A dumbbell shaped samples were subjected to a tensile force and tensile strength, tensile modulus, percentage elongation at break for each sample were calculated and recorded automatically by the machine and the results were recorded on the certificate. All measurement was recorded at room temperature and each sample composition was tested with three replicas.

#### 2.3.2 Flexural Strength

The flexural strength test on the blends was carried out in accordance with ASTM D-790. The specimen measuring 100 mm x 25 mm x 3.2 mm was placed on a support span horizontally at 80 mm gauge length and a steady load was applied to the centre by the loading nose producing three-point bending until the sample specimen failed. The maximum load (N) and the corresponding deflection (mm) were recorded accordingly as the sample specimen failed. Figure 1 presents the nature of the test samples used. To maintain reliability, every sample composition was evaluated using three replicas.



**Figure 1:** Nature and Appearance of Test Samples

#### 2.3.3 Scanning Electron Microscopy

The scanning electron microscope (SEM) from SEM Model no: AE200 was used to study the morphological characteristics of the fibre after various stages of the mechanical tests.

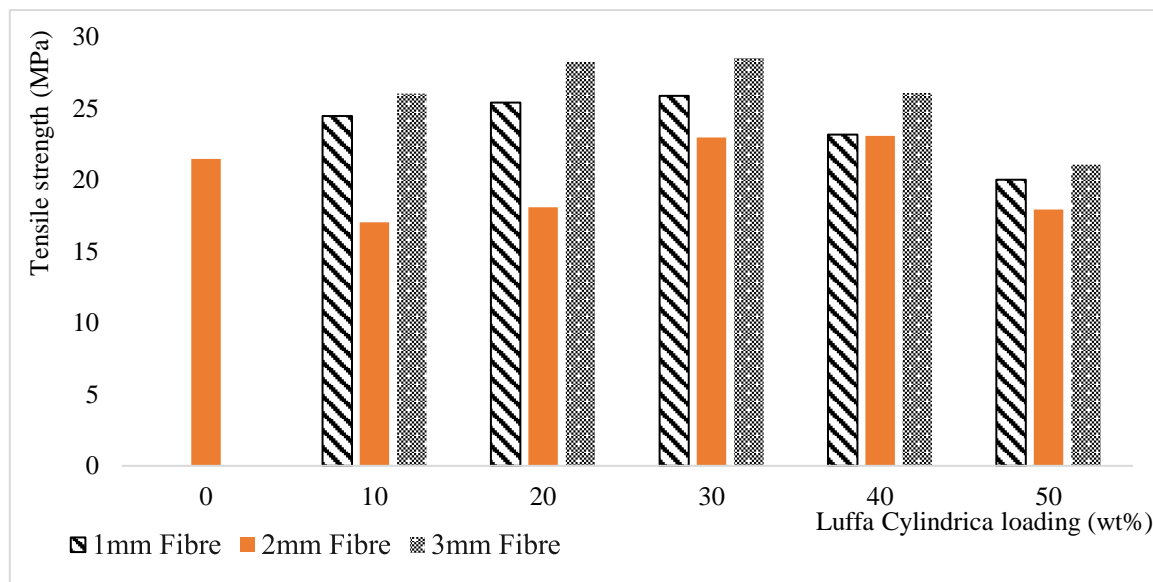
### 2.3.4 Statistical Analysis

All data presented are expressed as means of triplicate values. Single factor analysis of variance was carried out to compare the means of different data sets, and a value of  $P < 0.05$  was considered statistically significant.

