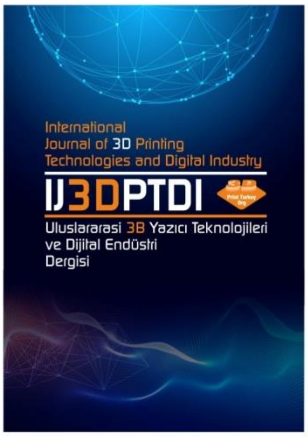

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PRODUCTION OF WASTE JUTE DOPED PLA (POLYLACTIC ACID) FILAMENT FOR FFF: EFFECT OF PULVERIZATION

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ABSTRACT

In recent years, there has been an outbreak of research on natural fiber-reinforced materials to reduce non-recycled material effects and produce environmentally friendly products. In parallel with the increasing popularity of additive manufacturing, the development of new natural fiber-reinforced materials in this field has also increased to improve pure material characteristics and reduce raw materials usage. This study presents the manufacturing process of 5% waste jute-reinforced PLA filaments and the characteristics of 3D printed parts. For the production of jute-reinforced filaments, polylactic acid (PLA) granules were pulverized to increase the material surface for better bonding between materials in the composite matrix structure. The effectiveness of pulverizing PLA granules was exposed by comparing it with the production of the same composite matrix with PLA granules. Both matrices were formed into filaments to produce 3D parts in Fused Filament Fabrication technology. Thermo-gravimetric analysis (TGA) and differential scanning calorimetry (DSC) will be presented in filament form. Besides, the mechanical properties of 3D parts will also be presented. Within the scope of the study, it is aimed to reveal the material size effect for producing natural fiber-reinforced filaments for additive manufacturing.

Keywords: PLA, Jute, Additive Manufacturing, FFF, Pulverization.

1. INTRODUCTION

3-Dimensional (3D) printing has gained a lot of attention and popularity with the help of producing complex geometries without special tools in good accuracy, and ease of production for prototyping. Various technologies have been presented for 3D printing. Fused Filament Fabrication (FFF) is probably the most popular used 3D printing technology [1]. In the working principle of FFF printers, filament-form material is fed through a heated nozzle, and designed parts are produced by the deposition of molten polymers on the printing bed. There has been increasing attention to research on producing different types of polymers and/or particle-doped filaments via FFF printers.

Recently additives from natural sources have been utilized for sustainable and ecologically friendly filament manufacturing [2]. Ease of availability and low cost also make these materials indispensable for doped polymeric materials for any application. The type and number of doped materials, the aspect ratio esp. for fibers, and the interface between the polymer and the reinforced materials are highly effective parameters on the final performance of produced bio-composite filament [3]. The main drawback of bio composite filament manufacturing is to achieve homogeneous filler dispersion. The effect of wood amount on tensile properties of PLA was studied [4]. It is determined there is an optimum particle content for the improvement of the tensile properties of PLA. In another paper, it is stated lower wood particle size can ease the fabrication of wood-reinforced PLA filament [5]. The particles particularly cellulosic materials can also be treated with different physical/chemical methods to improve particle distribution along the filament and also facilitate 3D printing [6-9].

The properties of the polymer can play an acting role in particle-doped filament manufacturing. The polymer can be modified by grafting and/or can be pulverized to enhance particle/polymer interface and particle distribution [10,11]. Pulverization of the polymer granules may enhance the homogeneity of the ground particle/polymer mixture prior to the extrusion processes. This study presents the manufacturing process of 5% waste jute-reinforced PLA filaments with FFF and the characteristics of 3D printed parts. For the production of jute-reinforced filaments, jute fibers were ground and polylactic acid (PLA) granules were pulverized with the aim of increasing the material surface for better bonding between materials in the composite matrix structure. Then, thermal degradation behavior is investigated by a thermogravimetric analyzer (TGA), and the mechanical properties were determined by means of maximum tensile strength, elasticity modulus, and breaking at elongation. The uniformity and distribution of jute particles in PLA filament were observed via fluorescence microscopy. In order to realize the effect of pulverization and dopping of jute, pristine PLA as in the granule form was tested as a control sample.

2. MATERIALS AND METHODS

2.1. Materials

PLA was used as matrix material in this research. This PLA was the product of FKuR Kunstsoff company, and its label is Bio-Flex F7510. The density of the used PLA is 1.25 gr/m3, the melting temperature is 155 °C and the melt flow rate is 2-4 g/10min. This material is efficiently processed with the FFF method and 100% recyclable raw material. PLA can be destroyed in the same way as petro-based plastics. However, it has the nature of biodegradability, which is an environmental advantage. PLA materials converted into different forms were modified with 5% jute by weight. No pre-treatment was applied to the reinforced jute fibers which were doped to increase the mechanical properties. Jute wastes were obtained from the carpet factory.

