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Technical Research

THE INFLUENCE OF INFILL DENSITY AND SPEED OF PRINTING ON THE TENSILE PROPERTIES OF THE THREE DIMENSION PRINTING POLYLACTIC ACID PARTS

***Muhammed Kasim** **Bashar Owed**

Mechanical Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq

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Abstract: The primary aim of this research was to determine effect of infill-density (ID), and the speed of print on the microstructure and tensile behavior of 3D printed elements by conducting the tensile test. The tensile behavior of 3D printed elements is essentially dependent on the ID that is stratified through printing.
Here specimens printed from PLA and divided into three group the first group printed at speed of 40mm/s and (50,75,100) % infill ratio. And second group printed at speed of 50 mm/s and (50,75,100) % infill ratio. The third group printed at speed of 60mm/min and (50,75,100) % infill ratio. The specimens printed in accordance with ASTM D638 of tensile test. From all specimens the best result obtained at first group specimen 3 at infill ratio of 100% and speed of print 40mm/min. from the microstructure examination the brittle fracture features (smooth region) and ductile fracture characteristics (deformed patterns) were observed in infill ratio (ID) percentage.

Keywords: *Three-dimension printing; fused filament fabrication; polylactic acid*

1. Introduction

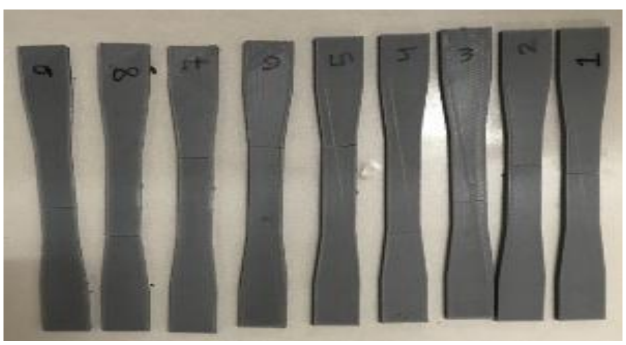
The demand for using additive manufacturing technology (AMT) has increased steeply in the recent years compared to the last decade [1]. In the additive manufacturing technology (AMT), the products are made layer-by-layer by which all kinds of intricate parts can be easily manufactured which cannot be fabricated by conventional subtractive processes [2]. AMT has several techniques to build the products in which the common technique is fusion deposition modeling (FDM) [3]. The FDM was invented in 1992 by American Company Stratasys [4]. The process of building an object in FDM is to heat a strip of thermoplastic material and then extruded the melting material via a nozzle to create the object layer-by-layer in the build platform under a robust machine control system. The nozzle and build platform move continuously and simultaneously in x, y, and z-direction to build the desired objects [5]. Nowadays the FDM process is being used to fabricate the parts in aerospace, automotive, spacecraft, and bioengineering industries [6]. Because of these applications, examining mechanical of 3D printed elements to check the capability under mechanical loading is necessary [7]. The FDM process processes the major feature of scalability and material flexibility. However, the part

