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Curriculum Development for Rapid Prototyping

Innovative Approaches in Additive Manufacturing Congress



IA4AM

Proceedings Book

16 July 2021

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Innovative Approaches in Additive Manufacturing Congress (IA4AM)

16 July 2021 ANKARA, TURKEY

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Stellenbosh University, South Africa



Dr. Ali Gökhan Demir

"Process innovations for enabling new materials and geometries in LPBF for biomedical implants"

Politecnico di Milano, Italy

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Effect of Infill Density and Infill Pattern on Mechanical Properties in Fused Deposition Modeling (FDM)

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ABSTRACT

While the final product is reached by extracting the material from the raw material in blocks in traditional manufacturing techniques, 3D models are obtained in a single process step by adding the raw material layer by layer in Additive Manufacturing (AM) technologies. 3D models obtained in Computer Aided Design (CAD) software can be saved in Stereolithography (stl) format and transferred directly to 3D printers. AM technologies, which produce the part closest to the CAD model with minimum waste material, are a revolution in the manufacturing industry. In addition to the advantages of AM technologies over traditional production methods, long printing times still pose a barrier to mass production processes. It is possible to reduce production time by changing the part orientation and printing parameters. Changing parameters also reduce costs by reducing the amount of material used and production time. In this study, sample pieces of 30 x 30 x 30 mm were produced using the Fused Deposition Modeling (FDM) machine, which works with the material extrusion technique from AM technologies. Polylactic acid (PLA) samples with 50%, 30% and 15% volumes of 70% were produced in 3 different patterns as octet, gyroid and triangle. The effects of infill density and infill pattern printing parameters on production time, amount of material and mechanical strength were investigated by applying compression test to the samples.

Keywords: 3D printing, additive manufacturing, FDM, infill density, infill parameters

1. INTRODUCTION

The definition of additive manufacturing (AM) or 3D Printing technologies, in other words, is "the process of combining materials to make parts, often from layer-by-layer 3D model data, as opposed to subtractive manufacturing and formative manufacturing methodologies." ISO/ASTM terminology standard. specified. AM technologies print using the stl file format, which contains the geometry of three-dimensional (3D) models. The stl file determines the volume of the model and the number of mesh triangle surfaces. The file in stl format is sent to the appropriate slicing software, layered and sent to 3D printing machines. The overall manufacturing process of AM technologies is shown in Figure 1.

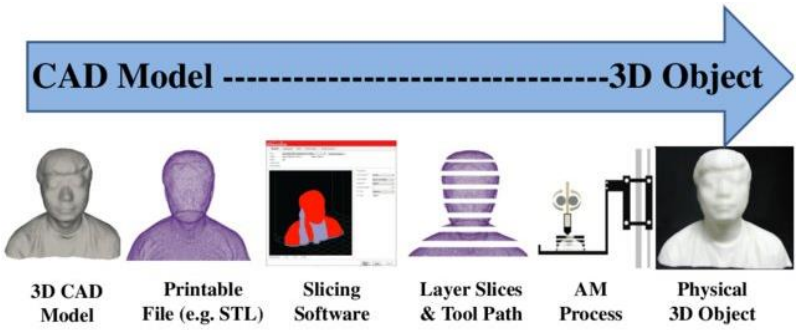


Figure 1. AM manufacturing process [1]

There are different AM technologies according to the material used and the way the material is deposited. According to ASTM, AM technologies are classified as material extrusion, vat photo-polymerization, powder bed fusion, material jetting, binder jetting, sheet laminations, and direct energy deposition. The correct production technique should be chosen in accordance with the geometry of the part to be produced.

The ability of AM technologies to produce parts with complex geometry in a single process step provides a significant advantage over traditional manufacturing methods. Creating the final model by accumulating the material layer by layer, instead of creating the part by removing it from the whole as in traditional manufacturing methods, reduces the amount of waste material and minimizes the environmental impact of production. Additive manufacturing technologies, which produce the part closest to the Computer Aided Design (CAD) model in minimum time, with almost zero material waste, are a revolution in the manufacturing industry. In addition, the

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granularity of the material used facilitates its supply and provides improvements in the supply chain. These advantages cause AM technologies to be used in many industries such as automotive and aerospace. It provides high quality production of light and durable parts and molds that are optimized in terms of material distribution. In addition to the advantages of AM technologies over traditional manufacturing methods, long printing times still pose a barrier to mass production processes. It is possible to reduce production time by changing the part orientation and printing parameters. Changing parameters also reduce costs by reducing the amount of material used and production time.

