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

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ÖZET: Üç boyutlu (3B) yazıcıların imalat alanında kullanılmasında; az sayıda üretilen ya da karmaşık şekillere sahip ürünlerin imalatı, artık malzemenin önüne geçilmesi, prototipleme ve tasarım aşamalarında daha çeşitli imkanlardan yararlanılması konusunda önem arz etmektedir. Bu kapsamda, 3B yazıcılarda kullanılan malzemelerden biri olan PET-G (Polietilen Tereftalat Glikol); dayanıklı, yüksek şeffaflıkta, kokusuz özelliklere sahip olmasından dolayı tercih edilmektedir. Bu nedenle, bu çalışmada 3B yazıcıda farklı doldurma şekillerinin PET-G malzemeden imal edilen ürünlerin mekanik özelliklerine ve yüzey pürüzlülüğüne etkilerini incelemek amaçlanmıştır. İmal edilen ürünlerin mekanik özelliklerine malzemenin yapısı kadar imalat şekli ve koşullarının etkisi de önemlidir. 3B yazıcılarda imalat yöntemi olarak günümüzde en yaygın kullanılan FDM (Fused Deposition Modelling) yöntemidir. Bu yöntemde, imalat koşulları için doldurma şekli ürünlerin mekanik özelliklerine ve yüzey pürüzlülüğüne doğrudan etki etmektedir. Bu bağlamda, 3B yazıcıda PET-G malzemeden farklı doldurma şekillerinde (rectilinear, triangular, full honeycomb), 50 mm/sn işleme hızında ve diğer çalışma parametreleri aynı koşullarda olmak üzere ürünler imal edilmiştir. Bu ürünlerin tek eksenli çekme testi, sertlik ve yüzey pürüzlülüğü ölçümleri gerçekleştirilmiştir. Testler sonucu elde edilen veriler karşılaştırılmış ve sonuçlar analiz edilmiştir.

Anahtar Kelimeler: *3B yazıcı, PET-G, FDM, doldurma şekli*

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. The 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 these methods used for this study is FDM (Fused Deposition Modeling) 3D printing method. The FDM method is considered that it has a direct effect on the mechanical properties and surface roughness of the product. The experiments for this study were carried out using PET-G materials with different printing filling structures (rectilinear, triangular, full honeycomb) at processing speed of 50 mm/s. The results from uniaxial tensile tests, hardness measurements, and surface roughness measurements of the printed products were analyzed and compared.

Keywords – *3D Printer, PET-G, FDM, Filling Structures*

1. 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, and stereolithography for constructing layers. Fused Deposition Modeling (FDM) is the most common used method (Kruth et al.,1998; Azari and Nikzard 2009). Cartesian printers (Herrmanna et al. 2014), delta printers and corexy printers (Roberson et al. 2013) are 3D Printer with different versions that use the FDM method. 3D Printers which manufacture metal products use selective laser sintering method (Chhabra and Singh, 2011). The FDM method is used with plastic materials PLA (polylactic acid), ABS (acrylonitrile butadiene styrene), PET (Polyethylene Terephthalate) for manufacturing (Billiet et al., 2012; Çelik 2015).

Depending on usage area, it is necessary to take in account some parameters such as surface roughness, weight, strength, and cost of the product for design and manufacturing. Printing parameters were emphasized in literature 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 (Sood et al. 2010; Wang et al. 2013; Wilson 1990). Occupancy rate, number of shells, layer thickness, extruder temperature, printing speed, filling structure, and material used parameters 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, and material structure. They have examined the effects of parameters such as strength of tension, torsion, and impact (Sood et al., 2010). Wang et al. have changed the filling structure while printing product and reduced material cost by decreasing internal volume (Wang et al., 2013). Wilson examined the stress distributions of printed parts with multiple filling structures and it observed that the stress distribution were changed according to density of the cells (Wilson, 1990).

In recent years, the PET-G comes into prominence as one of the most important engineering polymers with increased usage areas. The PET-G material is preferred in many applications because of its resistance to chemicals, malleability, transparency, and thermal properties. Among thermoplastics, the PET-G is superior to other plastic materials due to its properties such as strength, hardness, toughness, and stability (Ahrabi, 2009).