2.2. Preparation of PLA matrix

In order to pulverize PLA, polymer sizes were reduced by grinding in a mechanical shredder using liquid nitrogen and the surface area was increased. Liquid nitrogen has been found to contribute greatly to this grinding process. The particle size has been reduced from 5 mm to an average of 400 µm.

2.3. Preparation of Re-Jute

Jute fibers are produced from natural hemp by grinding in the Retsch SM 100 device. The ground hemp fibers were passed through a 500 µm sieve. Jute fibers have an average density of 0.86 g/cm3, a diameter of 10–400 µ and a length of 100–1200µ. No surface treatment has been applied to jute fibers.

Figure 1. Grinded jute fibers.

2.4. Compounding

The jute addition to the powder and graded PLA matrices was carried out with a mechanical mixer. The weight ratio was determined with digital precision balance (Accuracy: 0.001) branded Weightlab Instruments Wl 303l. Recycled Jute additives and PLA matrices were mechanically mixed with Thermo Digital's vortex mixer. Two different compounds were prepared in powder and granule form.

Figure 2. Jute and powder PLA mix, before entering the mixer.

2.5. Filament Production

Filament production was carried out with Arya Flux brand single screw extruder by using 5% re-jute added powder PLA and 5% re-jute added graded PLA compounds by weight. In order to produce samples with the FFF method, filaments with a diameter of 1.75 mm(-/+0.15mm) were produced.

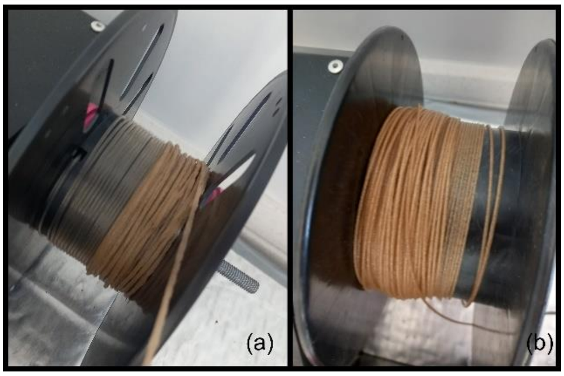

Figure 3. (a) Pellet PLA + jute, (b) Powder PLA + jute Fiber

2.6. Production of Samples

The effect of an 5% re-jute additive to two different PLA forms on the mechanical properties and thermal properties was investigated.

Tensile test specimens were produced in accordance with ASTM D-638 standard by using the FFF method using filaments having two different PLA forms. Due to the long production times in the FFF method, type-5 sample sizes, the sizes of which are specified in figure 2, were preferred.

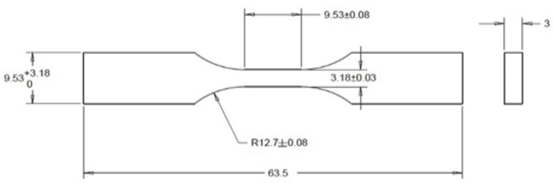

Figure 4. D638 ASTM standard type V tensile test sample.

The drawings of the test specimens were created with the AutoCAD Fusion 365 named CAD program. Using the drawing files in STL format, the gcode file required for production with FFF methods was created with the CAM program named CURA. Production parameters are given in table 1. Standard production parameters of PLA material were used.

Table 1. FFF Production Parameters.

Parameters	Value
Nozzle diameter	400micron
Infill Density	100%
Printing Temperature	200°C
Build Plate Temperature	70°C
Material Flow	100%
Print Speed	15 mm/s
Cooling Fan Speed	50%
Support	None
Build Plate Adhesion	None

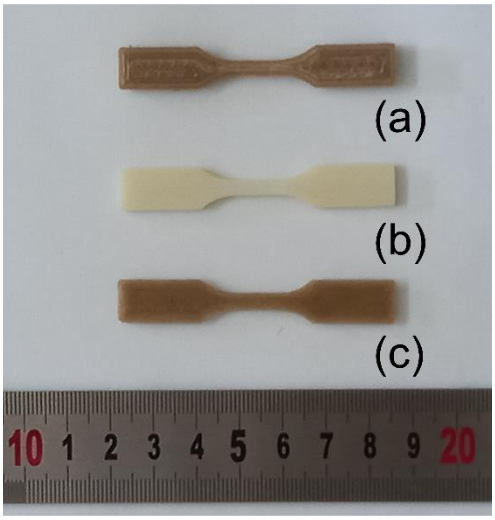

Figure 5. D638 tensile test specimen, (a) Pellet PLA + jute, (b) PLA, (c) Powder PLA + jute Fiber,

