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Determination of Energy Consumption During The Tensile Test Sample Production in 3D Printer Working with The Fused Deposition Modeling Method

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Highlights:

- Additive manufacturing
- Energy consumption
- Fused deposition modeling (FDM)

Keywords:

- 3D Printer
- Additive manufacturing
- Energy consumption
- Fused deposition modeling (FDM)

ABSTRACT:

Today, 3-dimensional (3D) printers are developing increasingly, and rapid progress is being made to become an alternative to traditional production methods. 3D printers, which produce with the Fused Deposition Modeling (FDM) method, commonly produce by using polymer materials in the form of filament with a diameter of 1.75 mm or 2.85 mm. This study, tensile test specimens were produced using PLA filaments of different diameters (1.75 mm and 2.85 mm) with two different 3D printers. The electricity consumption of 3D printers during the production of tensile test samples was measured. The energy consumed by both 3D printers in producing tensile test specimens was compared. Instead of simultaneously producing a single test sample, it has been determined that the power consumption per test sample will be reduced by producing many test samples together.

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INTRODUCTION

Today, 3D printers are developing increasingly, and rapid progress is being made to become an alternative to traditional production methods. For this purpose, products for use with 3D printers are produced and performance tests are carried out (Uzun et al., 2018; Kartal et al., 2021). In addition, tensile and flexural test specimens are produced with 3D printers using various production parameters, and studies are carried out to determine the mechanical properties of these test specimens (Kaptan and Kartal, 2020; Uzun and Erdogdu, 2020). With additive manufacturing, different methods are used in the production phase. The most economical and accessible of these are 3D printers that produce with the Fused Deposition Modeling (FDM) method. 3D printers produced with the FDM method commonly produce by using polymer materials in the form of filament with a diameter of 1.75 mm or 2.85 mm. Production with 3D printers takes longer than traditional methods. For this reason, it is crucial to determine the amount of time and energy to be spent on 3D printing. To determine the energy consumed during 3D printing, many studies have been carried out in the literature, some of which are given below.

