

A REVIEW STUDY ON THE EFFECT OF PRINTING PARAMETERS OF FUSED DEPOSITION MODELLING (FDM) METAL POLYMER COMPOSITE PARTS ON MECHANICAL PROPERTIES AND SURFACE ROUGHNESS

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Abstract. Fused deposition modelling (FDM) is a three-dimensional (3D) printing method under the additive manufacturing process. The process of FDM runs by depositing a melted filament which is a built material, layer by layer on a printing bed. This paper intends to sum up the latest research findings in recent years on the effects of printing parameters on the mechanical properties and surface roughness of 3D-printed metal polymer parts via FDM based on reported literature. Recently, various types of materials have been made and used as build materials that have their functions and properties. Metal polymer composite is considered as a new type of material for FDM which offers a wide range of applications in the manufacturing industry. The use of metal composite in FDM has been challenging due to several shortcomings in terms of mechanical properties and surface roughness of the printed part. Due to the anisotropic feature of an FDM printed part, the mechanical properties of the specimen are affected such as tensile strength and flexural while different types of materials are used to give different surface finishes on the printed part. Additionally, the mechanical properties and the surface roughness are also influenced by the printing parameters where the manipulation or adjustment on these parameters will give different results on these two properties. The layer thickness, infill density, raster angle, and printing temperature are among the printing parameters that can be altered. The use of optimal printing parameters for the metal composite can produce high-quality products and be able to contribute to developments in the manufacturing industry in the future. Therefore, a review study on the effect of printing parameters of FDM metal polymer composite parts on the mechanical properties and surface roughness was carried out.

Keywords: fused deposition modeling, tensile test, optimal printing parameters,

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Introduction

The manufacturing process can be divided into three categories which are subtractive, formative, and additive. The additive manufacturing (AM) process is considered relatively new compared to the other two manufacturing techniques. AM, as opposed to subtractive manufacturing approaches, is defined by the American Society for Testing and Materials (ASTM) as a process of generating items from 3D model data by fusing materials layer by layer [1]. With the availability of a 3D design model, any type of product regardless of its shape and complexity can be produced with this method. AM, also known as rapid prototyping and 3D printing has three processing approaches which are liquid-based, solid-based and powder-based methods. The widely known examples of the process for these three categories are stereolithography (SLA), fused deposition modelling (FDM), and selective laser sintering (SLS) respectively [2-3].

Advances in AM technology today begin as the result of continuous efforts made since half a century ago. Solid-modeling technology was introduced to the market in the 1980s. Since then, various studies and innovations have been done to improve this manufacturing technology. Dr. Kodama, a Japanese scientist, pioneered rapid prototyping in 1980. In 1986, Charles Hull invented SLA. The FDM, on the other hand, was created by Stratasys in 1992. SLS and SLM were then developed for metal printing [4-6]. Table 1 shows the temporal evolution of additive manufacturing.

Table 1. The temporal evolution of additive manufacturing [5].

Year	Additive Manufacturing Machine Developments
1980	Dr. Kodama from Japan filed a patent for a rapid prototyping device
1986	Charles Hull developed stereolithography
1988	DTM's first SLS machine
1992	Stratasys received the FDM patent
1995	The MIT granted Z Corporation an exclusive license
1999	Engineered organs have ushered in a new era in medicine
2000	MCP Technologies developed the SLM technology, which allows for the creation of a 3D printed working kidney
2005	Spectrum Z510, a colour 3D printer from Z Corporation, was introduced to the market
2006	The start of an open-sourced project (Rep Rap)
2008	The world's first three-dimensionally printed prosthetic leg
2010	Urbee is the world's first 3D-printed prototype vehicle
2011	Cornell University started working on a 3D printer for food
2012	The first printed and implanted prosthetic jaw was successfully fabricated
2015	The revolutionary CLIP 3D printing machine and carbon 3D issues

