INTERNATIONAL JOURNAL OF RESEARCH SCIENCE & MANAGEMENT

INVESTIGATION AND ANALYSIS OF INFILL DENSITY ON IMPACT PROPERTY OF PLA IN 3D PRINTING

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DOI: 10.5281/zenodo.1185587

Keywords: Infill density, FDM, Impact property, PLA.

Abstract

With increased interest using of 3D printing and the development of the STL file and the open-access CAD: It is important to determine which density and density patterns will provide the perfect strength for various applications. This is of great importance because in additives manufacturing (AM), the CAD model does not have any information about the Infill pattern.

In this work the effect of density in printed parts is analyzed by mechanical properties. The sample is generated with the effect of some parameters as well as with constant parameters (print speed, layer thickness, part orientation and shell thickness) based upon the Cura program data. The parts are constructed using polylactic acid (PLA) material with the "Cura software program" from Ultimaker 3D printer. Impact test shows that the increasing of impact strength and fracture toughness that depend on the infill density (20%, 35%, 50%, 65%, and 80%) of the impact specimens which Increasing of infill density leads to increasing of impact test value which obtains the maximum value of impact strength (18.5 KJ/m^2) and the maximum value of fracture toughness (7.197 $KJ/m^{3/2}$). Therefore, this paper discusses the empirical analysis of the effect of infill density on fused deposition modeling (FDM) specimens made of polylactic acid (PLA).

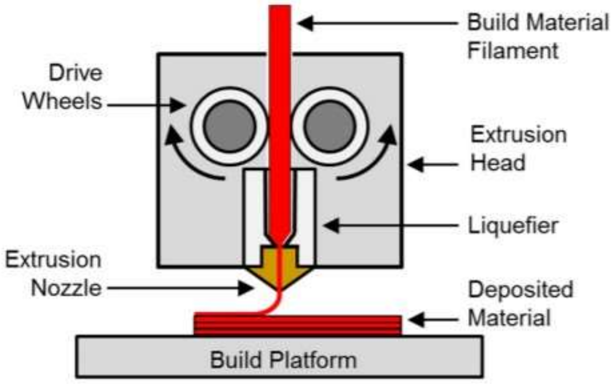
Introduction

The great 3-Dimensional printers for modeling systems which provide very quick feedback on designs related to fit, appearance and functionality. In additional, several times the printed part is strong and accurate enough to be used directly in the system. Sending the part to a fabricator instead of designing in CAD tool, approving the returned drawings, waiting the part to be fabricated, then wait for their arrival – you can simply CAD up a model and print it within a few hours. If the design has a problem, modify the model and reprint [2].

Manufacturing Additive (MA) is a process that creates parts based on a layer by adding and stacking materials. However, part accuracy, material properties, performance and cost are the limitations of this technology [3]

Fused Deposition Modeling (FDM) is one of the technologies of manufacturing additive. It is one of the most widely used manufacturing processes for model production [4]

FDM is added manufacturing technology (AM), which is operated by heated nozzle placed in layers of molten material to produce the required part. FDM uses three-dimensional printers and becomes one of the most popular Rapid Prototyping (RP) technologies in the last decade. FDM takes the part design with the help of the CAD program and exports it as a stereo lithography (STL) file and upload it to the slicer program. The file reads by the printer to melt the selected polymer filament and the liquefier temperature is increased to the desired temperature then start extrusion material. The printing filament that was used in this study was poly lactic acid (PLA). By heating, the liquefaction using two driving wheels, the polymer filaments are fed. Where the melting of the filament then was extruded through the nozzle on the build platform. Heating and extruding of filaments to the specified diameter, each is contained within the extruding head which moves in the X-Y plane depositing material on the build platform. One line of material is defined by the path and the deposition of multiple paths sid e by side to produce one layer of the three-dimensional printed part. After finishing each layer, the building platform will move to the bottom or the specified height layer, and then repeat the process to the remaining layers until the part is finished. Fig. (1) The main parts appear inside the extruding head and extruded filaments. [1]



Fig(1) drawing of the standard FDM process and the main parts inside the extrusion head.[1]

The operation of the head of FDM in the directions of the coordinates x and y is very accurate. When the platform is lowering in the z-direction, the layer by layer manufacturing is possible. If necessary, additional support materials are used to provide a building substrate if a component part shows an overhang, cavity or offset. These additional materials prevent part of the breakdown during the construction process. After the construction process, the supporting material can be removed easily by dissolving it in a warm water bath or breaking it [4].

