International Journal of 3D Printing Technologies and Dijital Industry
Uluslararası 3B Yazıcı Teknolojileri ve Dijital Endüstri Dergisi

THE EFFECT OF THE INFILL TYPE AND DENSITY ON HARDNESS OF 3D PRINTED PARTS

İsmail Böğrekci[a], Pınar Demircioğlu[a*], H. Saygın Sucuoğlu[a], Oğulcan Turhanlar[a]

[a]Aydın Adnan Menderes University, Faculty of Engineering, Mechanical Engineering Department, Aydın, TURKEY

[*]*Corresponding Author: pinar.demircioglu@adu.edu.tr*

(**Geliş/Received**: 30.09.2019; **Düzeltme/Revised**: 04.12.2019; **Kabul/Accepted**: 11.12.2019)

ABSTRACT

The aim of this study is to search out the effects of the infill type and density on hardness of the manufactured components with rapid prototyping technique. Computer Aided Design (CAD) models of specimens were prepared using Autodesk Inventor Software. Then the models were exported as STL file format for rapid prototyping. Disc shape specimens were produced with the diameter of 20 mm and thickness of 5 mm using Prusa İ3 desktop type 3D printer with 90-300 microns layer height manufacturing capacity. The printer settings were adjusted with Simplified3D software. The infill types were selected as rectilinear (linear), grid (diamond) and honeycomb (hexagonal). Layer heights were used as 200 microns for all of the samples. For each infill types; the specimens were produced with the infill density values of 15, 25, 50, 75 and 100%. The heated bed temperature was selected as 60 ^{0}C to increase the bonding and surface quality. The extruder temperature was set to 195 ^{0}C. Then the hardness of the manufactured specimens were measured with EMCO-TEST DuraScan micro hardness machine that has ability to perform Vickers and Knoop methods range between 10 gf and 10 kgf. In order to find the effects of the infill type and density on hardness of 3D printed specimens, the obtained results from Vickers micro hardness measurements were compared. The hexagonal infill with the density of 100% showed the highest hardness and also the hardness patterns could be presented from low to high as Diamond < Linear < Hexagonal.

Keywords: Desktop Type 3D Printer, Hardness of Rapid Prototyped Object, Infill Type and Density, Micro Hardness Measurement, Vickers Micro Hardness

1. INTRODUCTION

Rapid Prototyping (RP) has been preferred both to lower the cost and time and to keep up with advanced technological developments. 3D printing is commonly employed for making not only models but also finished products as Rapid Prototyping Technique. Thus value added products can be easily made via this manufacturing technique. There are numerous types of 3D printing methods or techniques such as Fused Deposition Modeling (FDM), Stereolithography (SLA), Selective Laser Melting (SLM) and Laminated Object Manufacturing (LOM) [1]. The desktop type 3D printer is extensively used because of being inexpensive, easy to use and suitable [2].

The most common materials used in FDM are thermoplastics; eg. acrylonitrile butadiene styrene (ABS), Polycarbonate (PC), poly-lactic acid (PLA), Polyphenylsulfone (PPSU), Polyetherimide (PEI), Polycaprolactone (PCL), polyvinyl acetate (PVA). PLA is the widely used material in FDM since its biodegradability and low cost [3-5].

In 3D printing, it should be taken into account that choosing proper material is vital for manufacturing right component by considering infill type and density. Infill type and density have relationship among object strength, time and material [6]. Infill density can be defined as the filled volume in a part and type is the geometric pattern of the infill (Figure 1) [7]. Bogrekci et al. studied about infill type and density to create a hybrid pattern for 3D printing optimization [8]. In another study, Bogrekci et al. found that hexagonal infill type had the highest structural strength [9].