Looking at the various types and categories of 3D printing available today, FDM is one of the most extensively used 3D printing technologies in comparison to other dimensional printing technologies. FDM is projected to be a long-term modern manufacturing platform for functional and structural items, as well as for industrial and home use [7-8]. Several factors such as printing speed, printing temperature, infill percentage, layer thickness, raster angle, infill pattern significantly affect the mechanical properties and surface roughness of 3D printed materials using FDM [9-10]. By understanding and studying the

mechanisms, advantages, disadvantages as well as the right way of handling the FDM technology, this process can be fully utilized to produce products for various applications. As a result, the goal of this work is to evaluate and summarize the impact of printing settings on the mechanical characteristics and surface roughness of FDM metal polymer composite components. In this paper, the review work was carried out by comparing various reported work in the recent 10 years to distinguish the characteristics of printed metal polymer composites from the printed commercial polymers. The review in this article is carried out by studying the overview on the FDM process, limitations of FDM, common material of FDM, metal polymer composite, and application of FDM metal polymer composites printed parts. Coverage on these subtopics aids in achieving the objective of the study.

Overview on FDM process. FDM is commonly utilized in the creation of custom-made parts for 3D modelling systems and production applications. The key components of the FDM machine consist of the filament feed mechanism, liquefier chamber, print head, and build platform surface [10]. The use of the FDM method first begins with the process of producing 3D designs through CAD software. The design is then saved as STL file format and subsequently sliced using slicer software. The finished sliced design is then saved as a G-code file and transferred to an FDM machine to start the 3D printing process [11]. During the printing process, the thermoplastic filament which is the build material is fed into an extruder head and heated up to a set temperature. The molten filament is then extruded via an extruder nozzle and placed line-by-line on a printing bed to begin the printing process. The molten filament material then cools and hardens in a short amount of time and adheres to the printing. The printing process is continued for the next layer and this process is repeated until the design of the object has been fully printed [13-14]. Figure 1 shows the basic structure of FDM.

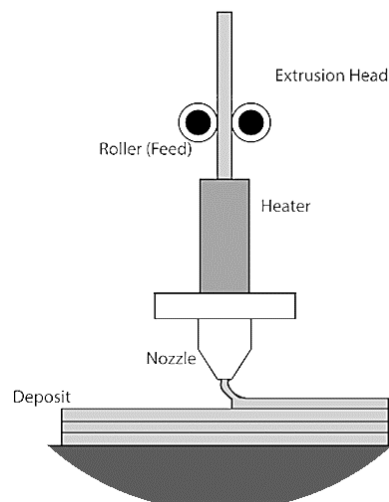


Figure 1. Basic FDM structure.

The use of the FDM method offers various advantages in terms of cost, handling, and flexibility. The key advantages of this technique are that no chemical post-processing is necessary, there are no resins needed to cure the printed part, the machines and materials are less expensive, and the process is cost-effective [3]. Moreover, other advantages can also be seen in terms of ease of implementation, minimal product material, ease of support removal, and the ability to fabricate functional parts making it ideal for a wide range of applications in

various types of industries such as aerospace, automotive, biomedical and tooling [15-16]. Benchmarking study by Venkataraman [16] reveals that in comparison to a standard metal mold fabrication method, FDM exhibited a reduction by 50% in cost and a cutback in lead time from nine weeks to one week.

Limitations of FDM. The advantages of the FDM method as well as its ability to produce various types of products are undeniable. However, there are still some drawbacks or limitations in this method to produce very high-quality products. Among the disadvantages of FDM are the seam line between layers, the need for the support structure, the long build time, and temperature-induced delamination [17]. The printing parameters have a considerable impact on the printing results, and any changes in these parameters might affect the quality of the printed object in terms of surface roughness or mechanical qualities. Figure 2 below shows the common printing parameters for FDM printed parts. Several parameters, such as nozzle and bed temperature, printing speed and orientation, layer deposition height, raster angle, and infill pattern have a significant impact on FDM printed parts [19-20]. Several experimental and theoretical studies have been conducted to analyze the surface roughness and dimensional aspects of FDM parts by various researchers [21-23]. According to the literature, the layer thickness parameter has a significant impact on the surface roughness of a printed item as well as the dimension accuracy [24-25]. The surface finish of the printed part becomes uneven due to the width and thickness deviation caused by the layer thickness [24]. As for the mechanical properties of the printed part, its weakness occurs due to distortion between layers [25]. Printing parameters such as part orientation and raster angle have an impact on mechanical qualities as these variables affect the anisotropic property of the printed part [26].

