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Investigation of Products Based on Different Writing Speeds using 3D Printer (Extruder)

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A B S T R A C T

In this study, the results of products depending on the printing speed of the 3D printer are discussed. The data was compared to the standard averages (SA) of products produced at different production speeds. The highest standard deviation is observed at a production speed of 100 mm.s^{-1}. In terms of product length (L), the highest deviation is at 40 mm.s^{-1}, while the lowest is at 60 mm.s^{-1}. The product closest to the desired 20 mm length was appeared at a speed of 60 mm.s^{-1}. For product height (H), the highest deviation is at 40 mm.s^{-1}, while the lowest is at 80 mm.s^{-1}. The product closest to the desired 1 mm height is at a speed of 80 mm.s^{-1}. Regarding product weight, the highest deviation is at 40 mm.s^{-1}, and the lowest is at 100 mm.s^{-1}. The results provide further details on the standard averages and standard deviations for each product at each production speed. The deviation percentage (PD) and the H/L ratio were also calculated to understand the magnitude of variation in the products. The H/L ratio was calculated to provide insight into the difference between the highest and lowest measurement results of the produced products. The results show that the highest differences among the products in terms of length, height, and weight are observed at a production speed of 100 mm.s^{-1}. Consequently, it was concluded that a production speed of 100 mm.s^{-1} resulted in the most significant variations in length, height, and weight between the products.

INTRODUCTION

3D extruders (printers) are devices used to produce three-dimensional objects created using computer-aided design software (Dou et al., 2020). 3D printers offer several advantages compared to traditional manufacturing methods. Among these, 3D printers are more cost-effective compared to traditional production methods, especially for small-scale production. 3D printers are also faster than traditional manufacturing methods, which is particularly important for prototyping and rapid production

(Anderson, 2017; Ming et al., 2020; Urquiza et al., 2021; Kamer et al., 2022). 3D printers are more flexible compared to traditional manufacturing methods, allowing for the production of complex and customized designs. 3D printers are utilized in various industries and applications (Ngo et al., 2018; Popescu et al., 2018; Kamer et al., 2022). Some of these applications include prototyping, rapid production, and low-volume manufacturing. Additionally, they are used for the fabrication of prosthetics, implants, and other medical devices. 3D printers are also employed to enhance students' design skills. Furthermore, this technology is used to create works of art and designs (Kroll & Artzi, 2011; Murphy & Atala, 2014; Akbaba & Akbulut, 2021). Today, the importance of 3D printers is increasing due to various factors. Among these, the cost of 3D printers has significantly decreased in recent years, making them more accessible to a broader range of businesses and individuals. 3D printer technology has also advanced significantly in recent years, allowing for the production of more complex and durable objects. New applications are constantly being explored, further increasing the significance of 3D printers (Kroll & Artzi, 2011; Short, 2015; Yaman et al., 2016; Kalsoom et al., 2016). Khosravani et al. (2022) focus on the characterization of 3D printed PLA (Polylactic Acid) parts with different raster orientations and printing speeds. The research aims to investigate the effects of 3D printing on the mechanical behavior and durability of these parts. Test samples were printed using PLA material, and tensile tests were conducted. The results obtained determined the strength and rigidity of the examined samples. Furthermore, the study documented the dependency of the durability and elastic modulus of 3D printed parts on raster orientation. The findings of this research can be used for the development of computational models and the design of structural components (Khosravani et al., 2022). 3D printing speed refers to the amount of time a 3D printer takes to produce a part. It is influenced by various factors, including the speed of the print head's movement, the extrusion rate of the material, and cooling times. 3D printing speed is important for several reasons. Faster prints contribute to more efficient production and shorter delivery times (O'Neill, 2022). In a 3D printer, the print head uses an extruder and a nozzle to produce a part. The extruder pushes the material out of the nozzle, and the nozzle deposits the material onto the part. The speed of the print head determines how quickly the part will be produced. The extrusion rate determines how fast the material flows and affects the strength of the part. Cooling times represent the time required for the material to solidify. Cooling times play a role in determining how quickly the part can be produced (O'Neill, 2022).

MATERIAL AND METHODS

Material

Polylactic Acid (PLA) is a commonly used filament type in 3D printing. In this study, ROBO90 brand PLA filament was used, and relevant visuals of the product are provided in Figure 1. The filament used is in the form of a roll with a 1.75 mm diameter. The main purpose of choosing transparent PLA filament was to make it easier to detect the effects that may occur in the structures of the produced products at the end of the experimental study.

