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SURFACE ROUGHNESS EFFECT ON THE 3D PRINTED BUTT JOINTS STRENGTH

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Abstract: Three-dimensional printing or 3D printing (also called additive manufacturing) is any of various processes used to make a three-dimensional object. Fused deposition modelling (FDM) is an additive manufacturing technology commonly used for modelling, prototyping, and production applications. It is one of the techniques used for 3D printing. FDM is somewhat restricted in the size and the variation of shapes that may be fabricated. For parts too large to fit on a single build, for faster job builds with less support material, or for parts with finer features, sectioning and bonding FDM parts is a great solution. The strength of adhesive bonded FDM parts is affected by the surface roughness. In this study, the layer thickness effect on bonding strength is experimentally studied and the results are discussed.

Keywords: 3D printing; surface roughness; pla; bonding strength

1. INTRODUCTION

Additive manufacturing (AM) is a manufacturing process that uses computer aided design (CAD) tools to build a solid model by adding material in a layer by layer method. Earlier, AM technologies were mostly helping prototyping purposes. With increasing developments, focused on mechanical properties, machine speed, and surface finish, AM processes have allowed the manufacturing of rapid tooling parts, bone scaffolds, metallic structures, complex foam like structures, and many more [1, 2]. According to ASTM standard F2792, there are 7 AM process categories, 1) binder jetting, 2) directed energy deposition, 3) material extrusion, 4) material jetting, 5) powder bed fusion, 6) sheet lamination, and 7) vat photo-polymerization. FDM is a material extrusion based AM method [3]. FDM is a relatively new technology, dating back to 1990s. Thenceforth, the development of FDM machine has passed different processing parameter modifications, investigated by many researchers, which mainly focused on mechanical properties.

Masood et al. [4] investigated on polycarbonate (PC) FDM fabricated specimens and found a tensile strength of about 75 % when compared with moulded and extruded PC parts. Ahn et al. [5] worked on a similar experiment using acrylonitrile butadiene styrene (ABS) and found an increase in ultimate tensile strength (UTS), about 8 %, due to the change of build platform raster angle (RA) from 45°/-45° to 90 °/0 ° using raster widths (RW) of 0.508 mm and 1 mm, respectively. An increased build time and improved surface quality was addressed as well. Montero et al. [6] found UTS of axially build (0°) specimens was increased about 200 %, compared to transversely build (90 °) specimen. Bellini and Guceri [7] investigated on specimens built with ABS for mechanical properties of XYZ, XZY, and ZXY build orientations. The highest ultimate tensile strength of 15.99 MPa, and elastic modulus of 1653 MPa was found for specimens build in XZY orientation. On the other hand, ZXY orientation built specimens showed the lowest UTS of 7.60 MPa and elastic modulus of 1391 MPa.

These studies showed the difference of the results using different building parameters. Researches have shown that FDM manufactured parts fall behind in UTS compared to that an injection moulded part can withstand. A method to increase the mechanical properties of a FDM manufactured part can be useful from the point of view of engineering applications that require specific performance criteria.

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Currently, several options for extrusion based FDM machines exist. Different processing parameters (e.g., build orientation, RA, RW, layer thickness, and more) are available on each of these machines. The processing parameters can be a key factor in the improvement of FDM system, particularly concentrating on mechanical properties. FDM systems may be capable of fabricating parts with improved mechanical properties using suitable building parameters. As a result, FDM systems will be able to compete with conventional injection moulding processes, when comparing mechanical properties, surface finish, and so on.

FDM is reasonably limited in the size and the shape that may be manufactured. For parts with less support material, too large to fit on a single build, for faster job builds, or for parts with finer features, sectioning and bonding FDM parts is a considerable solution. The adhesively bonding strength of FDM parts is affected by the surface roughness. The surface roughness and the bonding strength relation were explained by adhesion theory, notch effect due to the surface roughness and surface area. Lee et al. [8] have carried out fatigue experiments on adhesive bonded cylindrical joints. They determined a rapid decrease in the fatigue strength values over R_a=2.5 µm. Shaid and Hashim [9] reported that rough surfaced steel specimen's normal tensile stresses were lower than polished ones.

According to our literature review, there is not any scientific study showed a perfect relationship between layer thickness and adhesively bonding strength of FDM components. The object of this primary study is to explain the effect of the surface roughness on the bonding strength of FDM components under static loading.