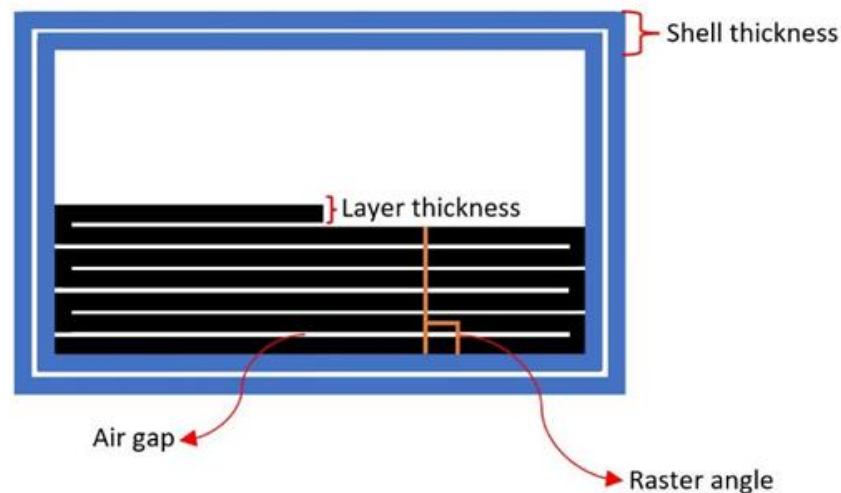


Figure 2. Common printing parameters in FDM

Common material of FDM. Build material is a unique feature in FDM as this method accepts many types of feedstock thermoplastic filament materials for the printing process, which makes this technology excellent for the consumer market. The most often used filaments for FDM machines are polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) [29-30]. The use of PLA is increasing and has received considerable attention as it is a biodegradable green material with excellent biocompatibility and sustainability. Furthermore, it requires less energy and temperature to produce high-quality prototypes and working components [29]. As for ABS, while it is not a biodegradable material, it provides less chance of nozzle clogging compared to PLA and it also has good impact resistance and toughness in terms of its mechanical properties. Apart from PLA and ABS, other types of filaments used for this process are made from polypropylene (PP), polyether imide (PEI), polycarbonate (PC), ceramic, short fiber composite and a metal-polymer composite [30].

Metal polymer composite. Processing metal-polymer composite via FDM method offers synergism in imparting polymeric and metallic properties at the same time. The combined properties of metal-polymer composites can be tailored for specific applications in comparison to the commonly used polymeric materials. Using such materials in additive manufacturing technologies provides additional benefits such as design flexibility, mass customization, lower cost, and shorter time-to-market delivery. The emergence of metal polymer composite as one of the new filament materials has provided better mechanical properties than neat PLA or ABS. The metal-polymer composite printed part is mechanically strong and stiff which leads to higher working life and dimensional stability [31]. Among the examples of metal-polymer composites filaments are copper-PLA, aluminium-PLA, iron-ABS, iron-nylon, aluminum epoxy, and many more [9, 33-34, 36].

Application of FDM metal polymer composites printed parts. Applications of FDM technology can be seen in a variety of industries such as automotive, aerospace, commercial machines, medical, consumer products and architecture [3, 9, 33, 37-38]. For a new type of filament material especially metal-polymer composites, their applicability in 3D printing technology has been proven by the production of several functional parts. The upside of the metal-polymer composites is that the material can be used to fabricate electroconductive polymers, thermally stable plastic, plastic-covered metals, radiation-protected composites, microelectronic devices, rapid tooling and biomedical implantation [33, 39]. A tungsten-polycarbonate composite, for example, might be used to fabricate x-ray radiation shielding structures, while magnetite-loaded ABS could be used to increase the performance of 3D printed motors [38-39]. In rapid tooling application, complex shape inserts has been made from iron nylon for injection moulding process. FDM-produced inserts made from this composite were fabricated at low cycle time and injection pressure in comparison to inserts made by other methods [32]. High-quality inserts can also be achieved by using other approved metal composites such as iron-ABS [33]. A 3D printed metal-polymer soft magnetic composite was manufactured employing stainless steel-ABS in addition to the metal composite application. The blend of mechanical and magnetic properties of the steel and ABS make this composite becomes very useful for magnetic sensing applications [40]. In aerospace and automotive application, metal parts can be produced through the 3D printing method by fabricating casting patterns. This technique has successfully produced a hollow static turbine blade and an engine block [41].