Giordano et al. (1997) investigated the mechanical properties of 3D printed Poly L-Lactide Acid (PLLA) parts. Test samples were produced as a binder using chloroform and low and high molecular weight PLA powders. To analyze the effects of printing conditions on the mechanical and physical properties of PLA test samples, they varied the printed binder per unit line length of powder. They also performed cold isostatic pressing after printing to improve the mechanical properties of the printed test specimens. Lanzotti et al. (2015) aimed to measure the ultimate tensile strength and nominal stress at the break of printed parts made of PLA by changing three important process parameters with a Replicating Rapid prototyping (Rep-Rap) 3D Printer: layer thickness, infill orientation and the number of shell perimeters. They designed the experiments based on a central composite design. They determined that using a response surface methodology allowed them to propose an empirical model linking process parameters and mechanical properties. Peng (2016) focused on and analyzed the energy consumption of 3D printing processes in the context of environmental impact. He did a preliminary study on a 3D printing process in which energy is divided into primary and secondary energy. He proposed energy models that provide a basic energy estimation and optimization approach for each part, improving actual production settings and supporting 3D printing product redesign. Song and Telenko (2017) analyzed material waste and energy consumption for commercial FDM printers using ABS material in a heavily used open store. They determined that about 34% of the plastic in the open studio was wasted. They found that the waiting time and preheating time for energy consumption differ for each job, and this causes variation in energy consumption. Kartal et al. (2018) investigated the effect of process parameters such as filling type (grid, triangle, and honeycomb), layer thickness, and filling density (10%, 20%, and 30%) on the construction time in the FDM rapid prototyping technique. Kartal ve Nazli (2018) experimentally investigated the effects of different parameters on tensile test specimens produced by equipment using PLA-type filaments and co-manufacturing with open source code. They based the test design on the L9 orthogonal array of the Taguchi Method and designed the experiments according to this plan. As a result, it was determined that the layer thickness parameters and the filler scanning interval parameters significantly improved in the increase in tensile strength. Peng and Yan (2018) studied energy consumption and surface roughness at the same time. ToFull factorial experiments were designed using a single desktop printer to investigate the effect of key process parameters such as layer thickness, printing speed and fill rate on energy consumption and surface roughness. It was determined that layer thickness was the most influential factor that had the opposite effect on energy consumption and surface roughness. In their study, Simon et al. (2018) investigated how the operating procedure and printing parameters affect energy consumption and particulate emissions using the FDM process. They determined that printing speed and material flow slightly affected the particle emission rate. Power profile analysis has shown that thrust-bearing heating and maintaining temperature are the major contributors to energy consumption. Hopkins et al. (2021) performed high-resolution power measurements for a series of low-cost fused filament fabrication and vat polymerization desktop 3D printers to gain insights into how to minimize the energy consumption of desktop 3D printers and estimate their energy use. As a result of their work, they developed quasi-experimental equations that can accurately predict energy use for each printing technology based on simple 3D printing measurements. Kartal et al. (2021) made the reproduction of a part by pouring epoxy into a mold formed by taking the mold of the spur gear wheels produced in a 3D printer with the silicone molding technique. Comparisons were made for the dimensional accuracy of all parts, Computer Aided Design data, parts made in three dimensions, and parts reproduced using silicone molds. They determined that it can be produced with 2.5% of the tooth diameter and 5% of the root diameter of the tooth. They have shown that this method can be used successfully in manufacturing processes and restoration works where measurement tolerances are allowed up to 5% on average. Korkut and Yavuz (2022) made detailed investigations on the energy consumed and the production time by using a sample known to have high strength in a 3D printer. The power and time consumption required for sample production were measured in a certain experimental order. As a result of the analyses, it has been observed that the parameters of platform temperature, layer thickness, printing speed, and nozzle temperature, from largest to smallest, affect the power consumed and the time spent. Warke and Puranik (2022) investigated the effect of Polylactic Acid (PLA) Polymer and Acrylonitrile butadiene styrene (ABS) components on energy consumption and printing time during the FDM process. They determined that ABS printing energy consumption is almost 1.5 to 2 times higher than printing with PLA.

In their previous work on 3D printers, the authors investigated the mechanical properties, flexural test specimens produced using different printing parameters (Kamer et al., 2021a), tensile test specimens made with ABS and PLA filaments using different bed and nozzle temperatures (Kamer and Temiz, 2021), tensile test specimens produced in different colors and different infill patterns (Kamer et al., 2021b) and tensile test specimens produced with ABS and PLA material at different printing speeds (Kamer et al., 2022).

This study produced tensile test specimens using PLA filaments of different diameters (1.75 mm and 2.85 mm) with two different 3D printers. The power consumption of 3D printers during the production of tensile test specimens was measured. The energy consumed by both 3D printers in producing tensile test specimens was compared.

MATERIALS AND METHODS

In this study, tensile test specimens were produced using 2.85 mm diameter Ultimaker PLA Pearl White filament (Ultimaker PLA Technical data sheet, 2022) and 1.75 mm diameter Raise3D Premium PLA Blue filament (Raise3D Premium PLA Technical Data Sheet, 2022). The 3D Printer and filament properties used in the production of test samples are given in Table 1.

Table 1. 3D Printer and filament properties used in the production of test samples

3D Printer	Ultimaker S5	Zaxe Z1 Plus
CAM program	Cura	XDesktop
Filament material	Ultimaker PLA Pearl White	Raise3D Premium PLA Blue
Filament diameter	2.85 mm	1.75 mm
Filament density	1.24 g/cm^3	1.2 g/cm^3
Melting temperature	151.8 °C	150 °C
Glass transition temperature (T_g)	59.1 °C	61 °C
Tensile strength (3D printed product)	52.5±0.9 MPa	46.6±0.9 MPa
Modulus of elasticity (3D printed product)	3250±119 MPa	2636±330 MPa

ASTM D638-14 Type-1 standard (ASTM D638-14, 2014) was used for sizing the tensile test specimens. A tensile test specimen was produced with the parameters specified in Table 2, using two different 3D printers using filaments of different diameters.

