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Influence of layer bonding on compressive strength of 3D printed structure: An experimental study

Hind B. Ali [1*], Dalia R. Alazawi [2]
[1,2] Materials Engineering Department, University of Technology, Iraq

*Corresponding author E-mail: 130047@uotechnology.edu.iq

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Abstract

The impact of 3D printing parameters is critical for expanding the application of technology in the design and construction. The effect of bonding layers on the compressive strength of the material is investigated in this research by variation of the layer thickness and print speed. Cube specimens with layer thicknesses ranging from 0.05 to 0.3mm and print rates of 40mm/s, were tested on compression with the DARTEC test equipment. It was found that layer thicknesses of 0.05mm and 0.15mm have similar elastic properties while the 0.15mm layer can take additional load after initial plastic deformation. Layer thickness of 0.30mm has significantly lower elastic zone load capacity, but the stress in plastic zone continue to grow. The findings are of great importance for in explaining the S-N curve in order to enhance part manufacture.

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Keywords: Layer bond, Compressive strength, 3D printing, FDM, Additive manufacturing

1 Introduction

An additive manufacturing process transforms a digital 3D design into physical objects. Using this method, thin layers of plastic, metal, or cement are laid down and then fused together to form a solid structure. The advent of 3D printing technology has already had a positive impact on industrial productivity. Industrial logistics and inventory management might be seriously affected in the long term by this technology, especially if it is successfully incorporated into mass manufacturing processes [1].

Currently, it is too slow for 3D printing to be used in large production series. Prototype components and devices may now be built with less tooling and in less time thanks to this new technology. Small-scale manufacturers would greatly benefit from this since it reduces their costs and time to market–the period of time between the creation of a product and its availability for sale–by a significant amount. Subtractive manufacturing processes like as drilling, welding, injection molding, and others need more material to make complex and finely detailed shapes [2]. 3D modeling and printing depend on the technique used and the model size and complexity, it might take anything from a few hours to several days to build a model using contemporary approaches [3].

Full three-dimensional printing procedure is akin to the process by which ink or toner is melted onto paper in a printer. When a solid material is needed at any point in the horizontal cross section of the machine, a liquid or powder is solidified or bonded at that location. Layers according to the prototype during the design of the new part/product are deposited, enable to manufacture a very complex part.

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Models for 3D printing may be created using a CAD program, a 3D scanner, or a regular digital camera and photogrammetry software, among other methods. In many ways, the hand modeling process for obtaining geometric data for 3D computer graphics may be compared to the fine arts such as sculpting. 3D scanning is the act of collecting digital data about the look and feel of a physical object in order to build a reliable digital representation of that object in three dimensions. After modeling, the CAD file transfer to STL file to insert in 3D modeling printing software [4]. Figure 1 shows a general principle in prating 3D models.

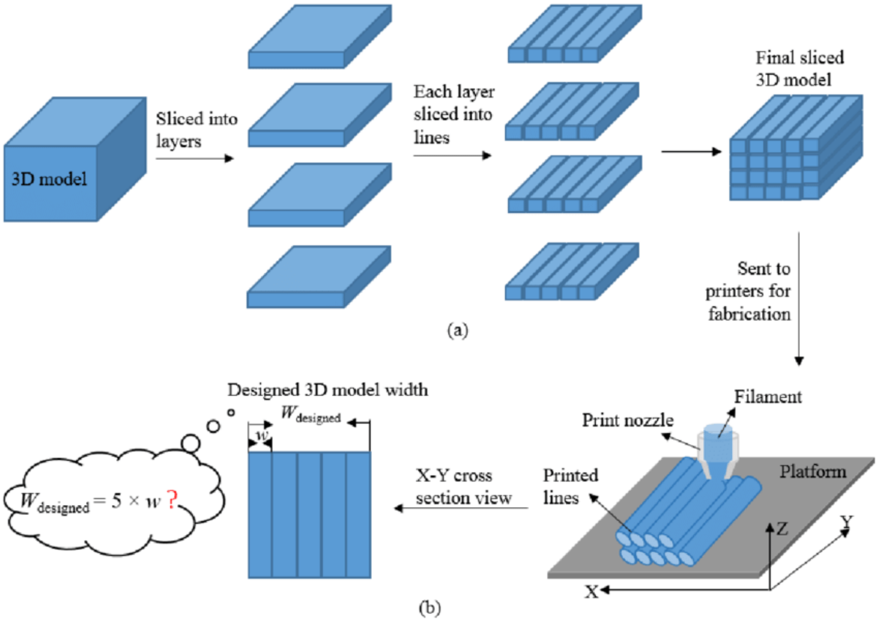

Figure 1. 3D printing process [6]

For printing a computer model from an STL file, error-checking has to be performed. G-code from the simulation software is sent to printer as X, Y, Z points to be printed [5].