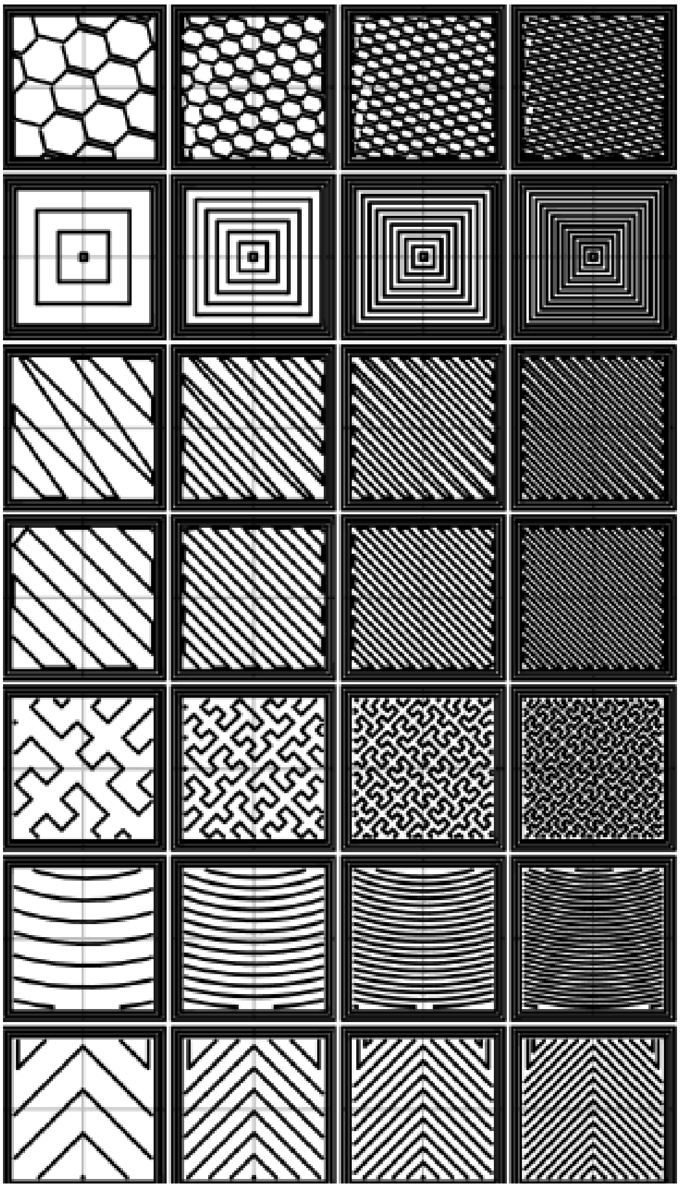


Figure 1. Infill types at different densities (Left to Right: 20%, 40%, 60% and 80%. Top to Bottom: Honeycomb Concentric, Line, Rectilinear, Hilbert Curve, Archimedean Chords, Octagram Spiral) [6].

Hardness analysis contributes to evaluate alterations on mechanical properties affected by chemical and physical changes. Besides, micro-hardness measurement provides information of identification, classification, quality about measured material. It is a nondestructive technique for evaluating local mechanical behavior of composite and fiber-reinforced materials [10]. It is an effective technique to measure small local variations in mechanical properties of materials due to changes in porosity gradients and composition [11].

In this study; the effects of the infill type and the density on the hardness of the produced parts with rapid prototyping technique were investigated. Disc shape specimens were produced with the diameter of 20 mm and thickness of 5 mm using Prusa İ3 desktop type 3D printer with 90-300 microns layer height manufacturing capacity. The infill types were selected as rectilinear (linear), grid (diamond) and honeycomb (hexagonal). Layer heights were used as 200 microns for all of the samples. For each infill types; the specimens were produced with the infill density values of 15, 25, 50, 75 and 100%. The hardness of the manufactured specimens were measured with EMCO-TEST DuraScan micro hardness machines that has ability to perform Vickers and Knoop methods ranging between 10 gf and 10 kgf.

2. MATERIAL AND METHOD

2.1. Design and Producing of Specimens

The micro hardness measurement samples were printed using Prusa İ3 desktop type 3D printer with 90-300 microns layer height manufacturing capacity with the 1.75 mm diameter PLA filament. The printer parameters were set with Simplified3D software (Figure 2).

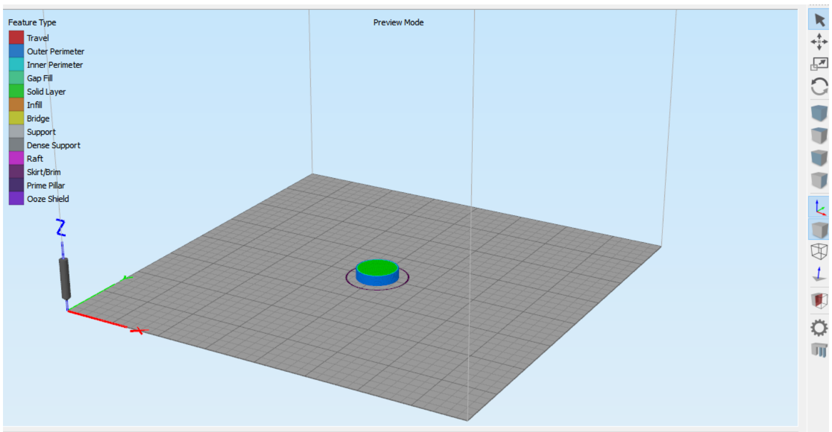


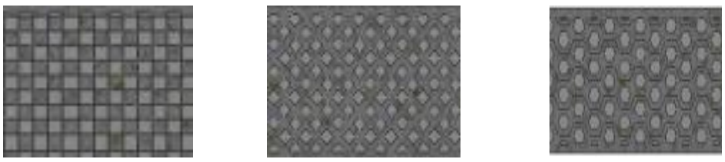
Figure 2. Printing settings of measurement samples.