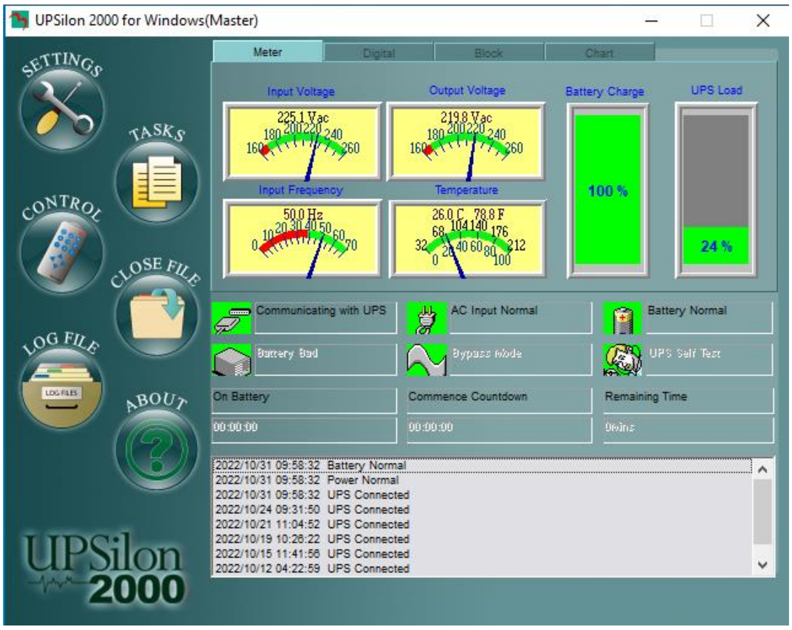
Table 2. Parameters used in the production of test samples

Nozzle temperature	208 °C
Bed temperature	60 °C
Printing speed	70 mm/s
Travel speed	150 mm/s
Nozzle diameter	0.4 mm
Layer thickness	0.2 mm
Wall thickness	0.4 mm
Infill density	100%
Infill pattern	Zig Zag
Standard	ASTM D638-14 Type-1 – 4 mm thickness

The power consumption of both 3D printers during the production of the tensile test sample was measured. During the production of tensile test samples, the power supply of 3D printers were provided by Tuncmatik Newtech Pro II X9 LCD 2 kVA Online UPS (1800 W) (Figure 1).

Figure 1. Tuncmatik Newtech Pro II X9 LCD 2 kVA Online UPS

The uninterruptible power supply is connected to the computer using the UPSilon 2000 computer software, and the amount of instantaneous power used by the 3D printers in the tensile test production can be monitored from the computer thanks to this software (Figure 2).