Figure 1. Images of the PLA filament used in the study

3D Extruder (Printer)

In this study, a Creality Ender 3 S1 3D extruder (Figure 2) was used. The calibration of the device's build platform and all other settings were performed prior to the production phase.

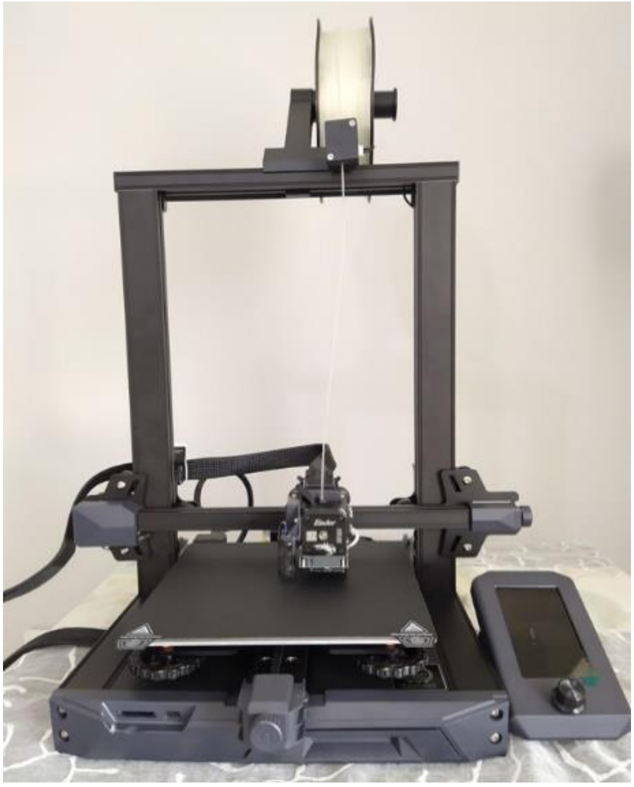


Figure 2. Image of Creality Ender 3 S1 (3D extruder)

Production and Inspection of Products with 3D Extruder

The study was carried out in three main stages as preparation of 3D Plate Production Modeling and Slicing (1), Obtaining Products with 3D Extrusion Filament and Extrusion Process (2), and Examination of the Obtained Products (2). In this study, plates with dimensions of 20×20 mm and a thickness of 1 mm (H) were designed and produced using PLA. The 3D modeling stage of the products made extensive use of the free Tinkercad program. The products were prepared using this program. The product designs prepared for the next stage, slicing, were converted to the STL (STereoLithography) format. STL file format is an abbreviation that stands for Standard Triangle Language or Standard Tessellation Language. Ultimaker Cura software was used as the slicer in the project. The products designed in 3D modeling in STL format were prepared for production with the 3D extrusion device through the slicing program.

RESULTS AND DISCUSSION

In 3D printers, printing speed determines how quickly the extruder deposits a layer of material. Printing speed is a critical parameter that affects the quality, duration, and cost of the print. As printing speed increases, the printing time decreases. However, an increase in speed may also lead to a decrease in print quality. This is because the layers may become less smooth and exhibit more layer separation. Printing speed varies depending on the material used and the geometry of the print. Generally, slower speeds are necessary for smooth and detailed prints, while faster speeds result in less detailed and rougher prints (Kamer et al., 2022). In this study, 20×20 mm plates with a thickness of 1 mm (h) made of PLA were used. For this purpose, a 3D modeling stage was conducted for each product. The products were prepared using relevant software. The product designs prepared for the next stage, slicing, were converted to the STL format. An example modeling created with the relevant software for this stage is provided in Figure 3(A). Visuals of the products produced with the 3D extruder are shown in Figure 3(B).

