Enhancing the Strength and Sustainability of Olefin Plastics Using Cellulose Fiber Reinforcement

Madhava Aditya Bharadwaj Pinapati[1] Md Shah Nawaz Arafat[1] Roger Tipton[1]

1. Department of Mechanical Engineering, UNC Charlotte, Senior 2. Department of Mechanical Engineering, UNC Charlotte

UNIVERSITY OF NORTH CAROLINA CHARLOTTE

Madhava Aditya Bharadwaj Pinapati
School email: mpinapat@charlotte.edu
Personal email : aditya.pinapati@gmail.com

Introduction and hypothesis

Developing Sustainable Biocomposites: Extracting Cellulose Nanomaterials (CMFs) from Hemp

Introduction

- Plastics have long dominated materials engineering, but their environmental drawbacks have intensified the need for sustainable alternatives. Cellulose nanomaterials (CNMs) have emerged as a promising solution due to their strength, renewability, and compatibility with biocomposites. This study explores hemp as a high-yield CMF source and its potential to reinforce biocomposites for more sustainable materials.
- We expect that optimizing these methods will improve cellulose quality and mechanical performance in composites. This includes enhancements in strength, moisture resistance, and thermal stability—without compromising biodegradability. Ultimately, our work supports sustainable material development through agricultural waste valorization.

Why Hemp?

- Hemp is an ideal candidate to set a benchmark for CMF extraction due to:
- High cellulose content, leading to a greater yield of CMF compared to other plant sources.
- Rapid growth cycle and low resource requirements, making it a sustainable feedstock.
- Strong, flexible fibers, which enhance the mechanical properties of biocomposites.

Methods and Materials section

CMF Extraction from Hemp

We began the extraction process by washing chopped hemp stalks in warm water at 60°C to remove surface dirt. The material then underwent two rounds of alkaline treatment at 80°C to break down lignin and hemicellulose, followed by two rounds of bleaching to further purify the fibers. Each chemical step was followed by thorough washing to remove residues. The final product was clean, white cellulose microfibers (CMFs), ready for composite development.

CMF Results

-Our extracted CMF showed a **burn temperature of 311 °C**, as confirmed by TGA.
-This value is within **3% of national lab standards** (320 °C and 315 °C).
-This consistency indicates that our **alkali and bleaching process is optimized** for high cellulose purity and thermal performance.
-Minimal deviation suggests **effective removal of lignin and hemicellulose**, preserving cellulose structure.
-Confirms readiness of CMF for **thermoplastic blending and injection molding.**

Fig 1: Dry CMF

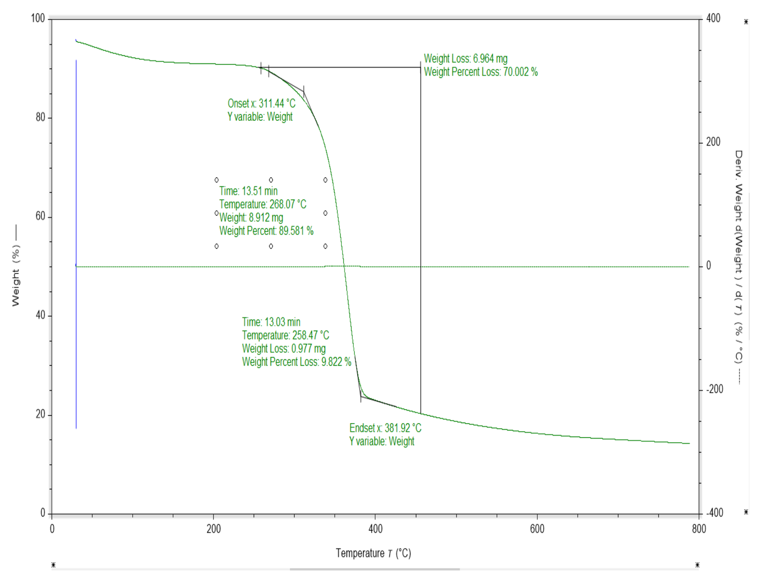

Fig 2:TGA Results

Results and Prototyping

Manufacturing

Manufacturing:
-After multiple washing, alkali, and bleaching treatments, the CMF was dried in a furnace at 200F for 8 hours.
-The fibers became lighter and softer due to the absence of liquid.
- The CMF was then weighed in about 250g. This was then mixed with polyethylene with a 10% CMF and 90% polyethylene ratio.
-The bioplastic was then extruded, ran through a water bath and then pelletized.
-The pelletized bioplastic is then used in the injection molding machine to make some dog bone samples and impact test samples.