2. MATERIALS AND METHODS

2.1 Thermoplastic Material: PLA

Polylactic acid or polylactide (PLA, Poly) is a commonly used material in FDM systems. PLA is biodegradable thermoplastic aliphatic polyester derived from renewable resources, such as corn starch or sugarcane. Being an amorphous polymer makes PLA an excellent choice for FDM systems. PLA contains the carbonate group in its chemical structure (Figure 1). Its strong mechanical property and higher glass transition temperature makes PLA fabricated parts usable in various applications.

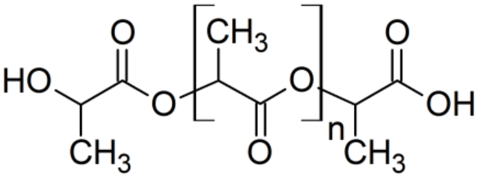


Figure 1. Chemical structure of PLA.

2.2 Preparation and Testing of Specimens

The tensile test specimens were manufactured using the RapMan 3.2. The machine has a build chamber of 270 mm×205 mm×210 mm. The x and y axis's dimensional accuracy is of either ±1 % of object dimension or ±0.2 mm whichever is greater. The z axis's dimensional accuracy is ± half the processed z resolution. The specimens were built using PLA and manufacturing temperatures were 190 °C. The XYZ build orientation was considered. The specimens were 3D-printed according to the ASTM D2094 bar-type specimen (12.7 mm×12.7 mm×38.1 mm). Three different layer thicknesses (125 µm, 250 µm and 500 µm) investigated as building parameters to manufacturing specimens.

The different surface roughness value has been obtained using different layer thickness parameter. The manufactured specimens surface roughness values have been measured using a profilometer. The specimens were cleaned with general purpose cleaner, Loctite 7061. After the cleaning, Loctite 9464 adhesive was applied on the manufactured specimens' surface and the specimens have been bonded. Then these bonded specimens have been left for curing at least 24 h at the room temperature. Loctite 9464 is a toughened two component epoxy adhesive suitable for multi-purpose applications requiring a long open time and high bonding strength. Loctite 9464 is ideal for a wide variety of substrates such as metals, ceramics and most plastics.

Tensile testing was performed according to ASTM D2094 standard using an Instron 8801 tensile testing machine. The tensile test was performed using a load cell of 5 kN which was sufficient for testing the low strength components. The prescribed force speed was 300 N/min during the tensile testing according to standard. The displacement between grips was measured during testing to calculate the elongation. The tensile properties (e.g., Ultimate Tensile Strength, elastic modulus, and tensile strain) were calculated by the Bluehill built-in software. At least three specimens were tested for every set of parameters.

3. RESULTS AND DISCUSSION

The manufacturing time may vary with the FDM machines, and processing parameters such as, layer thickness may vary build time significantly depending on the model dimensions. The effect of layer thickness can also be seen as it may preferably show good resolution or surface finish after manufacturing process but it will surely consume significant amount of time as more layers has to be built. Figure 2 shows the manufacturing times for three layer thickness. The average value of manufacturing times obtained were about 267 min for 125 μm layer thickness, 107 min for 250 μm layer thickness and 43 min for 500 μm layer thickness.