The technical specifications of Prusa İ3 desktop type Printer were given in Table 1.

Table 1. Technical specifications of Prusa İ3 3D Printer [12].

Properties	Unit	Value
Layer Resolution	μm	90-300
Build Volume	mm	200 x 200 x 180
XY Positioning Precision	μm	12
Z Positioning Precision	μm	4
Filament Diameter	mm	1.75
Extruder Temperature	^0C	170-275
Print Material	-	PLA , ABS

It is possible to manufacture the parts with PLA and ABS material using the extruder of Prusa İ3 3D Printer. The specimens were designed using a CAD software (Autodesk Inventor 2018). CAD files (ipt) were converted into a STL and imported into the Simplified3D software. The print settings e.g. percent infill, print orientation, layer height and extruder printing speed were controlled with software. The infill types were selected as rectilinear (linear), grid (diamond) and honeycomb (hexagonal) as shown in Figure 3 to compare the effect of infill type and infill density to hardness.



(a) (b) (c)

Figure 3. Specimens with (a) Linear (b) Diamond (c) Hexagonal infill types.

Disc shape specimens were produced with the diameter of 20 mm and thickness of 5 mm (Figure 4). For each infill types; the samples were produced with the infill density values of 15, 25, 50, 75 and 100%.

Layer heights were used as 200 microns for all specimens. The heated bed temperature was selected as 60 ^{0}C in order to increase the bonding and surface quality. The extruder temperature was set to 195 ^{0}C.

Figure 4. The produced disc shape specimen for hardness measurement.

The shells of the specimens were created with the thickness of 0.8 mm. Structure were designed and supported with grid (diamond) types of infill patterns. Layer heights were selected as 0.2 mm. The following control variables were also used for manufacturing;

- Shell of the specimens (0.8 mm),
- Number of shell (2),
- Print speed (80 mm/s).

2.2. Micro Hardness Measurement

The term micro hardness test usually used for small loads like 1kgf with static indentations. The indenter types are generally the Vickers diamond pyramid and the Knoop elongated diamond pyramid. The procedure for testing is similar to procedure for Vickers hardness test on a microscopic scale by higher precision instruments. The surface requirement is generally metallographic finish. The Knoop Hardness Number (KHN) is the ratio of the load applied to the indenter to an area.

$$KHN = F / A$$
$$KHN = F / A = P / CL^2 \tag{1}$$

Where:

F: Applied oad in kgf,
A: Projected area of indentation
C: 0.07028 (Constant of indenter relating projected area of indentation to the square of the length of the long diagonal).

P: Load applied in kilograms

L^2: Square of the long diagonal

The Knoop Hardness Indentation is shown in Figure 5.

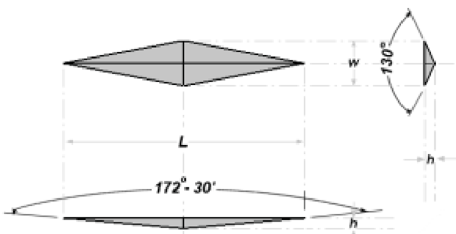


Figure 5. The Knoop Hardness Indentation [13].

The Vickers Diamond Pyramid hardness number (HV) is the applied load (kgf) divided by the surface area of the indentation (mm^2).

$$HV = \frac{2F \sin \frac{136^0}{2}}{d^2} \; ; \; HV = 1.854 \frac{F}{d^2} \qquad (2)$$

Where:
F : Applied load in kgf,
d : Arithmetic mean of two diagonals, d1 and d2 in mm,
HV: Vickers hardness.

Vickers Pyramid Diamond Intender is shown in Figure 6.

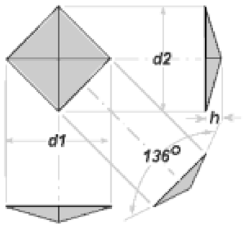


Figure 6. Vickers Pyramid Diamond Intender [13].

The micro hardness measurements were conducted using EMCO-TEST DuraScan that has ability to perform Vickers and Knoop in the load range between 10 gf and 10 kgf (Figure 7).