**Corresponding Author*: EHma037@uomustansiriyah.edu.iq

quality and anisotropic characteristics in nature are the main challenges in FDM. Several parameters are influencing the mechanical performance of 3D printed elements which are orientation of build (edge, flat, and upright) extrusion temperature, thickness of layer, nozzle diameter, printing velocity and infill density (ID), type of infill pattern, environmental conditions, raster/ infill orientation (0,45, and 90), top and bottom cover thickness [8-10]. Based on the literature, it was found that the build orientation should ensure the large contact area of a specimen with the platform while printing by which improved mechanical properties can obtained [11]. The flat and edge build orientation can ensure a large contact area in which the flat build orientation can print the parts without any manufacturing difficulties as compared to the edge build orientation [12]. Tymrak et al. [13] studied mechanical behavior of polylactic acid (PLA) plastics, and acrylonitrile butadiene styrene (ABS) by differing thickness of layer, and orientation of build. The results were explained which tensile strength was reduced with the function of layer thickness and improved mechanical strength was obtained at 0.2 mm thickness of layer with flat orientation of build. Lanzotti et.al. [3] examined tensile-strength of PLA 3D printed elements by FDM in which build orientation and layer thickness were varied. The observed results explained the highest ultimate tensile-strength of around 51MPa was acquired when the thickness of layer was 0.15 mm, and infill raster orientation was 45. Soad et al. [11] studied mechanical behavior of ABS 3D printed plastic parts by FDM in terms of tensile test, impact test, flexural test. The results were concluded that the tensile strength was raised when decreasing layer thickness whereas the impact-strength, and flexural-strength were raised with increasing the layer thickness. Fernandes Vicente et al. examined influence of infill pattern on mechanical behavior of ABS 3D printed plastics by FDM by conducting a tensile test. The different infill patterns such as line, rectilinear, and honeycomb infill pattern samples were produced improved mechanical properties when compared to rectilinear. Ahn et.al. [2] studied anisotropic mechanical improved behavior of ABS 3D printed plastics by FDM in terms of tensile and compressive strength. The authors varied the raster/ infill orientation, air gap, color of material, bead width and extruded temperature. The result concluded that the orientation of raster, and gap of air were the most influencing parameters on mechanical strength in comparison to other variables. Ziemian et.al. [15] studied the raster/infill orientation on mechanical-properties of ABS 3D printed plastics by FDM. The mechanical properties (compressive, flexural, tensile, fatigue strength, and impact) were examined and reported the optimal raster angle for having improved mechanical properties. Tsouknidas et al. [16] studied absorption of impact of PLA specimens printed by the FDM machine with various speeds of printing. The PLA specimens were exposed to compression load. The work has shown which the minimum speed of printing given highest tensile-strength. Torres et al. [17] evaluate the effect of the layer thickness, ID, and heat treatment of the PLA specimen printed by the FDM on the mechanical properties (stress-strain) examined by the torsion test. The experiment was conducted using the Taguchi method to control the various process parameters. In addition, the applications of artificial intelligence techniques and various optimization methods are being applied to monitor/control the FDM process during printing [18]. The materials utilized for 3D printed parts also influence the mechanical behavior in addition to various process parameters. Thermoplastics are the commonly used materials for 3D printing by the FDM process. Among the several thermoplastics, namely, ABS, PLA, polyamide (PA, nylon), Polyether ether ketone (PEEK), polyethylene terephthalate glycol (PETG), and high impact polystyrene resin (HIPS), PLA is a commonly used material for studying purpose. Further, PLA is a biodegradable one that can be best proper for tissue/ bone implementations of engineering [19,20]. Based on the literature, though some authors have investigated the mechanical behavior of ABS and PLA, there is no work related to varying ID and varying the speed of the print on tensile behavior of the PLA 3D printed parts using the tensile test. The ID of 50%, 75%, 100% were varied. And the speed of print varied of (40,50,60) mm/min and the standard used to fabricate the specimens is ASTM D638.

2. Material and method

2.1. Specimens' preparation



Three-dimensional Fused deposition modeling (3D FDM) was utilized to prepare samples for the investigation of the mechanical properties. 3D FDM can Build maximum size of 200*200*200 and top speed of 15 mm/s and works on the principle of "additives" by laying materials in layers. Plastic Thread or metal is provided in the form of wire from the coil to create a part under maximum operating temperature of 210 ° C. CAD models were created on the Solid works 2018 Modeling Program. Then, it was converted to STL. format. Samples was created by extruding small flat chains molten to form layers where material-hardens instantly after extrusion from nozzle. The nozzle can be shifted vertically and horizontally in digital format. To correctly different the panels, it is important to evaluate the base materials properties. Tensile samples were printed in accordance with ASTM D638 using the same materials used in all girder planes. Tensile test was performed using a tensile test device with 3 KN load cell. Nine samples were used to perform single-axis pressure tests. The Nine samples divided into three groups the first group contain three samples 1,2,3 in this group select the speed of print 40mm/min and infill ratio of (50,75,100) %. The second group contain three samples 4,5,6 in this group select the speed of print 50 mm/min and infill ratio of (50,75,100) %. The third group contain three samples 7,8,9 in this group select the speed of print 60 mm/min and infill ratio of (50,75,100) %. In tensile test compared the maximum load and ultimate strength and the yield strength and the maximum deformation and the modulus of elasticity between the samples tested. Figure.1 shows nine PLA 3d print under tensile load before and after the tensile test operation. Figure 2 shows the universal testing machine tester Model (WDW-50E). Figure 3 shows the specimen printed in the 3D printer. Table 1 explain the properties of PLA wire.