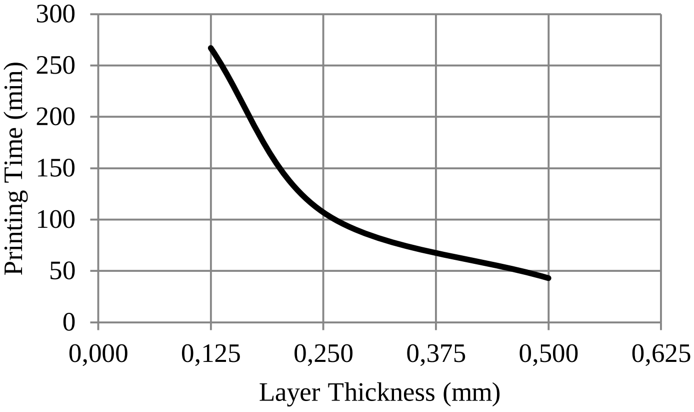


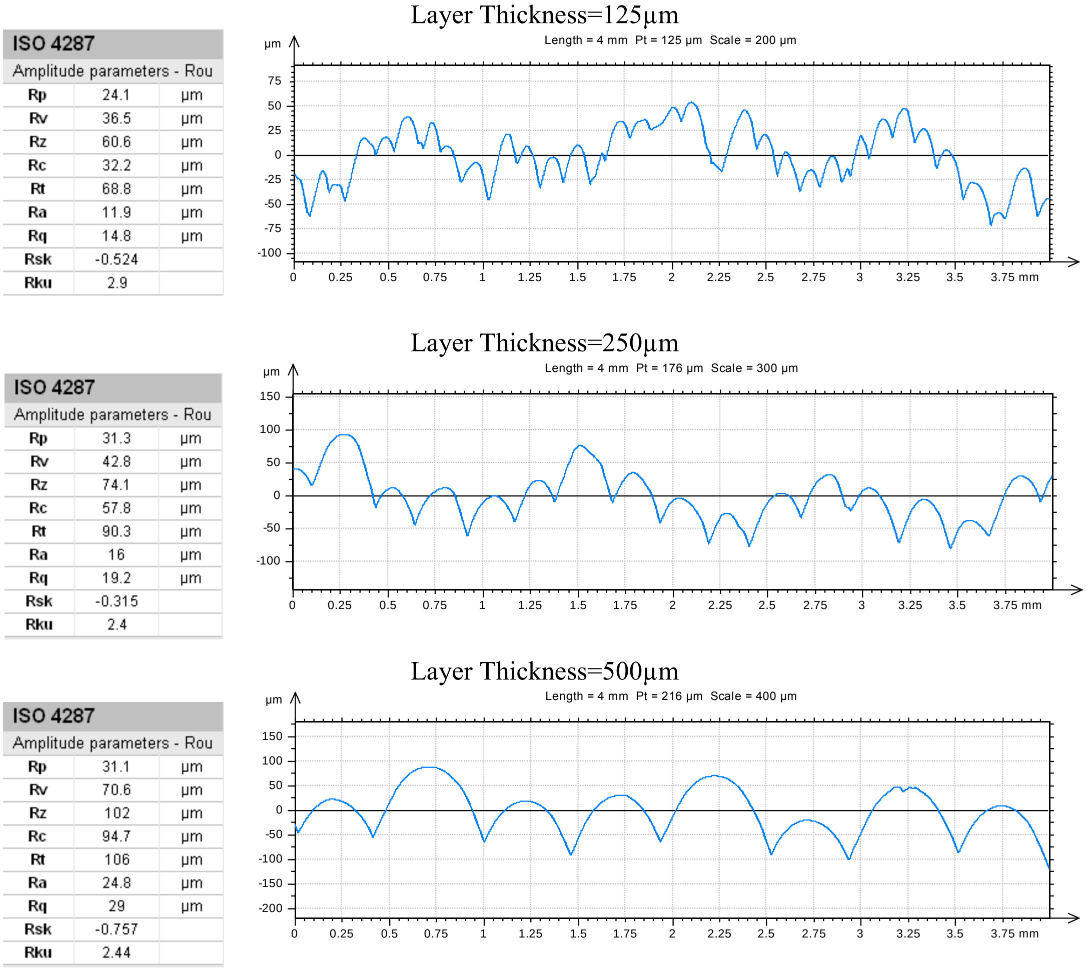
Figure 2. 3D printed specimens' manufacturing times for different layer thickness.

The optical views for the different layer thickness are shown in Figure 3. The gaps between rasters, and contour are more visible using 500 μm layer thickness. The gaps between rasters, and contour were minimized using the 125 μm layer thickness. In this orientation, the FDM tip had to cover less geometric area, which created more congested rasters. This ultimately showed little to no gap in between rasters.

Layer Thickness=125 μm Layer Thickness=250 μm Layer Thickness=500 μm

Figure 3. Optical images of specimens build in XYZ orientation with different layer thickness.

The manufactured specimens surface roughness values have been measured using a profilometer. Measured surface roughness values have been given in Figure 4. The apparatus is capable of measuring values such as R_p, R_v, R_z, R_c, R_t, R_a, R_q, R_{sk}, R_{ku}. As shown in Figure 4, obtained R_a values were 11.9 μm for 125 μm layer thickness, 16 μm for 250 μm layer thickness and 24.8 μm for 500 μm layer thickness.



ISO 4287		
Amplitude parameters - Rou		
Rp	24.1	µm
Rv	36.5	µm
Rz	60.6	µm
Rc	32.2	µm
Rt	68.8	µm
Ra	11.9	µm
Rq	14.8	µm
Rsk	-0.524	
Rku	2.9	

ISO 4287		
Amplitude parameters - Rou		
Rp	31.3	µm
Rv	42.8	µm
Rz	74.1	µm
Rc	57.8	µm
Rt	90.3	µm
Ra	16	µm
Rq	19.2	µm
Rsk	-0.315	
Rku	2.4	

ISO 4287		
Amplitude parameters - Rou		
Rp	31.1	µm
Rv	70.6	µm
Rz	102	µm
Rc	94.7	µm
Rt	106	µm
Ra	24.8	µm
Rq	29	µm
Rsk	-0.757	
Rku	2.44	

Figure 4. Measured surface roughness values of manufactured specimens.

