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Development of Banana/Sisal Fiber Reinforced Fully Biodegradable Hybrid Composite Rod – An Effort Towards Sustainable Manufacturing

Amrinder Singh Pannu[a,1] and Sehijpal Singh[b]
[a]*Mechanical and Production Engineering Department, Guru Nanak Dev Engineering College, Ludhiana, Punjab, India.*
[b]*Principal, Guru Nanak Dev Engineering College, Ludhiana, Punjab, India*

Abstract. To fight with global farming, dwindling fossil fuels and waste management issues in agricultural countries; effort has been made to develop fully biodegradable hybrid composite rod from fibers of banana leaf waste and sisal fiber reinforced in polylactic acid (matrix) at a different fiber fraction v/v (0%, 10% (5:5 i.e. B:S), 20%(10:10), 30% (15:15) and 40%(20:20). Rods were made as per ASTM standard (ASTM D7205) by using single screw extruder. The mechanical properties namely: tensile, compression, flexural, bending and impact testing with reference to ASTM standards (ASTM D6641, ASTM D4476 and ASTM D-256 respectively) were evaluated. Results show that pure PLA rod has a maximum tensile strength of 15.82 MPa, compression 33.48 MPa, flexural strength of 13.64 MPa and impact strength 1.98 kJ/m^2. In the case of maximum successful reinforcement (40% by volume), where 20% is banana and 20% is sisal fiber, maximum tensile strength comes out to be 41.32 MPa, compression 77.81 MPa, flexural strength 32.52 MPa and impact strength 4.27 kJ/m^2. Thermal analysis (Differential scanning calorimetry) was also done that shows increase of melting temperature by 14°C-17°C in 40% fiber reinforcement compared to the pure PLA composite. These rods can be successfully utilized in furniture, construction and sports industry.

Keywords. Polylactic Acid, Fully Biodegradable Composite Rod, Mechanical and Thermal Properties.

1. Introduction

Composite materials consists of two or more constituent materials having different chemical or physical properties and when mixed together, produce a material having characteristics completely different from parent materials. In this era of development of new materials with good properties, is going to be a challenge when different processing methods are available with their merits and demerits concerned with reinforcement compatibility with matrix. Composites are classified as non- biodegradable and biodegradable in nature. Biodegradable can be partially or fully,

[1] Corresponding Author. amrinderpannu@gndec.ac.in

depending upon the type of matrix and reinforcement. So where the biodegradability is the main concern, PLA is proved to be an emerging and high potential material as matrix for product development. At present PLA (Polylactic Acid) is widely used in most of the research works and till date work on PLA is going on. PLA are high modulus polymers having high strength and are thermoplastic in nature. Due to their biodegradable nature and common process of extraction and utilization of various biodegradable wastes, its uses are increasing day by day in all the fields of engineering and science. At the initial stage of research of biodegradable polymer, PGA (Poly- glycolic acid) was the first to be synthesized followed by PLA (poly-lactic acid) for their use as implant materials for the repair of various types of tissues (1) (2) (4). In medical field, PLA has been used as a drug delivery matrices and internal fixation of fractured bones (3). Moreover the renowned automotive industries like Mercedes Benz, Tata Motors, General Motors etc. are using these sisal and banana fibers for making plastic based components of their automobiles. Some uses of bio-based composites include internal door trim, seat-back trim, dashboard supports, rear shelves and exterior parts, such as transmission covers etc. These fibers are also used as reinforcement in constructional sector (5-8). Banana plant is a valuable and important bio resource existing in around 120 countries. The area of around 48 lakh hectares has been covered by this resource with annual production of around 100 million (9). The residues coming from the bunch of fruit and the trunk make it more valuable among other plants. Sisal belongs to the family of Asparagaceae. This plant grows in the arid and humid environment. Sisal production throughout world is around 4.5 million tons annually. In India there has been a yield of about 2.5 ton (dry fiber) per hectare annually from the sisal plant.

2. Development of Composite Rod

Composite rod has been developed by treating the reinforcement and matrix to enhance the interfacial bonding between PLA and banana/sisal.

2.1 Material and its Treatment

Both the fibers (Banana and Sisal) were extracted from the leaves of the respective plants. First of all fibers were dried in open sunlight for the removal of moisture for 24 hours for further chopping of the fibers.