## 3. Results and Discussion

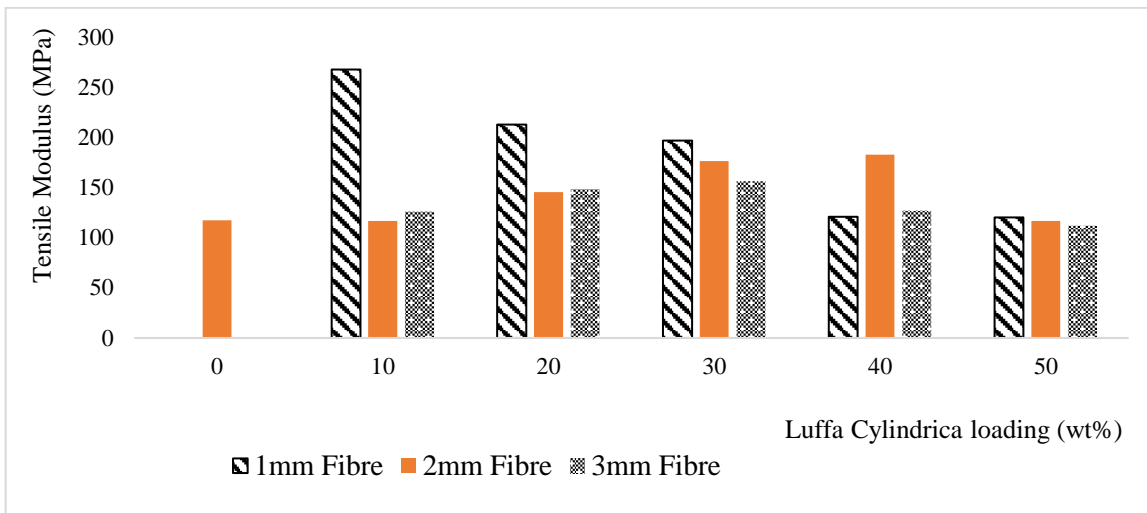
### 3.1 Effect of varying Fibre Loading and Fibre Length on Tensile Strength and Modulus

Figure 2 shows the tensile strength test results for the luffa fibre/PLA composites. The tensile strength of the luffa fibre/PLA composites were found to be significantly different ( $P < 0.05$ ). The results show a steady increase in tensile strength of the composites as the luffa fibre loading increases until it reaches a peak of 28.52 MPa at 30 % luffa fibre loading and at the 3 mm fibre length (sample at 30% luffa fibre was significantly different ( $P < 0.05$ ) from all samples followed by 20% luffa fibre loading at 20% fibre loading). Thereafter, a steady decrease in the tensile strength was observed. The increase in the tensile strength of the composites from 10 % to 30 % filler loading could be related to the better interfacial adhesion between the fibre and the matrix which aided stress transfer within the composite system of PLA thereby helping in stress distribution within the matrix as the sample experiences tensile forces.



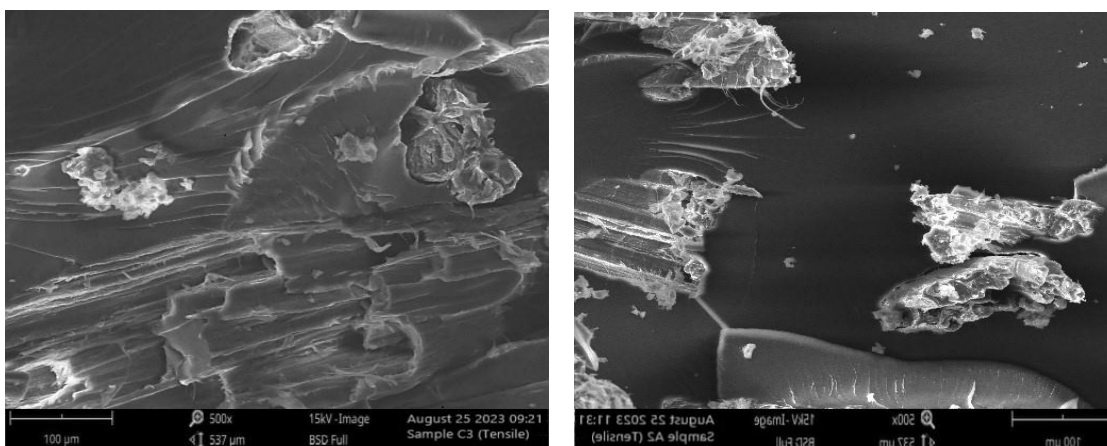
**Figure 2:** Fibre loading and fibre length on the tensile strength of PLA composites.

However, the decrease in the tensile strength from 40 % to 50 % filler loading may be due to high percentage ratio of filler to the matrix which led to low wetting of the fibre and thus reduced bonding strength between the filler and the matrix. Poor wetting of fibre by the matrix results in poor interfacial adhesion between the fillers and the matrix, hence, stress transfer was greatly affected which reduced and the tensile strength of the composite with loading. The 3 mm fibre length exhibited a better reinforcement property than 2 mm and 1 mm. Similar result was shown by (Sarukasan et al., 2021). However, the 1mm fibre length presented a better modulus with loading of the PLA as shown in Figure 3.