Influence of Process Parameters on the Mechanical Properties of FDM Metal Composite Parts

The mechanical properties of the 3D printed prototypes are essential to ensure that they can also readily be used as functional parts. Without the right printing parameters, a high amount of materials will be wasted, and the overall production cost and time will be increased. Investigating the right parameters to produce products with tailored properties is, therefore, crucial and can save a lot of costs which serve the purpose as a good alternative in fabrication products. Among the types of mechanical properties that were often discussed in various studies are tensile strength, yield strength, compression strength, impact strength, flexural strength, fatigue limit, stiffness, elongation. These research focus on PLA and ABS as experimental materials, which are often used in FDM technology. In these studies, many printing parameters were used as variables such as air gaps, nozzle temperature, printing orientation, infill pattern, number of shells, layer thickness and raster angle [42 – 50].

The characteristics of 3D printed metal polymer composites, on the other hand, have received the least attention in the literature. The research of metal polymer composites focuses on characteristics such as layer thickness, percentage infill, bed temperature, and numerous other parameters, based on the most recent reference sources. As a result, based on the limited recent references, this chapter analyzes significant printing factors that affect the mechanical characteristics of FDM printed metal polymer composite.

Layer thickness. Nabipour [51] conducted an experiment where the four printing settings were changed to see how they affected the tensile strength of copper-ABS printed pieces. Nozzle diameter, raster angle, layer thickness, and nozzle temperature were the four variables that were changed. The printing layers were 0.1 mm, 0.2 mm, and 0.3 mm thick. ANOVA study revealed that changes in layer thickness altered the tensile strength of the printed items. Thinner layer height adds to increased tensile strength owing to stronger adhesion between layers, according to the testing results.

Huu et al. [52] research used various layer thickness, built direction, and raster angles to study their influence on copper-PLA's compressive strength. The variation of the layer heights used was 0.2 mm, 0.25 mm, and 0.3 mm. The changes in the layer thickness for this experiment significantly affected the compressive strength of the printed part as its P-value is less than 0.05. The result is in favor of a thinner layer thickness because as the layer thickness decreases, the number of layers grows which leads to an increase in the bonding between the fibers and hence compressive strength. The findings obtained from the study on these metal polymer composite materials are in line with the study made based on neat PLA [69].

Infill percentage. Moradi et al. [53] have experimented to study the mechanical properties of bronze-PLA where infill percentage was one of the manipulated parameters. The other parameters involved were layer thickness and extruder temperature. Five variations of the infill percentage were used where the set manipulated values of the infill were 15%, 25%, 35%, 45%, and 55%. Tensile test was done on 20 printed specimens and ANOVA analysis was done to conclude the experimental results. The results showed that as the percentage of infill increased, the mechanical characteristics of the samples improved due to an increase in component adhesion. Similar results in mechanical trends were also noted with experiments conducted by Aw et al. [54]. The results of the study made based on this material are in line with the study made based on neat PLA [70].

Aw et al [54], in their research on zinc oxide-ABS, printed parts varied the parameter of infill density at 50% and 100%. The results showed that zinc oxide-ABS printed with 100% infill percentage had the highest specific strength and modulus value, indicating that it is lightweight with a high modulus and strength. Based on this research, it is possible to conclude that the infill percentage has a very particular role in flexibility and tensile strength because increasing the infill percentage resulted in a denser structure with reduced porosity in 3D parts. As a result, samples or specimens produced with a high percentage of infill might withstand a high tensile force even if they lacked flexibility.

Bed temperature. Sneha et al. [55] had experimented using bed temperature, layer thickness, and nozzle temperature as the manipulated variables. The filament used was bronze-PLA where the composition of the bronze was 14%. The variation of the bed temperature was set to 50 °C, 60 °C, and 70 °C. To study the printed parts' mechanical properties, two experiments were conducted which were flexural test and compression test. The results from these two tests concluded that bed temperature had the least impact on the strength of 3D printed samples, whereas the nozzle temperature had the greatest influence on the composite characteristics.