Table 1. The properties of PLA wire

property	Value
Yield strength	60MPa
Elongation to break	6%
Tensile modulus	3600Mpa
Diameter	3mm
Extrusion temperature	210°c

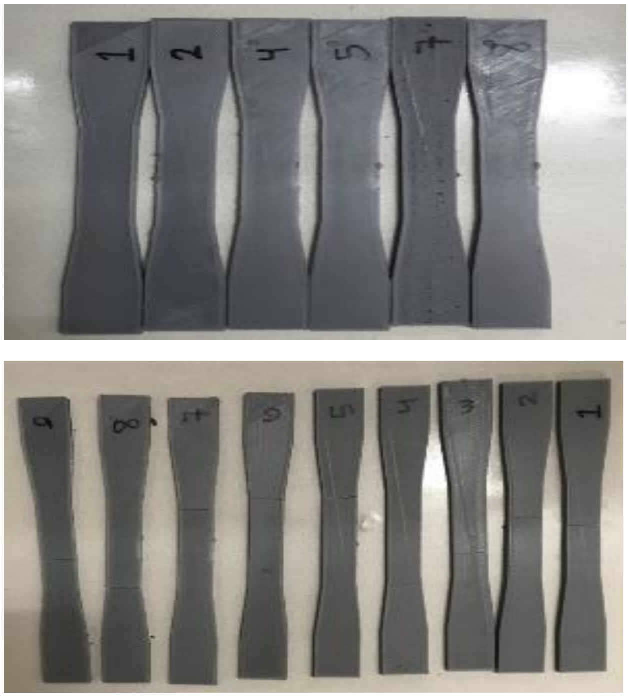


Figure1. 3D printed specimens under tensile test.

Figure 2. shows the universal testing machine tester Model (WDW-50E).

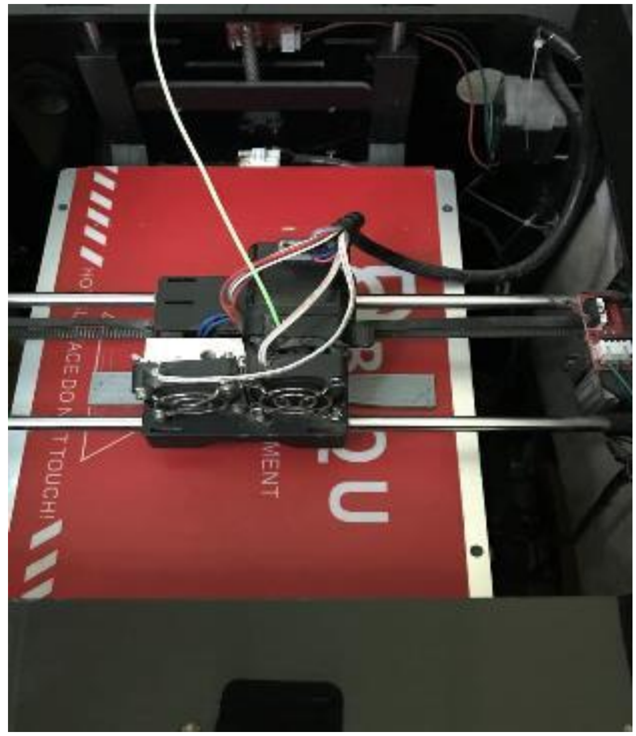


Figure 3. shows the specimen printed in the 3D printer.

2.2. Numerical consideration

- One of the most important numerical procedures is the method of Finite Element that may be utilized to get the solution of Large Numbers of problems of engineering.
- In this work FEM by help of systems of Analysis ANSYS Workbench 2019R3 program was utilized as the numerical tool to obtain the deformation due to applying the load on the specimens.
- The aim of using Ansys to verify the experimental Result in this work.

2.2.1 Preparation of Numerical Model

The dimension of the current Model is (165*19*4) dimension in mm as shown in the figure 4

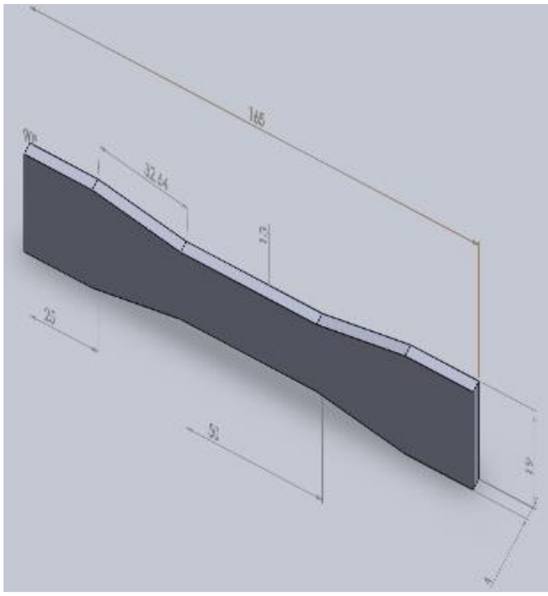


Figure 4. Shows the model used in the experimental design.

2.2.2 Creating the mesh of the model

The total element numbers in this work 3296 element and total nodes are 17219 node and element size 1.25 mm. The mesh size could be change to satisfy the model number of the node. As shown in the figure 5.

