Synthesis and Characterization of Sisal Fiber Reinforced PLA Biodegradable Composites

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Abstract: ***Biodegradable polymers and biomaterials are of significant interest for tissue engineering and orthopedic applications, such as bone and joint replacement. One possible advantage of these systems is that biodegradable implants can be engineered to provide temporary support for bone fractures, and because they can degrade at a rate matching new tissue formation, their use can eliminate the need for a second surgery . PLA products have been approved by the US Food and Drug Administration (FDA) for direct contact with biological fluids. Four of its most attractive advantages are renewability, biocompatibility, processability, and energy saving. PLA is very brittle, with less than 10% elongation at break. Optimization of the natural fiber-reinforced PLA composites, in terms of mechanical and other properties, is critical to minimize their cost, tailor their biodegradability, and broaden their areas of application. Inorganic fillers can also contribute to property modification. In this journal PLA is reinforced with treated chopped sisal fiber. In this study PLA is also mixed with 10% starch. and its mechanical properties are determined.***

Keywords: PLA, Sisal, Biodegradability, Impact strength, Biomaterial

1. Introduction

There have been significant advances in the development of biodegradable materials. In particular, use of these materials as implants to aid regeneration of orthopedic defects.

One possible advantage of these systems is that biodegradable implants can be engineered to provide temporary support for bone fractures, and because they can degrade at a rate matching new tissue formation, their use can eliminate the need for a second surgery. In addition to providing support for the tissue surrounding a defect, the scaffold can serve as a substrate for seeded cells, facilitating new tissue formation at the site of injury. Depending on the defect site and strategy to be employed, certain orthopedic biomaterials may be more suitable than others. These materials can either be obtained from natural sources, with or without subsequent modification. Commonly used natural biomaterials are Collagen, Gelatin, Fibrin, Chitosan. Among Synthetic polymers, Polycaprolactone, Polylactic acid (PLA), Polyethelene glycol[PEG] are few commonly used synthetic polymers.

In this experiment we have produced the composite made of PLA reinforced with treated chopped sisal fiber. Corn starch is also added as filler material. Prepared composites are tested for their mechanical strength.

2. Selection of Materials

2.1 Polylactic Acid [p.l.a]

Polylactic acid is an aliphatic polyester. It has outstanding advantages over other polymers. As early as the 1970’s, PLA products have been approved by the US Food and Drug Administration (FDA) for direct contact with biological fluids. Four of its most attractive advantages are renewability, biocompatibility, processability, and energy saving.[5]. PLA is derived from renewable and degradable resources such as corn and rice, it can help alleviate the energy crisis as well as reduce the dependence on fossil fuels of our society; PLA and its degradation products, namely H2O and CO2, are neither toxic nor carcinogenic to the human body, hence making it an excellent material for biomedical applications including sutures, clips, and drug delivery systems. PLA can be processed by extrusion, blow molding, and fiber spinning due to its greater thermal processability in comparison to other biomaterials.

Its degradation rate through hydrolysis is too slow. This process sometimes takes several years, which can impede its biomedical and food packaging applications [6]. PLA is very brittle, with less than 10% elongation at break, thus it is not suitable for demanding mechanical performance applications unless it is suitably modified.

2.2 Sisal fiber

Fibers can serve as fillers in the formation of PLA composites processable by compression or injection molding, to enhance the thermal stability, the hydrolysis resistance, or the mechanical properties of PLA. Several investigations on PLA composites prepared from natural and modified cellulose fibers have shown that their mechanical properties scale with the mass fraction of added fibers [7]

Sisal fiber is extracted from the leaves of the Agave sisalana plant with high cellulose content Since it has high tensile strength (700 MPa) and modulus (22 GPa), it has become one of the most commonly used leaf fibers in the composite industry. The leaves reach a length of 2 m. The plant originates from central America and is now cultivated in East Africa and East Asia.

Sisal fiber is extracted from the leaves by retting, scraping, or mechanical decortication. The sisal plant produces swordlike leaves with teeth and loses these tooth in maturity. Decortication is the most common method for extracting sisal fiber. In this process, the leaves are crushed between blunt knives and moisture and the fleshy pulp are removed from the fiber. Water is used to clean debris that is present in the leaves. The sisal fiber that is obtained is dried in the hot sun.

Figure 1: PLA Pellet and Sisal plant

Short sisal fiber reinforced PLA composites with various fiber content (10 - 40 %) were produced by melt blending followed by compression in Wu's study [108]. The tensile stress at break of the sisal-PLA composite decreases with the increase of fiber content. It was also found that the sisal–modified PLA (acrylic acid-grafted PLA) composites have significantly higher tensile stress at break than the unmodified PLA at the full range of fiber contents.

