The Effect of Printing Parameters on the Compression Strength, Electrical Conductivity, and Water Absorption Ability

Rasha Alkabbanie[1] & Sara Serwer[2] & Qusay Awwad[3] & Mohallab Al- Dawood[4]

[1,2, &3]Mechatronics Engineering Department, Faculty of Engineering, Tishk International University, Erbil, Iraq
[4]Mechanical Design Engineering Department, Faculty of Engineering, Damascus University, Damascus, Syria
Correspondence: Rasha Alkabbanie, Tishk International University, Erbil, Iraq.
Email: rasha.alkabbanie@tiu.edu.iq

Doi: 10.23918/eajse.v7i1p122

Abstract: 3d printing technologies are rapidly developing, having a strong impact on almost all areas of industry. The very known technology, the fused filament fabrication, mainly uses PLA to produce many objects used in a wide verity of applications. The aim of the study is to study the effect of the printing parameters such as layer height, feed rate, raster angle, and extrusion temperature on the electrical conductivity, the ultimate compression strength, and the water absorption ability of the printed objects. The results prove that the printing parameters have a significant effect on the mechanical and the electrical characteristics as well as the water absorption ability of the PLA printed samples.

Keywords: 3d Printing, PLA, Electrical Conductivity, Ultimate Compression Strength, Water Absorption, Printing Parameters

1. Introduction

Since it was invented in 1980s, Additive Manufacturing, AM has seen a rapid growth in the number of applications using this technology (AMFG, 2021). Additive manufacturing is highly suitable for aerospace applications since that aerospace objects have complex shapes and are fabricated of advanced materials, and since that aerospace parts are manufactured in relatively small batches (Guo & Leu, 2013). Also, the use of this technology in artistic industry provides new possibilities to obtain more complex designs and geometries (Negi et al., 2013). AM is also utilized to produce complex automated parts (Abdulhameed et al., 2019). It is used in producing prototypes for simulating, training, and pre-surgical planning of complex surgical operations and for fabricating customized implants and medical tools (Sanadhyav et al., 2015).

3d printing is a process of producing 3d objects from a digital file. In this process, the part is fabricated by laying down successive layers of material (Al-Maliki & Al-Maliki, 2015). The main types of 3d printing techniques are: (1) Binding Jetting where a liquid binding jetting agent is selectively deposited to stick the powder particles together (Shahrubudin & Ramlan, 2019). (2) Direct Energy Deposition which utilizes a focused energy source to melt a material deposited by a nozzle (TWI, 2020). (3)

Received: April 15, 2021
Accepted: June 12, 2021
Alkabbanie, R., Sara Serwer, S., Awwad, Q., & Al- Dawood, M. (2021). The Effect of Printing Parameters on the Compression Strength, Electrical Conductivity, and Water Absorption Ability. *Eurasian Journal of Science & Engineering*, 7(1), 122-133.

Material Extrusion which in the filament is fed from a coil through a moving nozzle and is molten, extruded out, and deposited on the growing object (Apium, 2020). (4) Powder Bed Fusion in which a heat source fuses the powder particles layer by layer (3DExperience, 2018). (5) Sheet Lamination which uses a laser beam to cut the sheet then the sheets are joined one after the other by an adhesive material or by being welded to each other's by the laser beam to produce the solid object eventually (Nikhil, 2020).

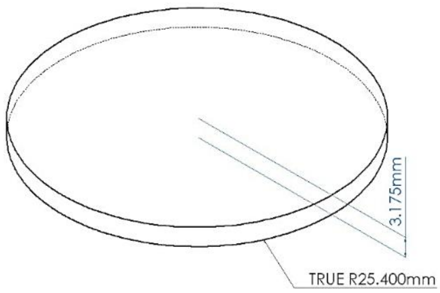
Many research such as (Ouhsti et al., 2020; Leite et al., 2018; Gonabadi et al., 2020) revealed that the properties of the objects produced by additive manufacturing are influenced by several printing parameters. The researchers in (Pentek et al., 2020) found that the printing parameters have a considerable effect on the electrical characteristics of the printed objects. This research shows that the value of the electrical resistance strongly depended on the infill density and the layer height.