(a) (b) (c)

Figure 1. Chopped Banana Fibers (a); Sisal Fibers (b); PLA Pallets (c)

So to develop the BSFRC rod, treatment of fibers is must to enhance the bonding between PLA, banana fibers and sisal fibers so that better physical and chemical properties can be obtained. For the extrusion of rod, there has been a need of fibers in chopped form. So after drying the banana leaves, sisal fibers chopping has been done in mixer grinder to get the size of 600 µm as per requirement (shown in Figure. 1 (a) and 1 (b) respectively). Thereafter to remove the dust and other unwanted contents from the chopped fibers, washing of fibers is done with the use of distilled water at temperature range of 55-65°C for around 1 hour and then they were laid to be dried in open air for the time of 48 hours at room temperature. To remove the lignin form the fibers, NaOH treatment (10%) was given at room temperature, and then again washed with distilled water before drying in open air. Polylactic acid pallets as shown in Figure. 1 (c) of 3052D grade were also dried in oven for 2 hours at the temperature of 70°C to remove the moisture from the pallets so that proper interfacial bonding between fibers and matrix can be attained during the extrusion process.

2.2 Development of Extrusion set up

To get the required size of rod as per ASTM standard, die must be developed accordingly. For the better solidification of rod at the exit, there has been a need of temperature controlled system to manage the temperature gradient over the length of developed die. Mild steel die has been made to extrude the rod. As per the requirement of ASTM D7205, the internal diameter of die has been made. Die is covered by four precisely controlled heaters so that proper solidification can be attained during the extrusion of the composite rod. Complete extrusion set up along with die has been shown in figure no 2.

Figure 2. Single Screw Extruder

2.3 Fabrication of Composite Rod

To develop the composite rod, fibers are mixed in the ratio of 0% (pure PLA), 10% (5% banana and 5% sisal), 20% (10% banana and 10% sisal) 30% (15% banana and 15% sisal) and 40% (20% banana and 20% sisal) (v/v) respectively in PLA matrix. To mix PLA with fibers, coconut oil (less than 1% by volume) is used so that the fibers adhere to PLA granules. Then the required mixture is put down into the barrel having speed of 30 rpm (optimum speed with experiments) and temperature in the range of 130-1600°C (3 heaters). Samples were made according to ASTM D7205 (shown in Figure. no 3) and named as PLA, PLA/BS1, PLA/BS2, PLA/BS3 and PLA/BS4 having a volume ratio of banana fibers and sisal fibers as 0%, 10%, 20%, 30% and 40% respectively as shown in Figure. no 4.

Figure 3. Single Screw Extruder Sketch showing dimensions of rod as per ASTM D 7205

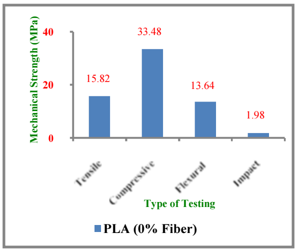
(a) (b) (c) (d) (e)

Figure 4. Developed Rods- PLA(a); PLA/BS1(b); PLA/BS2(c); PLA/BS3(d); PLA/BS4(e)

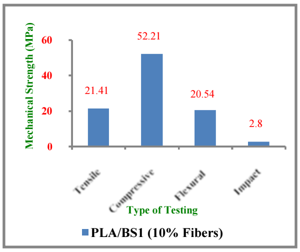
3. Results and Discussion

3.1 Mechanical Strength

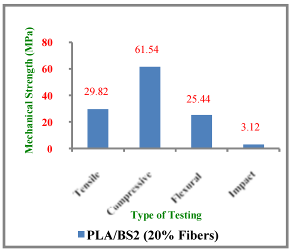
Figure. no 5(a) to 5(e) indicates the relative variation in mechanical strength of specimens prepared at various fiber fractions of banana and sisal fibers. With the increase in fiber ratio, the strength of composite rod increases. This trend continuous up to 40% fiber fraction.



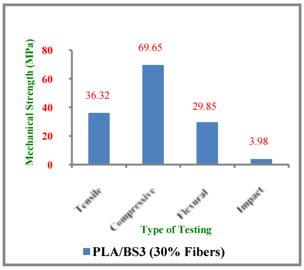
(a)



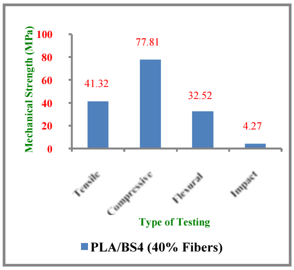
(b)



(c)



(d)