Pavan et al. [56] had also conducted a similar study using the same printing parameters and variable values to study their impact on the flexural property. In this study, the material used was copper-PLA and nine samples were printed according to ASTM D790. The results from the experiment done showed that the layer height had a significant impact on flexural strength, instead of bed temperature and nozzle temperature. From these two references, it can be inferred that the bed temperature parameter has a low significant influence on the mechanical properties of metal-polymer composites compared to layer thickness and nozzle temperature.

Other printing parameters combination. Apart from the works presented above, other research efforts on other combination of printing parameters have also been done. The parameters previously not discussed in the review above and used in other studies are raster angle, infill pattern, flow rate multiplier, and printing direction. The composite materials involved are aluminium-PLA, copper-PLA, and 17-4PH stainless steel composite. Table 2 shows several studies on the 3D printed mechanical properties of metal-polymer composites material. Meanwhile, Figure 3 shows an SEM microscopic image of a metal polymer printed part's cross-section.

Table 2. A compiled study on the effects of process parameter manipulation on the mechanical properties of various metal composite materials.

Source	Material	Parameters	Type of the test	Remarks
[57]	Aluminium-PLA	Raster angle	Tensile test	The maximum tensile strength and dynamic mechanical characteristics were found in specimens printed with a 0° raster angle, while the lowest values were found in specimens produced with a 90° raster angle.
[58]	Copper-PLA	Infill pattern	Flexural	Concentric infill patterns

				contributed to the highest flexural strength by 25.98 MPa.
[59]	17-4 PH Stainless steel composite	Nozzle temperature, flow rate multiplier, and layer thickness	Tensile test	The tensile qualities were most affected by the flow rate multiplier. The layer thickness came in second, followed by extrusion temperature, which had the least impact.
[60]	17-4 PH Stainless steel composite	Printing direction	Tensile Test	Layer direction affected the maximum ultimate strength.
[61]	Copper-PLA	Raster angle	Tensile Test	Maximum tensile strength was obtained at 0° raster angle, while the lowest value of tensile strength was achieved at 90° of raster angle.

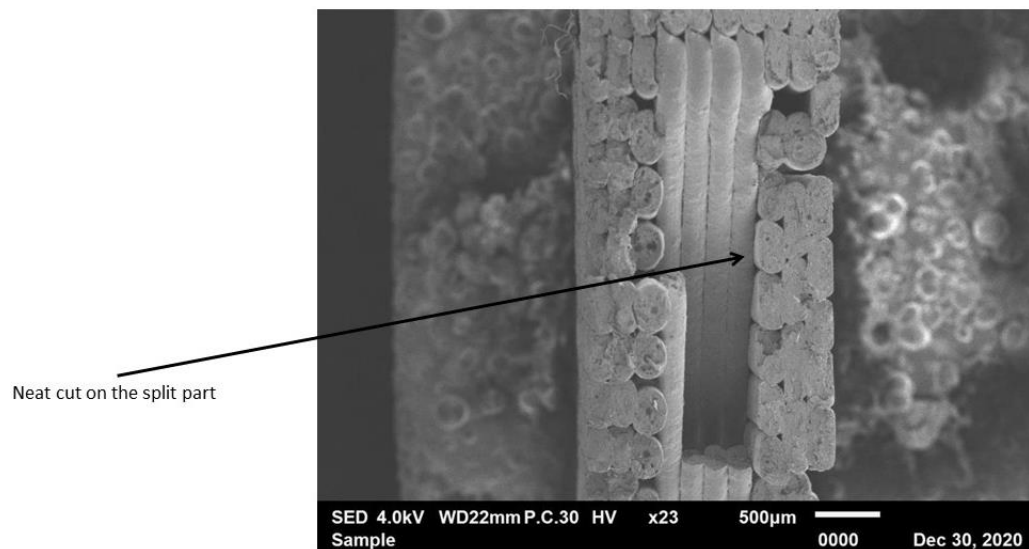


Figure 3. Cross-section of metal polymer composite printed part under SEM microscopy.

