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Research Article

Laboratory Tests of Plastic Recycling for 3D Printing Utilisation

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ABSTRACT

Fused Deposition Modeling (FDM) is the most common 3D printing technology. In an additive process, an object is created by successive layering of material until the entire object is created so those process with different settings is important. Tensile test specimens of two types of printed Polyethylene terephthalate have been carried out to examine the mechanical properties. Virgin Polyethylene Terephthalate (PET) and recycled PET are the used materials for this research. A total of forty test pieces of the two types were evaluated. The differences in stress-strain curves, tensile strength values and, elongation at break were compared among the tested samples.

Keywords: 3D printing; Recycling; Mechanical proprieties; Filament

INTRODUCTION

The 3D printing thermoplastic causes a release of gases at high temperatures. This occurs in the context with the ABS where there have been emissions noticed for carbon monoxide, hydrogen cyanide, and many volatile organics. The ultrafine particle emission with the ABS was higher compared to the PET filament causing potential health hazards [1]. This has been mainly because of the contaminates are associated with the poor health risks. Such risks should be taken into consideration before further investigation is done [2]. Hence, there is a need for maintaining a safe ventilation system during the 3D printing process. A fine example is the use of HEPA filters associated with desktops which are now in market and being considered for future 3D printers to prevent the health risks [3].

A 30% global requirement is met by 60% of plastic material derived from synthetic fibers. In textile industries, PET is also referred to as polyester that covers 18% of world polymer production and is the third-largest usable polymer after Poly Ethane (PE) and Poly Propylene (PP) [4]. The first PET bottle was taken out of patent by Nathaniel Wyeth in 1973. PET is also used in making a thin film and solar cells.

The objective of this paper is to examine the mechanical properties (tensile, shear, and hardness characteristics) of specimens formed from the virgin PET filament. The obtained results are compared with the samples fabricated from the PET filament that is generated from recycling of the original printed 3D specimens. The reason for selecting PET over other plastic polymers is its pliability for recycling purposes [5].

MATERIALS AND METHODS

Polyethylene terephthalate waste management and collection

The waste aggregated of PET plastic was prepared *via* grinding the plastic PET bottles. The grinding of PET plastic aggregate is carried out in three main steps: Collection of the plastic waste, drying of bottles and shredding and grinding of bottles to the specified particle size. The process of grinding was conducted at the FKF Zrt, a plastic recycling company, in Budapest, Hungary. Table 1 shows the different types of selective waste recycled in the last years by the company. The statistics are based on the monthly sorting of incoming waste material.

The clean and colored PET material was selected for the experimental work. The mechanical strength testing of 3D printed components was performed at the Department of Mechanical Engineering, Szent Istvan University. Initially, the specimen was dried before the extrusion process (Table 2).

The test was done in the laboratory of mechanical engineering in Szent Istvan University following receiving the specimens from the 3D printing Free Dee printing solutions. For specimen preparation the PET was first dried for extrusion this was followed by the shredding of the material and drying. After properly drying the material was ready for extrusion. The Next filament extruder was used for the extrusion of the PET (Figure 1).

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Table 1: Types and ratio of the collected selective waste during first trimester 2018.

2018		January		February		March	
		103 Kg	m/m%	103 Kg	m/m%	103 Kg	m/m%
PET	Clean	30,4	12,2	27,0	10,6	30,2	11,9
	Blue	38,5	15,4	30,4	11,9	32,6	12,8
	Coloured	10,9	4,4	16,0	6,3	18,9	7,4
Foil	Dyed	6,3	2,5	8,6	3,4	5,6	2,2
	Natural	4,1	1,6	7,3	2,9	5,0	2,0
Flacon		36,5	14,6	25,4	10,0	22,4	8,8
Hungarocell		0,3	0,1	1,0	0,4	1,4	0,6
Metal	Tinned metal	6,0	2,4	6,2	2,4	3,0	1,2
	Aluminum	6,1	2,4	6,4	2,5	3,3	1,3
Other Waste		111,1	44,4	126,3	49,6	131,8	51,8
Altogether		250,2	100,0	254,6	100,0	254,2	100,0
Recyclable		138,8	55,5	127,3	50,0	121,0	47,6
Non-Recyclable		111,4	44,5	127,3	50,0	133,2	52,4

Table 2: Thermal properties for PET.