Changes in the material and printing parameters affect the surface quality and strength of printed product. Types of material and filling structure with respect to cooling time also affect the surface roughness of printed product. Tensile and hardness tests are the most important inspection methods to specify strength of the materials. In this study, experimental samples from the PET-G material are used with respect to surface roughness, hardness, and tensile tests with different filling structures. Results are evaluated and presented in terms of mechanical properties.

2. Material and Methods

Test samples were designed as 3D model using computer program in order to manufacture the test samples on 3D Printer. 3D model data were transferred to the 3D slicing interface program. The printing parameters such as occupancy rate, filling structure, height of layers are defined as input in the program. Table 1 gives printing parameters.

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 manufactured using 3D printer shown in Figure 1.

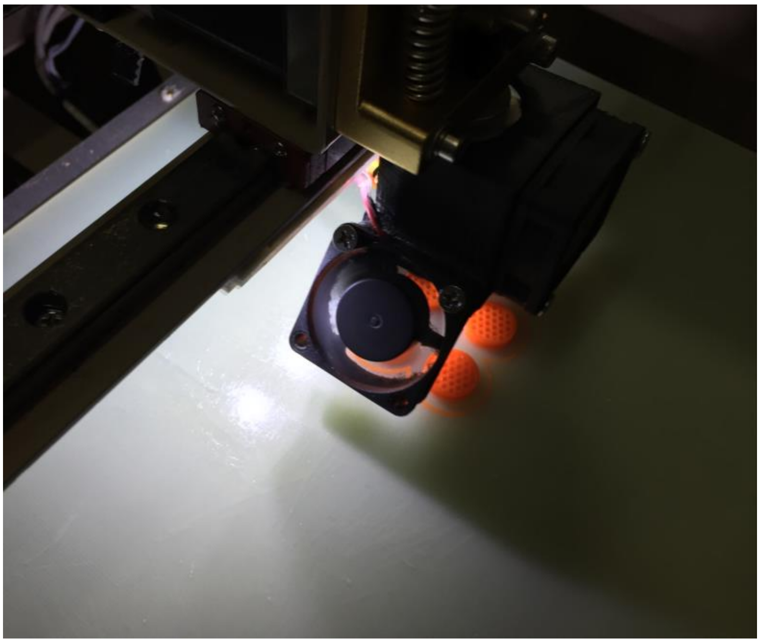
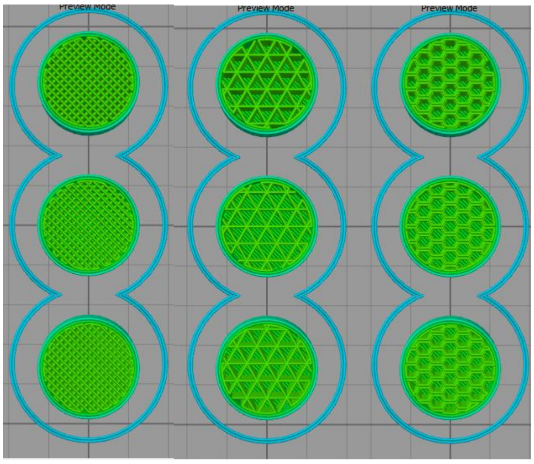


Figure 1. *Printing standard tensile test samples on 3D Printer*

Table 2. *The Properties of PET-G Material (Ahrabi, 2009).*

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

Samples were made of PET-G filament material with occupancy rate as 50 % and different filling structures. Three different filling structures (rectilinear, triangular and full honeycomb) were used for printing samples modeling shown in Figure 2. The properties of PET-G material are given in Table 2.



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

Figure 2. *Filling structures modeling*

Dimensions of standard (TS 138-A) tensile test samples used is shown in Figure 3 and picture of printed tensile test samples are given in Figure 4.

