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Investigation of 3D Printing Filling Structures Effect on Mechanical Properties and Surface Roughness of PET-G Materials Products

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Abstract – 3D printing filling structures at prototyping and design stage are increasingly important issue for products with complicated shapes. The objective of the present study is to investigate 3D printing filling structures effect on mechanical properties and surface roughness of PET-G (Polyethylene Terephthalate Glycol) material products. PET-G material was preferred because of its durability, high transparency and odor characteristics. A variety of methods are used to manufacture products. Each has its advantages and drawbacks. One of the these methods to adopt for this investigation was FDM (Fused Deposition Modeling) 3D printing method. The FDM method was considered that it has a direct effect on the mechanical properties and surface roughness of the product. The experiments were carried out using PET-G materials with different printing filling structures (rectilinear, triangular, full honeycomb), at processing speed of 50 mm/s and all other operating parameters fixed same conditions on 3D printer. Uniaxial tensile tests, hardness measurements and surface roughness measurements of the printed products were carried out. The results were analyzed and compared.

Keywords *– 3D printer, PET-G, FDM, filling structures.*

I. INTRODUCTION

Three-dimensional (3D) printing operation is a manufacturing process to form from three-dimensional solid part data. 3D Printers manufacture products with fusing deposition material by layers. There are several methods such as plastic melting, laser sintering, stereolithography for constructing layers. Fused Deposition Modeling (FDM) is the most common used method [1,2]. Cartesian printers [3,4], delta printers [5] and corexy printers [6,7] are some of different 3D Printer versions that use the FDM method. 3D Printers which manufacture metal products, use selective laser sintering method [8,9]. The FDM method is used with plastic materials (PLA, ABS, PET) for manufacturing [10, 11].

Depending on usage areas, it is necessary to take in account some parameters such as surface roughness, weight, strength, cost of the product. Printing parameters were emphasized in many literature researches that have a direct effect on mechanical properties and surface roughness of the product and it is predicted that better parameters and results can be obtained in terms of product quality [12-14]. Occupancy rate, number of shells, layer thickness, extruder temperature, printing speed, filling structure and used material factors are affecting product quality. It is necessary to know how printing parameters affect the product quality in order to ensure proper conditions for usage area.

Anoop Kumar Sood et al. have described the FDM as a technology used in the production of complex surfaces. They have investigated quality of the parts built with this technology and they have considered four important printing parameters as layer thickness, filling angle, filling width, material structure. They have examined the effects of these parameters such as strength of tension, torsion and impact [12]. Wang et al. have changed the filling structure while printing product and reduced material cost by decreasing internal volume [13]. Wilson examined the stress distributions of printed parts with multiple filling structures and it is observed that the stress distribution changes according to density of the cells [14].

In recent years, PET-G comes into prominence as one of the most important engineering polymers with increased usage areas. PET-G material is preferred in many applications because of its resistance to chemicals, malleability, transparency and thermal properties. Among thermoplastics, PET-G is superior to other plastic materials due to properties such as strength, hardness, toughness and stability to weak acids, bases, most solvents. [15].

Changes in the material and printing parameters affect the surface quality and strength of printed product. Types of material and filling structure also affect the surface roughness of printed product according to cooling time. Tensile and hardness tests are the most important inspection methods to specify strength of the materials and values from such tests are used directly in engineering applications [16]. In this study, experimental samples from PET-G material have been subjected to surface roughness, hardness and tensile tests with different filling structures. Results were evaluated and presented in terms of mechanical properties.

II. MATERIALS AND METHOD

Firstly, the sample was designed as 3D model using computer program in order to print the test samples on 3D Printer. This 3D model data, were transferred to the 3D slicing interface program. With this program, the printing parameters such as occupancy rate, filling structure, height of layers are defined as in Table 1.

Table 1. Printing Parameters

Printing Parameters	
Filament diameter (mm)	1,75
Nozzle diameter (mm)	0,40
Extruder temperature (°C)	240
Table temperature (°C)	70
Occupancy rate (%)	50
Extrude width (mm)	1,00
Table height (mm)	0,15
Layer thickness (mm)	0,200
Printing speed (mm/s)	50
Filling structure	Rectilinear, triangular, full honeycomb

Samples were printed on 3D printer, shown in Figure 1.