To the best of our knowledge, there are very few research studied the influence of the 3d parameters on the electrical conductivity of the printed objects. In the study by (Nadir et al., 2019), researchers found that the water absorption of the samples increased by using thicker printing layers. The research (Fernandes et al., 2018) revealed that increasing the extrusion temperature led to a higher porosity in the printed objects and consequently increased the water absorption ability. In the study (Vicente et al., 2019), results show that using protective coatings based on acrylic and polyurethan varnish caused a significant decrease in water absorption ability. Researchers in (Leite et al., 2018) illustrated that the treatment with acetone solutions were not efficient in decreasing the percentage of water absorption as the amount of acetone. Also, this study showed that the water absorption was reduced by using polyurethane treatment.

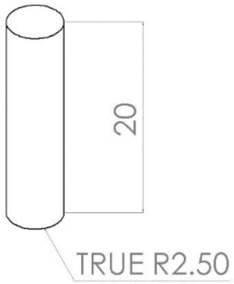
2. Methodology

This research aims at providing a better understanding of the effect of the 3d printing parameters namely, the layer height, the extrusion temperature, the feed rate, and the raster angle on the electrical conductivity, the ultimate compression strength, and the water absorption ability of the printed objects. The following tests were chosen for this study:

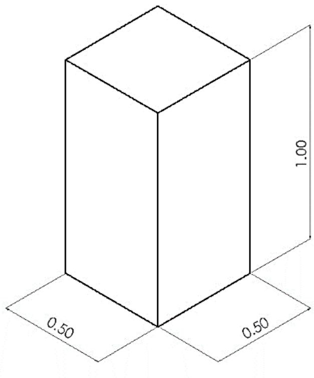
- The Electrical Conductivity Test.
- The Mechanical Compression Test
- The Water Absorption Test.



a: The water absorption test sample



b: The electrical conductivity test sample



c: The compression test sample

Figure 1: The tests samples

2.1 Printing Technique

In this research, the fused filament fabrication technique was used for producing the tests specimen. In this technique, the threads are drawn from a coil and fed through and extrusion nozzle. The material is heated in the nozzle till it melts and extruded onto a base (build platform). Both the platform and the nozzle are controlled by a computer that interpret the dimensions of the object into x,y, and z coordinates which to the nozzle and the platform move accordingly. Figure (2) shows the fused filament fabrication process.

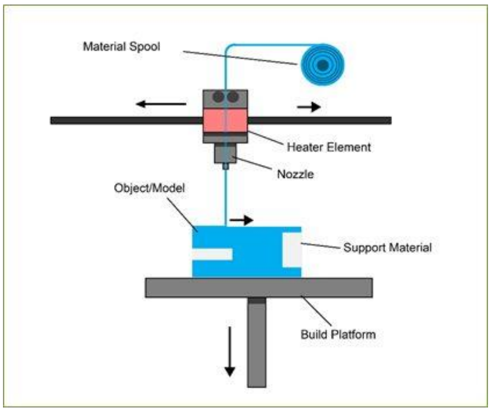


Figure 2: The fused filament fabrication process (UNLIMITED, 2016)

The 3d printer used in this study to 3d print the samples is the "Up Box" 3d printer.

2.2 Material

The material that the samples are made of is PLA. PLA is a biodegradable thermoplastic polymer based on lactic acid. It can be produced from 100% renewable resources. It is used in a large number of applications such as healthcare and medical industry. This material is eco-friendly, biocompatible, and processable (Omnexus, 2020).

2.3 The Experimental Tests

2.3.1 The Electrical Conductivity Test

The electrical conductivity is a physical property that shows how well a material conducts electricity (Robinson, 2018). The standard test of the electrical conductivity is ASTM B 193-87. In this test, the conductivity is calculated by measuring the electrical resistance and dimensions of the sample (TOUCHSTONE, 2016). The electrical resistance is measured by an ohmmeter. Copper plates are attached to the specimen by silver paste and the test voltage is applied to these plates.