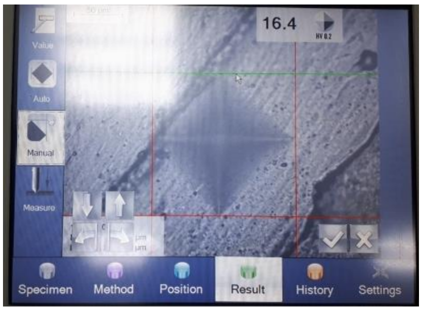
Figure 7. EMCO-TEST DuraScan micro hardness test machine.

Testing device has automatic 6 position turret ability to eliminate need of manual exchange of intenders and objective lenses. It has also vertically movable test head and fixed stage in z direction for optimal precision and stability. It is equipped with high resolution camera and automatic image evaluation feature to assure the highest possible repeatability and reproducibility. Some important technical specifications are given in Table 2.

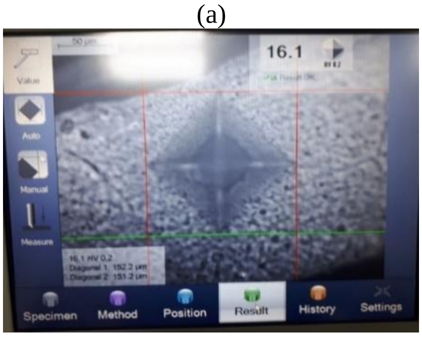
Table 2. Technical Specifications of EMCO-TEST DuraScan micro hardness machine [14].

Specification	Unit	Value
Stage Size XY	*mm*	135x135
Stage movement XY	*mm*	25x25
Effective stroke XY	*mm*	25x25
Stage resolution	μm	10
Positioning accuracy	*mm*	0.01
Maximum sample weight	*kg*	50
Maximum sample height	*mm*	260
Test load range	*kgf*	0.1-10
Evaluation camera	-	½” high resolution CMOS 1.3 mega pixel
Power supply	*V/Hz*	110-230 / 50-60
Dimensions (H x W x D)	*mm*	670x505x420
Weight	*kg*	68

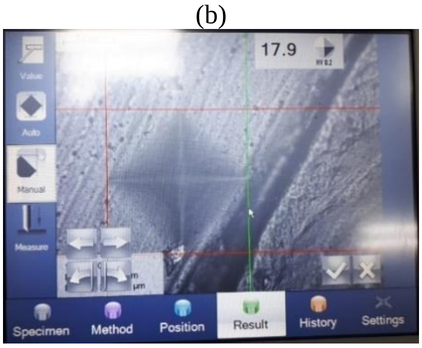
For the micro hardness, measurements were carried out with HV 0.1 test scale. According to the scale; 0.9807 N force was applied to the specimens [14]. Applied micro hardness measurements for different samples are shown in Figure 8.



(a)



(b)



(c)

Figure 8. Micro hardness measurements (a) 25% with diamond infill, (b) 15% with diamond infill, (c) 75 % with linear infill.

3. RESULTS AND DISCUSSION

The measured hardness values of specimens with hexagonal, linear and diamond were compared. The micro hardness test results are given in Table 3.

Table 3. The obtained results from micro hardness measurements in unit of N/mm^2.

	Hexagonal (HV)	Linear (HV)	Diamond (HV)
15%	17.8	16.3	16.1
25%	18.9	16.8	16.4
50%	21.6	17.3	17.1
75%	22	17.9	17.5
100%	22.8	19.2	18

The results obtained from the simulation showed the differences between the different parameters of infill density and pattern, also called mesostructures, of the specimens. High level density resulted in a low amount of voids and high hardness values. While the HV was in the range of 16.1 to 18 N/mm^2 for hexagonal infill structure, it is up to 22.8 N/mm^2 for hexagonal structure. The results obtained in this study agreed with the results from the investigation regarding the infill pattern and strength [9] (Table 4). The pattern effect on hardness can be presented as Hexagonal > Linear > Diamond.

Table 4. Comparison of the structural strength for different infill patterns with infill density of 50% [9].

	Equivalent maximum stress (MPa)				Strain (%)			
No. of Steps	**Raw PLA**	**Linear**	**Hexagonal**	**Diamond**	**Raw PLA**	**Linear**	**Hexagonal**	**Diamond**
1	7.6	11.8	10.1	14.2	0.8	1.1	0.9	1.3
2	17.2	23.6	19.3	28.3	1.5	2.1	1.7	2.6
3	25.7	35.4	28.3	42.4	2.3	3.2	2.8	3.9
4	34.3	47.3	38.0	56.6	3.1	4.3	4.1	5.2
5	42.9	59.1	47.4	70.7	3.8	5.3	5.1	6.5
6	51.5	70.9	57.2	84.9	4.6	6.4	6.1	7.8
7	60.0	82.7	66.2	99.0	5.4	7.5	7.2	9.1
8	68.6	94.5	77.0	112.3	6.2	8.5	8.1	10.4

The diamond pattern showed the lowest hardness values. This could be due to a low density and infill structural shape effect. It could be concluded from the results that infill density and type had a direct effect of the hardness and structural strength.

