Impact of 3D Printing Process Parameter in Printing of Composite Molds on Energy Consumption

Abdulaziz Sadeq Abdullah Qasem[1*], Anis Fatima[2] and Muhammed Wasif [3].

[1] NED University of Engineering and Technology, Department of Industrial and Manufacturing Engineering, Karachi 75270, Pakistan.
[2] Michigan Technological University, Manufacturing Mechanical Technology Department, Michigan 49931-1295, USA.
abdul.aziz2857@gmail.com

Abstract. This research delves into the optimization of 3D printing techniques for mold production, with a specific focus on understanding the critical factors influencing and interplaying with energy consumption. First, it aims to discern the pivotal parameters that significantly impact the quality of the printed mold surfaces, such as layer height, print speed, and nozzle temperature. Concurrently, it strives to establish a correlation between these printing parameters and the amount of energy consumed during the 3D printing process. By doing so, this study intends to shed light on the delicate balance between achieving desired quality of a part and minimizing energy usage. The anticipated outcomes of this study hold a potential towards sustainability in 3D mold manufacturing.

Keywords: additive manufacturing, 3D printing, surface roughness and power consumption.

1 Introduction

3D printing has become increasingly prominent in composite manufacturing. In this context, it is utilized to create molds or tools that are then used to produce composite components. These 3D-printed molds or tools can feature intricate geometries and characteristics that would be difficult or impossible to achieve through traditional manufacturing techniques. Multiple 3D printing technologies are applicable to composite manufacturing, including fused deposition modeling, stereolithography, and selective laser sintering. The optimal technology depends on factors such as the materials involved, the part's shape and size, and the required production volume[1]. Overall, 3D printing presents significant advantages in terms of efficiency, performance, and adaptability in composite manufacturing, enabling the production of customized, high-quality components that traditional methods cannot easily replicate. Additive manufacturing, also referred to as 3D printing, solid freeform (SFF), or rapid prototyping (RP), is a process that builds objects from digital models, typically layer by layer, without requiring tools, dies, or manual intervention[2].

Manufacturing serves as a foundational element of advanced societies, playing a crucial role in achieving sustainable development[3]. In many resource-limited regions, manufacturing practices are based on outdated standards compared to those in more developed areas. Cultural and economic factors often influence the adoption of technology and tools in creating sustainable solutions. Manufacturing improves quality of life by providing essential goods and services. Given its significant energy consumption, addressing sustainability in manufacturing is essential for global development[3]. Research indicates that technology alone can drive sustainability[1, 4, 5]. Experts argue that current technologies will suffice for

I. U. Ahad (ed.), *Proceedings of the 4th International Conference on Key Enabling Technologies (KEYTECH 2024)*, Atlantis Highlights in Engineering 35,
https://doi.org/10.2991/978-94-6463-602-4_14

decades to come[6]. Sustainable manufacturing focuses on using resources wisely and applying existing technology to create environmentally responsible solutions. Recent studies highlight the importance of energy efficiency. Johnson et al. (2024) noted that optimizing energy usage in manufacturing could reduce environmental impact by 25%[7]. Additionally, Liu et al. (2024) showed that energy-efficient 3D printing technologies can result in significant cost reductions and lower carbon emissions[8].

2 Experimental details

For this study, three thermoplastic plastics, namely, Polylactic acid (PLA), Acrylonitrile Butadiene Styrene (ABS) and Polyethylene Terephthalate Glycol (PETG) were selected. The selection criterion for the material was sustainability, as all of them were biodegradable and renewable thermoplastic polymer. Molds were 3d printed in two design configurations (a) convex, 60 mm length, 50 mm width and 12.5 mm height for the peak curve radius of +45.416 mm, and 5 mm for the side walls while design (b) concave, comes with 60 mm length, 60 mm width and 5 mm height for the peak curve radius of -92.50 mm, and 10 mm for the side walls. For robust analysis, both designs molds were printed three times as illustrated in Table 1. The 3d printing paraments of mold manufacturing are presented in Table 2. Energy data was measured during 3d printing of the molds by AEMC PEL 103 power logger. It was directly clipped on power cables.

Table 1. 3D Printed Molds numbering to design and material.

Name	PLA	ABS	PETG
Convex (a)	1.1	2.1	3.1
	1.2	2.2	3.2
	1.3	2.3	3.3
Concave (b)	1.4	2.4	3.4
	1.5	2.5	3.5
	1.6	2.6	3.6

Table 2. 3D printing parameters for all Molds

Name	Parameter	value
	Fixed parameter	
Layer height	Layer height	0.2mm
	First layer height	0.25mm
Parameter	Parameter	2
Horizontal shells	Solid layers in the top and in the bottom	4*4
Flow	First layer flow ratio	120%
	Bridge flow ratio	1
Overlap	Infill/perimeter overlap	25%
Infill	Fill density	20%

	Fill pattern	Rectilinear
	Top and bottom fill patterns	Monotonic
Brim	Brim	Outer brim only
	Brim width	5mm
Reducing printing time	Combine infill every	One layer
	Inner perimeter speed	50mm/s
	Small perimeter speed	15mm/s
	External perimeters speed	70mm/s
Speed	Infill printing speed	50 mm/s
	Travel speed	70mm/s
	First layer speed	30mm/s
Filament	Filament diameter	1.75mm
	Filament density	1.04g/cm^3
	Seam position	Aligned
Advanced	Fill angle	45
	PLA printing nozzle temperature	210°C
	PLA printing bed temperature	45°C
Temperatures*	ABS printing nozzle temperature	240°C
	ABS printing bed temperature	100°C
	PETG printing nozzle temperature	240°C
	PETG printing bed temperature	80°C

*Temperatures were used as per material melting point guidelines by manufacturer.

