Abstract: Three-dimensional (3D) printing technologies are the most promising method in the production of functional parts. Although 3D printing technology includes various methods, fused deposition modelling (FDM) is the most widely used one. In FDM, generally polylactic acid (PLA) filaments are used to fabricate 3D geometry by stacking individual layers. In fact, FDM is a complicated process with numerous parameters that affect printing quality. Printing parameters such as printing orientation, layer thickness, printing orientation angle, filling ratio, filament feed rate, etc. have significant impact on the quality and performance of FDM printed parts. Since the mechanical properties are very important for functional parts, the effect of these parameters on the mechanical properties of the PLA specimens has been extensively studied. However, there is no sufficient data in the surface characterization literature of these parameters. In this study, the effect of layer thickness and printing temperature on the surface properties of PLA specimens printed using FDM was investigated.

Keywords: PLA, FDM, 3D PRINTING, SURFACE CHARACTERISTIC

1. Introduction

Surface roughness or roughness is a surface component that can be measured with deviations in the normal direction of an actual surface. If these deviations are large, the surface is rough; if it is small, the surface is characterized as smooth. Roughness determines the performance of the part because it plays a significant role in determining how the parts interact with the environment. Another important issue is that the roughness on the surface forms the starting regions for the cracks.

In terms of the surfaces of the engineering materials, roughness is thought to be detrimental to the performance of the part. In tribology, rough surfaces commonly have higher friction coefficients than smooth surfaces and wear faster. For this reason, the surface structure is closely related to the friction and wear properties of the surface. Adjusting the roughness values during manufacture can be difficult and expensive. Thus, manufacturing at roughly controllable level may be desirable. For example, a glossy surface may come shiny and be slippery to the finger (TouchPad). For this reason, a controlled roughness is required. Otherwise, controlled roughness may be required. For instance, the controlled roughness has the effect of improving the adhesion strength.

Kovan et al. pointed out that the strength of the adhesive bond connection between the 3D printed parts is affected by the surface roughness. It has been determined that layer thickness and printing orientation in 3D printed parts have significant effects on adhesion strength. In the case of low layer thicknesses, the layer produced on the side edge has the highest adhesive strength, whereas in the high layer thickness, the horizontal layer has the highest adhesive strength [1]. Another example is the cylinder bore where the minimum roughness is required so that the oil can be held on the surface.

Three-dimensional printing is a production method that uses only digital technology to produce pieces, as opposed to machining methods such as turning, milling, drilling, etc., in which the material is cut out. Although the focus of 3D printing technologies has been developed primarily for prototype purposes, it has become possible to fabricate metallic structures, artificial bones and a much wider variety of functional parts, with increased emphasis on mechanical properties [2, 3]. PLA is the most widely used material and Fused Deposition Modelling (FDM) is the most widely used technology in this production method which is also called additive manufacturing. FDM has many advantages, such as the use of cheap materials, the lack of expensive equipment, and the ability to create complex geometry. However, FDM has limitations, such as roughness on the surfaces. Methods that will remove these constraints and achieve better surface quality have been studied by many researchers.

Ko and Lee designed a 5-axis machine tool that can make the final cut to improve the low surface quality caused by the 3d printing method. Thus, it has been verified that the surface roughness of the manufactured work pieces can be improved by the final cut [4].

Griguras and Kramar examined the hybrid production process of 3D printing and milling. To enhance the surface quality of the part, the outer surface of the parts produced by 3D printing is milled. Optimization of the technological parameters of hybrid production is made according to minimum production time, minimum surface roughness and minimum material usage. By using a larger nozzle size, the production time is shortened and obtained the same surface quality. [5].

Dewey and Ulutan researched the use of CO₂ laser polishing as an adjunct post-treatment to FDM-produced PLA parts to improve the surface features of the products. In their study, instead of reducing the layer thickness in 3D printing, the total processing time could be reduced without sacrificing surface quality. In addition, larger layer thicknesses and lasers have shown that the surface could be processed rapidly [6].