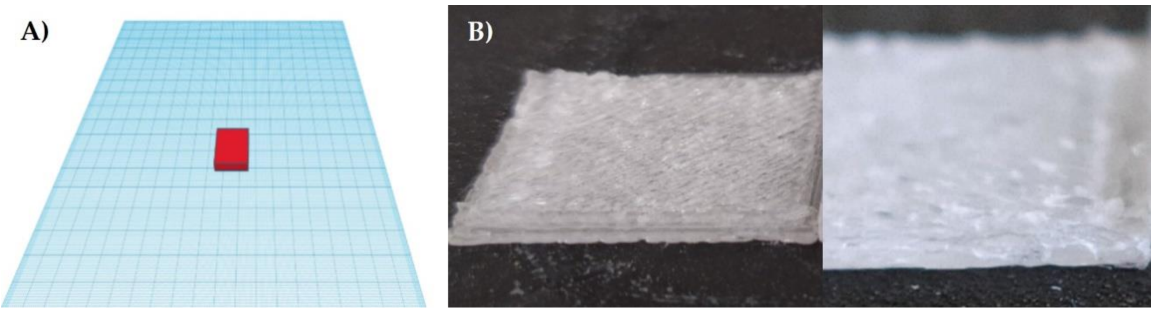


Figure 3. A) Product model with dimensions of 20×20×1 mm prepared using the modeling program and B) Visuals of the produced product

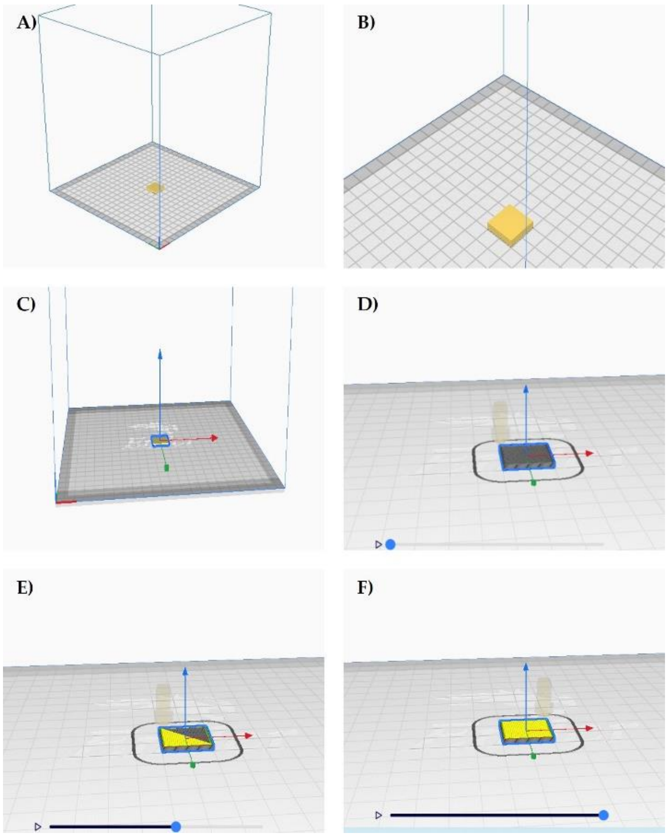


Figure 4. Stages of the 3D extrusion process created with the slicing program. A) General view; B) Product image designed in 3D modelling; C) Display of the x, y, z coordinates of the product; D) initial state before extrusion begins; E) 50% extrusion process; F) 100% extrusion process

Figure 5 provides the standard averages (SA) of the products produced at different production speeds and compares them with each other. Generally, the highest standard deviation is observed at a production speed of 100 mm.s^{-1}. In terms of product length (L) (Figure 5A), the highest is 20.66 mm at 40 mm.s^{-1}, while the lowest is 20.53 mm at 60 mm.s^{-1}. The product closest to the 20 mm design appears at a speed of 60 mm.s^{-1}. For product height (thickness, H) (Figure 1C), the highest is 1.17 mm at 40 mm.s^{-1}, while the lowest is 1.10 mm at 80 mm.s^{-1}. The product closest to the 1 mm design is at a speed of 80 mm.s^{-1}. Regarding product weight (Figure 5E), the highest is 388 mg at 40 mm.s^{-1}, and the lowest is 366 mg at 100 mm.s^{-1}.

In the study conducted by Yang & Yeh (2020), the impact of printing speed on the surface morphology, color variation, and mechanical properties of Wood-Plastic Composite (WPC) components was investigated. Different printing speeds (30 mm.s^{-1}, 50 mm.s^{-1}, 70 mm.s^{-1}) were used to print WPC components in the experiments, and the results were compared. Regarding the effect of printing speed on surface morphology, it was observed that components printed at lower printing speeds (30 mm.s^{-1}) had a smoother and more uniform surface. In contrast, at higher printing speeds (70 mm.s^{-1}), irregularities and roughness were observed on the surface of the components. Analysis of color variation revealed the influence of printing speed on color change. Parts printed at lower printing speeds exhibited lower color differences, whereas parts printed at higher speeds showed more significant color differences. This was attributed to the greater heating of wood fibers at lower printing speeds, resulting in a darker color. In mechanical property tests, it was found that printing speed did not have a substantial impact on the mechanical strength of the components. No significant differences were observed between tensile and flexural properties based on printing speed. However, the study did identify an effect of printing speed on the compression properties of the printed parts. Components printed at higher speeds had lower compression resistance. In conclusion, this study highlighted the influence of printing speed on the surface morphology, color variation, and certain mechanical properties of WPC components. It was determined that lower printing speed resulted in a more homogeneous surface and lower color variation. However, there was no significant impact of printing speed on mechanical properties (Yang & Yeh, 2020).

