Feasibility studies on bio composites using PLA and Epoxy for structural applications.

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Abstract: Biopolymers are eco-friendly substitute materials to synthetic polymers due to their abundant resource, biodegradability, and ease of processing. In recent years biopolymer-based polymers attracted many researchers because of cost, lightweight, and recyclability. One of the most promising biopolymers used in many applications such as food, packaging, and medical and pharmaceutical industries is Polylactic Acid (PLA). Polymer scientists in the last decade widely investigated. Biopolymer is going to replace many synthetic materials. Desired properties of biopolymer can be obtained by blending with various additives. This research aims to reduce the dependence of synthetic polymer by reinforcing PLA in an Epoxy matrix. The Percentage of PLA is varied from 10 to 50% in a step of 10% using Solution Casting Technique. The mechanical, Functional (FTIR), thermal properties are investigated. The Epoxy and PLA composites with 20% PLA has shown improvement in Tensile strength compared to 10 and 30%.

Keywords: Epoxy L12; PLA (3052D); Tensile strength; Flexural strength; FTIR; TGA.
1. Introduction
As an alternative to plastic composites, natural biopolymer reinforced polymer composites have excellent promise. Research is now focused on using natural polymers (NP) as load-bearing ingredients in composite materials due to their structural properties. They are comparatively economical, biodegradable, and light in weight. In an NP reinforced composite material, NP provides resilience and rigidity and serves as strengthening. Polylactic acid (PLA) has a wide variety because of the biocompatible and biodegradable properties. PLA has lately gained a lot of interest from proponents of green chemistry and sustainable growth.

Biopolymers are gaining importance because of their outstanding properties, such as abundant availability, strong barrier capacity, biodegradation, and low weight. Biopolymers are sustainable and eco-friendly, which can be used as an ideal replacement for petroleum-based composites. However, their impact strength, tensile strength, and thermal stability are comparatively low. Thus, adding reinforcement in the micro or nano form improves the properties[1].

PLA is one of the promising bio composites, which is not much explored. Reinforcement of micro and nanofillers in a PLA matrix will improve the mechanical properties. The study showed PLA reinforced with fibers oxidized with TiO2 films increased tensile and impact properties[2][3][4]. The PLA is highly brittle can be overcome through adding plasticizer, HCNT (Helical Carbon nanotube). The addition of plasticizer improved the flexibility and ductility of PLA[5] [6]. PLA is a biopolymer that can be recycled. The study shows the recycling pattern of 3D printed PLA with continuous carbon fiber reinforced plastics. Their mechanical behaviour has been studied. The recycled 3D printed recycled PLA with continuous carbon fiber has improved tensile and flexural properties compared to PLA.[7]. PLA reinforced with Carbon nanotube (CNT) shown a decrease in tensile strength as CNT percentage increases. Several studies have been carried out on the inclusion of nanoparticles, which improved PLA's mechanical properties. Inclusion Magnesium (Mg) has improved the youngs modulus and hardness of the composite[9]. PLA is a biodegradable material.
Several studies have been carried out on the thermal degradation of the PLA composites, showing that the neat PLA is more thermally stable than PLA Composites[10].

The current work is based on the synthesis of Epoxy and PLA based bio composite using the solution casting method. The synthesized Epoxy and PLA composites are analysed for mechanical and thermal properties.

2. Materials and Methods

This section of the article discusses the materials and methods used to synthesize the composites and testing methods used in the composites' characterization.

2.1 Materials:

The materials are procured from Atul India Ltd. Table 1 shows the properties of Epoxy resin. Epoxy resin L-12 is used as it possesses good mechanical, electrical, superior adhesive properties. Epoxy is used primarily in automotive and aerospace applications.

| Material                  | Unit          |
|---------------------------|---------------|
| Density                   | 1162 Kg/m³    |
| Tensile strength          | 50-60 MPa     |
| Compressive Strength      | 110-120 MPa   |
| Flexural                  | 130-150 MPa   |
| Viscosity                 | 9000 -12000. at 25 °C . m Pa.s |

PLA Being the Widley used biopolymer, derived from starch, sugarcane, or roots of tapioca. PLA is a thermoplastic material with significant mechanical and biodegradability properties, and it is used in medical and 3D printing applications. The PLA of grade 3052 D was brought from Nature works, USA, and supplied by Chennai’s third-party vendor. Physical and mechanical properties are depicted in Table 2 and Table 3.

| Characteristics       | unit            |
|------------------------|-----------------|
| Melting Temperature    | 120-170 °C      |
| Load                   | 2.16 kg         |
| Specific Gravity       | 1.25            |
| Particle Size          | 1.18-4.75 mm    |

| Properties              | Value           |
|-------------------------|-----------------|
| Density                 | 1.25 Kg/m³      |
| Tensile Strength at Yield| 62 MPa          |
| Flexural Strength       | 108 MPa         |
| Elastic Modulus         | 1287 MPa        |
2.2. Methods:

Due to the shortage of petroleum resources and environmental pollution, synthetic polymer is losing its significance. Biopolymer has gained prominence because of its abundant resources, ease of processing, and superior mechanical properties. Hence, the current work focuses on reducing synthetic polymers usage by blending the matrices with a Biopolymer using Solution casting Technique (SCT). The Dosage of PLA in epoxy matrices is varied from 10 to 50% in steps of 10%. A known quantity of Epoxy was taken, which is initially heated to reduce the resin's viscosity. PLA, which is in the Granular form, is dissolved in THF (Tetrahydrofuran) Solution to dissolve the PLA granules. The K-6 hardener, along with PLA added to the epoxy matrices with constant stirring. The prepared blend of epoxy/PLA is poured into the molds of size 230 mmX160 mm X 3mm, and the molds are allowed to cure for 24hr at room temperature. Figure 1 shows the casted specimen. Tensile and Flexural specimens are prepared according to ASTM standard D638 and D790. The samples are coded, as shown in Table 4.

![Figure 1](image1.png)

**Figure 1.** Casted Specimens of Epoxy and PLA

3. Characterization techniques:

FTIR experiments have been performed using agate mortar to prepare the powder sample of Bio-Composites, and FTIR tests on a 4 cm-1 instrument in KBR pellets are made using the powder sampled from the PLA-Epoxy spectrum Perkin-Elmer. TGA experiments are carried out using SDT Q600 TA Instruments, USA, to determine volume and speed (velocity), according to temperature or time in the controlled atmosphere, of changes in the sample's mass. The measurements are used to test thermal and oxidative stability and structural characteristics. Mechanical properties like Tensile strength and flexural strength using Universal testing machine Tinius Olsen 10 ST.

3.1 Tensile testing:

The tensile test is used to determine how high a composite polymer breaks down and to what degree the sample continues to this rupture point. Tensile measures include a tensile stress-strain scheme used for tensile modulus determination. The tensile test conducted using a 10-tonne Micro Universal Testing System (UTM) Tinius Olsen 10 ST. In compliance with ASTM D638, the specimens are prepared to a size of 165 mm X 19 mm X 3 mm, which is shown in Figure 2. A uni-axial load was applied at both ends. The tensile specimen's gauge length is 138 mm, and a 3 mm/min crosshead speed is fixed. The UTM tensile evaluation is carried at the Materials Research Center of the University.
3.2 Flexural testing: -Flexural strength testing is used to determine the force essential to bend a composite material beam. The Flexural strength test determines the resistance to a material's flexing or stiffness. The specimen was subjected to a 3-point bending test. The samples were made according to ASTM D790 standard, which is as shown in Figure 3. The dimensions of the samples are 127 mm x 12.7 mm x 3.2 mm. Flexural strength is the ability of a material perpendicular to its longitudinal axis to overcome bending forces. The Tensile Test experimental views are depicted in Figure 4.

| S.No | Sample Codes | Epoxy (wt %) | PLA (wt %) |
|------|--------------|--------------|------------|
| 1    | B10          | 90           | 10         |
| 2    | B20          | 80           | 20         |
| 3    | B30          | 70           | 30         |

Figure 2. Tensile Test Specimen

Figure 3. Flexural Strength Test Specimen

Figure 4. Tensile Test setup under Micro Universal Testing Machine and Testing Views A-B
4. RESULTS AND DISCUSSION

Fourier Transform Infrared Spectroscopy (FTIR) was based on the peak position and the frequency concerned\cite{11}. Epoxy resin exhibited peaks in figure 5 (a) at 913 cm\(^{-1}\) which confirms the epoxy group. PLA consists of lactic acid, rich in carbon chains as C=O groups, in case of PLA – Epoxy composites FTIR peaks appeared at 3306 cm\(^{-1}\) due to -OH stretching, peak at 2920 cm\(^{-1}\) was the stretching vibration peak of -CH\(_2\). The peak at 1754 cm\(^{-1}\) was the stretching vibration peak of C=O (Ref paper PLA-PVP.pdf). 1365 cm\(^{-1}\), 1459 and 1185 cm\(^{-1}\) were, respectively, attributed to methyl and deformation vibration of C-H and C-O-C stretching vibration, at 1081 cm\(^{-1}\) was the stretching vibration peak of C-O, which proved the existence of ester which showed the difference with lactide. Epoxy group peak is disappeared due to opening of epoxy group\cite{12\cite{13\cite{14}}. The findings of this investigation show in Figure 5 (b) that spectra patterns B10, B20 and B30 have emerged. Because of this the underlying similarity of PLA and Epoxy is made up of carbon and oxygen atoms. B 20 indicates a prominence plateau at 1605 cm\(^{-1}\) for C=O stretching, 2962-2929 cm\(^{-1}\) for C-H stretching, this analysis found a slight difference in intensity and transition between PLA and Epoxy. This study stated that the absorption of carbonyl in the PLA-Epoxy group decreased. This consequence of this study suggests that certain PLAs associated with the poxy because the C-O band moved.