Maidin et al. have tried to improve the surface characteristics of the FDM specimen by applying ultrasonic vibration in their work. As a result of the study, it was found that the best surface quality was obtained with a 21 kHz frequency applied during FDM production [7].

These hybrid processes, which combine machining, laser and ultrasonic processes with FDM processes, result in better surface quality. However, in all of these methods, machinery and production costs significantly increase. For this reason, the effect of the printing parameters on the surface properties of the different printing parameters has been investigated by many researchers, as it is known that the printing parameters affect the surface properties of the 3D printed parts.

Chaïdas et al. searched the surface roughness of PLA models fabricated by 3D printing technique. It is found that surface roughness decreased with increasing material melting temperature [8].

In You’s study, aimed to optimize the printing parameters of the PLA material used in the 3D printer. In the study, the printing temperature, printing speed and infill ratio were examined at 195-215 °C, 10-70 mm/s and 10-100%, respectively. It was reported that the print quality is the same at almost every printing temperature. In addition, it was determined that the surface roughness is directly proportional to the printing speed and inversely proportional to the infill ratio. [9].
Buj-Corral et al. produced implants with a 3D printer using PLA, a biocompatible polymer, for both prosthetic and support applications. In their studies examining the effect of implant supports and pressure variables, it was stated that the support structure is the main parameter affecting the roughness parameters of the solubility. In order to obtain low roughness values, it is recommended to select a high support structure [10].

Ramli et al. investigated the surface roughness and accuracy of open-source 3D printers, named Mendel Max and Kossel Mini. Spherical, cubical and cylindrical models were produced from PLA and ABS materials using different layer thicknesses and filling ratios on both machines. As a result, when the surface qualities of the models obtained in both machines were compared, it was determined that the surface quality of PLA is better than ABS. In addition, it was reported that the surface properties were better when the layer thickness was 0.178 and the infill ratio was 20% [11].

Valerga et al. stated that 3D printing has some limiting characteristics, and that one of them has a surface quality of the product. In their work, they examined two important production parameters, the effect of printing speed and the extrusion temperature on the surface quality. As a result of this study, it was found that the increment in extrusion temperature of PLA leads to poor surface quality, but the increasing in printing speed improves the surface features [12].

Altan et al. researched the effects of 3D printing parameters on surface roughness and tensile strength. PLA samples are manufactured at different layer thicknesses, printing temperatures and printing speeds. It has been found that the most effective parameters affecting surface roughness are layer thickness and print speed. As the layer thickness decreases, lower surface roughness values are obtained [13].

Hafsa et al. carried out the dimensional accuracy and surface roughness of precision casting models of ABS and PLA produced by 3D printers with different layer thicknesses. The results show that the surface quality of the ABS model produced by reducing the layer thickness is better than the other models. In addition, it has been reported that PLA models give a greater cast model product and the surface quality enhances with increasing layer thickness [14].

These studies exhibit the difference in the outcomes attained by using various printing parameters. The investigations reveal that the surface properties of FDM-fabricated parts are inferior to those of injection moulded parts. 3D printing parameters that will enhance the surface qualities of FDM-manufactured parts is expected to be very useful in engineering applications.

According to our literature research, there is no scientific study which shows the relationship between the printing parameters of the parts produced by FDM and the surface roughness, taking into account the printing layer thickness and extrusion temperature. In this work, PLA samples were manufactured using fused deposition technique (FDM). The influence of the extruder temperature and the layer thickness on the surface roughness were investigated depending on the printing orientation.

2. Material and Methods

In the FDM production technique, the most commonly used filament material is PLA, which is a biopolymer. Environmentally and user-friendly, this material is derived from organic materials such as corn, sugar. These properties, as well as their mechanical properties, make it widely preferred in FDM systems.

In this work, surface roughness measurement specimens were manufactured using a Zmorph printer with PLA material of 1.75 mm diameter produced by Frosch. The 3D printer is capable of producing a model with dimensions of 250x235x165 mm with a positioning accuracy of 14 μm for X and Y axes and 0,625 μm for Z axis.