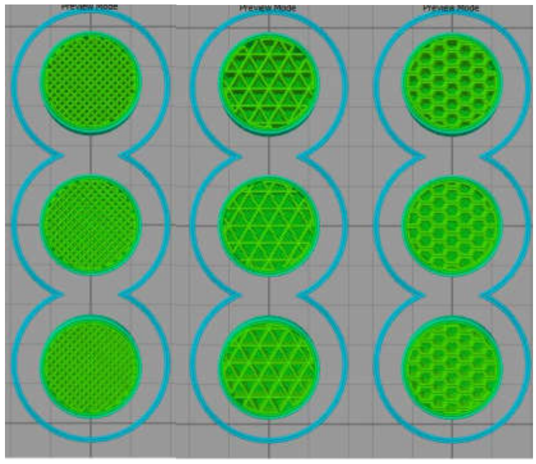
Figure. 1 3D Printer [17]

In this study, samples are made of PET-G filament material with occupancy rate as 50 % and different filling structures. The physical and chemical properties of PET-G material are given in Table 2.

Table 2. The Physical and Chemical Properties of PET-G Material [18]

Material Properties	
Material	PET-G
Filament color	Orange
Filament diameter(mm)	1,75
Density	1,27 g / cm³
Tensile strength at yield	50 MPa
Tensile modulus	2140 MPa
Elongation	120 %
Melting point	135 ºC
Heat deflection temp.	70 ºC

Three different filling structures (rectilinear, triangular and full honeycomb) were used for printing samples, shown in Figure 2.



a) Rectilinear **b)** Triangular **c)** Full Honeycomb

Figure. 2 Filling structure

Standard (TS 138-A) tensile test samples are shown in Figure 3. and its printing is shown in Figure 4.

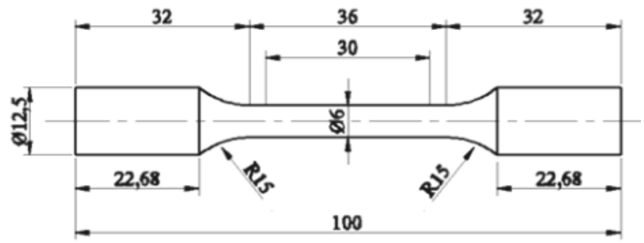


Figure. 3 Standard (TS 138-A) tensile test samples

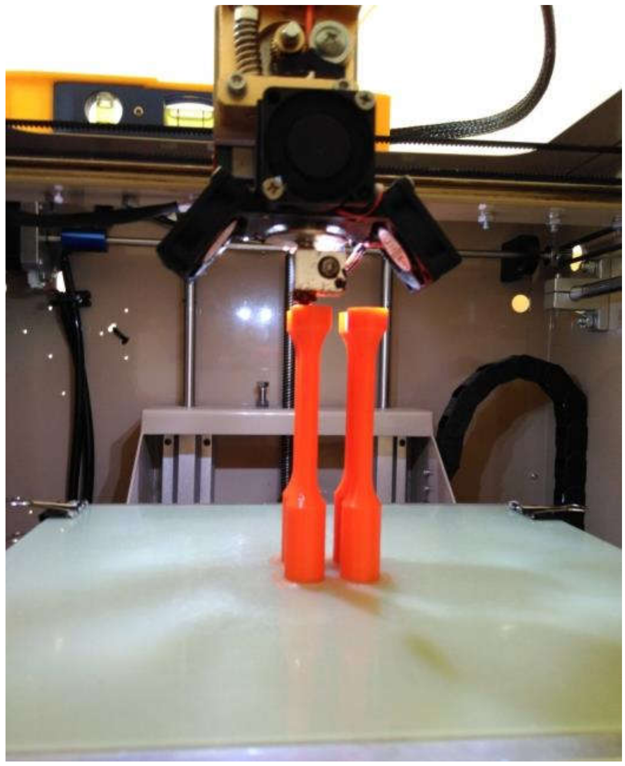


Figure. 4 Printing standard tensile test samples on 3D Printer

Tensile tests were carried out on a 40 tons BESMAK brand tensile testing machine at Duzce University Scientific and Technological Research Application Research Center (DUBIT) laboratory. The state of damaged sample and tensile test machine are shown in Figure 5. Tensile tests were carried out at a fixed tensile test speed of 2 mm/min for each test sample equal conditions.