Material	Polyethylene Terephthalate
Melting point (°C)	225
Drying time (hours)	4-5
Drying temperature (°C)	160

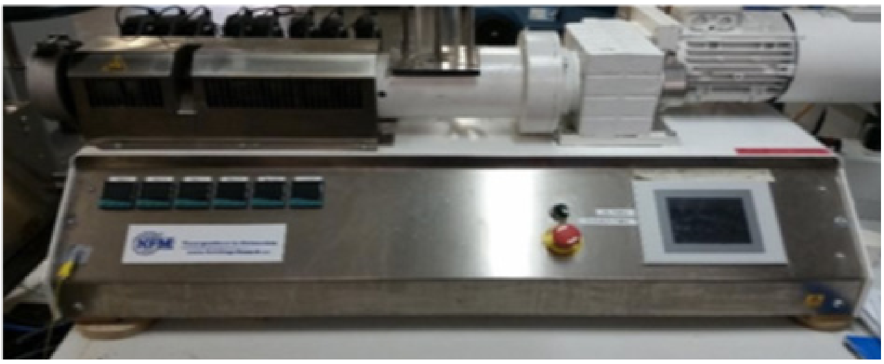

Figure 1: Sample of extrusion machine during the preparation of the specimens.

There were 3 different diameters used for the shredding of the material being maintained at a constant heat temperature range along with the speed of the fan. The measurement was ready after 3 tests. The Table 3 below shows the setting for the everyday test.

Experiments and mechanical tests

The tests start by studying the filament quality control by measuring the diameter of the recycled PET and the filaments in intervals of 1 meter. This will be followed by testing the surface and the cross-sections of the materials and finding out the melting points allowing us to study the thermal properties [6,7]. The second test will be studying the tensile testing for the raw materials (Figure 2).

The initial test specimens were manufactured using the virgin PET filament with a nominal diameter of 1.75 mm. The specimens were produced at 210 degree Celsius with a 0.4 mm nozzle, thickness and width of tensile specimens of the shear specimens were measure using a digital micrometer with 0,01 mm accuracy Tensile testing were performed on Testometrinc Zwick/Roel Z100 with a head travel speed of 5 mm/min (Figure 3). The tensile specimens were then fabricated according to the American Society of Testing Materials (ASTM) standard ISO 527-1:2012 as in Figure 2; (Table 4).

Table 3: Setting and parameters using during the preparation.

Test	Diameter of shredded material(mm)	Temperature range(°C)	Filament fan speed (%) and extruder(rpm)
1	2,85	240-245	80-5
2	2	240-245	80-5
3	1,75	240-245	80-5

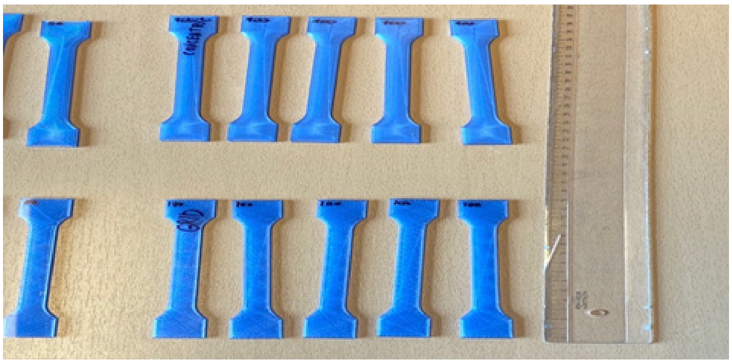

Figure 2: Testing materials standard for the specimens.

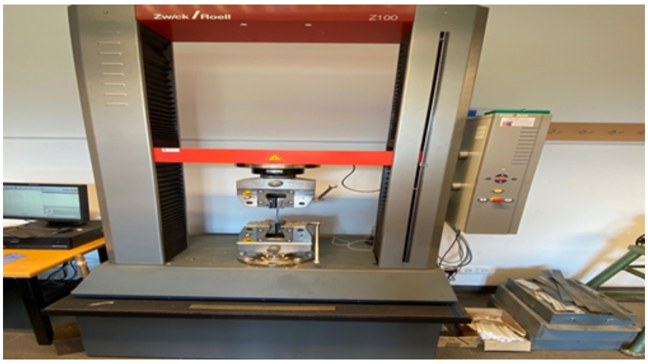

Figure 3: Testing tensile specimens, Testometric.

Table 4: Tensile Properties of Virgin versus Recycled Polyethylene Terephthalate 3D Printed Specimens.