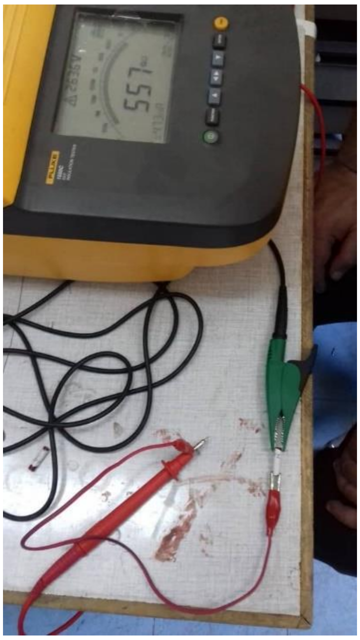


Figure 3: The electric conductivity test

2.3.2 The Water Absorption Test

The test was conducted according to the standard ASTM D570 (OMNEXUS, 2020). Firstly, the samples were dried for a certain period of time at a specific temperature then they were left in the room temperature to cool. Upon cooling, the samples were directly weighted. After this, the samples are placed in water at 23 Celsius degree for 24 hours. Then they were removed from water, dried with a piece of cloth and eventually weighted.

Figure 4: The water absorption test

2.3.3 The Mechanical Compression Test

The compression test was performed in accordance with ASTM D695, and each test being duplicated twice. Compression test can be described as the forces that are pushed inwards on a sample through interaction of materials with them from opposite sides or through a compression or crush. To distribute the load on the entire surface area on the opposite sides of the test sample, the sample was placed between two plates where the load is distributed by pushing the plates together by universal test machine. As a result, the compressed sample is shortened by the force direction applied in the vertical direction.

Figure 5: The compression test

3. Results and Discussion

3.1 The Layer Height and the Electrical Conductivity

It was realized that the higher to layer is the higher is the electric conductivity and this is illustrated in Figure (6).

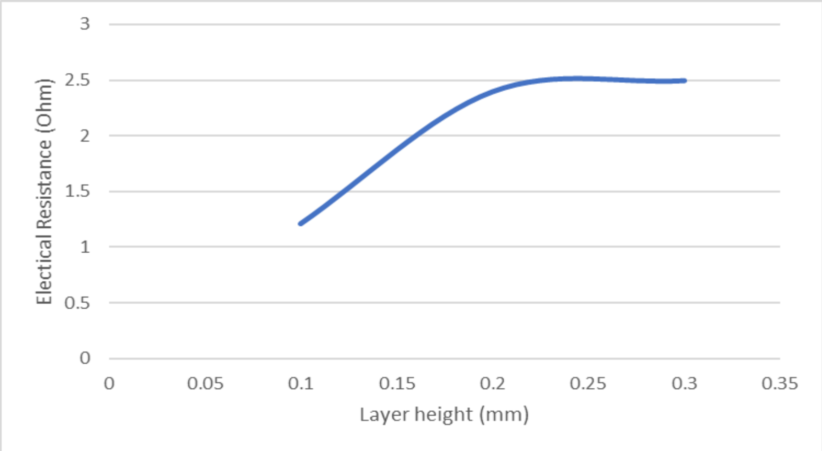


Figure 6: The layer height vs. the electrical resistance

3.2 The Feed Rate and the Electrical Conductivity

It was observed that when increasing the feed rate, the electric conductivity increases, and this shown in Figure (7).