Infill Density

The technique of FDM has the parameters of the process are: Infill percentage of the object's volume that is filled with material is the process parameter that investigated and analyzed in this paper with different percentage of infill density (20%, 35%, 50%, 65% and 80%) while the other parameters are kept constant (Print speed: 50mm/s, Layer thickness: 0.1mm, Shell thickness: 1.2 mm)

Mechanical Properties

Mechanical behavior of the part is the interaction of material on mechanical stress. Depending on the mechanical properties, the direction of the force applied and the size of the component geometry, the applied force is caused the component deformation. In this paper the impact properties of specimens printed with different infill density parameter are presented. Tests were performed according to ISO 180 is the method for Izod impact testing fig (2) at temperature of 23°C the specimens were loaded until they broken.

Representation of the impact properties of materials refers to its ability to absorb and dissipate energies used to measure the strength of material under impact or shock loading. To calculate the impact strength in (J/m^2) the impact energy is divided by the cross section area at fracture and expressing in the following equation: [5] & [6]

$$Impact\ strength\ (Gc) = \frac{Uc}{Ac} \qquad (1)$$

Where:
G_c: Impact Strength of Material (J/m^2).
U_c: Impact Energy (J).
A_c: Cross-Sectional Area of Specimen (m^2).

While other mechanical properties as a fracture toughness, which describes the capability of a material containing a crack to resist part and can be expressed and calculated by the equation below: [6]

$$The\ strength\ of\ the\ fracture(Kc) = \sqrt[2]{E.Gc} \qquad (2)$$

Where:
K_c: Fracture Toughness of Material (N/m $^{3/2}$)
E: Flexural Modulus of Material (*MPa*).

ISSN: 2349-5197
Impact Factor: 3.765

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The smaller value of fracture toughness this is meaning the less material toughness.

Fig.2. Izod impact test

Test specimens

The samples have been used in the test according to ISO 180. Accordingly, samples were built as parts. Five samples according to the design of test were printed on Ultimaker 2+ printer fig (3). For samples construction has been used filaments of Polylactic Acid (PLA) fig (4). The speed of extrusion was maintained at 50 mm/s while the temperature of the extrusion was 235 o C. These parameters were constant throughout the test.

Fig. 3. Ultimaker printer

Fig.4. Impact testing specimen

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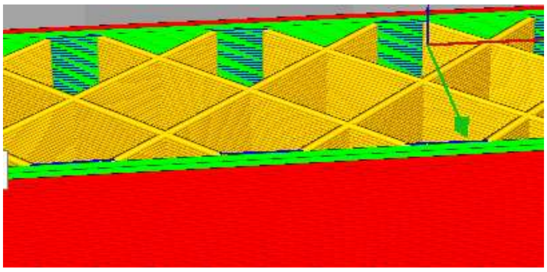