On Battery: 00:00:00
Commence Countdown: 00:00:00
Remaining Time: 0mins

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2022/10/31 09:58:32  Battery Normal
2022/10/31 09:58:32  Power Normal
2022/10/31 09:58:32  UPS Connected
2022/10/24 09:31:50  UPS Connected
2022/10/21 11:04:52  UPS Connected
2022/10/19 10:26:22  UPS Connected
2022/10/15 11:41:56  UPS Connected
2022/10/12 04:22:59  UPS Connected
```

Figure 2. Screenshot of UPSilon 2000 computer software

During 3D printing, the printers room temperature and indoor temperatures were measured with the temperature measurement probe with code 0602 0646 of the Testo 925 measuring device (Figure 3).

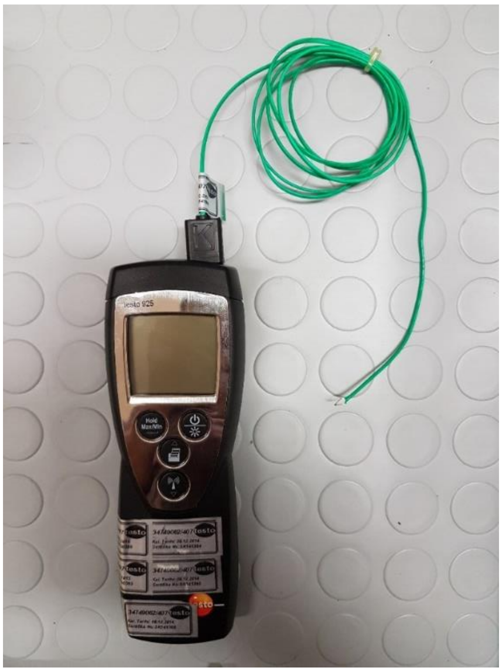
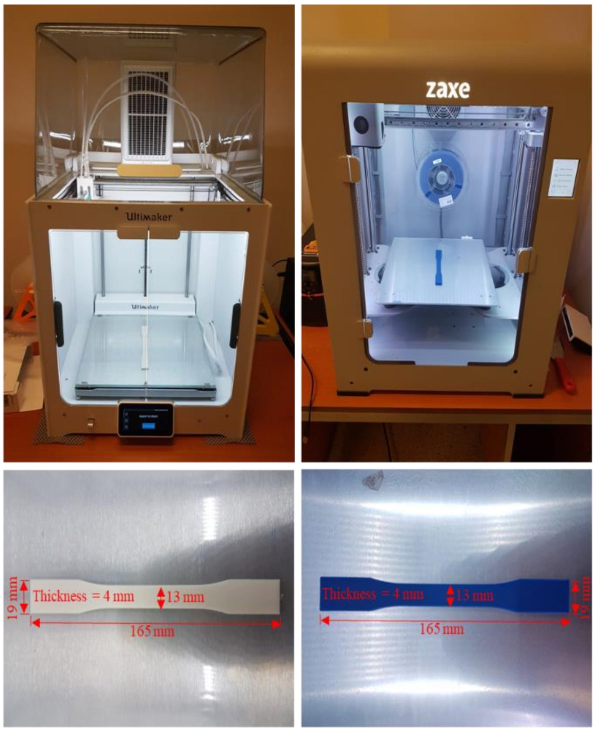


Figure 3. Testo 925 measuring device and temperature measuring probe with code number 0602 0646

RESULTS AND DISCUSSION

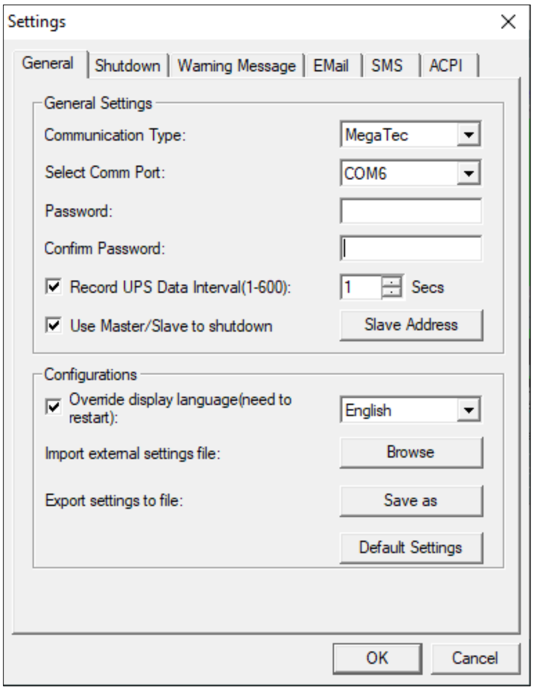
The images of the tensile test specimens produced using PLA filaments of different diameters (Raise 3D 1.75 mm and Ultimaker 2.85 mm) with both 3D printers are shown in Figure 4.



(a) Ultimaker S5 (b) Zaxe Z1 Plus

Figure 4. Tensile test specimens produced with both 3D printers

The data acquisition time of the UPSilon 2000 computer software from the uninterruptible power supply was set to 1s (Figure 5), and the data collected during 3D printing was saved to the computer in Excel format.



General Settings

Communication Type: MegaTec

Select Comm Port: COM6

Password:

Confirm Password:

☑ Record UPS Data Interval(1-600): 1 Secs

☑ Use Master/Slave to shutdown

Configurations

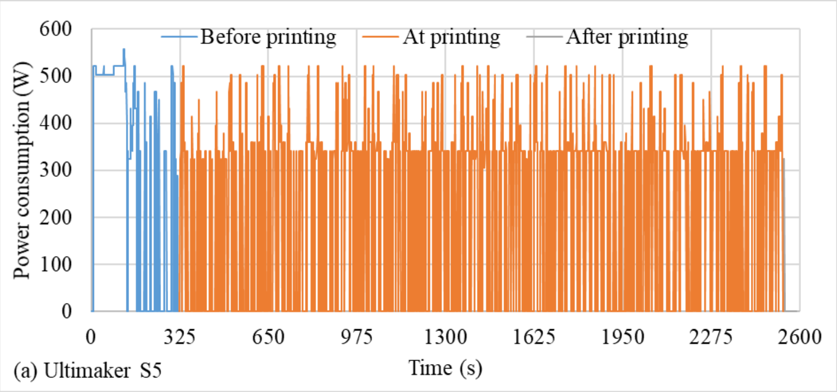
☑ Override display language(need to restart): English

Import external settings file:

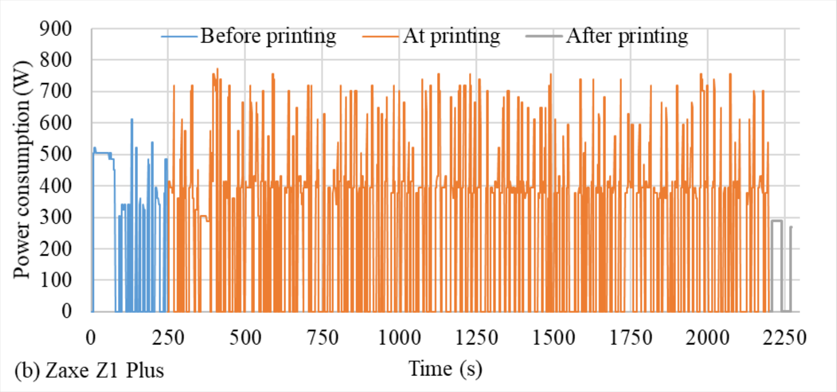
Export settings to file:

Figure 5. UPSilon 2000 software settings window

The graphs in Figure 6 were created using the instantaneous power consumption data during the printing stages. When Figure 6a is examined, it is seen that the instantaneous power consumption during printing with the Ultimaker S5 3D printer is generally between 0~350 W, and in some cases, it reaches approximately 500 W. When Figure 6b is examined, it is seen that the instantaneous power consumption during printing with the Zaxe Z1 Plus 3D printer is generally between 0~400 W. In some cases, it reaches approximately 700 W. As can be seen from the graphics, it can be said that the Zaxe Z1 Plus 3D printer consumes more instantaneous power than the Ultimaker S5 3D printer in any case.



(a) Ultimaker S5



(b) Zaxe Z1 Plus