	Virgin	Recycled
Number of specimens	20	20
Average tensile yield strength (MPa)	34.871	29.742
Standard deviation	1.593	2.778
Average tensile modulus of elasticity (MPa)	3670	3346
Standard deviation	224	413

RESULTS AND DISCUSSION

Tensile properties for virgin and recycled polyethylene terephthalate

Extensometers for polyethylene material were not needed as the extension/strain ratio was sufficient to estimate strain. The PET tensile specimens' strain/extension ratio was 0.243 after plotting the strain from extensometers against the crosshead extension. The strains from the crosshead extension, which form part of the modulus calculations, were estimated *via* the aforementioned method (Figure 4).

As aforementioned, with the Stress-Strain diagrams it is also possible to determine the desired properties, such as the Young Modulus, Yield Strength and Tensile Strength. In the following analysis, it will be presented, for each material, the Stress-Strain curves as well as the tables representing the mechanical properties analysed from the three trials performed, at each printing temperature. Starting by the ABS samples, in Figure 5 it is presented the Stress-Strain curve correspondent to the average of values collected, for each printing temperature.

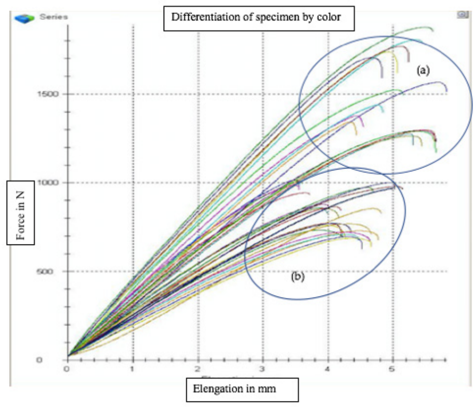

Figure 4: Tensile Elongation of a recycled (a) and virgin (b) 3D printed PET.

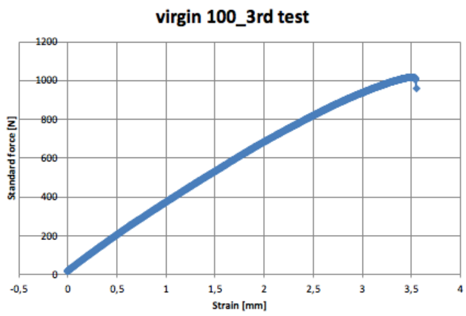

Figure 5: Strain force curve of 3rd sample test of 100% virgin 3D printed PET.

Tensile strength and hardness properties of virgin and recycled material

The PET samples revealed to have similar Strain-Stress curves, independently of the printing temperature [8]. This can traduce similar values for the three properties in study. It is important to refer that all the PET specimens fractured almost immediately after their maximum Tensile Strength values. The PET mechanical properties obtained from the tensile test are presented in Tables 5 and 6, at each percentage (Figure 6).

Table 5: Tensile strength of Virgin PET Filament.

Virgin PET	Test numbers	Average tensile strength (MPa)
100%	5	25,26
80%	5	21,34
60%	5	23,92
40%	5	18,10

Table 6: Tensile strength of Recycled PET Filament.

Recycled PET	Test numbers	Average tensile strength (MPa)
100%	5	43,15
80%	5	34,214
60%	5	37,80
40%	5	24,33
40%	40%	40%

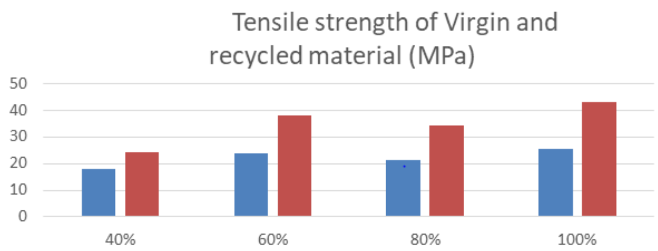

Figure 6: Tensile strength of a recycled and virgin 3D printed PET.
Note: (▬) Virgin PET, (▬) Recycled PET

The test results were generated both with the virgin and the recycled test specimens studying the same parameters: tensile, shear, and hardness properties. 40 samples each from the virgins and the recycled were tested for the yield strength and the tensile modulus of the elasticity. The overall summary of the results is shown in Tables 7 and 8.

Table 7: Shear Strength of Virgin versus Recycled Polyethylene Terephthalate 3D Printed Specimens.

	Virgin	Recycled
Number of specimens	20	20
Average shear yield strength(MPa)	28,448	29,253
Standard deviation	0.69	2

Table 8: The hardness of Virgin versus Recycled Polyethylene Terephtalate 3D Printed Specimens.