In the literature, it is seen that there is an intensive study on the effect of infill density and properties on mechanical properties. One of these is the study by Fernandez-Vicente et al. where different printing patterns showed less than 5% variation in maximum tensile strength [2]. Abbas et al., on the other hand, have been conducted an experimental analysis of the effect of filler density on compressive strength in FDM samples made of polylactic acid [3]. In the study, it has been observed that as the filling density increased, the compressive strength and compression times of the samples increased. Unlike other studies, Lubombo et al. has investigated the stiffness and strength of cellular structures with different geometries under uniaxial tensile loading and flexural loading both on the edge and flat [4]. In the literature, many studies are investigating the mechanical properties of different materials printed with FDM depending on the infill density and pattern. Among these materials, PLA, ABS, nylon, PETG, PEEK and composite materials can be mentioned [2-8].

In this study, sample pieces of 30 x 30 x 30 mm were produced using the Fused Deposition Modeling (FDM) machine, which works with the material extrusion technique from AM technologies. The effects of infill density and infill pattern printing parameters on production time, amount of material and mechanical strength were investigated by using poly-lactic acid (PLA) in the production process. Studies examining the effects of infill density and pattern parameters on mechanical strength are very limited. Compression test was applied to the samples created using different infill densities and patterns and the results were discussed.

2. MATERIAL AND METHOD

2.1. FDM Printing

FDM, which prints with material extrusion technique among AM technologies, is the most widely used method because of its low cost, ease of use, allowing the use of materials with low environmental impact and not requiring inspection. In the printing process, mostly filamentous thermoplastic materials are used. The working principle of the system is based on the principle of extruding the filament material from the nozzle by heating it with a fluidizing head (Figure 2).

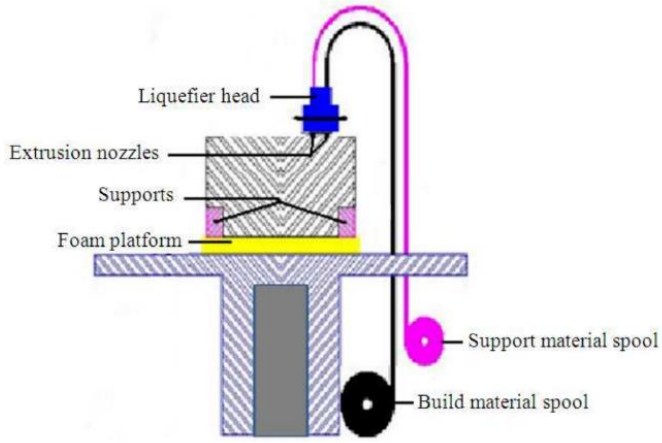


Figure 2. FDM technique working principle [9]

In the printing process with FDM, the same or different support material is used as the production material. The amount of support material used varies according to the geometry and orientation angle of the part planned to be produced. Parameters such as the amount of support material used in the production process, part orientation,

layer thickness, print bed temperature, nozzle temperature, infill density, infill pattern, filament diameter, nozzle diameter and nozzle speed are the parameters that affect the print result [10].

The image of the Ender-6 3D printer working with the FDM technique used in the study is shown in Figure 3. The specifications of the Ender-6 printer are given in Table 2.

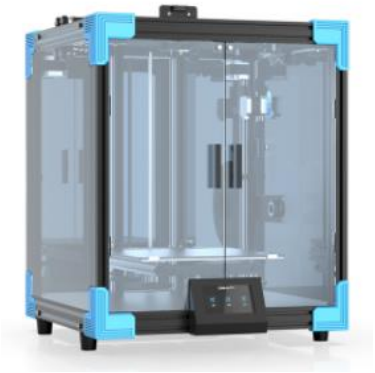


Figure 3. Ender 6 3D printer [11].