Figure 6. Instantaneous power consumption graphs in the printing stages

Using the data saved on the computer in Excel format, the power consumption of both 3D printers at each printing stage was calculated separately. The power consumption data obtained from the calculations are given in Table 3.

Table 3. Power consumption data from calculations

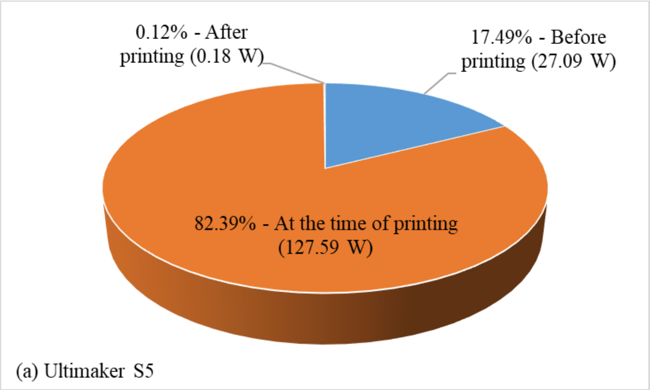
Printing stages		**Ultimaker S5**		**Zaxe Z1 Plus**	
		Time (s)	Consumption (Wh)	Time (s)	Consumption (Wh)
Before printing	Preheating	232	360.31	196	266.88
	Axis movements before printing	89	156.54	52	240.92
At the time of printing	First layer printing	212	166.50	212	294.62
	Printing remaining 19 layers	2008	211.16	1744	274.44
After printing	Cooling and finish	47	13.79	68	143.47
General consumption data	Time (s)	**2588**		**2272**	
	Consumption (W)	**154.86**		**171.02**	
	(Wh)	**215.41**		**270.98**	

Considering that 3D printing generally consists of three stages, namely before printing, at the time of printing and after printing, the average power consumption data for these stages and the temperature measured during printing are given in Table 4. It has been determined that the room and chamber temperature values during printing are identical in both printers. It has been determined that the power consumption before printing preparation is higher in the Ultimaker S5 3D printer. It is seen that the power consumption at the time of printing and after printing is higher in the Zaxe Z1 Plus 3D printer. When the general power consumption data is examined, it has been determined that although the total printing time of the Ultimaker S5 3D printer is longer, it consumes less energy and has a lower unit power consumption than the Zaxe Z1 Plus 3D printer. In addition, when Table 4 is examined, it is seen that instead of producing a single test sample simultaneously, the power consumption per test sample will be reduced by producing many test samples together.

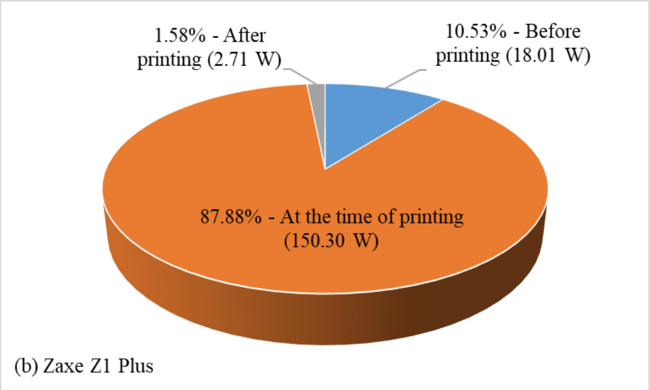
Table 4. Average power consumption data for printing stages

Printing stages	**Ultimaker S5**			**Zaxe Z1 Plus**		
	Time	Consumption		Time	Consumption	
	(s)	(Wh)	(W)	(s)	(Wh)	(W)
Before printing	321	303.81	27.09	248	261.44	18.01
At the time of printing	2220	206.90	127.59	1956	276.63	150.30
After printing	47	13.79	0.18	68	143.47	2.71
General consumption data	**2588**	**154.86**	**215.41**	**2272**	**171.02**	**270.98**
Room temperature	30			30		
10 cm top temperature of the printing bed °C	36			36		
Chamber temperature below the printing bed	33			33		