3. Specimen Preparation

The most common manufacturing processes are injection molding and compression molding (using film-stacking). The injection molding method can provide good degree of fiber wetting because the fiber and PLA matrix can be mixed properly in an extruder. The disadvantage of this method is that the reinforcement structure of the composite is limited to chopped short fibers. However, compression molding can use a variety of reinforced structures, including short fiber mat chopped short fiber, unidirectional filaments and textile fabric.

3.1 Alkaline Treatment of Fiber

The dry fiber is treated by means of alkali and this method is also called as Mercerization. This is the appropriate method to remove the natural and synthetic impurities to produce the good quality of fibers which helps bond between fiber and matrix. Removal of impurities decrease the diameter & aspect ratio will be increased. This treatment improves the good mechanical properties by increasing the surface roughness [2,7]

The chemical reaction is shown below.

$$\text{Fiber}-OH + NaOH \rightarrow \text{Fiber-o-Na}+H_2O$$

The dry fibers are soaked in a 5% of Na0H solution and allow it for two hours to remove the natural and artificial impurities such as cellulose, hemi cellulose, pectin, lignin. Dust and dirt of the fiber. The ratio 1:25 weight fraction is maintained for the fiber and the solution.

Figure 2: Sisal fiber in NaOH solutions

After 2 hours the fiber is washed in distilled water to remove the solution and dried for a day. Treated fibers are cut to a length of 2 to 4mm

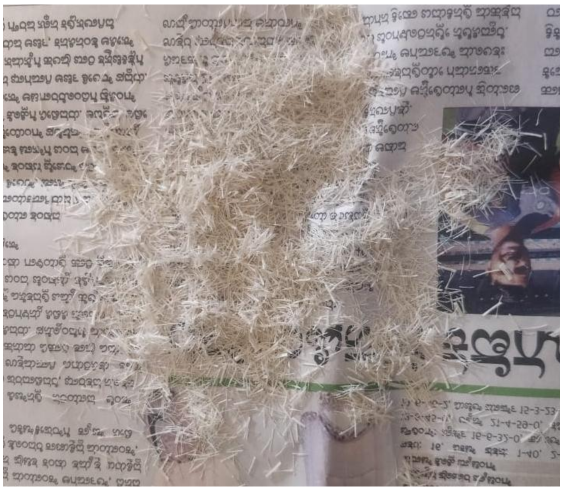


Figure 3: Chopped short sisal fiber

3.2 Corn starch

Starch is a polymeric carbohydrate consisting of numerous glucose units joined by glycosidic bonds. This polysaccharide is produced by most green plants as energy storage. It is the most common carbohydrate in human diets and is contained in large amounts in staple foods like potatoes, wheat, maize (corn), rice, and cassava. Poly (lactic acid) (PLA) blended with starch or reinforced by cellulose are two promising techniques for developing biodegradable polymer materials, since both starch and cellulose are commercially available and are derived from renewable resources [8]. Since hydrophobic aliphatic polyester PLA and hydrophilic starches are thermodynamically immiscible, which would generally lead to poor adhesion between the two components.

3.3 Compounding of specimen

Specimen is prepared using injection molding technique in CIPET Cochin in the following composition. PLA is obtained from NATURTEC, Chennai. Specimen preparation and testing is done in CIPET, Cochin.

Different proportions of mixing PLA [Matrix] with treated chopped natural fibers and filler are given below.

Table 1: Percentage composition of Specimen

Samples	% of PLA	%of Sisal	% of starch
VIRGIN	100	0	0
A	90	10	0

B	80	10	10

The Polylactic acid composite is injection molded in thermoplastic injection molding machine and molds. The pre-conditions for injection molding of Polylactic acid composite are as follows:

- Pre-drying +75 °C / 8 h, dehumidifying dryer.
- Temperature profile + 200 / 185 / 185 / 180 °C.
- Injection pressure < 1000 bar.
- Mold temperature +5…20 °C.
- Recommended nozzle diameter > 2 mm (not mandatory).