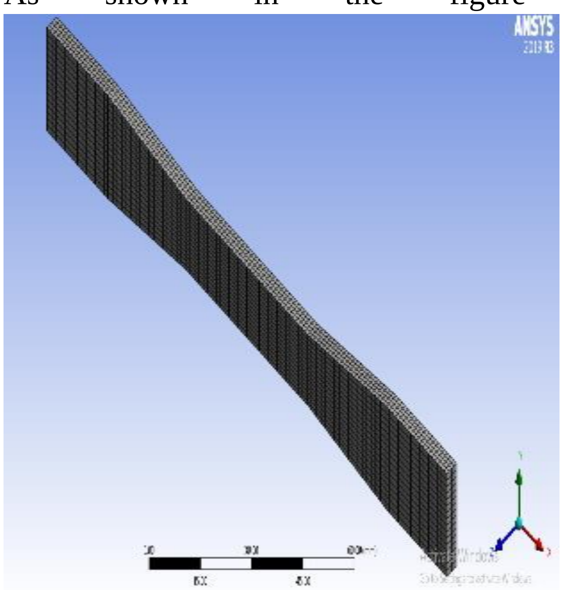


Figure 5. shows the mesh of the model of poly lactic acid

2.2.3 Appling Load, Boundary condition and deflecting the analysis type

the term load contains the boundary condition (support and displacement) the load selected is 2.85KN component of invers x direction subjected in the left side of the model as shown in the figure 6.

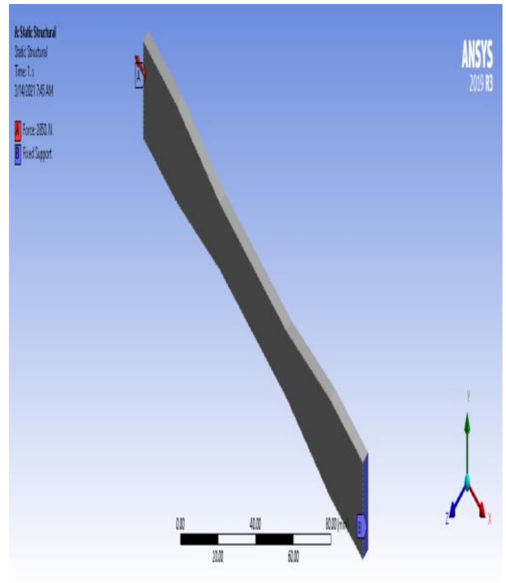


Figure6. shows the boundary condition of the model

3. Result and Discussion

3.1. Tensile test result of group (A)

The speed of print selected in this group is 40mm/min The properties of material (yield stress, ultimate stress, young modulus, maximum deflection and load) resulted from the test of tensile are shown in the table 2.

Table 2. the mechanical properties of group (A)

Infill density	50%	75%	100%
Load KN	1.2	1.7	2.85
Stress MPa	24	36	55
Yield stress	11.25	21	21.3
E(MPa)	659.3	824.13	1305
Exp.Deformation	2.2	2.5	3.2
Num.Deformation	2.0448	2.1727	2.9142
Error %	7.05	13.09	8.93

From the table 2 above illustrate the maximum ultimate stress is 55MPa and the maximum yield stress is 21.3MPa obtained at the specimen number 3 at infill ratio of 100%. This indicate that the specimen 3 is more ductile for specimens 1,2 at the same time, the three specimens are not considered brittle materials because they have higher ultimate stress than the yield stress. From the table it can be noticed the maximum elasticity modulus of this group in specmen3 at 1305MPa this indicate that specimen 3 have higher elasticity and higher resistance to tensile stress from specimen 1,2 because the increase in the modulus of elasticity is caused by the increase in the stress applied with increased strain.

3.2. Tensile test result of group (B)

The speed of print selected in this group is 50 mm/min The properties of material (yield stress, ultimate stress, young modulus, maximum deflection and load) resulted from the tensile test are shown in the table.3

Table 3. The mechanical properties of group (B)

Infill density	50%	75%	100%
Load KN	1.178	1.638	2.738
Stress MPa	26	36	52
Yield stress	12.5	14	18
E (MPa)	627.9	813.95	1098.83
Exp.Deformation	2.6	2.5	3
Num.Deformation	2.261	2.2308	2.8119
Error %	13.03	10.76	6.27

In this group after replacing the speed of print from 40mm/s to 50 mm/s and printed 3 specimens 4,5,6 we can see that from the table 3 maximum ultimate-stress is 52 MPa, and maximum yield-stress is 18 MPa at specimen 6 of infill ratio 100% and the maximum modulus of elasticity is 1098.83MPa. We can note that reduce in yield stress and modulus of elasticity in this specimen of infill ratio because the change in speed of print from 40mm/s to 50 mm/s which will lead to reduce the time of print from 55min for specimen 3 to 40min for specimen6 and reduce the mechanical properties.

