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A Study on Suitability of Recycled Polyethylene Terephthalate for 3D Printing Filament

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Abstract: *This paper presents a novel 3D printing technology using recycled polyethylene terephthalate (PET) to produce a 3D printing filament. The commonly used 3D printing filaments are acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA), but they are very expensive and not environment friendly.There is a great interest about how the filament should be made from recycled materials and be eco-friendly. In addition, there has been extreme growth and excitement about the possibilities of using 3D printing technology to boost world economy. In this research, the recycled waste PET materials were converted into high value and useful products such as dog bones test samples, 3D printing filaments, mobile robot chassis, drone blades etc. This technology involves the conversion of a computer aided designed (CAD) file into a 3D physical object. The aim of this research was to find recycled PET specification and extrusion parameters for 3D printing filament. The American Society for Testing and Materials (ASTM) standard dog bones were printed from a Reprap printer to test mechanical and thermal characteristics. The mechanical and thermal properties of recycled PET such as melt flow, tensile strength, Young modulus, and yield strain were observed to go along with the printed PLA filament parameters. It has been found that recycled PET has melt flow index=2.85g/10min, tensile strength=35.7 Mpa, Young's modulus=2457 Mpa, melting temperature=250 °C, extruding temperature=250-260°C. These properties compare well with the commercial filaments hence within acceptable range, making recycled PET fit as a 3D printing filament. The results obtained contribute to practice by providing parameters that can be used during recycling process of PET and also conservation of the environment through recycling. The result also contributes to theory by providing the properties of recycled 3D printed PET.*

Keywords: *3D printing filament, PET, PLA, ABS, Reprap printer.*

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I. Introduction

1.1 Overview

Additive manufacturing (AM), recognized by some as the "future industrial revolution," is speculated by a good number of people to change the way products are built by minimizing the need for complete supply chains, relatively large inventories, high costs of labor, and global emissions [1]. The 3D printing technology is one of the AM techniques that utilize three-dimensional (3D) Computer Aided Design (CAD) drawings to manufacture 3D objects [2]. The 3D printing technique slices an object into membranes and builds the object through the deposition of one layer of this material on top of the other until the entire model is molded [3]. Unlike traditional molding processes, 3D printing art has little waste material left and does not require molds to complete manufacturing [1-3].

Existing 3D printing processes use variety of materials such as Acrylonitrile-Butadiene-Styrene (ABS), Polylactic Acid (PLA), etc., but they are very expensive and not environment friendly[1,2]. Therefore, this research aimed at finding recycled PET specifications and extrusion parameters for 3D printing filament.

1.2 Acrylonitrile-Butadiene-Styrene (ABS) versus Polylactic Acid (PLA)

In ABS threedissimilar monomers namely; butadiene, acrylonitrile, and styrene combine to produce a single polymer [2, 4]. The different properties of these monomers contribute to the exceptional impact strength that makes ABS a stiff thermoplastic polymer appropriate for consumer durable products. Fig.1 shows the representation of the asset mix and arrangement of ABS [4].

The monomers present two phases of the polymer blend. The styrene-acrylonitrile copolymer (SAN) is the first copolymer phase that gives ABS itshardness,rigidity, and thermal resistancewhereas toughness comes about due to polybutadiene rubber particles which are evenly distributed in SAN matrix thus offering the second phase blend [6]. ABS present long-term load carrying ability with stress values above its tensile strength, yet thehardnessand modulus of elasticity are superior [6,7].

Polylactide (PLA) is a biodegradable polymer produced from lactic acid. It is preferred among the biopolymers because of itsdegradability and renewability nature [8]. PLA isa naturally occurring material and can be produced either by fermentation or chemical synthesis [8, 9]. Fig.2 illustrates PLA production by fermentation process. Table 1 shows some PLA material properties and ISO standard testing conditions.