Three different layer thicknesses (0.1 mm, 0.2 mm and 0.4 mm) and three different printing temperatures (190 °C, 210 °C and 230 °C) were used in the production of test samples. With specially prepared 3D printing codes, for all samples; 3 shells were used around the sample and on the upper and lower surface, and the inside of the sample was printed using the specified printing angles (-45°/+45°) and 35% infill ratio. The PLA material was extruded at a speed of 60 mm/s onto a 65 °C heated printing bed. In Figure 1, different printing orientations are shown according to ASTM F2921 terminology. In this study, all samples were manufactured in the same printing orientation (upright position). However, investigating the effect of other printing orientations (flatwise and edgewise) on surface roughness will be extremely useful for engineering applications.

In surface roughness measurements, a profilometer (MahrSurf PS-10, MAHR) was used. Measured parameters for surface roughness evaluation included Ra, Rz and RSm. The measurement results were displayed on an LCD screen and recorded on the computer.

3. Results and Discussion

Production time with 3D printer differs according to FDM machines and printing parameters such as layer thickness. Also, depending on the size of printed part, the printing time varies considerably. The effect of the layer thickness can be seen as great
surface feature and resolution after the printing process, but a significant increment in the manufacturing time is observed by decreasing layer thickness. The mean values of the production time of the test samples in this study are 70 min for a layer thickness of 0.1 mm, 40 min for a layer thickness of 0.2 mm and 23 min for a layer thickness of 0.4 mm. Despite the decreasing layer thickness with notable rising in printing time, the changing of printing temperature does not cause a considerable variation in the required printing time.

Optical images of specimens with different layer thickness for 210 °C are shown Figure 3. For the optical results of samples with different layer thicknesses, the peripheral prints are more visible and distinctive at a layer thickness of 0.4 mm. The gaps between the scan and the surrounding prints appear to be the smallest when 0.1 mm layer thickness is used. At 0.1 mm layer, the extruder of the FDM creates a more compact scan because it covers less geometric area. Hence, very small gaps occur between the scans or no gaps occur.

Fig. 3. Optical images of specimens with different layer thickness for 210 °C

The surface roughness of the samples with different layer thicknesses printed in the upright printing direction is exhibited in Figure 4. As can be seen, in the layer thickness of 0.1 mm, there is almost no effect on the surface roughness of the printing temperature. With increasing layer thickness, the surface roughness values build up at all printing temperatures. In addition, the lowest surface roughness value at a layer thickness of 0.4 mm is obtained at a printing temperature 210 °C. The highest surface roughness values at both 0.2 mm and 0.4 mm layer thicknesses are obtained from samples printed at 230 °C.

Fig. 4. Surface roughness for different layer thickness

Figure 5 presents the surface roughness of samples with different printing temperatures printed in the upright printing orientation. Similar to Figure 4, the effect of the printing temperatures on the surface roughness at all layer thicknesses is quite low. With increasing layer thickness, the surface roughness values rise at all printing temperatures. The best surface quality was acquired at a 210 °C printing temperature and a layer thickness of 0.2 mm. The worst surface properties were obtained from samples having 0.2 mm and 0.4 mm layer thicknesses and which were printed at 230 °C extrusion temperature.

Fig. 5. Surface roughness for different printing temperatures

The surface profiles of samples with a 210 °C printing temperature with different layer thicknesses are illustrated in Figure 6. As can clearly be seen, there are significant differences between the surface roughness profiles and values obtained with varying layer thicknesses. The effect of the layer thickness can be clearly understood from the behaviour of the surface profile.

Fig. 6. Surface profiles for different layer thickness at 210 °C
4. Conclusions

The effect of the surface roughness on layer thickness and printing temperature of PLA samples fabricated with FDM was studied. The results showed that the printing parameters have a very important role in surface roughness. Increasing layer thickness at printing temperatures in upright printing direction increases surface roughness values. Between printing temperatures, a lower printing temperature gives a better surface quality.

The application of various printing parameters for different materials will contribute to the development of engineering designs. In this way, the surface characteristics of the parts produced by 3D printers will be better understood.

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6. References