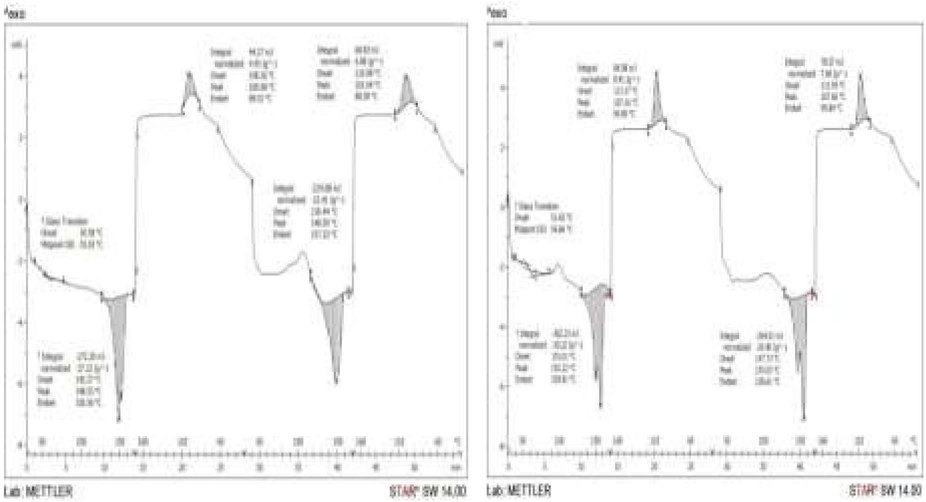
(e)

Figure 5. Mechanical Strength of the- pure PLA rod (a); pure PLA/BS1 rod (b); pure PLA/BS2 rod (c); pure PLA/BS3 rod (d); pure PLA/BS4 rod (e)

All these strength values are maximum when the fiber fraction ratio is 40%. The reason behind this was good bonding between the fibers and the matrix. So overall there has been an increase of 161.18 % in tensile strength, 132.40 % in compression strength, 138.41 % in flexural strength and 115.65 % in impact strength with reinforcement of fibers in polylactic acid as compare to pure PLA sample.

3.2 Thermo-mechanical Analysis

It is one very important method to investigate the effects of temperature on the polymers known as glass transition. The ratio of heat flow and heating rate is known as heat capacity of the product under consideration. This testing (DSC) was conducted on the METTLER TOLEDO Star 3 machine. The DSC curves are shown in (Figure. 6 (a) and (b)) for the neat PLA rod and banana sisal fiber reinforced composite rod sample having fiber volume fraction of 40%. Temperature range for the cycle was set between 30°C to 160°C to investigate the thermal transitions. In concern with the melting of the composite sample, it has been observed that melting began in temperature range of 142°C -148°C for neat PLA rod sample (as shown in Figure. no 6 (a)) while for banana and sisal fiber reinforced composite rod sample with 40% fiber fraction, melting starts between 151°C to 155°C. So it is concluded that with the reinforcement of fibers, melting point of developed composite goes up by 14°C-17°C as compare to the neat PLA sample which proved strengthening of composite.



(a) (b)

Figure 6. DSC curve for neat PLA sample (a); DSC curve for PLA/B4 sample (b)

In this work, waste fibers are used in chopped form and good tensile strength has been obtained by developing the fully biodegradable composite rods through extrusion process. Some of the applications where these rods can replace the synthetic rods or wood based composites are: Guide rails, Road markers, Flag whips, Wickets, Greenhouse structures, Selfie stick and Construction of furniture etc.

4 Conclusion

The following conclusions were drawn from the mechanical and thermo-mechanical analysis:

- Full biodegradable composite in form of rod has been developed successfully where both matrix and reinforcement are biodegradable.
- Extrusion found to be the successful method for making composite products like rod by using any type of fiber in chopped form.
- Tensile, compression, flexural strength increased by around 2.5 times at 40% fiber reinforcement having tensile strength of 41.32 MPa at 40% reinforcement whereas for neat PLA it was just 15.82 MPa, in compression testing, maximum strength was 77.81 MPa at 40% reinforcement and 33.48 MPa with neat PLA and in flexural testing, value found to be 32.52 MPa at 40% reinforcement and 13.64 MPa with neat PLA.
- In case of impact testing, strength observed was around 2 times with maximum value of 4.27kJ/m^2 at 40 % reinforcement and 1.98 kJ/m^2 when neat PLA sample was tested.
- Differential scanning calorimetry (DSC) revealed that the melting point of composite enhanced by around 15.5°C with 40% reinforcement as compare to neat PLA that shows enhancement in the properties of the developed composite.

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