Influence of Process Parameters on The Surface Roughness of FDM Metal Polymer Composite Parts

In the 3D printing process, obtaining and maintaining a good surface finish of printed parts is very challenging. Compared to other manufacturing processes, the surface roughness of a prototype part made through this method is excessively rough. However, the cause of this problem has been identified and it is related to the printing parameters [62-63]. As a result, selecting appropriate parameters is essential in order to improve manufacturing solutions.

Unlike the mechanical properties discussed in the previous section, less attention has been given to the surface quality obtained for 3D printed metal polymer composites. To date,

studies involving metal polymer composites and their printed parts' surface roughness are very few. Sukindar et al. [64] had conducted research on the surface roughness of copper-PLA by manipulating five process parameters which were printing speed, extrusion temperature, layer thickness, and raster angle.

Due to few and limited references on the influence of FDM printing parameters on metal composites studies, especially related to surface quality and surface roughness, the following subtopics discusses the influences of layer thickness, raster angle and extrusion temperature on the surface roughness of metal polymer composite printed parts obtained from Sukindar et al's findings. Comparisons of metal polymer composite printed materials with polymer-based materials and other polymer composites are discussed.

Layer thickness. The variation of layer thickness used by Sukindar et al. [64] was 0.1 mm, 0.2 mm, and 0.3 mm. The layer thickness was ranked number 2 based on its P-value in its influence on the surface roughness. Based on the data and result presented, Ra values uniformly increase as the layer thickness increases. This finding is in line with another study which stated that the increase in layer thickness causes two cylindrical-shaped materials having a higher radius to be stacked up one above the other and increases the step-like effect, eventually increasing the surface roughness [65]. The differences between copper-PLA's rough and smooth surface finish due to different layer thickness can be seen clearly in Figure 4 and Figure 5. These findings are in line with studies done by using fiber polymer composites, which are a nylon-aramid composite and also carbon fibre-PLA. The studies' results show that a lower value of layer thickness contributes to a good surface finish [66-67].

Raster angle. Sukindar et al. [64] used variations of raster angle at 45°, 70°, and 90° to evaluate its influence on surface roughness. The results of this study show that a raster angle of 45° contributed to the highest Ra values, while a 90° of raster angle gives the lowest values of Ra. Another study performed using nylon-aramid gives a similar result where a raster angle with an angle of 90° is found to be one of the best optimum parameters to obtain good surface roughness [66]. Based on another study, raster angle gives little effect on the surface quality [68], whereas the results of this surface roughness experiment on copper-PLA gave a slightly different result as the increase in raster angle from 70° to 90° gave a significant change in Ra value. It can be said that these two different results may be coming from the different types of build materials used as ABS was used in the referred study.

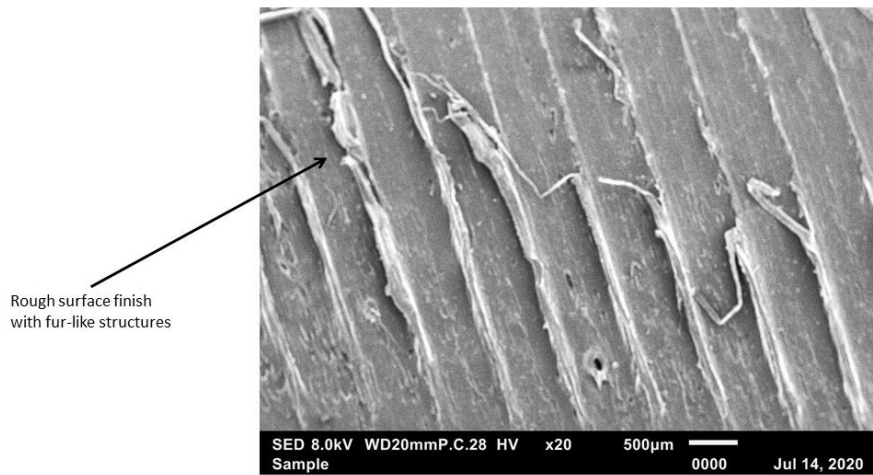


Figure 4. Top view of the printed part with 0.3 mm layer thickness under SEM microscopy [64].