Tablo 2. Ender-6 FDM Printer specifications

Print Size	250x250x400mm
Print Mode	SD card
Resolution	±0.1mm
Supported OS	MAC, LINUX, WIN7/8/10
File Formats	STL, 3MF, AMF, OBJ, Gcode
Printing Material	PLA/TPU/Wood/Carbon Fiber, etc.

2.2 Filament material for FDM

In the FDM technique, the molten polymeric material is sprayed from the hot nozzle to the printing bed. The materials frequently used in the FDM technique are PLA, Acrylonitrile butadiene styrene (ABS), Nylon and Polyethylene terephthalate glycol (PETG). PLA used in this study is a biodegradable and recyclable material. It can be easily processed between 180-200 ºC. PLA's ability to be easily extruded minimizes polymer degradation, making it a suitable material for the FDM technique. Also, the high surface energy of PLA causes good cohesion, which is very important for the FDM technique. Although it is a brittle material, its hardness and strength are high. The properties of PLA material are given in Table 3.

Table 3. Properties of PLA material [12]

Properties	Units	Value
Diameter of Filament	mm	1.75
Density	g/cm3	1.20-1.25
Melting Point	ºC	190-220
Flexural Modulus	MPa	2504.4
Flexural Strength	MPa	65.02
Tensile Yield Strength	MPa	62.63
Elongation at Break	%	4.43
Impact Strength	KJ/m^2	4.28

2.3. Design of experiment and Printing Parameters

30x30x30 mm samples with three different infill densities and infill patterns were produced using PLA material on a Ender 6 FDM printer. The values shown in Table 4 were kept constant while each piece was printed. As seen

in Table 5, 3 different filling densities were determined for three different patterns and a total of 9 different test samples were prepared.

Tablo 4. FDM printing parameters

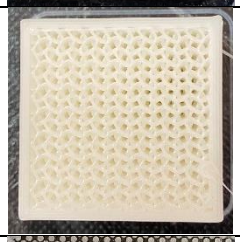
Print Parameters	Values
Printing Speed	75 mm/s
Layer Height	0.3 mm
Wall Thickness	1.32 mm

Table 5. Printing time and material comsumption for different pattern and infill density

Pattern	Infill Density	Printing Time (min)	Material Consumption (gr)
Gyroid	15%	45	12
	30%	68	15
	50%	96	20
Triangle	15%	40	12
	30%	51	15
	50%	63	20
Octet	15%	40	12
	30%	51	15
	50%	62	20

Table 6 shows the cross-section geometries of the samples used in printing with different infill patterns and infill densities.

Table 6. Samples with different infill densities and patterns

Pattern/Density	15%	30%	50%
Octet			
Gyroid			
Triangle			

2.4. Compression testing

Compression tests were performed with a computer-controlled Instron 50 kN machine and the results were processed in the computer environment. In the compression test, a load of 50 kN and a velocity of 5mm/min were applied to the models in the vertical direction. In the compression test, if the material does not break even though the amount of compression of the material reaches 15 mm, the test is conditioned to terminate.



Figure 4. Instron 50kN Compression Testing Machine

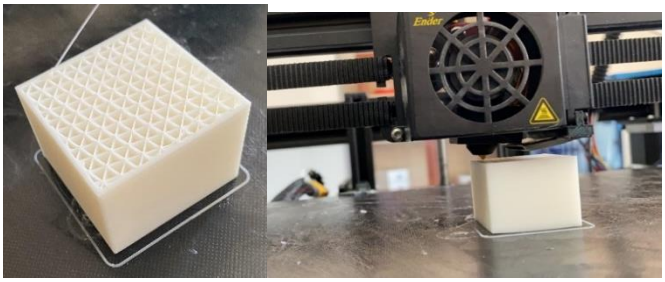
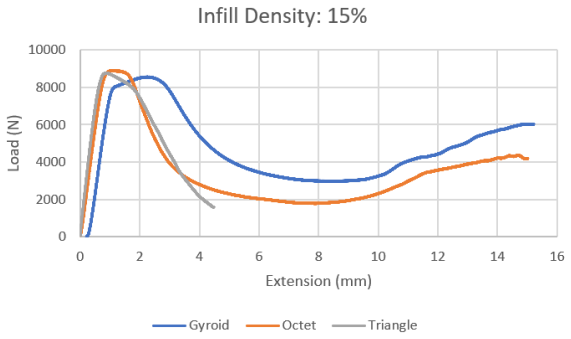