The average power consumption percentiles of the printing stages during the production of the tensile test specimen in both 3D printers are given in Figure 7. When the graph is examined, it is seen that the percentage of power consumption before printing of the Ultimaker S5 3D printer (17.49%) is approximately 1.66 times higher than the Zaxe Z1 Plus 3D printer (10.53%). On the other hand, the percentage of after-printing power consumption of the Zaxe Z1 Plus 3D printer (1.58%) was determined to be approximately 13 times higher than the Ultimaker S5 3D printer (0.12%). Finally, the power consumption of the Zaxe Z1 Plus 3D printer at the time of printing (150.30 W) was determined to be approximately 1.18 times higher than that of the Ultimaker S5 3D printer (127.59 W).



(a) Ultimaker S5



(b) Zaxe Z1 Plus

Figure 7. Average power consumption percentiles for printing stages

CONCLUSION

In this study, tensile test specimens were produced using Raise3D Premium PLA Blue filament with a diameter of 1.75 mm with a Zaxe Z1 Plus 3D printer and a 2.85 mm diameter Ultimaker PLA Pearl White filament with an Ultimaker S5 3D printer. The power consumption of 3D printers during the production of tensile test specimens has been compared. The results obtained from the measurements and calculations are given below.

- It has been determined that the indoor temperature values during printing are the same in both printers.
- It has been determined that the power consumption before printing preparation is higher in the Ultimaker S5 3D printer.
- It has been determined that the power consumption at the time of printing and after printing is higher in the Zaxe Z1 Plus 3D printer.
- When the general power consumption data is examined, it has been determined that although the total printing time of the Ultimaker S5 3D printer is longer, it consumes less energy and has a lower unit power consumption than the Zaxe Z1 Plus 3D printer.
- Instead of producing a single test sample at the same time, it has been determined that the power consumption per test sample will be reduced by producing many test samples together.

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Conflict of Interest

The article authors declare that there is no conflict of interest between them.

Author's Contributions

The authors declare that they have contributed equally to the article.

REFERENCES

ASTM D638-14. (2014). Standard test method for tensile properties of plastics. *ASTM International*, West Conshohocken, PA. doi:10.1520/D0638-14