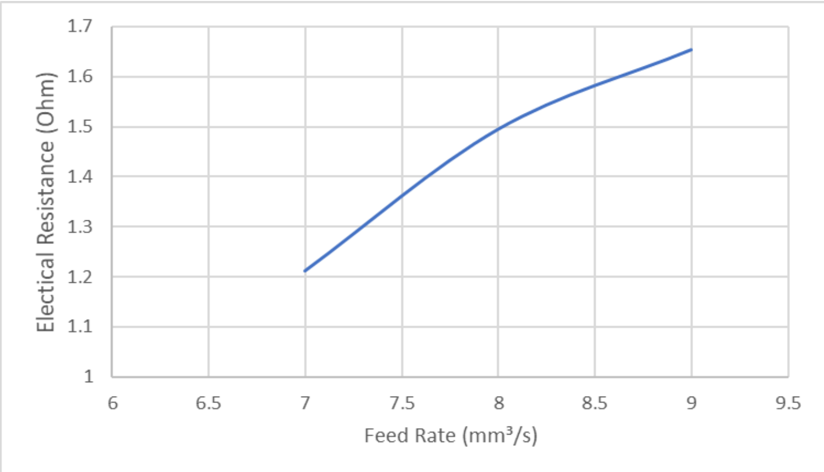


Figure 7: The feed rate vs. the electrical resistance

3.3 The Extrusion Temperature and the Electrical Conductivity

It was realized that the extrusion temperature does not affect the electrical conductivity as shown in Figure (8).

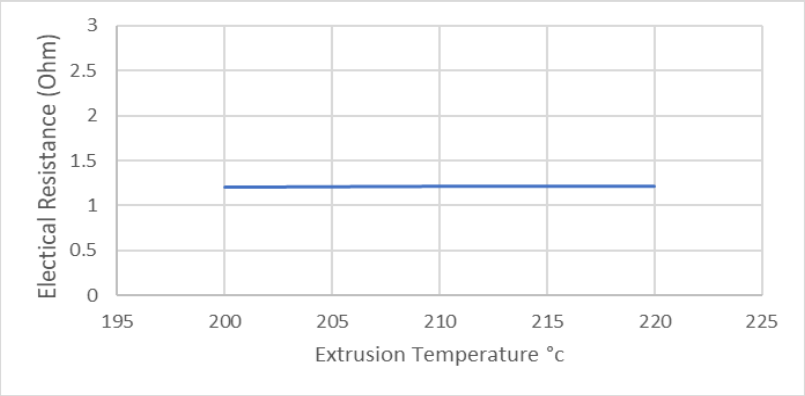


Figure 8: The extrusion temperature vs. the electrical resistance

3.4 The Raster Angle and the Electrical Conductivity

It was observed that when using aa larger raster angle, the electrical conductivity increases, as shown in Figure (9).

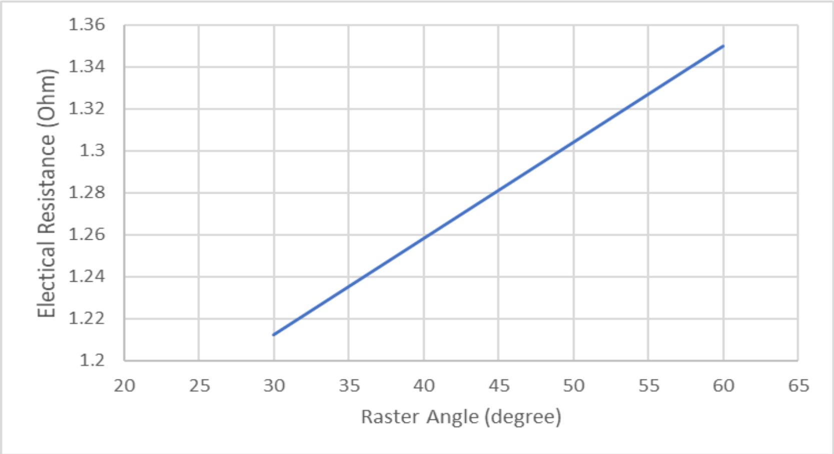


Figure 9: The raster angle vs. the electrical resistance

3.5 The Layer Height and the Water Absorption Ability

The experimental results indicated that when increasing the layer height, the water absorption ability increases as shown in Figure (10).