Figure 5. Compression test process

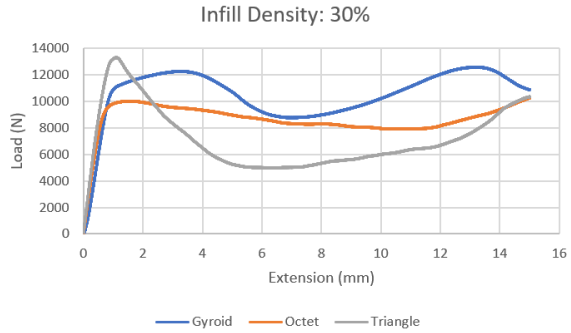
3. RESULTS AND DISCUSSIONS

3.1. Results of Yield

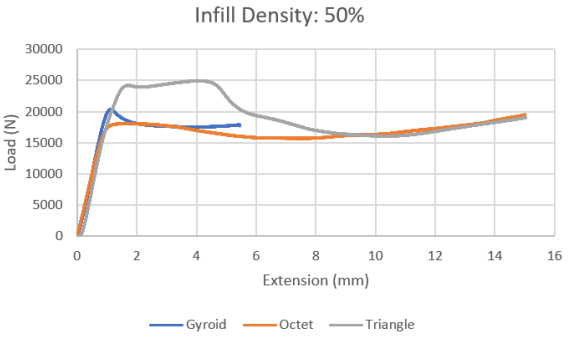
Compression test was applied to a total of 9 samples in the compression test. The obtained data were processed in computer environment and converted into graphics. The graphs show curved Gyroid filled models in blue, Octet filled models in orange, and curved Triangle filled models in gray (Figure 6). Figure 6 shows the load expansion data for all models and occupancy rates.



(a)



(b)



(c)

Figure 6. Load-Extension graphics

When calculating yield strength, the cross-sectional areas perpendicular to the pressure direction must be known. The area due to the wall thickness is 151.5 mm^2. The value of the remaining cross-sectional areas is directly proportional to the 15%, 30% and 50% occupancy rates. Table 8 shows the values of these cross-sectional areas.

Table 8. Cross-sectional areas perpendicular to the direction in which the samples are subjected to compression load

	15% (mm^2)	30% (mm^2)	50% (mm^2)
Gyroid	264	376	526
Octet	264	376	526
Triangle	264	376	526

The yield strength is calculated theoretically with the following formula.

$$\sigma_{yield} = F_{yield}/A_0 \quad (1)$$

The yield strengths of each sample were calculated using data from the compression test, Equation 1 and the results are shown in Table 9.

Table 9 – Yield strengths according to filling parameters and filling density

	Yield Strength (mPa)		
Infill Density	octet	gyroid	triangle
15%	33,6	32,3	33
30%	27,2	33,4	35,3
50%	37	38	47

The yield point is a characteristic property of the material. In the studies, it is known that the yield strength of molded PLA test samples is 45 - 55 MPa, and the yield strength of test samples printed with 3D printers is around 30 - 35 MPa. The yield strength data of test specimens printed from 3D printers largely match the calculated data. The main purpose of this study is to give the information that the data such as specific strength, toughness and elongation are healthy and can be interpreted depending on the filling ratios and filling parameters of the materials.

However, as seen in Table 9, the yield strength of the triangular filled structure is above the average. This means that the triangular filled structures printed with the device used and the printing parameters shown in Table 4 perform better than the octet and gyroid fill parameters. This is clearly seen in figure 7.