![FTIR spectra of Bio-composites B 10, B20 and B30](image)

TGA studies on Epoxy and PLA Bio-composites are seen in Figure 6. The plots demonstrate that the percentage mass of the PLA/Epoxy thermal decomposition depends on the sample temperature (B 10, B20 and B 30). The SDT Q600 TA Instruments, USA, was heated by approximately 5.5 mg of the sample at a rate of 20 μc/min. First, second and third weight loss of 0.5284mg (9.047%) at 148°C, 4.537mg of weight (56.04%) at 411.30°C and 0.1255mg of weight (2.148%) at 871.53°C of B 10, first, and second weight loss of 0.1977mg (3.602%) at 150.09°C and 2.817mg (51.31%) at 408.59°C for B20.
and first, second and third weight loss of 0.2263 mg (3.953%) at 58.38°C, 0.4118 mg (7.194%) at 155.88°C and 4.211 mg (73.56%) at 413.81°C for B30 observed and showed better thermal degradation with respect to the weight percentage of PLA in the epoxy matrix.

Figure 6. TGA of Bio composites B10, 20 and B30

The blending of a composite is a method used to improve the mechanical properties; the main challenge in blending is polymers' mutual compatibility. PLA has shown good mechanical properties when it is blended with thermoplastic polymers[15]. Mechanical behavior investigations of Epoxy and PLA composite were carried out for tensile and flexural testing. The Epoxy and PLA composite were prepared with a varied percentage of PLA in the Epoxy from 10 to 50%. However, the epoxy and PLA composites with PLA above 30% showed lower tensile and flexural strength with increased elasticity, and hence results of these combinations are not reported in this work.

The results of tensile Strength are as shown in Table 5. The Figure 7 shows that 20% PLA showed a higher value of Ultimate Tensile Strength of 29.10 MPa: when compared to 10 and 30% composites with values 17.43 and 19.73 MPa, respectively. Tensile strength of Epoxy and PLA composites increased as PLA content increased in the epoxy resin till 20%. When the amount of PLA less than 20% terminal carboxylic groups of PLA and epoxy resin underwent ring opening and polymerization reaction resulting in chain extension. At the same time regularity of the molecular alignment was increased accompanied by increased crystallinity and intermolecular interaction thus increasing the tensile strength of Epoxy and PLA composites.

However, the amount of PLA greater than 20% the tensile strength of epoxy and PLA composite decreased slightly, because of branching in the molecular chain of PLA increased, while the distance
between PLA molecule also increased which in turn decreased the crystallinity and intermolecular force of PLA thus decreasing tensile strength.

| Sl.No | Sample Codes | Ultimate Tensile Strength (MPa) |
|-------|--------------|---------------------------------|
| 1     | B10          | 17.43                           |
| 2     | B20          | 29.10                           |
| 3     | B30          | 19.73                           |

**Figure 7.** Variation of tensile strength for varied PLA percentage.

3-Point Bending flexural tests are carried out based on ASTM D790 standard, to determine the maximum bending load that the composites can withstand. The following equation is used to calculate the flexural strength. The result is depicted in the Table 6.

\[
\sigma_x = \frac{3FL}{2bh^2}
\]

Where the \( F \) = Maximum Load in N, \( L \) = Support Span in mm, \( b \) = Width of the Specimen in mm, \( h \) = Thickness of the Specimen in mm.

The Figure 8 shows that the flexural strength decreases as the percentage of PLA increases. The composites of 10% PLA showed higher flexure strength due to homogenous mixture formation involving both Epoxy and PLA. Decreased in flexural strength for higher PLA percentage is observed due to ductile nature of the composites.
Table 6. Flexural Strength Epoxy/PLA Composites.

| Sl.No | Sample Codes | Flexural Strength (MPa) |
|-------|--------------|-------------------------|
| 1     | B 10         | 57.55                   |
| 2     | B 20         | 51.70                   |
| 3     | B 30         | 47.44                   |

Figure 8. Variation of Flexural strength for varied PLA percentage.

5. Conclusion

The present work feasibility study of Epoxy and PLA composites with different PLA dosages has been investigated. The results showed that the epoxy and PLA composites with 20% PLA showed improved tensile strength and reduced flexural strength compared to 10 and 30%. FTIR and TGA showed improved functional bonding and thermal degradation with an increase in the weight percentage (wt. %) of PLA in the Epoxy matrix. Hence the Epoxy and PLA with 20% PLA would be an improved composite material for chosen structural applications.

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