Mechanical properties of waste silk fibre reinforced PLA bio composites manufactured through hand layup method

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Abstract: In recent years, biodegradable and eco-friendly composites have gained popularity. Using the hot moulding technique, biodegradable polylactic acid (PLA) bio composites reinforced with waste silk fibre were fabricated in this paper. They also underwent a variety of mechanical tests like tensile strength and modulus. While not surface-treated, the waste silk fibre reinforced PLA matrix bio composites mechanical properties. The fibre content of 30 wt per cent is optimal for achieving superior properties. Owing to the reinforcing effect of silk fibres, the quasi-static mechanical properties of waste silk fibre/PLA bio composites were enhanced.

Keywords: Mechanical behaviour, waste silk fibre, Tensile strength, UTM, Hand layup process.

1. Introduction
This field of materials science has become particularly active and promising in creating eco-friendly and renewable composites. These polymers could be used in many areas, such as the home as well as the medical industry and other industries [1-3]. Although plant fibres have been successfully synthesised and applied to furniture, automobile fittings, and inshore floors, there have been relatively few studies on bio composites reinforced with natural animal fibres such as silk, wool or hair [4-14].

Silk fibres have superior crystallinity, toughness, and tensile strength to plant-based natural fibres [15]. A lot of effort has been put into both woven and nonwoven silk fibre reinforced plastics. These silk fibre reinforced plastics had a greater range of mechanical properties than flax fibre reinforced epoxy composites[16]. Flexural and tensile moduli are increased by 2 percentage points and 27 percentage points when comparing pure Poly Lactic Acid to 5 weight per cent silk [17]. Poly Butylene Succinate composites were investigated, and silk fibre loading was examined to see its effect on the material's mechanical properties. As well as having superior mechanical properties and excellent biocompatibility, animal fibre can be easily customised and tailored to meet specific needs and
requirements. The use of silkworm silk as a textile material dates back more than 5,000 years [18]. In tissue engineering and in-clinic surgery, it is possible to use materials that are both mechanically robust and long-term degradable. In recent years, short chopped silkworm silk has been reported to be used in polypropylene matrix resin, polybutylene succinate, polychloroprene rubber, an unsaturated polyester and styrene mixture, polycarbonate, and nitrile rubber [19]–[21]. This suggests that using silk as reinforcement could be an effective way of improving the performance of biodegradable polymer matrix resins by enhancing their mechanical properties and flexibility. In this research work, Untreated waste silk fabric was used to reinforce PLA biocomposites prepared via hand layup process and also analysis the mechanical properties of the composite.

2. Materials and Methods
As part of this study, waste silk yarns were produced by piercing silk wastes and cocoons using specific machines supplied by silk yarn producers. Twisted yarns were used to create the fabric. Warp and weft threads are interlaced to form a plain weave. Untreated plain-woven fabric with 56 warps and 15 weft strands per centimetre was used as the reinforcement. Its surface density was 19.62 grammes per square centimetre (g/cm²). The matrix material was made of PLA films with a thickness of 35 microns. It had a density of 1.78 grammes per cubic centimetre and a melting temperature of 132 to 143 degrees Celsius.

![Schematic of matrix and fibre composition](image)

**Figure 1.** Schematic of matrix and fibre composition

Silk fabric/PLA biocomposites were layered by hand. It was initially cut into 250 mm x 120 mm pieces of waste silk fiber (WSF), followed by 120 mm squares of PLA film. The PLA film flows in the same direction as the fabric’s warp or weft. Layout, alignment and stacking of layers of 15 to 25 plies took place. The stacked plate material was then placed in a self-made steel mold. A 180-millimeter-diameter preform was used. Presses were used to heat and press the mixture, ranging in temperature from 140°C up to 162°C. For 25 to 35 minutes, they were applying a pressure of 4.1 MPa.
To cool it down to room temperature, it was removed from the mould. The biocomposite laminate panel could be cut into test specimens after it was removed from the mould. Each sample contained 0, 10, 20, 30, and 40% wt per cent fibre. A comparison of matrix and reinforcement weight percentage contributions in pure and hybrid composite specimens is shown in Table 1. Due to the different fibre contents, the silk fibre/PLA biocomposite specimens ranged in thickness from 2.30mm to 3.70mm. A PLA film and silk fibre mate arrangement are shown in Figure 1. The schematic of conventional hand layup method is shown in figure 2.

### Table 1. Weight percentage contribution of matrix and reinforcement

| Designation of composites | WSF | PLA Film |
|---------------------------|-----|----------|
| WSF0/PLA                  | 0   | 100      |
| WSF10/PLA                 | 10  | 90       |
| WSF20/PLA                 | 20  | 80       |
| WSF30/PLA                 | 30  | 70       |
| WSF40/PLA                 | 40  | 60       |

2.1. **Tensile Test**

Twenty-five-millimeter-wide ASTM D-3039 specimens were cut from waste silk fibre/PLA biocomposites. Tests were performed at ambient temperature on Naveen make 400-tonne Universal test machine, which was computer-controlled. At 3 millimetres per minute, the crosshead was specified for a load cell of 20 kilogrammes. The specimen’s longitudinal strain was monitored using an extensometer. Load and displacements were recorded simultaneously.