4. CONCLUSION

In this research, the effects of infill density and pattern on hardness of 3D printed parts have been studied. Findings from the analyses showed that:

1. The specimen with the hexagonal pattern had the maximum hardness for all infill density values in the range of 17.8 to 22.8 HV.
2. The minimum hardness values were obtained from the diamond infill with the values between 16.1 and 18 HV.
3. The deposition trajectory and the interlayer bonding were different for hexagonal, diamond and linear patterns. It could be a reason for hardness differences.
4. The classification among the different infill patterns related to hardness was; Hexagon > Linear > Diamond.
5. Infill type and density have effect on hardness values for the 3D printed parts.

Further researches are planned to understand the effect of the infill pattern types, environmental conditions such as extruder temperature to hardness and other mechanical properties with analyses and experimental studies.

REFERENCES

1. Garone, P., "Exploring the Use of Desktop 3D Printing for Microfluidics Prototyping", Thesis in the Field of Biotechnology for the Degree of Master of Liberal Arts in Extension Studies, Harvard University, USA, 2017.

2. Ngo, T.D., Kashani, A., Imbalzano, G., Nguyen, K.T.Q., Hui, D., "Additive manufacturing (3D printing): A review of materials, methods, applications and challenges", Composites Part B, Volume 143, Pages 172–196, 2018.

3. Chua, C.K., Wong, C.H., Yeong, W.Y., "Standards, Quality Control, and Measurement Sciences in 3D Printing and Additive Manufacturing", Academic Press is an imprint of Elsevier, 2017.

4. Miron, V., Ferrandiz, S., Juarez, D., Mengual, A., "Manufacturing and characterization of 3D printer filament using tailoring materials", Manufacturing Engineering Society International Conference (MESIC), Procedia Manufacturing, Volume 13, Pages 888-894, Vigo, Spain. 2017.

5. Byrley, P., George, B.J., Boyes, W.K., Rogers K., "Particle emissions from fused deposition modeling 3D printers: Evaluation and meta-analysis", Science of Total Environment, Volume 655, Pages 395-407, 2019.

6. Harpool, T.D., "Observing the Effects of Infill Shapes on the Tensile Characteristics of 3D Printed Plastic Parts", Master of Science on the Department of Mechanical Engineering and the Faculty of the Graduate School of Wichita State, Wichita, 2016.

7. Baich, L., "Impact of Infill Design on Mechanical Strength and Production Cost in Material Extrusion Based Additive Manufacturing", Master of Science in Engineering in the Industrial and Systems Engineering Program, Youngstown State University, Youngstown, 2016.

8. Sucuoglu, H.S., Bogrekci, I., Demircioglu, P., Turhanlar, O., "Development of Hybrid Pattern for Three Dimensional Printing Optimization", Sigma J Eng & Nat Sci., Volume 36, Issue 3, Pages 667-675, 2018.

9. Sucuoglu, H.S., Bogrekci, I., Demircioglu, P., Gultekin, A., "The Effect of Three Dimensional Printed Infill Pattern on Structural Strength", El-Cezeri Journal of Science and Engineering, Volume 5, Issue 3, Pages 785- 96, 2018.

10. Mandal, U.K., Aggarwal, S., "Studies on rubber–filler interaction in carboxylated nitrile rubber through microhardness measurement", Polymer Testing, Volume 20, Pages 305-311, 2001.

11. Novitskaya, E., Khalifa, H.E., Graeve, O.A., "Microhardness and microstructure correlations in SiC/SiC composites", Materials Letters, Volume 213, Pages 286-289, 2018.

12. 3B Yazıcılar.net, "Migbot Ultra Prusa i3 3D Yazıcılar", [Migbot Ultra Prusa i3 3D Printers] [article in Turkish], http://3boyutluyazicilar.net/the-migbot-ultra-prusa-i3-3d-yazicilar/ , March 2, 2019.

13. Ankara Yıldırım Beyazıt Üniversitesi, "Hardness Test", https://aybu.edu.tr/muhendislik/makina/contents/files/HARDNESS%20TEST (1)/, March 2, 2019.

14. EmcoTest, "DuraScan G5", https://www.emcotest.com/de/produkte-services/ haertepruefmaschinen/durascan-g5/ February 2, 2019.