3.3. Tensile test result of group (C)

The speed of print selected in this group is 60 mm/min The properties of material (yield stress, ultimate stress, young modulus, maximum deflection and load) resulted from the tensile test are shown in the table.4

Table 4. the mechanical properties of group (C)

Infill density	50%	75%	100%
Load KN	1.1	1.7	2.7
Stress MPa	24	37	50
Yield stress	10.5	12	16.6
E (MPa)	599.36	755.64	1014.3
Exp.Deformation	2.3	2.7	3.15
Num.Deformation	2.1627	2.3702	2.7608
Error %	5.96	12.21	12.35

In this group after replacing the speed of print from 50mm/s to 60 mm/s and printed 3 specimens 7,8,9 we can see that from the table 4 maximum ultimate-stress is 50 MPa, and maximum yield-stress is 16.6 MPa at specimen9 of infill ratio 100% and the maximum modulus of elasticity is 1014.3 MPa. We can note that reduce in yield stress and modulus of elasticity in this specimen of infill ratio because the change in speed of print from 50mm/s to 60 mm/s which will lead to reduce the time of print from 40 min for specimen 6 to32 min for specimen 9 and reduce the mechanical properties.

4. Result of Numerical ANSYS

In this work total deflection and the equivalent stress will obtained from the program as shown in the Figure 7,8.

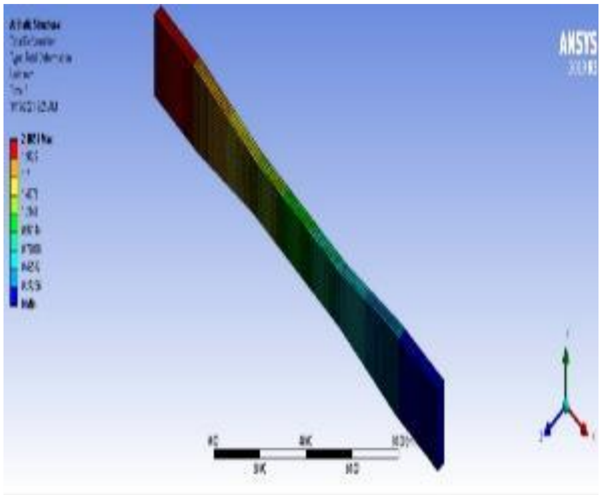


Figure7. result of numerical program ANSYS deformation

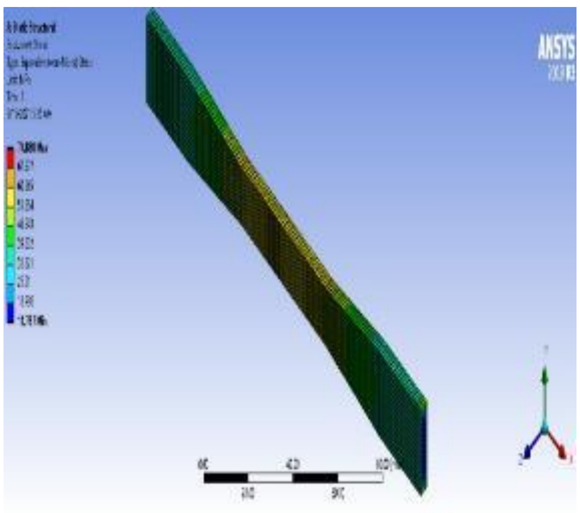


Figure8. result of numerical program ANSYS equivalent stress

5. Conclusions

1. The experimental result appears that the Tensile test characteristic (strength, modulus of elasticity, strain) improved as the infill ratio (ID) percentage increased at 100% because, at a high infill ratio, the bond between atoms become strong in addition to the density of the specimens become high at the infill ratio high.
2. The Tensile test characteristic (strength, modulus of elasticity, strain) improved as the print speed becomes slow at a speed of 40 mm/s because the time of print becomes large and gives high toughness for the specimen printed.
3. From the microstructural examination, the brittle fracture features (smooth region) and ductile fracture characteristics (deformed patterns) were observed in all infill ratio (ID) percentages.
4. The ductile fracture mode features (deformed pattern) increased as the infill ratio (ID) percentage increased.
5. The numerical model's total deformation and equivalent strength manifested its acceptance compatibility with the experimental result.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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