Fig 3: Bio-composite Pellets

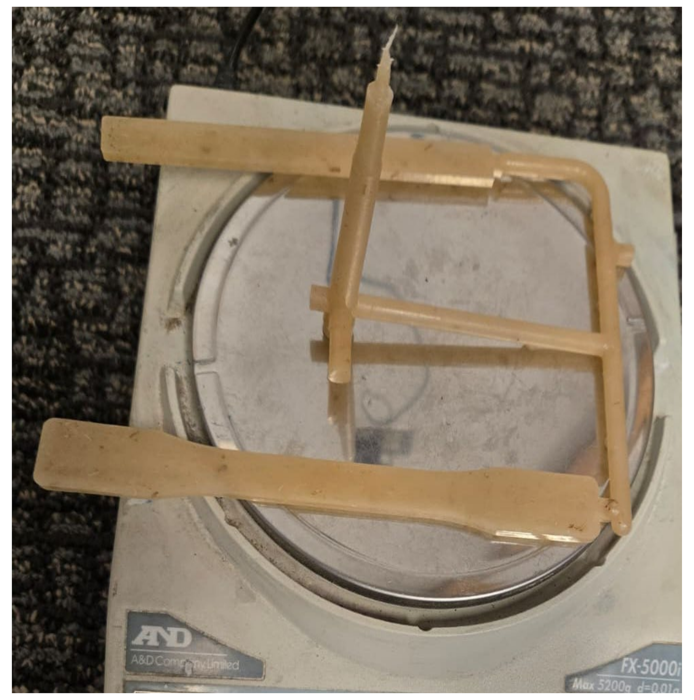

Fig 4: Injection molded Samples

Experimental Results

- The **Young's Modulus** of the hemp bio-composite was **52.79 kgf/mm²**, over **three times higher** than polyethylene's **16.08 kgf/mm²**, indicating significantly improved stiffness.
- The **maximum stress** for the bio-composite reached approximately **0.98 kgf/mm²**, slightly higher than polyethylene at **0.89 kgf/mm²**, showing better load-bearing capacity.
- The **strain at break** for polyethylene extended to nearly **100%**, while the bio-composite fractured around **15%**, reflecting decreased ductility due to fiber reinforcement.
- Overall, the addition of CMF enhances both **strength and rigidity**, making the composite more suitable for structural applications where **stiffness and dimensional stability** are critical.
- In addition to improved strength and stiffness, the biocomposite includes **10% renewable content**, lowering fossil fuel usage and enhancing **sustainability without compromising performance**.

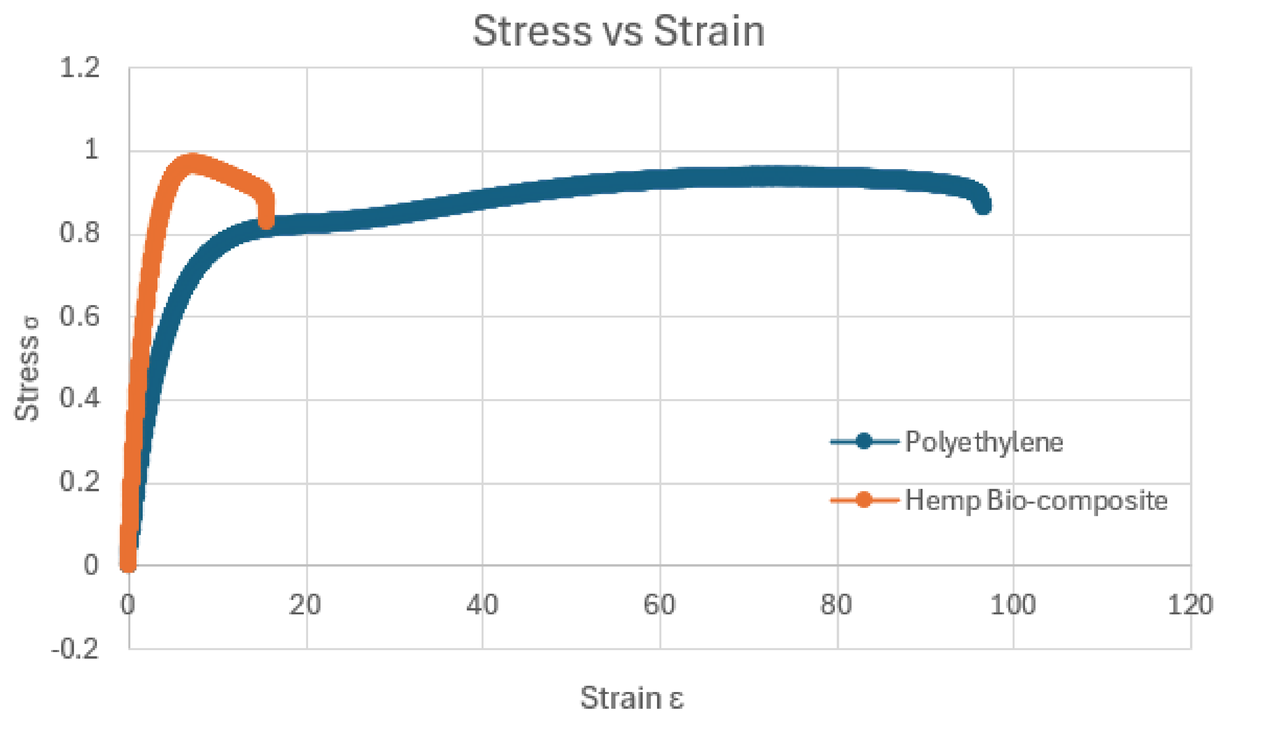

Fig 5: Comparison of Polyethylene and Bio-composite Stress Strain Curves

Acknowledgements: I would like to acknowledge Dr. Tipton from the Mechanical Engineering Department, the Office of Undergraduate Research (OUR), Polymer Center of Excellence and Department of Mechanical Engineering for their support in this research project. This work was conducted at the University of North Carolina at Charlotte