Kamer et al. (2022) conducted a study examining the mechanical properties of test samples produced at different printing speeds using PLA material. Samples produced with U2G and U2E 3D printers were measured for mass, hardness, surface roughness, and porosity values. Tensile tests were also performed, and SEM images of fracture areas were captured after the tensile tests. As the printing speed increased, the mass of the products decreased. Moreover, higher printing speeds led to a reduction in the upper surface hardness and tensile strength of the products, while increasing porosity and the arithmetic mean roughness values. Additionally, an increase in printing speed resulted in a decrease in the effective Young's modulus of the products, making the material more brittle. In conclusion, the study found that printing speed has a significant impact on the mechanical properties of samples produced with PLA material. This study emphasizes the importance of considering printing speed when using a 3D printer for production. Furthermore, it observed that different 3D printer models have varying effects on the mechanical properties of the products (Kamer et al., 2022).

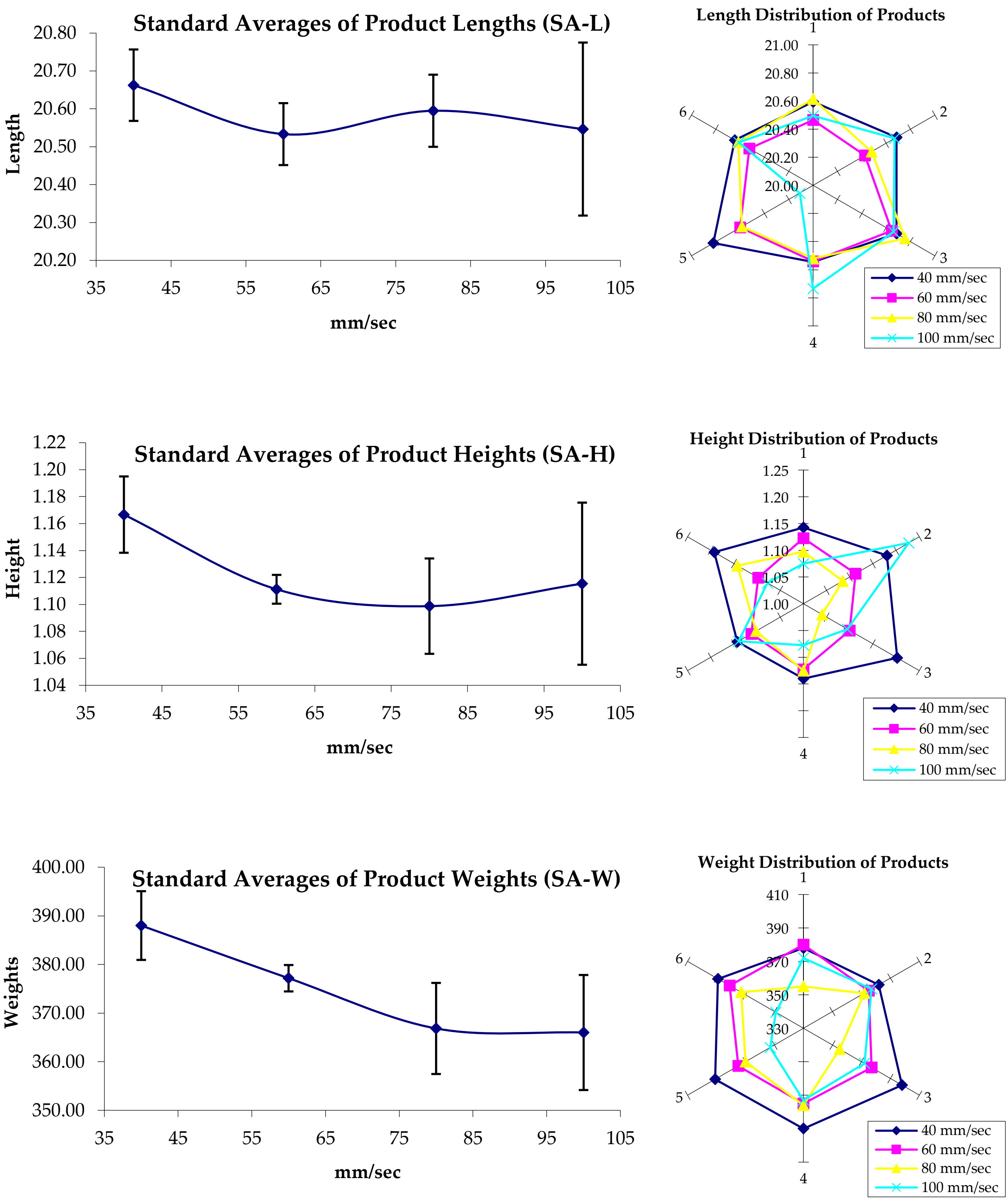
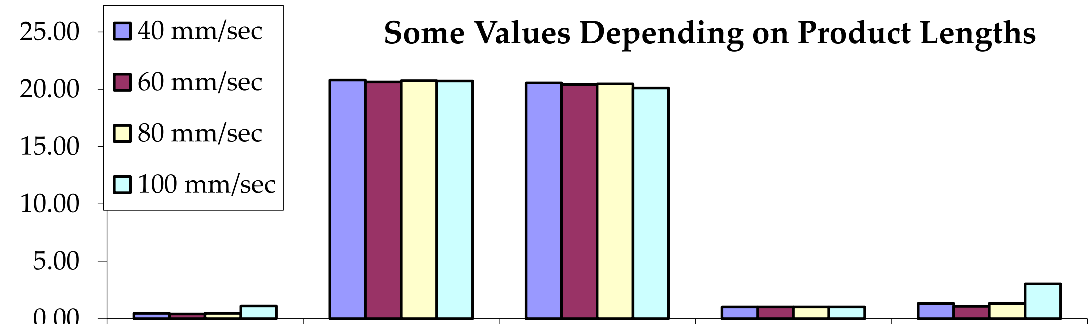
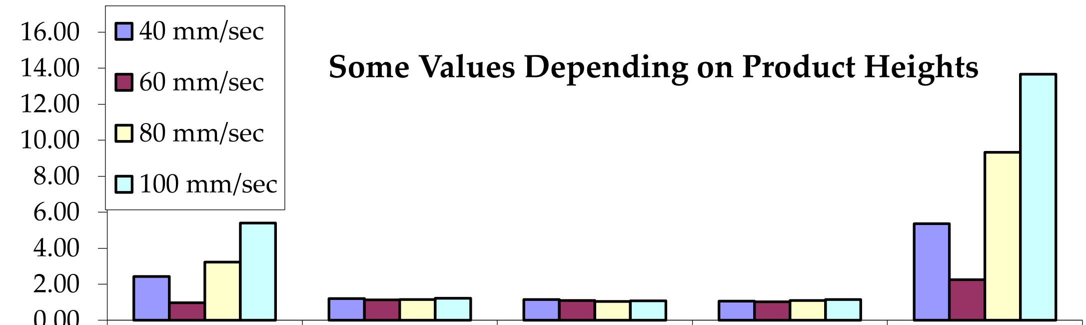


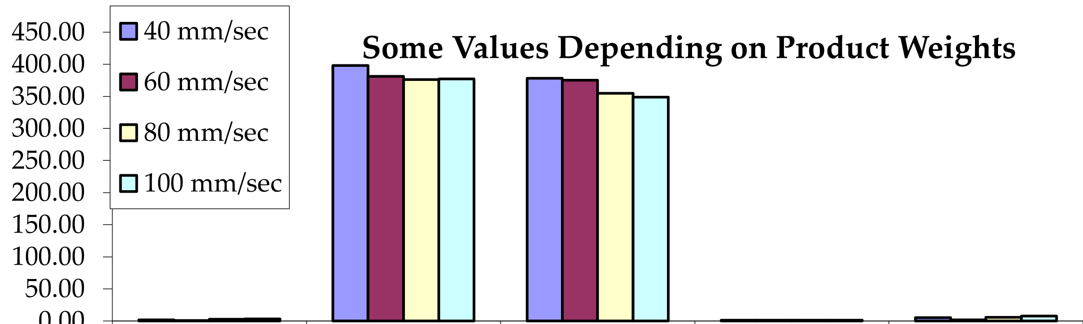
Figure 5. Data on products according to production speeds