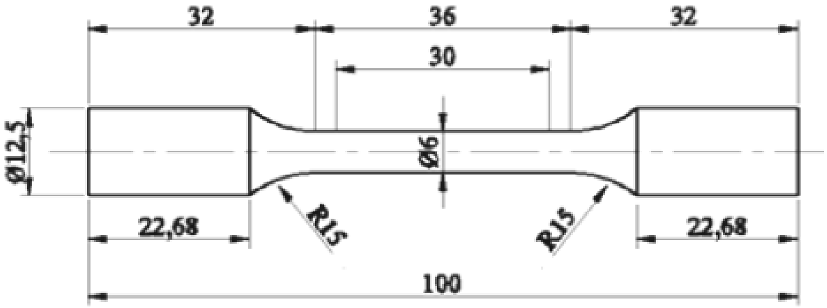


Figure 3. *Dimensions of standard (TS 138-A) tensile test samples*

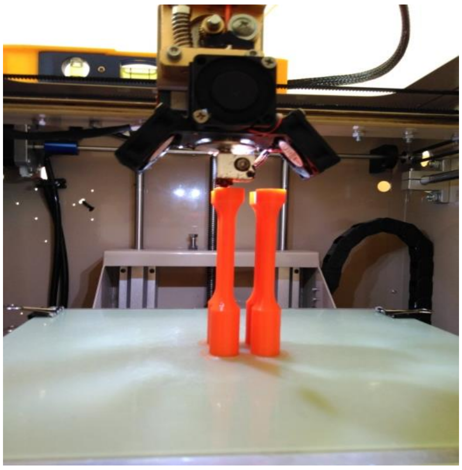


Figure 4. *Printed standard tensile test samples*

Tensile tests were carried out on a 40 tons BESMAK brand tensile testing machine at Düzce University Scientific and Technological Research Application Research Center (DUBIT) laboratory. Figure 5 gives tensile test machine and damaged test sample. Tensile tests were carried out at a fixed tensile test speed of 0,033 mm/s.

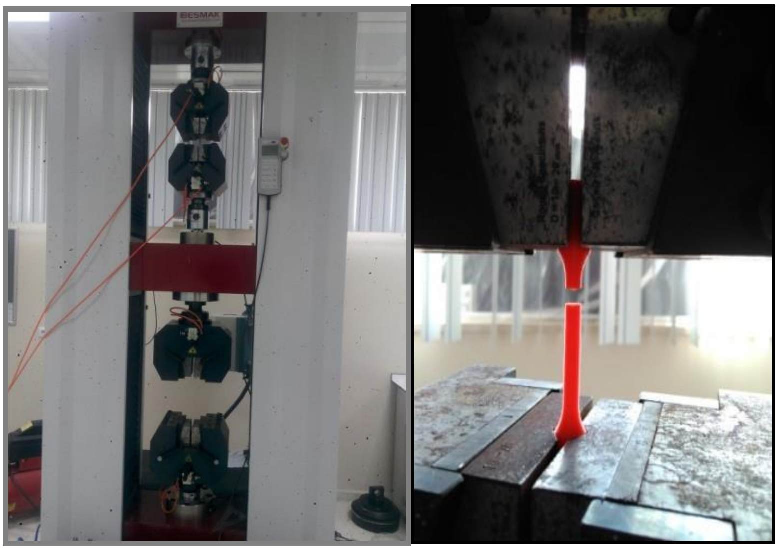


Figure 5. *Tensile test machine and damaged sample*

Surface roughnesses were measured before the tensile strength tests conducted. Surface roughness average (Ra) of the samples was measured for the all three different filling structures. Three averaged values were taken from each sample for hardness test. Shore D (SD) hardness meter was used for hardness tests.

3. Results and Discussion

Tensile strength results are given in Table 3.

Table 3. *Tensile test results*

	Tensile Strength (Mpa)			
Filling Structure	**1.Test**	**2.Test**	**3.Test**	**Average values**
Rectilinear	47,69	48,57	48,06	48,11
Triangular	29,25	30,61	29,97	29,94
Full Honeycomb	32,83	34,83	33,98	33,88

From the test results, tensile strength values are ascending sort for filling structures as triangular, full honeycomb and rectilinear respectively. The minimum tensile strength value is 29,25 MPa for triangular filling structure and the maximum tensile strength value is 48,57 MPa for 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

Elongation tensile test results are given in Table 4. Figure 6 gives plots of average tensile stress versus strain values for filling structures. 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 for this is considered that the effect of rectilinear filling structure increases toughness with spreading into smaller pores. Shore D hardness test results are given in Table 5.