1.1 PLA material

Polylactic acid (PLA) as a biopolymer is biodegradable material made from renewable resources such as maize starch and sugar cane. This material is commonly used in canning, plastic cups, packing, and plastic water bottles. PLA is more ecologically friendly than ABS since it is derived from plants [7]. The characteristics of the material is a higher surface hardness and increased brittleness causing cracks if twisted. Parts made out of this material can be cut, cooled, sanded, painted, and bonded together using adhesives; however, acetone cannot be used to increase the smoothness of the final surfaces [8].

When PLA wires are exposed to air for an extended period of time, bubbles and spurs emerge at the extrusion nozzle during printing. This has the potential to clog the nozzle and decrease the surface quality of the produced product. Staining and discoloration may also occur on the item. Although hot air may be used to dry wet PLA wires, heating may change the crystallization rate of the material as well as the thermal characteristics of the wires, which may impact the printing temperature [9].

PLA has a tendency to jam (or clog) the printer's nozzle since it is more viscous and swells more when melted. To avoid clogging the nozzle, it is strictly recommended adhering to manufacturer's recommendations. The holographic layers often do not shrink when cooled - so warping and cracking of the seams are not a concern, and the holographic print can be removed from the print surface more easily than with ABS. This material does not require a thermal surface (though utilizing it appropriately might increase the quality of the resultant shape), and it is not necessary to enclose the printer (but, again, may give better results). To improve the degree of adhesion to the print surface, it is recommended covering with masking tape (also known as paint tape) [10, 11].

The purpose of this work is to investigate effect of bonding layer factors on the compressive strength of the material. Particularly, variation of the layer thickness and print speed as parameters and its impact the compressive strength is investigated in this research.

2 Materials and methods

In this research WINBO 3D PRINTER with one nozzle version WB.CL.V03 printing machine is used. After layering steps on 3 axes, the printing process of test sample is done and compression strength test was performed using DARTEC 100KN universal testing machine. The setting of the parameters used in this study is given in Table 1.

Table 1. Setup condition for PLA

Parameter	Range
Nozzle temperature	230 – 270 C
Table bed temperature	30 - 70 C, optimum 40 C
Printing isolated	Glass and griding silicon

The test sample for the compressive strength test is originally designed with the following dimensions: X = 15 mm, Y = 15 mm, Z = 30 mm. The sample is shown in Figure 2.

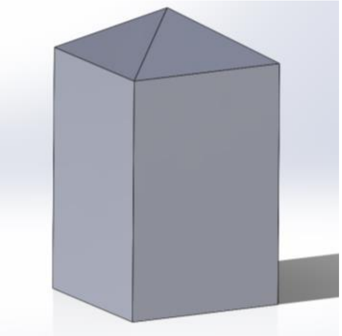

Figure 2. Test sample: Cure software G-code

3 Results and discussion

To produce test samples, eight attempts were made until the successful setup was achieved. In the first attempt: Small dimensions (X = 15 mm, Y = 15 mm, Z = 30 mm) to reduce time of printing from 150.45 min to 37 min so that it reduced material content and increase mesh structured. Characteristics of sample are medium base capacity, small scale and bed temperature of 30 ºC. It was designed to obtain a small mesh and small layering space to analyze compressive strength loads over all printed part and the mesh go crosse slides to exact full material covering.

In the second attempt: Small dimension (X = 15 mm, Y = 15 mm, Z = 30 mm) to reduce time of printing from 150.45 min to 37 min so that it reduced material content and increase mesh structured. The structure represents a modified previous attempt to small mesh and small layering gap but with higher bed temperature. It is noticed that with the third attempt the print was not successful.

In the fourth attempt: printed dimensions of the sample were X = 15 mm, Y = 15 mm, Z = 30 mm, with 101 layers, with the layer thickness of 0.3 mm. The fan setup was modified to provide better air flow. It was observed that layers melt better by closing the fan, so when the nozzle finish cycle and begin at the next, the next melting layers melts the below layer because it didn’t get solidify yet.