	Virgin	Recycled
Number of specimens	20	20
Average hardness (shore D)	73,10	68,71
Standard deviation	0.725	2

The yield point was studied by setting an offset value of 0.11 mm. The tensile modulus was measured by using a pre-set relationship between the crosshead extension and the strain using the tensile specimens. Using the reference, the extension to the strain ratio can be studied to estimate the strain without using the extensometers for the same materials.

These results are highly encouraged in nature. Although, there were differences between the original and the recycled. But, the average mechanical properties of the recycled specimens were lower than those of the virgin specimens by about 3 to 9 %. Also, to highlight the fact was an increase in the variability of the results of the recycled material as shown by the increased standard deviation.

The current research demands a more sustainable method of chemical recycling; with lesser energy demands and computability for mixing plastic wastes. There should be less need for sorting and expanding the technology towards using non-recyclable polymers. Based on the literature review it was found that mechanical recycling is the only available technique for the recycling of plastic solid waste. The main procedure is the removal of the organic residue by washing followed by shredding, melting, and re-molding of the polymer to produce a material that is compatible with virgin plastic to blend and create a material that is suitable for manufacturing [9-11]. The current technologies that are being used beyond the traditional mechanical recycling involve using pyrolysis for the selective production of gases, fuels, or waxes *via* the use of the catalysts; hereby being referred to as chemical recycling. Although due to high energy cost requirements it is not widely used. Another alternative option is incineration i.e. the collection of energy in the form of heat *via* the burning of the materials. This method is convenient for the treatment of mixed waste as it avoids the need for sorting out but does not help in many recapitalizations of the recovery and reuse of the components due to them being burned. As well it is not an energy-efficient method like recycling; they have a well-equipped laboratory for testing recycled plastic waste [12].

CONCLUSION

In the frame of the research project, it was found that most of the laboratory tests were done in co-operation with the FKF Zrt. The company works in strong conjunction with the faculty of mechanical engineering also have a well-equipped lab for the testing of recycled plastic waste; the previous test has shown that the conductive antistatic ABS has many advantages like excellent mechanical strength, impact resistance with dimensional stability along with the high flow creep resistance and excellent heat and low-temperature resistance. The PET filament was found better. The main problem associated with the rPET extrusion is the stoppage of the material flow. During the middle of the extrusion the extrudate eventually stopping coming out of the die causing the HDPE filament to thin and then break. The pristine HDPE extrusion did not proceed without any complications.

There was a decrease found in the properties such as the tensile strength, hardness because of several factors. This could be because of the degradation in the properties of the recycled filament itself or because of the problems arising from the 3D print such as the extrusion interruptions or to the limit in the inter-layer adhesion. As the individual filament properties could not be studied hence these were not included in that study. There was some issue associated with the recycled filament like nozzles clogging, along with the issues in the printing and can lead to defects in the specimens. The main issue associated with the filament re-extrusion was it done without using a filter hence there could be some microscopic.

The p-value was significantly lower than 0.003. Due to the presence of the clogging impurities, there were some differences present in the printing process with the recycled filaments; as the filtering was not done in the extrusion process that well. The main source for this increase in variation was the variation present in the recycled filament because of the difficulties described above. The study provided new data in the field of 3D recycling as well as on recycled 3D printed PET with the final inference that there is no difference in properties between the recycled and the virgin after comparing mechanical properties of Polyethylene terephthalate material. Hence it helps in providing a sustainable environment where one can recycle plastic and reduce the emission of CO_2. Getting the 0.003 significant value show the main achievement and the validity of this hypothesis.

The results are supporting and encouraging overall with the further development of the recycling technology for 3D printing as well as the potential for the home and small business recycling of the 3D printed waste. This technique has certain benefits but not without potential health hazards. These include lower carbon dioxide production along with the recycling of the filament with a decrease in landfill usage. There is also a scope of reducing the costs by recycling locally by engaging people in small groups, a business where they can produce recycling equipment by investing in the range of $3000; such an investment can be recovered following the production of about one hundred pools of filament. There are many benefits associated with risks of recycling the filament-like nozzle clogs, mechanical property degradation, and an increased particle release. The clogging of the nozzle can be reduced by reducing the contamination with the help of further research into the use of large nozzles and high forming temperatures.

Such good results on the performance of the parts with the recycled PET filament should be done along with kinds of plastics such as ABS to show their viability along with the benefits of filament recycling like the 3D printing industry.

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