	PD	H	L	H/L	H-L%
40 mm/sec	0.46	20.82	20.55	1.01	1.33
60 mm/sec	0.40	20.65	20.43	1.01	1.07
80 mm/sec	0.46	20.76	20.48	1.01	1.34
100 mm/sec	1.11	20.74	20.11	1.03	3.04



	PD	H	L	H/L	H-L%
40 mm/sec	2.43	1.20	1.14	1.05	5.36
60 mm/sec	0.96	1.12	1.10	1.02	2.25
80 mm/sec	3.22	1.14	1.04	1.10	9.33
100 mm/sec	5.39	1.23	1.08	1.14	13.67



	PD	H	L	H/L	H-L%
40 mm/sec	1.82	398.00	378.00	1.05	5.15
60 mm/sec	0.72	381.00	375.00	1.02	1.59
80 mm/sec	2.55	376.00	355.00	1.06	5.72
100 mm/sec	3.23	377.00	349.00	1.08	7.65

Figure 6. Some calculations for products according to production speeds

CONCLUSION

The speed at which a 3D printer operates plays a crucial role in determining the quality, duration, and cost of a print. This parameter, known as printing speed, refers to the rate at which the extruder deposits layers of material. In the study, it was produced 24 products for the plate at different extrusion speeds: 40, 60, 80, and 100 $mm.s^{-1}$. It was obtained six products for each of these four speeds. It is evident that the production speed of 100 $mm.s^{-1}$ exhibits the highest standard deviation. In terms of product length (L), the highest standard deviation is observed at 40 $mm.s^{-1}$, with a value of 20.66 mm, while the lowest is seen at 60 $mm.s^{-1}$, with a value of 20.53 mm. The product closest to the desired 20 mm length was produced at a speed of 60 $mm.s^{-1}$. For product height (thickness, H), the highest standard deviation is recorded at 40 $mm.s^{-1}$, with a value of 1.17 mm, while the lowest is observed at 80 $mm.s^{-1}$, with a value of 1.10 mm. The product closest to the desired 1 mm thickness was manufactured at a speed of 80 $mm.s^{-1}$. Regarding product weight, the highest standard deviation is found at 40 $mm.s^{-1}$, with a value of 388 mg, while the lowest is observed at 100 $mm.s^{-1}$, with a value of 366 mg. To facilitate comparison, the Deviation Percentage (PD) was calculated, representing the ratio between the SD and SA. The PD values indicate the magnitude of the variation in dimensional measurements between the products produced at different production speeds. Furthermore, the H/L (highest to lowest) ratio was calculated to provide a better understanding of the production standard by examining the ratio between the highest and lowest measured values of the products. A value close to 1 suggests that the produced products are within the standard range. The H-L% values were calculated to gain insights into the magnitude and proportion of the differences between the highest and lowest values in the products. The PD values for product length indicate that products produced at 40, 60, and 80 $mm.s^{-1}$ speeds are relatively similar, while the products manufactured at 100 $mm.s^{-1}$ exhibit a PD value twice as high as the others. This suggests that as the production speed increases, the differences in product lengths also increase. Similar trends were observed in H/L and H-L% calculations. When considering product height (thickness), there was once again a higher difference in products produced at 100 $mm.s^{-1}$. The same holds true for product weights, although the differences are relatively lower. Consequently, among the production speeds, 100 $mm.s^{-1}$ results in the highest differences in product length, height (thickness), and weight. Overall, these findings provide valuable insights into the dimensional variations among products manufactured at different production speeds, allowing for a better understanding of the impact of speed on product quality. In conclusion, among the production speeds analyzed, the production speed of 100 $mm.s^{-1}$ results in the highest differences among the products in terms of length, height (thickness), and weight. This information provides valuable insights into the variations in product dimensions and can help inform decision-making in the production process. In conclusion, printing speed is a critical parameter in 3D printing that affects the quality, duration, and cost of a print. While faster printing speeds can reduce printing time, they may lead to a decrease in print quality, resulting in less smooth and detailed prints. The optimal printing speed varies depending on the material used and the geometry of the print. Proper adjustment of parameters during the 3D slicing process is essential to achieve the desired characteristics in the final printed object.

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Compliance with Ethical Standards

Authors' Contributions

Both authors made contributions in necessary fields during the preparation of samples, conduction of experiments, evaluation of results, and writing of the article. Both authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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