In the fifth attempt: printed dimensions of the sample were the same as in the previous ones, bur the number of layers was reduced to 76 due to increased layer thicknesses. The sample is actually modified previous attempt, with fan on 50, and high layers gap, while structure illustrated that, it still melts even when increased the flow and layers thickness. The structure was fully covered by crosses except a few on shell thickness.

In the sixth attempt: printed dimensions of the sample were X = 15 mm, Y = 15 mm, Z = 30 mm with 76 layers. The structure represented that, after finish mostly 30% of the shape, the layer bonding recorded unfinished barriers, small scale occurs non-solidify of every layer. Sample preparation results with eight attempts is shown in Figure 3.

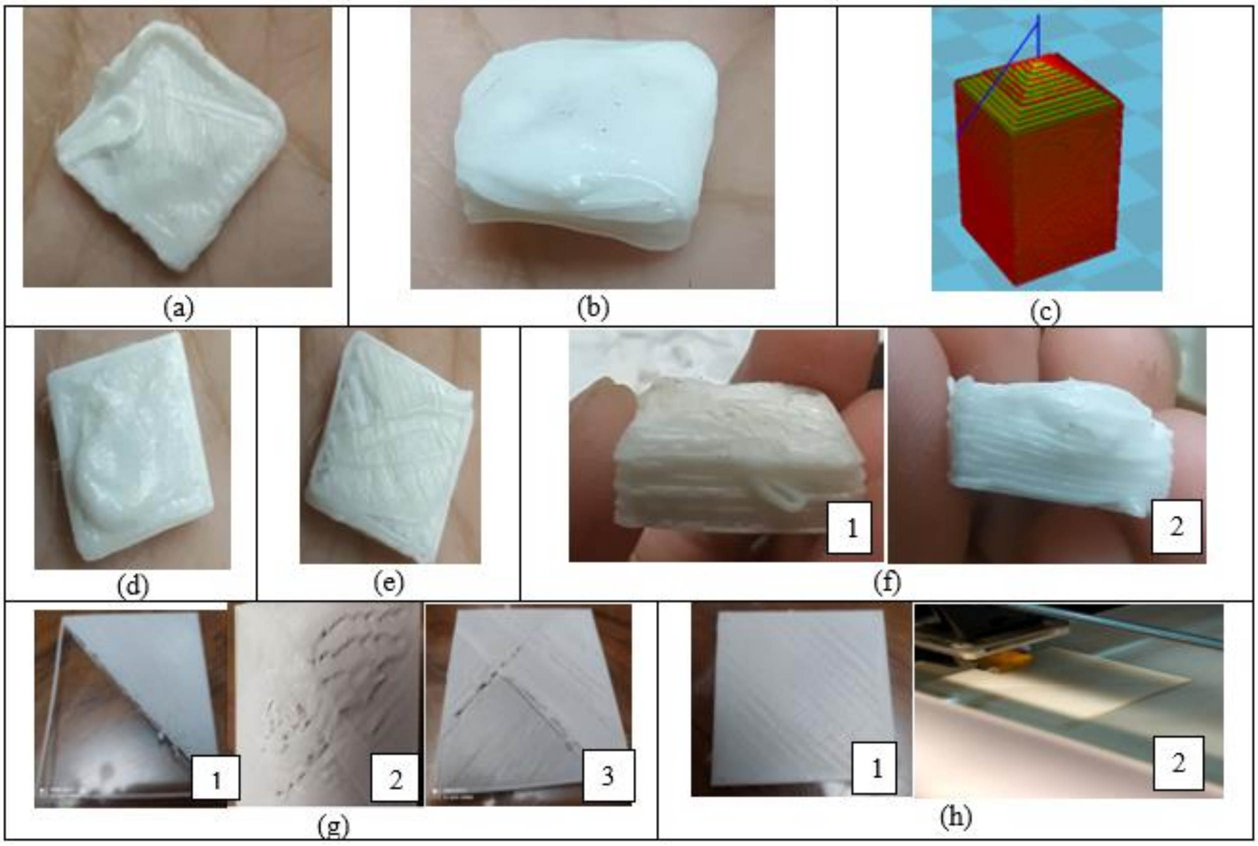

Figure 3. Sample preparation: a) First attempt; b) Second attempt; c) Third attempt; d) Fourth attempt; e) Fifth attempt; f) Sixth attempt; g) Seventh attempt; h) Eight attempt

In the sixth attempt: printed dimensions of the sample were X = 75 mm, Y = 75 mm, Z = 150 mm, a larger sample to avoid the previous problem related to fan and layer melting. It was observed that the first print was not finished due to flow problems and less machine setup. After detecting problem and another machine setup, cracks inside bonding structure were noticed (Figure 3-g2). and the third printing has the same classifications but with change of printing position on the table, nearest home nozzle as shown in Figure 3-g3. The sample was 5 times bigger with the following print parameters: fan was on 50, feed rate was on 150. Noticed problem are with this setup: problems with the flow and fan together, but the covering layers is improved than the last attempts.