This allowed for calculating five specimens’ mean tension modulus, tensile strength and length from their force-displacement curves.
2.2. Flexural Test
Specimens measuring 120 mm in length and 25.4" wide were subjected to three-point bending tests using the same apparatus used for tensile tests, in accordance with ASTM D-790. The crosshead speed was 2 millimetres per second, and the loading roller radius was 8 millimetres. 75-mm-long splices result in a higher span-to-thickness ratio. Automatic recording of the load and crosshead displacement was made. Using an average of five specimens with the same fibre content, we were able to calculate the flexural modulus and strength.

3. Results and Discussions

3.1. Fibre loading effects on flexural strength and modulus
Pure PLA and pure PLA reinforced with waste silk fibre epoxy composites have different flexural properties, as shown in Figure 3. (flexural strength and flexural modulus). The flexural properties increased with increasing silk fibre loading. Straw reinforced composites showed a similar trend, according to the researchers. Composites' flexural properties improve as the polymer chain becomes entangled with reinforcement as fibre loading increases. When silk fibre loading was 40 wt%, flexural strength and moduli increased by 50.68 per cent and 44.64 per cent, respectively.

![Figure 3. Variation of Flexural Strength and Modulus for Different Fibre Loading](image)

In composite specimens, it is the interfacial interactions that have a major impact on the flexural moduli. Figure 3 shows the fibre content and flexural properties of biocomposites (flexural strengths and moduli). There is greater strength in the current waste silk bio composites than there is in pure PLA. This suggests that the matrix-fibre bond is a major factor in plastic deformation. When transferring elastic deformation throughout a composite, interfacial properties determine the stiffness of a composite material. The addition of fibre to these biocomposites generally increases the matrix stiffness. For successful fabrication of waste silk-PLA biocomposites, the optimal waste silk fibre loading was determined to be 40 wt.%.

3.2 Fibre loading effects on tensile property
Five different weight percentages of waste silk fibre reinforced PLA biocomposites were tested using uniaxial tension tests to determine their tensile modulus, tensile strengths, and elongations (0, 10, 20, 30, and 40 wt per cent). Figure 4 illustrates five different weight percentages of waste silk fibre reinforcements. The elongation ratio of waste silk fibre/PLA biocomposites is shown in Figure 4 as a function of silk fibre content (in percent). Waste silk fibre reduces the elongation and elasticity of
purified PLA under tension. Example: When PLA/SF40 bio composites contain 40 wt per cent waste silk fibre, their elongations are approximately 26.92 per cent lower than those of pure PLA (PLA/SF0). When fibre content is increased from 0 to 30 weight per cent, the average elongations decrease at first, but then increase as the fibre content is increased further (40 wt. per cent). PLA biocomposites are also more malleable for a given fibre content because of the fibre reinforcement.

![Figure 4](image)

**Figure 4.** Percentage of elongation for Different Fibre Loading in PLA Matrix

Figures 5 and 6 compare the corresponding results for tensile modulus and tensile strength. Biocomposites containing a higher amount of waste silk fibre have superior mechanical properties than pure PLA composite specimens for a given fibre concentration. This is 75.64 per cent and 75.92 percent higher than pure PLA composites, respectively, when the waste silk fibre content is 30 weight percent. With an increase in fibre content from zero weight percent to thirty weight percent, bio composite tensile moduli and strengths increase. According to the research, thirty-per cent fibre content results in lower tensile modulus and strength than zero-per cent-fibre-content samples.

![Figure 5](image)

**Figure 5.** Effects of Fibre Loading on PLA Matrix for Tensile Modulus

In bio-composites with high fibre content (40 wt.%), mechanical properties degrade as a result of incomplete filling of the melted PLA matrix in the reinforcing waste silk fibre during processing.
With a fibre content of 40%, these incomplete fillings also had chopped short waste silk fibre reinforcement and "separated" short silk fibre reinforcement.

![Variation of fibre Loading on Tensile Strength](image)

**Figure 6.** Variation of fibre Loading on Tensile Strength

### 4. Conclusions

Untreated waste silk fabric was used to reinforce PLA biocomposites. Tension and flexural tests were conducted to determine the mechanical properties. Maximum strength and modulus are achieved with a fibre content of about 30 wt per cent. Due to the reinforcing effect of silk fibres, the quasi-static tensile and flexural properties of waste silk fibre/PLA biocomposites were improved. Interface strength should be increased by chemical or physical means between waste silk fibre and PLA matrix.

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