The characteristic stress-strain curves, using the results mentioned above, are shown in Figure 5. The graph is plotted using the average value obtained for three layer thicknesses (125 µm, 250 µm and 500 µm). The graph shows the result for elastic modulus, as there was not much difference observed using different layer thicknesses. The graph illustrates the benefits of performing parameter modification in contrast with manufacturing time.

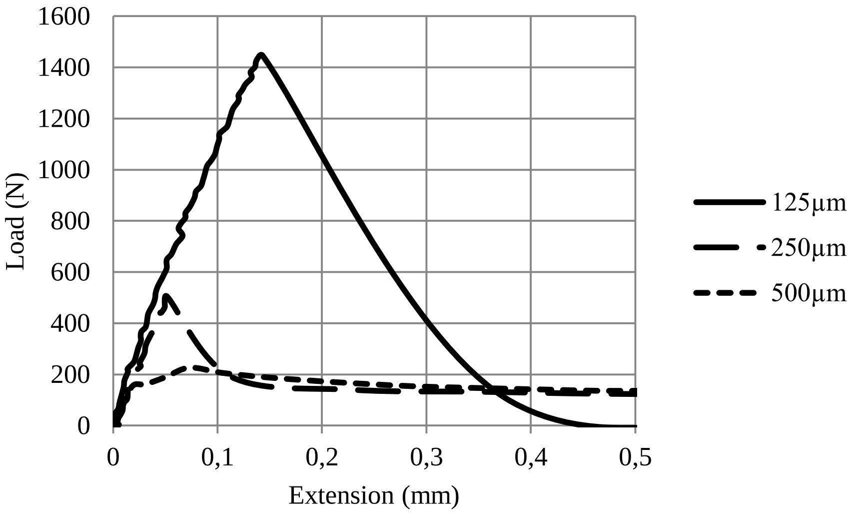


Figure 5. Characteristic load-extension curves for three layer thickness.

The maximum adhesive bonding loads are shown in Figure 6 for the XYZ build orientations and 3 different layer thicknesses. The highest increase in maximum adhesive bonding loads was obtained using the 125 μm layer thickness, compared to the loads obtained from other parameters. The highest percent increase obtained in maximum load was 640 % (226 N to 1446 N), in comparison to the results obtained using 500 μm layer thickness, for XYZ build orientation.

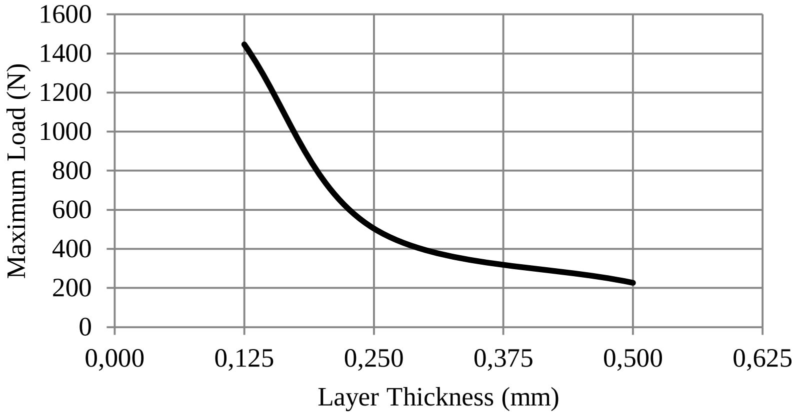


Figure 6. Maximum adhesive bonding loads for different layer thicknesses values.

4. CONCLUSIONS

It was found that layer thickness can play a vital role in improving adhesive bonding properties of FDM produced parts. The optical image analysis led to the realization that the gap between rasters can have a detrimental effect on bonding properties. The removal of those gaps actually led to the improvement of the bonding properties. Among three layer thickness, 125 μm showed higher adhesive bonding load in comparison to the other two. The lowest value of R_a was deposited when 125 μm layer thickness was obtained in compare to the other two layer thickness. This might be the reason of improvement in achieving higher adhesive bonding loads. This fact has to be considered when adhesive bonding of FDM fabricated parts for engineering applications.

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