With the eight attempt the print was successful and the test samples were made. Dimension of the sample were X = 75 mm, Y = 75 mm, Z = 150 mm, which was used for testing. By loading variable masses within limits during the printing by printer itself which test compression loads on every layer and then analyze the whale part according to the effect of layer bonding [12, 13].

In the second testing with the DARTEC 100KN universal testing machine, elastic yield values for the 0.30 mm specimens were much lower than the other two-layer heights, with a reduction of around 40%. This experiment was discontinued early because the 0.30 mm specimens failed to reach a maximum peak load before the 9mm displacement cut-off point. Gradient load/displacement for these samples shows a definite upward trend at the time of 6.5mm displacement, which indicates that further impacts were starting to take place at that point. After a significant amount of compression, the layers will no longer function in accordance with their initial state, but will instead adhere to each other. The elastic loading of the specimens should not be affected by this, although it may be a concern for all specimens. Test results for three samples (layer thicknesses: 0.05 mm, 0.15 mm and 0.30 mm) are shown in Figure 4.

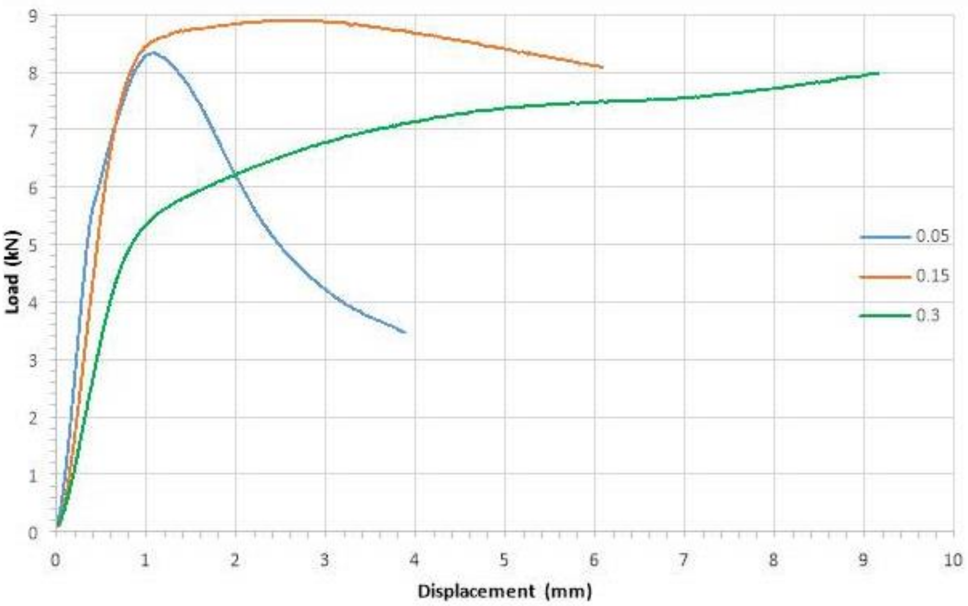

Figure 4. Strength-stain diagram for tested samples

A stronger impact on the resilience of FDM structures seems to be exerted by layer bonding. In both compression and tensile loading, the elastic yield strength of the layer rises as the layer height increases. If you increase the print speed, you will lower the elastic yield strength and ultimate strength under compression and tensile loading, respectively. By altering the layer height and print speed parameters of FDM constructions, it is possible to reduce the time it takes to create the structure while maintaining its strength.

6. Conclusion

Layer thicknesses of 0.05 mm and 0.15 mm have similar elastic properties, while layer thickness of 0.15 mm can continue to take additional load after initial plastic deformation. In addition, the sample with the layer thickness of 0.05 mm do not behave perfectly plastic but reach an ultimate yield strength quickly before rapidly decreasing in strength. The elastic zone load capacity of 0.30 mm layer thickness is much lower, but the plastic zone load capacity is significantly higher, and the layer thickness do not reach their maximum strength until a large degree of deformation has occurred.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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