

**PROJECT ID: NSF-SCH-2025-372**

**PROJECT TITLE: Design, Fabrication and Characterization of Thermo-Biopolymer Matrices with Eco-Friendly Composite Materials**

**NAME OF THE STUDENT: K.M. Muhammadh Shihabudhdheen**

**NAME OF THE SCHOOL: Sana Model School**

**ADDRESS OF THE SCHOOL: Kaatuppakam, Chennai**

## **Title**

**“Design, Fabrication and Characterization of Thermo-Biopolymer Matrices with Eco-Friendly Composite Materials”**

## **Abstract**

In this project, we will develop biodegradable polymer (biopolymer) matrices that exhibit good thermal stability and mechanical properties. We will reinforce them with natural or sustainable fillers, test their properties (thermal, mechanical, morphological), compare treatments (e.g., surface treatment of filler), and evaluate their potential applications (e.g. packaging, construction, insulation). The goal is to show that biopolymer composites can be viable alternatives to conventional polymers in certain thermal-applications, thereby also reducing environmental impact.

## **Background of the study**

- Polymers are large molecules made up of repeating units. Thermoplastic polymers soften on heating and can be remolded; thermosets cure to a permanent shape.
- Polymers derived from biological sources, which are biodegradable or from renewable resources (e.g. polylactic acid - PLA; polyhydroxyalkanoates - PHA; starch-based polymers).
- **Thermo-biopolymer:** They are biopolymers optimized for better thermal resistance (they retain shape and strength at higher temperatures), suitable for applications like biodegradable packaging, insulation, etc.
- **Problem statement:** Many biopolymers are mechanically weak, deform or degrade at relatively low temperatures, or have poor water resistance. By reinforcing them with fillers, treating the fillers (surface modification), or by blending, one may improve their thermal/mechanical performance.

- **Recent research:** PHA blended with graphene/CNF enhances thermal stability and mechanical modulus. [arXiv](#) Also, combining natural fillers (shells, pulp etc.) with biopolymers improves mechanical properties in inexpensive bio-composites. [MDPI](#)

## Aim

To develop and compare thermo-biopolymer matrices using PLA reinforced with treated natural fillers (coconut coir and banana pseudo-stem fiber), in order to study their effect on thermal stability, mechanical strength, and biodegradability.

## Objectives

1. To prepare biopolymer composites using a selected biopolymer matrix (e.g., PLA, PHA, or starch-based) and sustainable natural fillers (e.g., banana fiber, coconut coir, treated wood fibers, shell powder).
2. To characterize the thermal properties: thermal stability (using TGA – Thermogravimetric Analysis), heat deflection temperature and thermal conductivity.
3. To characterize mechanical properties: tensile strength, flexural strength, impact strength.

## Hypothesis

Does incorporating treated natural fillers into a biopolymer matrix improve thermal stability and mechanical strength, and is there an optimal filler concentration that maximizes performance without excessively reducing biodegradability?

## Materials & Methods

### Materials

- Biopolymer matrix: e.g., PLA pellets, or PHA, or a starch-based polymer.
- Natural fillers: examples could be: banana pseudo-stem fiber, coconut coir fiber, wood sawdust, rice husk, shell powder (e.g., eggshell, seashell), etc.
- Chemicals for filler treatment: e.g., sodium hydroxide (NaOH) for alkaline treatment.
- Tooling: molds for compression or casting..
- Characterization equipment: balance, oven, TGA (if available), DSC (Differential Scanning Calorimetry), mechanical testing machine (for tensile / flexural),

possibly thermal conductivity measurement (e.g. heat flow meter or simpler methods).

## Variables

Name of the Material	Type (dependent/independent variable)
NaOH (caustic soda)	independent
Coconut coir	independent
Banana pseudo-stem	independent
PLA pellets	dependent
mould	dependent

## Experimental Design

### 1. Preparation of filler

- Collect natural filler, clean, dry.
- Grind to desired size (say < 1 mm).
- Treat with NaOH solution (say 2–5%) for a defined time (e.g., 1 h), then wash, dry.

### 2. Composite fabrication

- Mix biopolymer with filler at different loadings: e.g., 0% (control), 5%, 10%, 20% by weight.
- For PLA, you might melt mix or manually mix and compress. Use molds (e.g., steel or aluminum), apply heat and pressure (for PLA, temperature ~160-180 °C).
- For starch-based, you may use casting if possible.

### 3. Curing / solidification

- Cool down, allow biopolymer to solidify.

### 4. Testing / Characterization

#### a. Thermal Properties

- TGA: measure weight loss with temperature to see when major degradation starts.
- DSC: to find glass transition temperature (T<sub>g</sub>), melting point, crystallization.
- Heat deflection temperature or Vicat softening temperature.
- Thermal conductivity.

#### b. Mechanical Properties

- Tensile test: strength, elongation at break.
- Flexural test.
- Impact test.

### c. Biodegradability / Environmental Test

- Soil burial of small specimens, measure weight loss over time.
- Water absorption test: soak in water, weigh periodic.

### Data Comparison of Bioplastic and Commercial Plastic:

Property Tested	Homemade Bioplastic	Commercial Plastic (Polyethylene)
Transparency (1–5 scale)		
Water Resistance (1–5 scale)		
Time to Begin Degrading (in soil)		
Tensile Strength (approx.)		
Biodegradable?		

**DATA TO BE FILLED AFTER EXPERIMENT**

### Discussion and conclusion

- Treated fillers will lead to better adhesion with matrix, fewer voids, leading to higher mechanical strength (higher tensile strength and modulus) compared to untreated filler composites.
- Thermal stability (the temperature at which decomposition begins) will increase with filler content up to some point.
- However, very high filler content may reduce ductility (less elongation) and may lead to more brittleness.
- There may be an optimum filler loading (say 10-15%) beyond which gains diminish or properties degrade.
- In a nutshell thermo-biopolymer can be engineered to have significantly better thermal and mechanical properties than the pure biopolymers, while still being Eco-friendly. This can pave way for sustainable alternatives in certain application. Hence this will surely be a viable replacement for commercial or pure biopolymer

### Risk and safety:

- Use gloves and goggles while handling NaOH (caustic soda), heating mould and hot equipment's.

## **Bibliography:**

- The work on biocomposites using PHA + graphene/CNF showing enhanced thermal and mechanical properties. [arXiv](#)
- Thermal, morphological and mechanical properties of BioPE matrix composites with argan byproducts as fillers. [MDPI](#)
- Thermoplastic starch-based blends with improved thermomechanical properties. [MDPI](#)