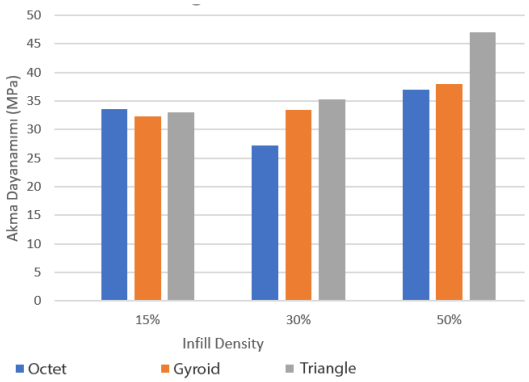


Figure 7. Yield strengths according to filling parameters and filling density

As can be seen in Figure 7, the yield strengths of the samples are very close to each other according to their filling ratios. When the experimental results were analyzed, a 50% > 30% > 15% interpretation of the yield strength of the samples was obtained. This interpretation does not, however, conclude that material with a higher filler density is better. In the analyzes made, it is understood that the 50% triangular structure shows much better yield strength than the others. This information guides new experiments for the triangle structure.

3.2. Toughness

The compression test was carried out to a maximum compression of 15 mm. As a result of the tests, it was understood that the samples showed ductile material behavior and the materials were deformed until they were compressed 15 mm. Since hardening occurs in the material after approximately 4 mm compression, the toughness data were examined in the part up to 4 mm compression. The toughness of the materials was calculated and compared using the data in the Load - Elongation plots in figure 8. The comparison is based on the dimensions of the parts under the graphics areas. Accordingly, the highest toughness value was observed at 15% and 30% filling densities in the Gyroid model. Octet and Triangle followed the gyroid model. In samples with 50% filling density, the triangular structure has the highest toughness. Octet and Gyroid structures follow the triangular structure.

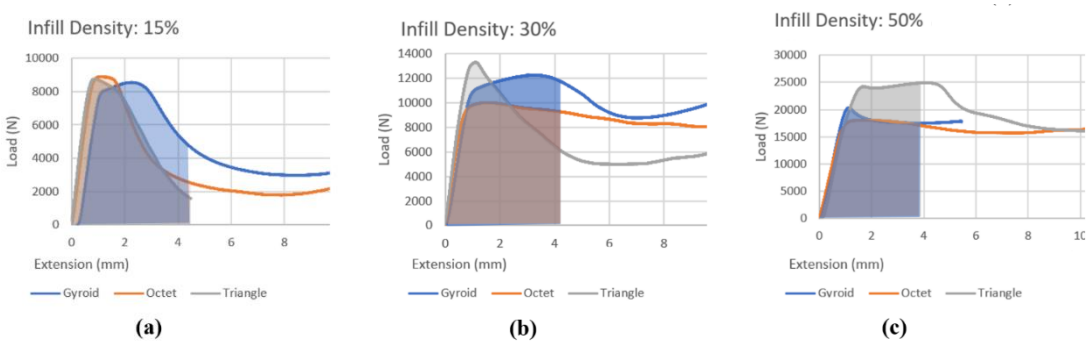


Figure 8. Toughness graphics: (a) 15% density (b) 30% density (c) 50% density

According to previous data, triangle was the most durable structure under all conditions. On the other hand, in the toughness comparison, the triangle structure shows the lowest toughness properties at 15% and 30% filling rates, while it shows higher toughness properties at 50% fullness.

4. CONCLUSIONS

A total of 9 samples with three different filling patterns and 3 different filling speeds were printed in the same conditions on a rare 6 brand 3D printer. Compression test was applied to these samples. Yield strengths were calculated with the data obtained from the compression test. As the filling ratio increased, the yield strengths showed better values. When examined in terms of filling pattern, triangular structure has the best yield strength. The triangular structure is followed by the gyroid structure and the octet structure.

In the comparison made in terms of toughness properties, the area under the curves obtained in the compression test was used. When examined in this context, the material showing the best toughness properties is the 50% triangular structure.