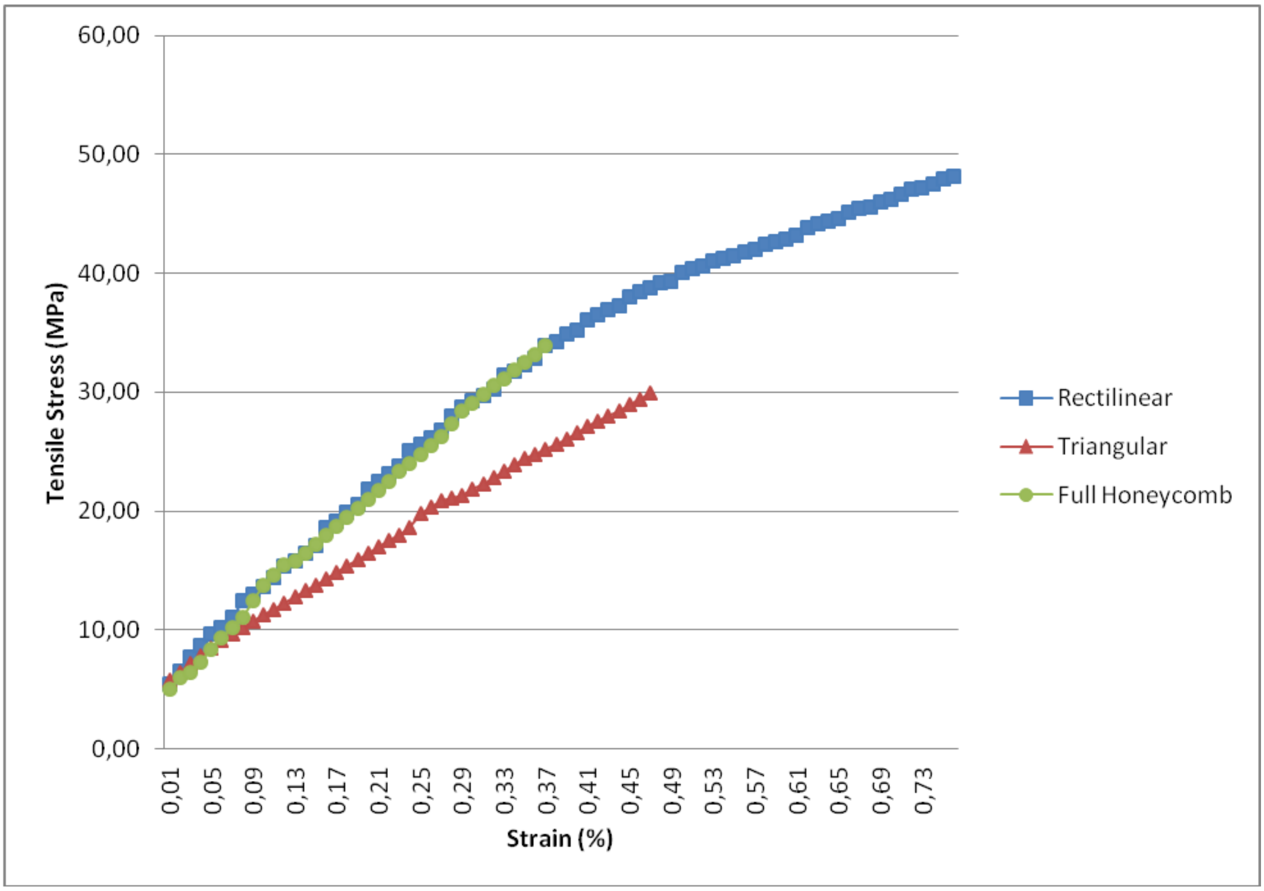


Figure 6. *Average stress versus strain values for filling structures*

Table 5. *Shore D hardness test results*

Shore D hardness test (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

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. Hardness average values are close to each other due to layers that completely full printed on outer surfaces.

Surface roughness test results are presented in Table 6.

Table 6. *Surface roughness test results*

Surface roughness average (Ra) test				
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

The maximum surface roughness value given in Table 6 is 14,024 microns for full honeycomb filling structure and the minimum surface roughness value is 10,384 microns for triangular filling structure. It can be seen from Table 6 that surface roughness average values are close to each other. Roughness value of triangular filling structure is lower than the value of rectilinear filling structure and full honeycomb filling structure.

4. Conclusion

In this study, the effects of filling structures on mechanical properties and surface roughness of PET-G material products were investigated for different filling structures (rectilinear, triangular and full honeycomb) using 3D printer. Uniaxial 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 as follows;

- Rectilinear filling structured samples have greater tensile strength and percentage elongation values than triangular and full honeycomb structured samples.
- Shore D hardness and Surface roughness averaged values for three filling structures are close to each other.
- The use of PET-G material on 3D printer with 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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