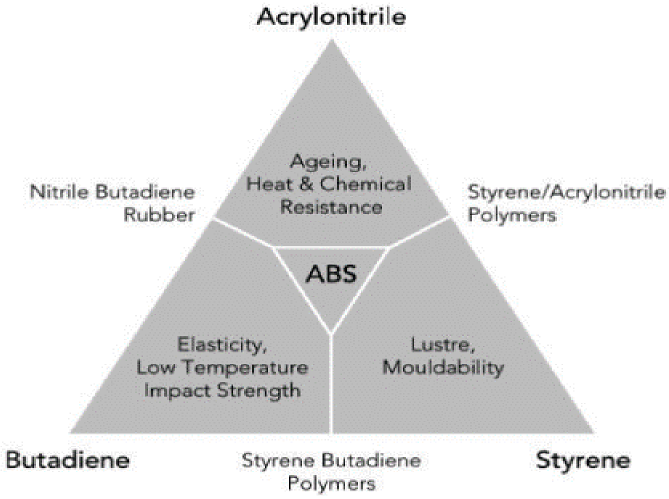

Fig.1: Representation of the asset mix and arrangement of ABS [4]

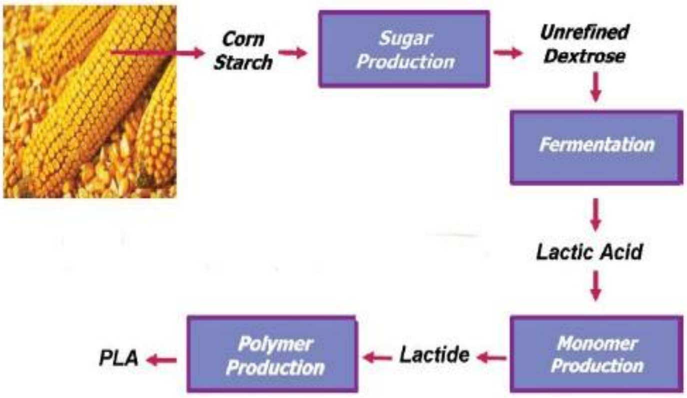

Fig.2: PLA production by fermentation process [11]

There is great interest among researchers on how filamentscan be made from recycled materials and be eco-friendly [10]. In this research, the recycled waste polyethylene terephthalate (PET) materials was converted into high value and useful products such as dog bones test samples, 3D printing filaments, mobile robot chassis, drone blades etc. This technology involves the conversion of a computer aided designed(CAD) file into a 3D physical object. The aim of this research was to find recycled PET specification and extrusion parameters for 3D printing filament.

Table 1: PLA material properties and ISO standard testing conditions

Physical Properties	
Density (g/cm^3)	1.25
Melt flow rate (g/10 min)	2.4 – 4.3
Mechanical Properties	
Flexural modulus (MPa)	350–450
Elongation at yield (%)	10-100
Tensile strength at yield (MPa)	53
Thermal Properties	
Melting point (°C)	120–170
HDT (°C)	40–45, 135
GTT (°C)	55–56

II. Experimental Work

2.1 PET Plastic Material Processing

In this research, the PET material processing involved were: Collection of material, i.e., all sorts of PETplastics werecollect for further treatment but this study only usedPET water bottles. Washing and separation, i.e., the PET water bottles were soaked in water to aid removal of the labels while washing at the same time. Shredding and drying, i.e., the plastic shredder cuts the material into small recyclable matter. The shredder cuts the plastic into flakes. The flakes were sieved using a 5mm filter in order to obtain approximate uniform flake size.

2.2 Filament Production

In this work, the filament was produced using Brabender Twin Screw DSE 20 model extruder that was having six (6) temperature zones. The first two (2) zones function were feed zone heating, the second two (2) zones function were compression zone heating, and the last two (2) zones were pumping zone heating the die. Cold-air gun, water-bath, and table blower cooling methods were used during extrusion optimization. An electric spooling device served as a puller for the filament during production while the filament was wrapped around a plastic profile tube.