**Figure 3:** Effects of fibre loading and fibre length on the tensile modulus of the composite.

Tensile modulus describes the ability to resist extension. Fibre loading is found to be statistically significant against the tensile modulus of the composites ( $P < 0.05$ ). The results show greater modulus obtained with the shortest fibre, i.e. 1mm fibre length. However, the modulus dropped with increase in fibre loading and fibre length. This will not be unconnected with the fact that short fibre provided a greater amount of compactness in the composite which provided the greatest amount of resistance before failure. However, clearly, all showed a greater modulus than the pure PLA. Modulus of composites increased with filler loading until a peak is reached when there will be decline in the trend due to poor adhesion (Kolawole et al., 2019); this is at variance to result observed in the samples loaded with 1 mm fibre length filler. This could be expressing a new phenomenon obtained in formulating this composite by exploring this relatively new fibre in composite formulation. Meanwhile, the composite formulated with 2mm and 3mm fibre length corroborated the findings of (Kolawole et al., 2019). Figure 4a and b presents the SEM micrograph of the failed sample tested. Sample C3 (sample loaded with 30 % 3 mm luffa fibre) and sample A2 (sample loaded with 10 % 2 mm luffa fibre) which represents the best and the poor performing samples from tensile strength test results. A uniform fibre distribution and bundle fibre breakage could be seen in Figure 4a whereas Figure 4b shows image of scanty filler and uneven fibre distribution as the image revealed fibre random concentration in the matrix.



(a)

(b)

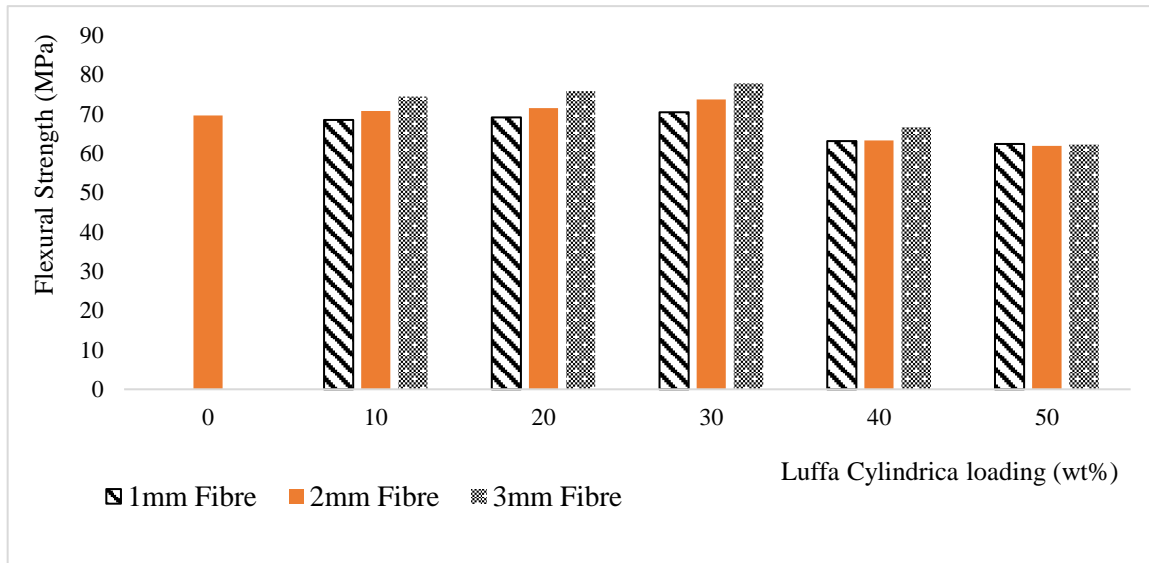
**Figure 4:** (a) Tensile Strength Sample (C3) (b) Tensile Strength Sample (A2)

### 3.2 Effect of varying Fibre Loading and Fibre Length on Flexural Strength

Figure 5 shows the flexural strength test results for the luffa fibre/PLA composites. Although there is statistical difference on the effects of fibre loading on the flexural strength at  $P < 0.05$ , there is only a little but steady increase in flexural strength of the composites was observed as the luffa fibre loading increases until it reaches a peak of 77.81 MPa at 30 % luffa fibre loading for 3 mm fibre length. Thereafter, a steady decrease in the flexural strength was observed as the filler loading increased from 40 % to 50 %. The increase in the flexural