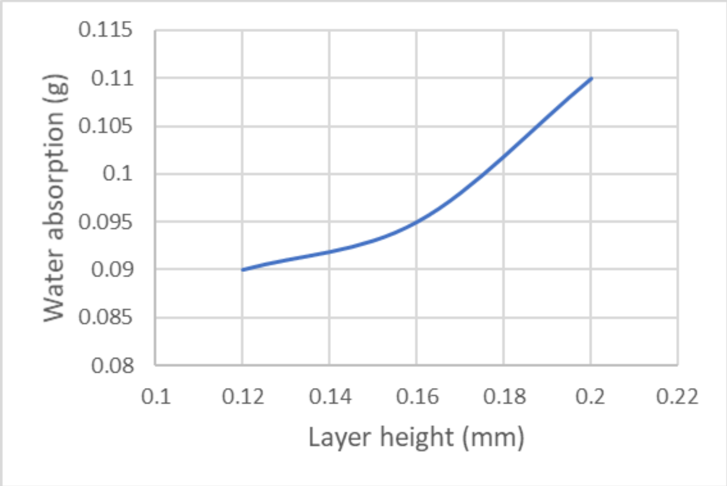


Figure 10: The layer height vs. the water absorption

3.6 The Extrusion Temperature and the Water Absorption Ability

It was realized that when using a higher extrusion temperature, the water absorption increases as shown in Figure (11).

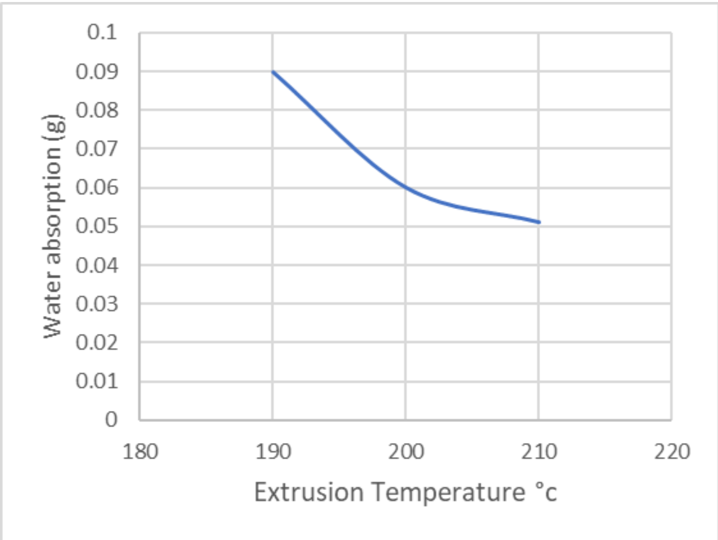


Figure 11: The extrusion temperature vs. the water absorption

3.7 The Path Type and the Water Absorption Ability

It was realized that the water absorption ability, when using a linear path, is less than the same when using a circular path, as illustrated in Figure (12).

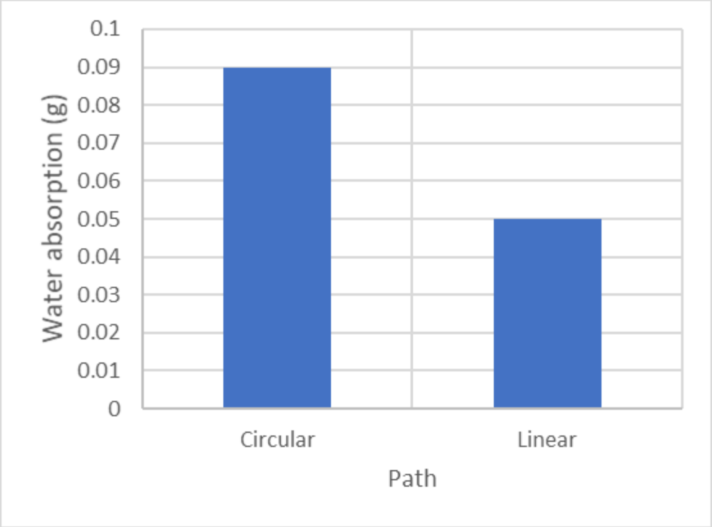


Figure 12: The path type vs. the water absorption

3.8 The Layer Height and the Compression Strength

The figure below describes the relation between the layer thickness and the maximum compression strength for the PLA material. It is realized that the PLA samples have been greatly influenced by layer height. The maximum compression strength increases by increasing the thicknesses of layers.