Giordano, R. A., Wu, B. M., Borland, S.W., Cima, L. G., Sachs, E.M. & Cima, M. J. (1997). Mechanical properties of dense polylactic acid structures fabricated by three dimensional printing. *Journal of Biomaterials Science, Polymer Edition*, 8(1), 63-75. doi:10.1163/156856297X00588

Hopkins, N., Jiang, L. & Brooks, H. (2021). Energy consumption of common desktop additive manufacturing technologies. *Cleaner Engineering and Technology*, 2, 1000068. doi:10.1016/j.clet.2021.100068

Kamer, M.S., Dogan, O., Temiz, S. & Yaykasli, H. (2021a). Investigation of the mechanical properties of flexural test samples produced using different printing parameters with a 3D printer. *Cukurova University Journal of the Faculty of Engineering*, 36(3), 835-846. doi:10.21605/cukurovaumfd.1005909

Kamer, M.S. & Temiz, S. (2021). Investigation of the mechanical properties of tensile test samples produced with a 3D printer using different bed and nozzle temperatures with ABS and PLA filaments. *Kahramanmaras Sutcu Imam University Journal of Engineering Sciences*, 24(4), 341-358. doi:10.17780/ksujes.997195

Kamer, M.S., Temiz, S., Yaykasli, H. & Kaya, A. (2021b). Investigation of the mechanical properties of tensile test samples produced in different colors and different infill patterns with a 3D printer. *Uludag University Journal of The Faculty of Engineering*, 26(3), 829-848. doi:10.17482/uumfd.887786

Kamer, M.S., Temiz, S., Yaykasli, H., Kaya, A. & Akay, O.E. (2022). Comparison of mechanical properties of tensile test specimens produced with ABS and PLA material at different printing speeds in 3D printer. *Journal of the Faculty of Engineering and Architecture of Gazi University*, 37(3), 1197-1211. doi:10.17341/gazimmfd.961981

Kartal, F. & Nazli, C. (2018). Examination of tensile test specimens produced in three-dimensional Printer. *International Journal of 3D Printing Technologies and Digital Industry*, 2(3), 30-36.

Kartal, F., Nazli, C., Yerlikaya, Z., Simsek, F. & Cetin, M.H. (2018). Optimization of fused deposition modeling process parameters for building time. *International Journal of 3D Printing Technologies and Digital Industry*, 2(1), 96-103.

Kartal, F., Nazli, C., Yerlikaya, Z. & Kaptan, A. (2021). Replacement of flat gear wheels made in a 3D printer using RTV2 silicone. *International Journal of 3D Printing Technologies and Digital Industry*, 5(1), 34-42. doi:10.46519/ij3Dptdi.810269

Kaptan, A. & Kartal, F. (2020). The effect of fill rate on mechanical properties of pla printed samples. *Igdır University Journal of the Institute of Science and Technology*, 10(3), 1919-1927. doi:10.21597/jist.706003