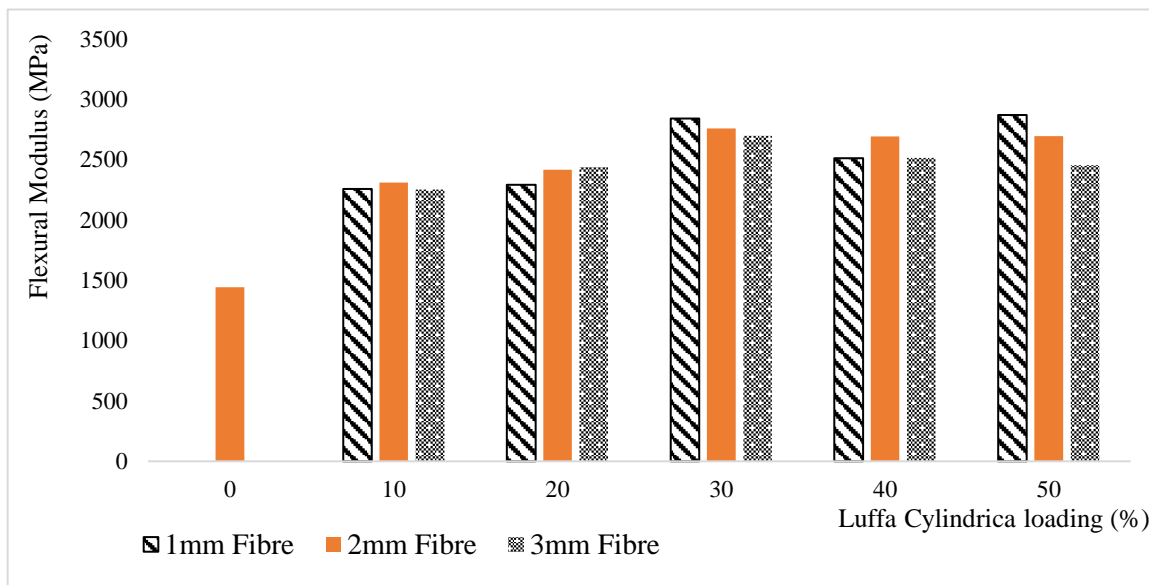
strength of the composites from 10 % to 30 % filler loading could be related to the better interfacial adhesion between the fibre and the matrix which aided stress transfer within the composite system thereby helping stress distribution within the matrix as the sample experiences bending forces. The matrix was able to transfer the load to the fibre effectively. However, the decrease in the tensile strength from 40 % to 50 % filler loading was due to high percentage ratio of filler to the matrix which led to lower bonding strength between the filler and the matrix and resulted in filler agglomeration giving rise to poor interfacial adhesion between the fillers and the matrix. Hence, stress transfer reduced and so does the flexural resistance (Akhyar, et al., 2024).

The results also show that 3 mm luffa fibre exhibited reinforcement property aiding an increase of about 11% flexural property when compared to the pure matrix. Increase in fibre length produced some increment of property compared to lower length fibres, i.e. 1 mm and 2 mm. This is in line with the result obtained by Vineeth and Sanil (2017).