2.3 Melt Flow Index (MFI)

In this work, the melt flow index (MFI) was obtained by using Melt Flow Indexer (MFI)-Plastometer. The purpose of MFI was to quantify the ease of flow of the recycled PET melt versus virgin PET and was measured in grams per 10 minute (g/10min).

2.4 3D Printing of the Dog-bones

In this research, the dog-bone CAD file was converted into STL file according to ASTM D638 and ISO 527-2 and Dog-bones were then printed by using 3D printer according to the standard test sizes. Table 2 shows the 3D printing parameters used:

Table 2: 3D printing parameters

3D Printing Parameters	Value
Extruder Temperature	255 °C
Platform Temperature	70 °C
Infill	100%
Printing speed	90mm/s
Layer height	0.2mm
Number of top layers	3

2.5 Tensile Testing

In order to test and contrast results, the dog-bone produced from the 3D printer was tested. This was done to acquire consistent data of the dog-bone such as engineering stress and strain, tensile strength, deformation, Young modulus, etc. The pure PET and recycled PET were tested with the geometric tensile testing machine. These tests were conducted at a load speed of 51mm/min in accordance with ISO 1133 standard. The number of samples tested was set to seven to be as accurate as possible by obtaining an average value, and test specimen dimension was 120 × 12.8 × 3.1 mm.

III. Results

In order to decide the mechanical properties of reused PET to suit 3D filament (Fig.5) and the inconstancy in these properties, this examination took a gander at the relationship between MFI rates; the rigidity of reused PET contrasted with ABS and PLA and delivered the filament. Table 3 and 4 beneath demonstrates the obtained information.

3.1 Tensile Testing and MFI

Table 3: Comparison table for 3D filament

Tests	PLA	ABS	Tested or Pure PET(Mean Value)	Tested rPET (Mean Value)
Melt index (g/10min)	2.4 – 4.3	22- 48	3.37	2.85
Tensile Strength (MPa)	50 - 55	30 - 52	17.7	35.7
Young's modulus (MPa)	3500	1700 – 2800	971	2457
Strain at Yield (%)	10 - 100	3 – 75	16.12	16.12
Melting temperature (°C)	120 - 190	200 - 230	250	250
Extruding Temperature (°C)	160 – 220	210- 230	250-260	250-260

3.2 Extruding

Table 4: Parameters table of recycled PET (Filament Die)

Test run	Extrusion temperature zone (°C)	Extrusion speed (rpm)	Cooling method	Pulling device voltage (V)	Filament size (mm)
1	255	20	Cold air gun	9.5	1.86±0,01
2	255	15	Cold air gun/ table blower	8.4	1,72±0.01
3	255	15	Room temperature	8.6	1.6±0.01
4	255	15	Room temperature	8	1.78±0.02
5	255	15	Room temperature	8.1	1.76±0.02
6	255	15	Room temperature	8.4	1.75+0.02

Figure 5. Sample of recycled PET 3D filament

IV. Discussion

The melt flow (MFI) of reused PET and virgin PET were studied to compare to ABS or PLA. The tested value of pure PET gives 3.37 g/10min and recycled PET provides 2.85 g/10min. Their difference of 0.52 g/10min indicates a decrease of 15%. This reduction in value of the recycled PET can be evaluated as a result of molecular degradation of the chain that hinders the melt flow to become lesser. Comparing 2.85g/10min melt flow of recycled PET to PLA, it can be stated that the flow rate only falls within the range of 2.4 – 4.3 g/10min and this signifies the possibility of using recycled PET as a 3D printing filament.