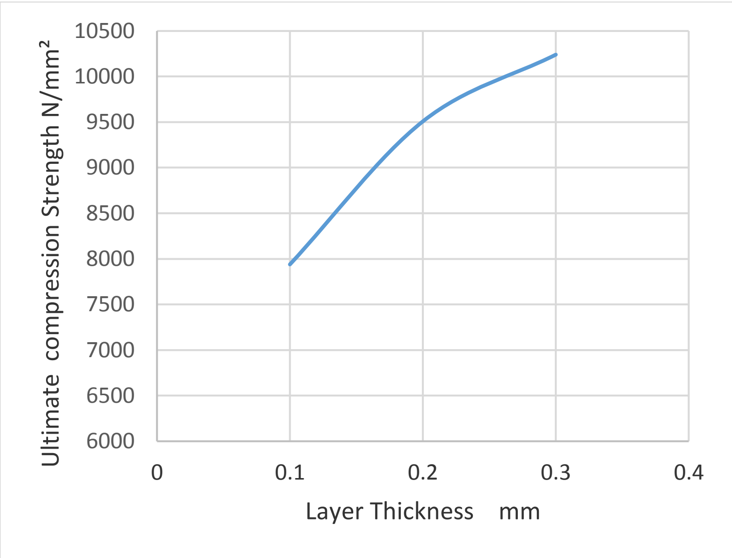


Figure 13: The layer height vs. the compression strength

3.9 The Extrusion Temperature and the Compression Strength

The average curves obtained from the tests performed at the three different temperature values (200°C, 210° C, and 220°C) are reported in Figure (14). It can be clearly observed that as the temperature increases the maximum compression strength decreases.

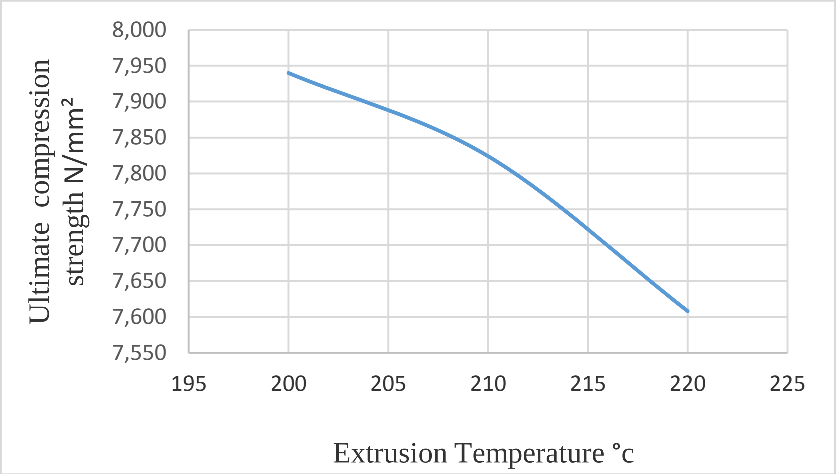


Figure 14: The extrusion temperature vs. the compression strength

3.10 The Raster Angle and the Compression Strength

The results presented in Figure (15) indicate that the maximum compression strength decreases as the raster angle changes from 30 to 60. So, the relation between maximum strength with raster angle is proportional.