**Figure 5:** Effects of fibre loading and fibre length on the flexural strength of composite

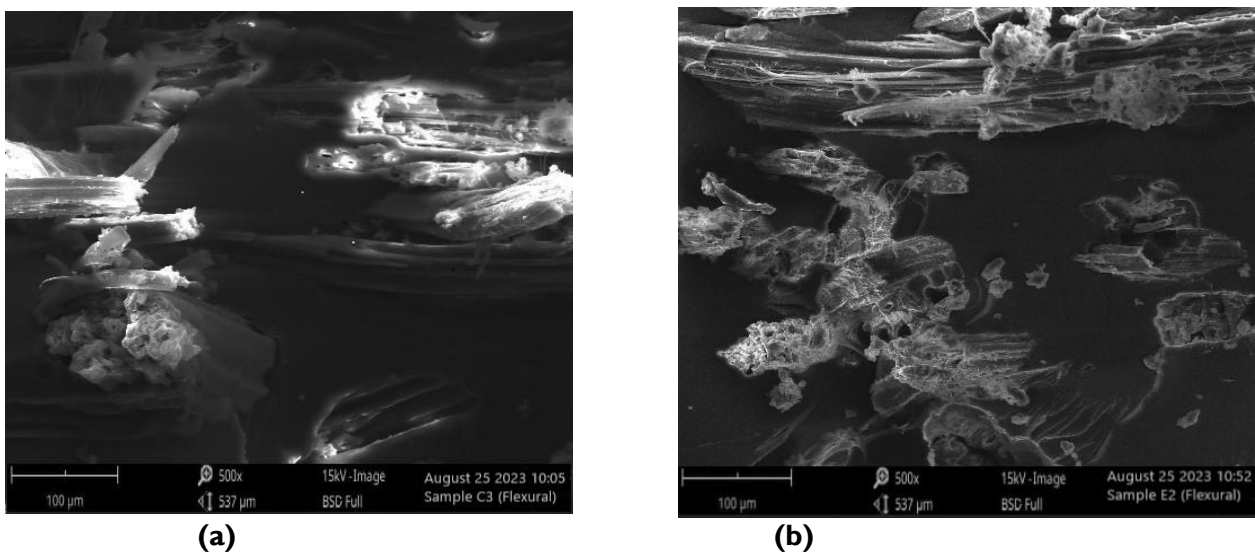
Also, Figure 6 represents the flexural modulus test results for the luffa fibre/PLA composites produced. Flexural modulus describes the ability of the composite sample to resist bending extensibility.



**Figure 6:** Effects of fibre loading and fibre length on the flexural modulus of PLA composites

Natural fibres have greater amount of modulus in them because of the presence of cellulose. Luffa fibre has about an average of 60% cellulose in them (Bichang et al., 2022). Therefore, increase in fibre loading will improve the modulus content of the composite. There is an evidence of fibre loading being significant against

flexural modulus of the PLA composites ( $P < 0.05$ ). The results indicate that the flexural modulus of the samples increases with increase luffa fibre loading up to the last loading for the 1mm fibre length. The same trend was observed in all the different fibre length used. This implies that the presence of the fibre in the matrix enhanced the stiffness of the polymer core thereby resisting free chain mobility of the matrix as bending force was applied. The Luffa fibres have between 50 – 90% cellulose content, which provided the extra strength obtained in their composites. The major component of vegetal fibres is the cellulose, which is a polymer of  $\beta$ -D-Glucose oriented in which  $-\text{CH}_2\text{OH}$  group is alternating above and below the plane of the cellulose molecule thus producing long, unbranched chains present in the secondary cell wall of the fibre. It is responsible for the high mechanical strength of fibres and acts as a reinforcing material. Because the small fibre length composite' had greater amount of compactness, it was able to interact with the matrix much better and therefore gave better resistance under load. Also, Figure 7a and 7b describe the result of the scanning electron microscopy of the formulated composites. Surface morphology image for sample C3 (sample filled with 30 % 3 mm luffa fibre) and the sample E2 (sample loaded with 50 % 3 mm luffa fibre) as the best and the poor performed samples from flexural strength test results. A uniform fibre distribution and bundle fibre stretched could be seen in Figure 7a whereas Figure 7b shows image of scanty filler and uneven fibre distribution as the image revealed fibre random concentration in the matrix.



**Figure 7:** Flexural Strength Sample (a) C3 (b) E2

#### 4. Conclusion

This study investigated the effects of fibre length and fibre loading on the tensile and flexural properties of *Luffa cylindrica* reinforced polylactic acid composites. The results revealed that both fibre length and fibre loading significantly influenced the mechanical properties of the composites. Optimal tensile and flexural properties were observed at 30% fibre loading with a 3 mm fibre length, with tensile strength peaking at 28.52 MPa and flexural strength at 77.81 MPa. This improvement is attributed to better interfacial adhesion and stress transfer between the fibre and matrix, resulting in enhanced mechanical performance. However, at higher fibre loadings (40% to 50%), a decrease in both tensile and flexural strength was observed, likely due to poor fibre wetting and interfacial adhesion, leading to stress concentration and reduced load-bearing capacity. Shorter fibre lengths (1 mm) demonstrated better tensile modulus, highlighting the influence of fibre compactness in resisting deformation.

Overall, the study suggests that *Luffa cylindrica* fibres can be effectively used to reinforce PLA composites, with an optimal fibre loading and length combination providing the best mechanical properties. These findings offer valuable insights for the design and application of bio-composites in various industries, particularly in sustainable materials development.

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