Korkut, V. & Yavuz, H. (2022). Examining the influential parameters on reducing both energy and time requirements in open-source 3D printers. *Igdır University Journal of the Institute of Science and Technology*, 12(1), 403-411. doi:10.21597/jist.903159

Lanzotti, A., Grasso, M., Staiano, G. & Martorelli, M. (2015). The impact of process parameters on mechanical properties of parts fabricated in PLA with an open-source 3-D printer. *Rapid Prototyping Journal*, 21(5), 604–617. doi:10.1108/RPJ-09-2014-0135

Peng, T. (2016). Analysis of energy utilization in 3D printing processes. *13th Global Conference on Sustainable Manufacturing – Decoupling Growth from Resource Use- Procedia CIRP*, 40, 62-67. doi:10.1016/j.procir.2016.01.055

Peng, T. & Yan, F. (2018). Dual-objective analysis for desktop FDM printers: energy consumption. *25th CIRP Life Cycle Engineering (LCE) Conference – Procedis CIRP*, 69, 106-111. doi:10.1016/j.procir.2017.11.084

Raise3D Premium PLA Technical Data Sheet. Access address: https://s2.raise3D.com/public/media/2019/07/Raise3D_Premium_PLA_TDS_V4.pdf (Accessed date: July 02, 2022)

Simon, T.R., Lee, W.J., Spurgeon, B.E., Boor, B.E. & Zhao, F. (2018). An experimental study on the energy consumption and emission profile of fused deposition modeling process. *46th SME North American Manufacturing Research Conference – Procedia Manufacturing*, 26, 920-928. doi:10.1016/j.promfg.2018.07.119

Song, R. & Telenko, C. (2017). Material and energy loss due to human and machine error in commercial FDM printers. *Journal of Cleaner Production*, 148, 895-904. doi:10.1016/j.jclepro.2017.01.171

Ultimaker PLA Technical data sheet. Access address: https://support.ultimaker.com/hc/en-us/articles/360011962720-Ultimaker-PLA-TDS (Accessed date: July 02, 2022)

Uzun, M. & Erdogdu, Y.E. (2020). Investigation of the effect of using unreinforced and reinforced PLA in production by fused deposition modeling on mechanical properties. *Igdır University Journal of the Institute of Science and Technology*, 10(4), 2800-2808. doi:10.21597/jist.799230

Uzun, M., Gur, Y. & Usca, A. (2018). Manufacturing of new type curvilinear tooth profiled involute gears using 3D printing. *Journal of Balıkesir University Institute of Science and Technology*, 20(1), 278-286. doi:10.25092/baunfbed.398462

Warke, S. & Puranik, V.S. (2022). Comparison of energy consumption of ABS and PLA while 3 D printing with fused deposition modeling process. *Materials Today: Proceedings*, 66, 2098-2103. doi:10.1016/j.matpr.2022.05.509