Recycled PET gives an average tensile strength estimation of 35.7 Mpa while the virgin PET gives a value of 17.7 Mpa out of the five-runs performed as shown in Fig.6. The recycled PET value is observed to increase significantly. This difference could also be attributed to the different grade of materials used for specific processing methods. As a result of this, the recycled PET used in this analysis may have contained different plastic grade that is produced by various methods. It should also be recalled that 100% of the gathered PET plastics were bottles. Therefore, this could mean that the plastic grades to be recycled should be produced by injection mould blowing. Comparing the recycled value PET to ABS or PLA tensile strength, it is observed that there is a very small value gap between both of them. Young's modulus value of the tested virgin PET as the average value of 971 Mpa and the recycled one gives an average value of 2457 Mpa as shown in Fig.7. It has been established from this research that the rigidity of the recycled PET increased significantly and can be linked with ABS that has the mild flexibility that makes PET a possible material for the filament.

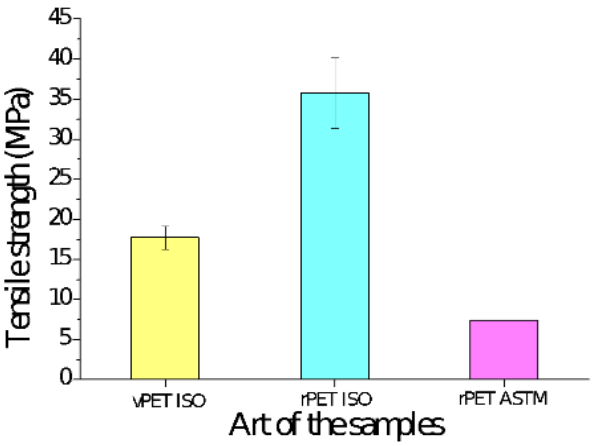

Figure 6. Tensile Strength

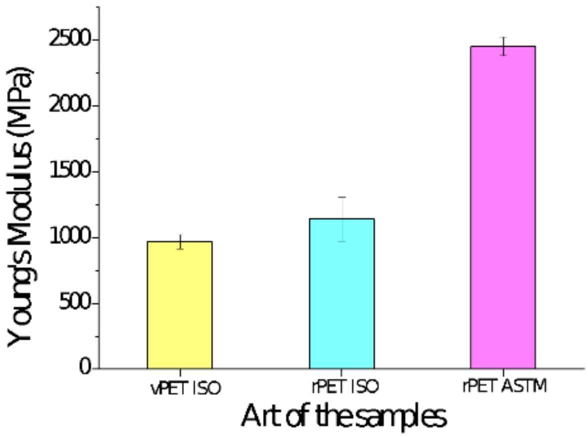

Figure 7. Young's Modulus

Based on the data obtained during filament production, the puller speed is seen to be a considerable influence during the optimization only because the voltage is reduced by a percentage factor before producing the desired size. Eventually, the parameter specifications of obtained for recycled PET filaments are given in table 5:

Table 5: Parameter specifications

Extrusion Temperature (degrees Celsius)	Extrusion speed (rpm)	Cooling method	Pooling device voltage (V)	Filament size (mm)
255	15	Room temperature	8.4	1.75+0.02

V. Conclusion

This study coversrecycling procedure of PET, acquiring 3D filament detail and generation parameters. Examination of ABS, PLA and PET was done to see the conceivable relationship between the materials and it is observed that reused PET information obliges PLA information on yield strain, melt flow, melting temperature and extrusion temperature. As observed, changes in mechanical properties were checked by measuring tensile properties and flow rates of the materials.This research used water bottles as the source of the PET material. Whereas the researcher believes that the quality of PET wastes may vary from one source to another, the results obtained in this study can be utilized to any quality of PET material.The outcome of this research clearly demonstrates that the puller speed is critical during extrusion and has aninfluenceon the quality of the filament with a drastic enhancement of 60% close to the 1.6 mm filament size. Other critical factors influencing filament quality include the distance between the puller and the die and the cooling method during extrusion. It can be concluded that recycled PET was found suitable for use as filament on the data obtained and in relation with both PLA and ABS data.

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