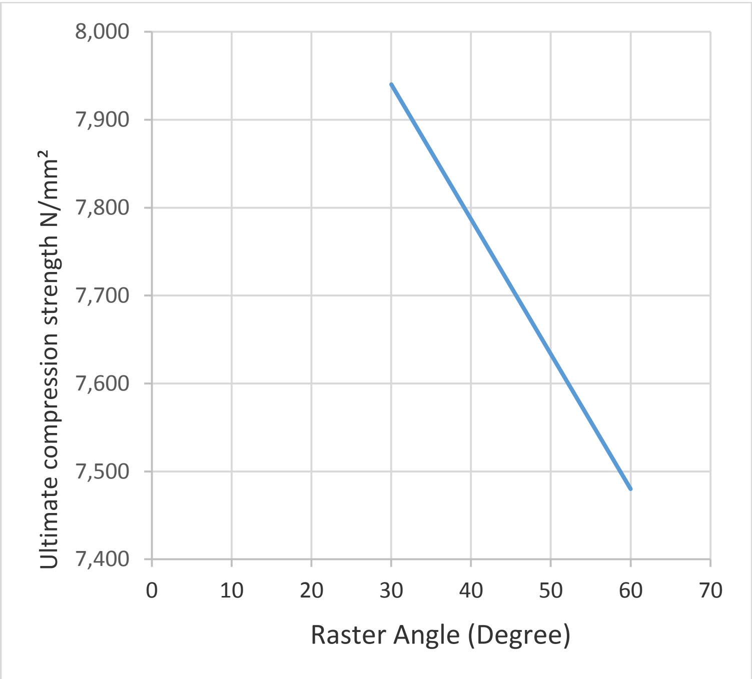


Figure 15: The raster angle vs. the compression strength

3.11 The Feed Rate and the Compression Strength

Figure (16) illustrates the relation between feed rate and the ultimate compression strength. It can be observed that the maximum compression strength increases when the feed rate increases.

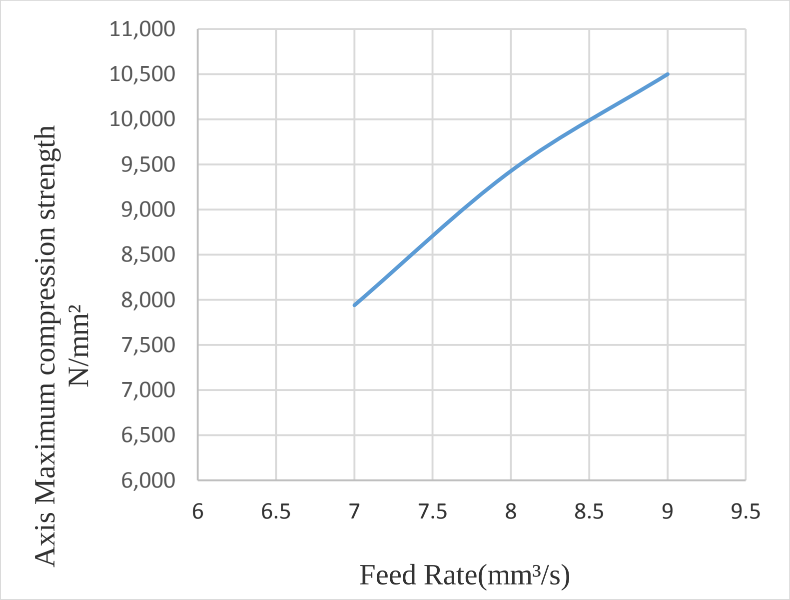


Figure 16: The feed rate vs. the compression strength

4. Conclusions

- The electrical conductivity increases by increasing the layer height, increasing the feed rate, and increasing the raster angle. While changing the extrusion temperature doesn't affect the electrical resistance.
- The water absorption increases by increasing the layer height and increasing the extrusion temperature.
- The ultimate compression strength increases by increasing the layer height, decreasing the extrusion temperature, decreasing the raster angle, and increasing the feed rate.

References

3DExperience. (2018). *3D Printing - Additive*. Retrieved from 3DExperience: https://make.3dexperience.3ds.com/processes/powder-bed-fusion#:~:text=Powder%20Bed%20Fusion%20(PBF)%203D,therefore%20forming%20a%20solid%20part.

Abdulhameed, O., Al-Ahmari, A., Ameen, W., & Mian, S. H. (2019). Additive manufacturing: Challenges, trends, and applications. *Advances in Mechanical Engineering*, 11(2), 1687814018822880.

Al-Maliki, J. Q., & Al-Maliki, A. J. Q. (2015). The processes and technologies of 3D printing. *International Journal of Advances in Computer Science and Technology*, 4(10), 161-165.

AMFG. (2021). *AMFG Autonomous Manufacturing* . Retrieved from https://amfg.ai/industrial-applications-of-3d-printing-the-ultimate-guide/

Apium. (2020). *Metal Extrusion 3D Printing* . Retrieved from Apium : https://apiumtec.com/en/material-extrusion-fff-3d-printing

Gonabadi, H., Yadav, A., & Bull, S. J. (2020). The effect of processing parameters on the mechanical characteristics of PLA produced by a 3D FFF printer. *The International Journal of Advanced Manufacturing Technology*, 111(3), 695-709.