Figure 4: Injection molding equipment

3.4 Specimen preparation

Specimen are prepared asper the ASTM standards

Figure 5: Prepared test specimen

Specimen dimensions: -ASTM D638 of tensile test

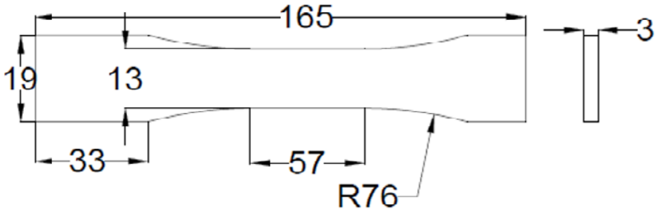


Figure 6: Tensile test specimen

Specimen dimensions: -ASTM D790 of flexural test

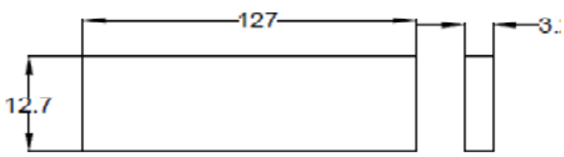


Figure 7: Flexural test specimen

Specimen dimensions: -ASTM D256 of impact test

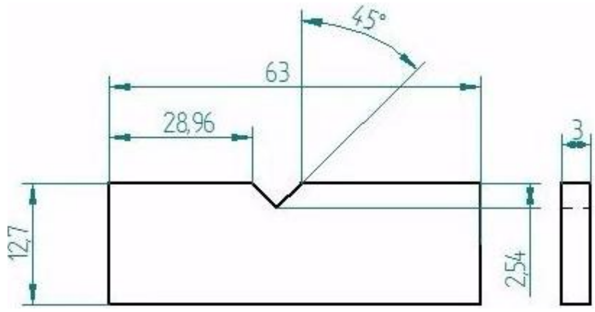


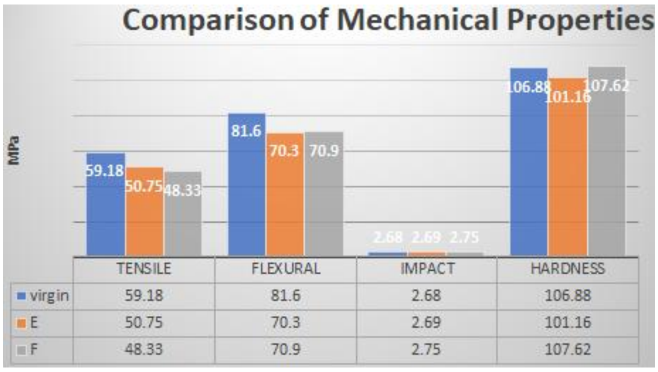
Figure 8: Impact test specimen

4. Results and Discussion

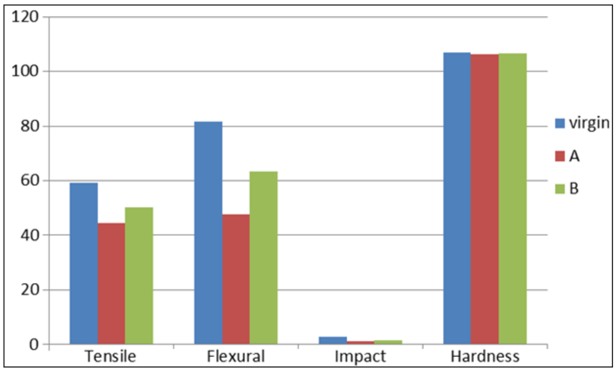
Table 2: Results obtained after test

Sample code	Tensile strength as per ASTM D638 [MPa]	Flexural strength as per ASTM D790 [MPa]	Impact Strength as per ASTMD 256 [MPa]	Rockwell Hardness as per ASTM D785 [Scale R]
Virgin	59.18	81.6	2.68	106.88
A	50.75	70.3	2.69	101.16
B	48.33	70.9	2.75	107.62

The effect of filler and Sisal fiber reinforcement on polylactic acid polymer matrix is analyzed.



Graph 1: Mechanical properties of Virgin PLA with 10% sisal fiber



Graph 1: Mechanical Properties of Virgin PLA with10% Sisal Fiber and 10% Filler

It is found that reinforcement of 10% Sisal fiber is reducing its mechanical properties such as Tensile strength, Flexural strength. But noticeably Impact strength of the prepared specimen is increased marginally.

Addition of filler material has increased tensile strength by 6MPa when compared with only Sisal Fiber

Addition of filler material has increased the Impact strength of specimen by 4% when compared with virgin PLA.

5. Conclusion

PLA is brittle in nature. Addition of 10% Sisal fiber has increased the impact strength marginally. It gives scope to make specimen with increased % of sisal fiber. Sisal fiber % can be increased 20%,30%,40% to check the increased impact strength. Also the effect of the increased fiber % on Tensile and Flexural strength to be investigated.

Also addition of 10% Starch as filler material along with 10% sisal fiber increased the impact strength by 4% when compared with Pure PLA. Further experiments should be conducted to determine the effect of starch on Mechanical strength particularly on Impact strength.

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