Fig.5 infill density 20%

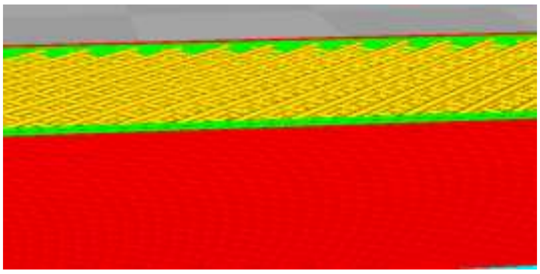

Fig.6 infill density 35%

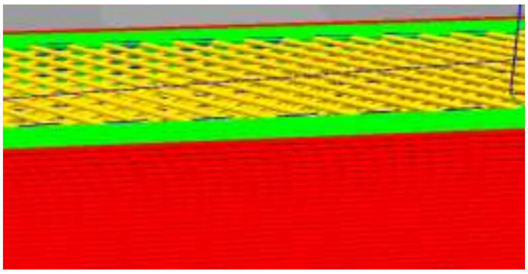

Fig.7 infill density 50%

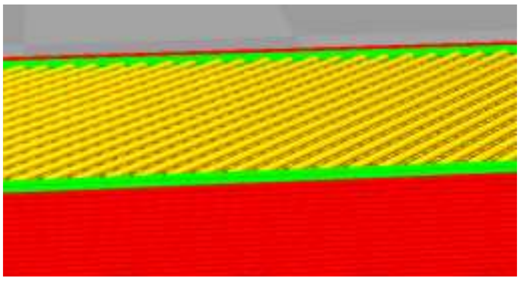

Fig.8 infill density 65%

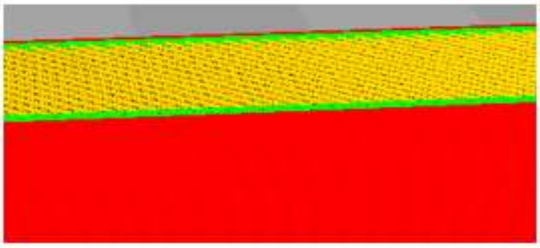

Fig.9 infill density 80%

Results and Discussion

The Impact test represents one of important dynamic mechanical tests, where the specimen exposed to very fast moving load. From this test the impact strength (Gc) and fracture toughness (Kc) of composite materials can be calculated by depending on the energy needed (Uc) to fracture of specimen.

The results illustrates in table (2) shows that the value of impact test for specimens printed with different infill density which shows the increasing impact property of specimens with increasing of infill density also value of impact strength increasing when the infill density percentage increases. This refers that the values of fracture toughness increasing with the infill density increases.

It should be noted that infill density is 20% that mean an infill density around 20% is used for models with a visual purposes, higher densities can be used for end-use parts and the higher infill density 80% means that there is more plastic on the inside of your print, leading to a stronger object. As shown in fig. (10&11) the increasing of fracture toughness values is due to increased bonding in the material by increasing the infill density.

Table 1. show the Property of PolyLactic Acide (PLA) at 100% infill density

Properties	Typical value
Izod impact strength, unnotched (at 23˚C) (KJ/m^2)	19.5±0.7

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Table 2. Impact Test

No. of test	Infill density %	Time (min.)	Fracture energy (J)	Gc (J/m^2)	Gc (KJ/m^2)	Kc (KJ/m$^{3/2}$)
1	20	42	0.6	6000	6	2.049
2	35	49	1.05	10.500	10.5	3.586
3	50	52	1.35	13.500	13.5	4.860
4	65	59	1.75	17.500	17.5	6.309
5	80	62	1.85	18.500	18.5	7.197

Conclusion

1. Although the standard has been improved by increasing the infill density according to the results which is shown in Figure (9), the time spent on printing is significant increasing, which requires a higher cost. From this conclusion, the infill density can be adopted as a critical variable in estimating the cost of 3D printing products.
2. Increasing of infill density leads to increasing of impact test value which obtains the maximum value of fracture toughness (7.197 KJ/m $^{3/2}$).
3. Increasing of infill density leads to increasing of impact test value which obtains the maximum value of impact strength (18.5 KJ/m^2)
4. Most industrial products require a balance between toughness and light weight. This is what our research has done by reducing weight according to reducing the infill density to achieve the desired toughness for each product.
5.

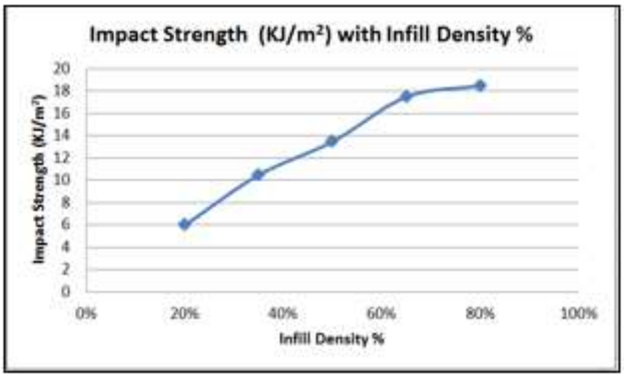

Fig. 10. The relation between impact strength and infill density

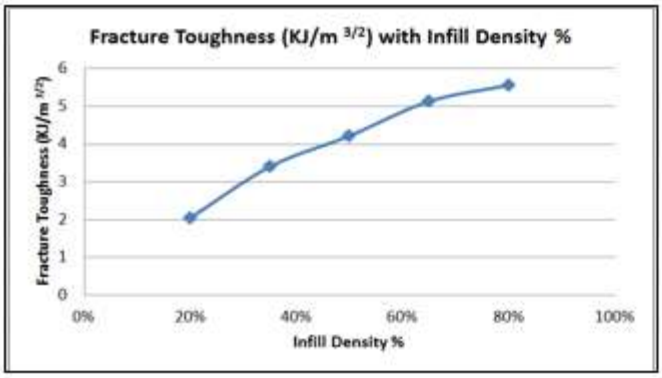

Fig. 11. The relation between time and infill density

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