3 Results and discussion

The graph presented in Figure 1 shows the power consumption while printing individual molds. It is apparent from Figure 1 that the shape of the part and the process parameters, such as speed, filament specification, and layer height, do not significantly affect power consumption but the surface finish and the overall integrity of the printed object. Instead, the material used has a substantial impact on power consumption. The power consumption for printing ABS filament (mold numberings' 2.1-2.6) is the highest at 0.309 KVAh. For PLA (mold numberings' 1.1-1.6) and PETG (mold numberings' 3.13.6) filaments, the power consumption is 0.165 KVAh and 0.263 KVAh, respectively. Figure 1 also illustrates a direct proportional relationship between power consumption and the material employed for 3D printing.

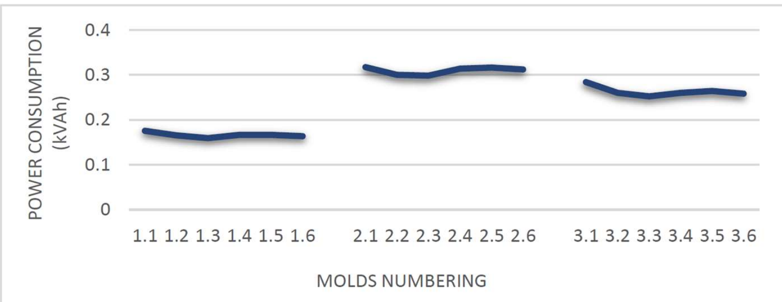

Fig. 1. Power consumption in 3D printing of composite molds

As illustrated in Figure 2, Mold fabricated from ABS filament (molds numbering 2.1-2.6), exhibited the highest ampere demand in contrast to its counterparts, PLA filaments (molds numbering 1.1-1.6) and PETG filaments (molds numbering 3.1-3.6). This observation is aligned with the anticipated outcome, considering the elevated printing temperatures associated with ABS filament being amorphous. Further, results suggest that the power required to transform the material form and its properties in printing processes is the main contributor of increased power consumption in 3d printing. Moreover, it is established that for crystalline material the melting appoint is fixedwhile for non-crystalline material (amorphous) the temperature is keep raising in melting process [9-10].

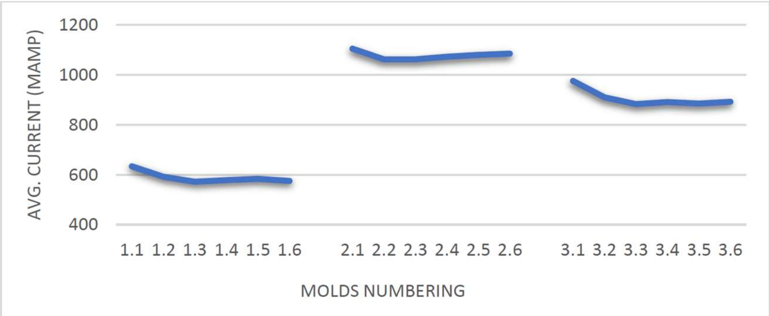

Fig. 2. Current consumption in 3D printing of composite molds

4 Conclusion

This research paper is an experimental approach of additive manufacturing3D printing of composite molds to observe the co-relation between printing parameters and energy consumption. It identifies that the temperature of nozzle and bed have a significant impact on ampere and on the power consumption of the process. It is also concluded that there is no general rule to optimise power consumption using process parameters instead it majorly depends on the melting temperature of the material used for 3d printing. Moreover, literature suggests that there are limited studies available on power utilization of 3D printing process. In general, there is a need to reconsider the 3d printer thermal conditions of motor and extruder in developing energy efficient 3D printers.

Disclosure of Interests. The author has no competing interests to declare that are relevant to the content of this article.

Acknowledgement: The authors acknowledge the financial support from Erasmus+ CBHE project GetInnovative4Impact, funded by the European Union (Project Number: 101083121). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

References

1. Rajak, D.K., et al. *Recent progress of reinforcement materials: a comprehensive overview of composite materials.* **8**(6):6354-6374,(2019).
2. Alsoufi, M.S. and A.E.J.A.J.M.E. Elsayed. *How surface roughness performance of printed parts manufactured by desktop FDM 3D printer with PLA+ is influenced by measuring direction.* **5**(5):211-222,(2017).
3. Gross, B., S.Y. Lockwood, and D.M.J.A.c. Spence. *Recent advances in analytical chemistryby 3D printing.* **89**(1):57-70,(2017).
4. Whitehead, S., et al., *Comparison of methods for measuring surface roughness of ceramic.*
5. **22**(6):421-427(1995).
6. Woodwell, G.M.J.S.,*Effects of Pollution on the Structure and Physiology of Ecosystems: Changes in natural ecosystems caused by many different types of disturbances are similar and predictable.* **168**(3930):429-433,(1970)
7. Ghosh, A.K., et al., *Processability in open mould processing of polymeric composites.*179203,(2020).
8. Johnson et al., 2024. *Energy Efficiency in Sustainable Manufacturing*. Sustainability Journal.
9. Liu et al., 2024. *Energy-Efficient Technologies in 3D Printing*. Additive Manufacturing Journal.
10. Peng, T.J.P.C., *Analysis of energy utilization in 3D printing processes.* **40**:62-67(2016)