2.7. Experimental Testing

2.7.1 Tensile Tests

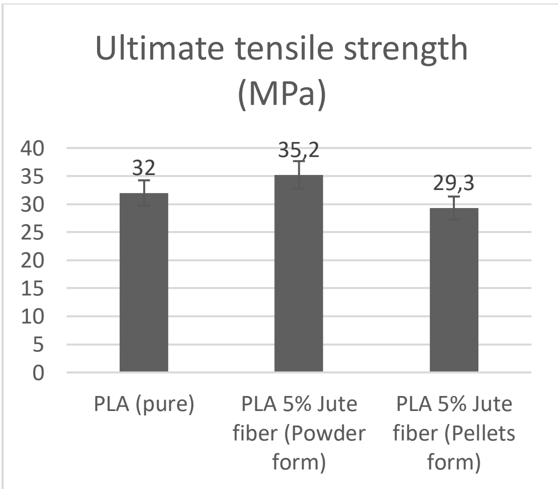

Figure 6. Tensile test results.

Tensile tests were performed according to the related standard (D638 ASTM). 5 samples were used for each configuration. Instron 1114 testing machine was used with its data acquisition system at a constant crosshead speed of 0.5 mm/min. Pulverized PLA compound clearly, gives better results than Pure PLA and pellets PLA + jute as seen in figure 6.

2.7.2 Thermal Analysis

Thermogravimetric analysis (TGA) is used to investigate thermal resistance. The results show that pulverized PLA approximately 5% degraded due to liquid nitrogen application during grinding as seen in figure 7 and 8.

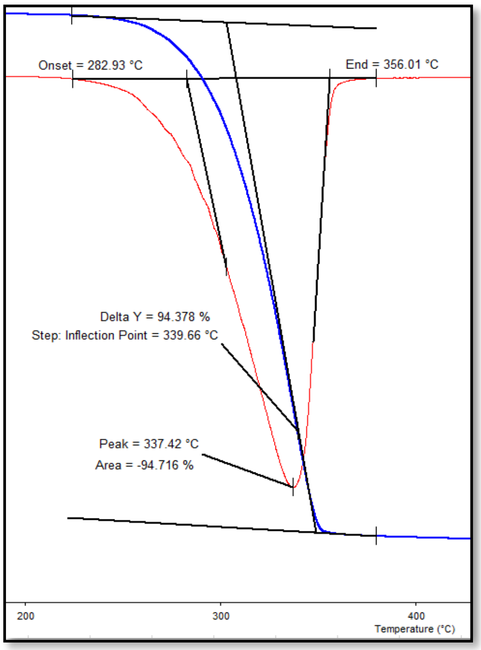

Figure 7. TGA analysis for Powder PLA + jute.

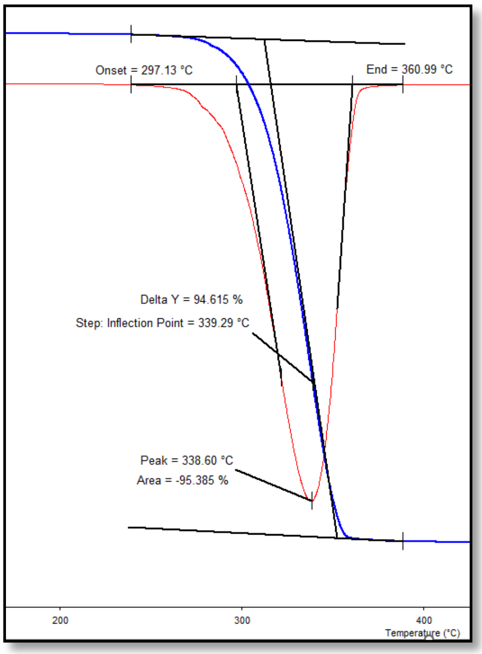

Figure 8. TGA analysis for Pellet PLA + jute.

3. CONCLUSIONS

This study shows that if a natural fiber supported compound is to be made, same fiber and matrix sizes for single screw extrusion will increase the homogeneity of the mixture and the interfacial bonding, which is clearly seen in the tensile tests. The compound made with powder PLA gave better results mechanically, but it is anticipated that such a mixture will be made with twin screw extruder for future studies will give better results. If access to twin screw extrusion is not available, pulverizing the granule can be seen as an alternative and successful method.

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