Figure. 5 Tensile test machine and damaged sample

Surface roughness measurements were made before the tensile tests. In these measurements, surface roughness of the samples are examined in three different filling structures (rectilinear, triangular and full honeycomb). Surface roughness test device is used to surface measure roughness average (Ra).

Three averaged values were taken from each sample for hardness test. Shore D (SD) hardness meter was used for hardness tests.

III. RESULTS AND DISCUSSION

Tensile strength results are given in Table 3.

Table 3. Tensile test results – Tensile strength

Tensile Strength (Mpa)				
Filling Structure	**1.Test**	**2.Test**	**3.Test**	**Average values**
Rectilinear	8,50	9,05	8,73	8,76
Triangular	5,20	6,05	5,65	5,63
Full Honeycomb	5,50	6,75	6,22	6,15

According to the tensile test results, tensile strength values of filling structures are ascending sort as triangular, full honeycomb and rectilinear. The minimum tensile strength value of samples is 5,30 MPa with triangular filling structure and the maximum tensile strength value of samples is 9,05 MPa with rectilinear filling structure.

Table 4. Tensile test results – Elongation at break

Elongation at break (%)				
Filling Structure	**1.Test**	**2.Test**	**3.Test**	**Average Values**
Rectilinear	0,75	0,76	0,78	0,76
Triangular	0,43	0,47	0,50	0,47
Full Honeycomb	0,34	0,36	0,42	0,37

Percentage elongation tensile test results are given in Table 4. The results support the tensile strength values obtained. The maximum percentage elongation value at break is 0,78 % with rectilinear filling structure and the minimum percentage elongation value at break is 0,34 % with full honeycomb filling structure. When the average values are compared, it is realized that rectilinear filling structure has more percentage elongation at break than the other filling structures. The reason is considered that the effect of rectilinear filling structure that increases toughness with spreading into smaller pores.

Shore D hardness test results are given in Table 5.

Table 5. Shore D hardness test results

Shore D Hardness Test Results (SD)				
Filling Structure	**1.Test**	**2.Test**	**3.Test**	**Average values**
Rectilinear	64	63,5	63	63,5
Triangular	67	59	63	63
Full Honeycomb	55,4	63	57	58,5

According to hardness test results, the hardness values of full honeycomb, triangular and rectilinear filling structures increase respectively. It can be seen from Table 5 that the maximum hardness value is 67 SD with triangular filling structure and the minimum hardness value is 55,4 SD with full honeycomb filling structure. Average hardness values are close to each other due to layers on outer surfaces completely full printed.

Surface roughness test results are presented in Table 6.

Table 6. Surface roughness test results

Surface roughness average (Ra) test results				
Filling Structure	**1.Test**	**2.Test**	**3.Test**	**Average Values**
Rectilinear	11,736	12,178	12,309	12,074
Triangular	10,384	12,304	12,047	11,578
Full Honeycomb	11,402	14,024	12,719	12,715

According to the surface roughness values given in Table 6, the maximum surface roughness value is 14,024 microns with full honeycomb filling structure and the minimum surface roughness value is 10,384 microns with triangular filling structure. It can be seen from Table 6 that the averaged surface roughness values are close to the others filling structures. However, there are some differences. Triangular filling structure has less roughness than rectilinear filling structure and full honeycomb filling structure due to their surface roughness values.

There is no correlation between surface roughness values and tensile strength values of tests.

IV. CONCLUSION

In this study, the effects of filling structures on mechanical properties and surface roughness of PET-G material products were investigated by using different filling structures (rectilinear, triangular and full honeycomb) by 3D printer. Unaxial tensile tests, hardness measurements, and surface roughness measurements of the printed products were carried out. The results were analyzed and compared. The following outcomes can be drawn.

- Rectilinear filling structured samples have a tensile strength of 42 % times greater than others.
- Rectilinear filling structured samples have greater percentage elongation values at break than others.
- Shore D hardness averaged values are close to each other due to fulfilled outer layers.
- Surface roughness averaged values are close to each other due to fulfilled outer layers.
- The use of PET-G material on 3D printer, selecting rectilinear filling structure is more suitable than other filling structures because it has higher tensile strength with less material. The results are consistent with the previous findings in the literature.

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