Guo, N., & Leu, M. C. (2013). Additive manufacturing: technology, applications and research needs. *Frontiers of Mechanical Engineering*, 8(3), 215-243.

Leite, M., Fernandes, J., Deus, A. M., Reis, L., & Vaz, M. F. (2018, May). Study of the influence of 3D printing parameters on the mechanical properties of PLA. In 3rd international conference on progress in additive manufacturing (Pro-AM 2018).

Leite, M., Varanda, A., Ribeiro, A. R., Silva, A., & Vaz, M. F. (2018). Mechanical properties and water absorption of surface modified ABS 3D printed by fused deposition modelling. *Rapid Prototyping Journal*.

Nadir, A., Mirko, K., Kwon, J. H., & Manja, K. K. (2019). Effect of printing layer thickness on water absorption and mechanical properties of 3D-printed wood/PLA composite materials. *The International Journal of Advanced Manufacturing Technology*, 102(5-8), 2195-2200.

Negi, S., Dhiman, S., & Sharma, R. K. (2013). Basics, applications and future of additive manufacturing technologies: A review. *Journal of Manufacturing Technology Research*, 5(1/2), 75.

Nikhil. (2020). *3D Printing Processes – Sheet Lamination*. Retrieved from Engineers Carage : https://www.engineersgarage.com/3d-printing-processes-sheet-lamination-part-8-8/

OMNEXUS. (2020). *Acrylonitrile Butadiene Styrene (ABS) and its Features*. Retrieved from OMNEXUS: https://omnexus.specialchem.com/selection-guide/acrylonitrile-butadiene-styrene-abs-plastic

OMNEXUS. (2020). *Water Absorption 24 hours*. Retrieved from OMNEXUS: https://omnexus.specialchem.com/polymer-properties/properties/water-absorption-24-hours

Ouhsti, M., El Haddadi, B., & Belhouideg, S. (2020). Effect of printing parameters on the mechanical properties of parts fabricated with open-source 3D printers in PLA by fused deposition modeling. *Mechanics and Mechanical Engineering*, 22(4), 895-908.

Pentek, A., Nyitrai, M., Schiffer, A., Abraham, H., Bene, M., Molnar, E., ... & Maroti, P. (2020). The effect of printing parameters on electrical conductivity and mechanical properties of PLA and ABS based carbon composites in additive manufacturing of upper limb prosthetics. *Crystals*, 10(5), 398.

Robinson, A. (2018). How to Test Electrical Conductivity. Retrieved from SCIENCING: https://sciencing.com/space-science-kits-that-are-out-of-this-world-13763827.html

Sanadhya, S., Vij, N., Chaturvedi, P., Tiwari, S., Arora, B., & Modi, Y. K. (2015). Medical applications of additive manufacturing. *Int J of Scientific Progress and Research*, 12(01), 11-17.

Shahrubudin, N., Lee, T. C., & Ramlan, R. (2019). An overview on 3D printing technology: Technological, materials, and applications. *Procedia Manufacturing*, 35, 1286-1296.

Touchstone. (2016). *Conductivity Testing – Electrical Properties Testing*. Retrieved from Touchstone: https://www.trl.com/electrical-properties-testing/

TWI. (2020). *What Is Directed Energy Deposition (DED)?* Retrieved from TWI: https://www.twi-global.com/technical-knowledge/faqs/directed-energy-deposition

Unlimited, 3. P. (2016). *FDM Fused Deposition Modeling*. Retrieved from 3D Parts Unlimited: https://www.3dpartsunlimited.com/blog-post/fdm-fused-deposition-modeling/

Vicente, C., Fernandes, J., Deus, A., Vaz, M., Leite, M., & Reis, L. (2019). Effect of protective coatings on the water absorption and mechanical properties of 3D printed PLA. *Frattura ed Integrità Strutturale*, 13(48), 748-756.