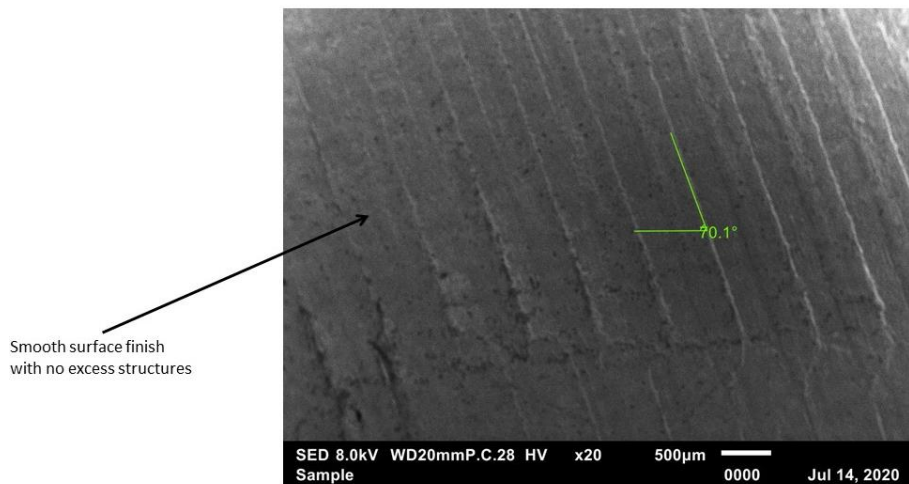


Figure 5. Top view of the printed part with 0.1 mm layer thickness under SEM microscopy [64].

Extrusion temperature. Various extrusion temperatures of 190 °C, 210 °C, and 230 °C were used in Sukindar et al. [64] study. The result obtained showed that when the extrusion temperature increases, the Ra values increases as well. A study done using another composite material manipulated its nozzle temperature to three values. The results showed that the lowest temperature value in the study gave the lowest Ra value [66]. As found in another study, changes in the extrusion temperature are said to cause the melted filament shapes to be slightly different from each other [65]. This condition contributed to a slight change in the Ra values. However, the process parameter of extrusion temperature was ranked number 4 based on its P-value on its influence on the surface roughness. These findings give a general overview that extrusion temperature does affect the surface roughness of PLA material which can be used as a guideline in printing metal composites such as PLA/aluminum and PLA/steel. It is also concluded that optimum printing temperature should be applied for each material to obtain a good surface finish.

Conclusion

This review paper mainly focuses on investigating the effects of various printing parameters on the mechanical properties and surface roughness in printing metal composite material using FDM technique. The layer thickness and infill percentage have the greatest impact on the mechanical characteristics of 3D printed metal polymer composites, whereas the bed temperature has the least impact. However, bed temperature has a critical role to ensure the first printed layer adheres to the bed, especially for materials that tend to warp like ABS material. Based on the previous research, it is essential to identify which factor has a significant effect on the mechanical properties of 3D printed metal composite. Studies have shown that lowering the layer thickness and increasing the infill percentage provided stronger and more rigid 3D printed parts. Surface roughness is another aspect that has been reviewed in this paper. Layer thickness and raster angle are the printing parameters that mainly affect the final parts. To have a smooth surface finish, printing at lower layer thickness and increasing the raster angle provide a lower Ra value. Other factors should also be considered such as extrusion temperature as each material have a different optimum printing temperature. Controlling the right temperature is essential during FDM process. If the temperature is too low, it might clog the nozzle and if the temperature is too high it will affect the overall surface structure of the printed parts. The number of studies related to the influence of printing parameters on 3D printed metal polymer composites is still relatively low. Thus, the influence and correlations of many types of printing parameters have yet to be identified. Only a handful of printing parameters have been reported. It is hoped that in the future, studies related to metal polymer composites and various other printing parameters can be carried out to investigate the influence of printing orientation, infill pattern, the number of shells, air gaps, the surrounding temperature on the mechanical properties, and surface roughness.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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