As a result of the analyzes made, it was seen that the sample with the highest yield strength and toughness properties among the gyroid, octet and triangular samples with 15%, 30% and 50% occupancy rates was triangular with 50. % solidity ratio. It is envisaged to increase the occupancy rates of the structure with the triangle and to obtain the optimum strength value with minimum material.

CONFLICT OF INTEREST STATEMENT

No potential conflict of interest was reported by the authors.

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Innovative Approaches in Additive Manufacturing Congress (IA4AM)

FRIDAY, 16 JULY 2021

PROGRAM

Time*	
09:00-10:00	**OPENING** Prof. Dr. Ismail SAHIN
09:30-10:30	**1st SESSION**
	Moderator: Dr. Harun Gokce
	Adaptive Laser Metal Deposition (LMD) toolpaths for repair and coating complex geometries *Igor Ortiza, Piera Alvareza, Angeles Montealegrea*
	Analytical Modelling of Heat Distribution in Powder Bed Fusion Process *Oğulcan Eren, H. Kürşad Sezer*
	3D Printing of shoe lasts for industrial manufacturing of custom shoes *Aurelian Zapciu, Catalin Amza, Diana Popescu*
	Design for Additive Manufacturing Application for Motorcycle Knee Pad *Diyar Biçer, Nur Zeynep Cengiz, Hüdayim Başak*
Break	
10:45-11:45	**INVITED SPEAKER / Prof. Anton Du PLESSIS - Stellenbosch University** "Porosity in laser powder bed fusion additive manufacturing"
Lunch	
12:30-13:30	**2nd SESSION**
	Moderator: Assoc. Prof. H. Kursad Sezer
	Design of 3D Printed Customisable Post-Stroke Rehabilitation Devices to Provide a High-Quality User Experience *Benjamin Darmanin, Philip Farrugia, Edward Abela*
	Nanotechnology Applications in Food Additives *Ece Çelik, A. Gülçin Sağdıçoğlu Celep*
	Additive Manufacturing in teaching and education *Doru Cantemir*
	A conceptual drone leading gear design based on 4D printing

	Eda Nur Düzenli, Harun Gökçe
Break	
13:45-14:45	**3rd SESSION**
	Moderator: Dr. Harun Gokce
	Effect of infill density and infill pattern on mechanical properties in Fused Deposition Modeling (FDM) *Alparslan Yazar, Neslihan Top, Ramazan Bülbül, Ismail Sahin*
	3D-printed hand orhoses: Devolepment and evaluations methods *Diana Popescu, Christian Tarba, Catalin Amza*
	Using Voronoi Diagram in Unmanned Aerial Vehicle Design *Nurullah Yüksel, Hüseyin Rıza Börklü*
	Design for 5-Axis CNC Machining Post Processing of Additively Manufactured Metal Parts *Osman Tuna Gökgöz, H. Kürşad Sezer*
Break	
15:00-16:00	**INVITED SPEAKER / Dr. Ali Gökhan DEMİR - Politecnico di Milano** "Process innovations for enabling new materials and geometries in LPBF for biomedical implants"
Break	
16:15	**CDRP-EN PROJECT EVALUATION SESSION**
	Moderator: Dr. Harun Gokce
	RP Based Product Design *Jonathan C. Borg, Sean Aigus, Philip Farrugia*
	Rapid Tooling *Jonathan C. Borg, Sean Aigus, Philip Farrugia*
	RP based on Reverse Engineering *Catalin G. Amza, Diana Popescu*
	Rapid Prototyping and using systems *Catalin G. Amza, Diana Popescu*
	Rapid Prototyping Materials *Catalin G. Amza, Diana Popescu*
	3D Printing Technology and Industrial Perspective *İsmail Şahin, Tayfun Fındık, Murat Dörterler*
	The Future of Rapid Prototyping *Harun Gökçe, Alper Altunçekiç*
	Challenges in Rapid Prototyping *Petr Primus, Marek Trestik*
	Current Techniques and Methodologies in Rapid Prototyping

	Doru Cantemir
	Introduction to Rapid Prototyping *Antonino Imbesi*
Closing	

*** Brussels time**