SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Design and Simulation of Fused Deposition Modelling 3D Metal Printer Based on Fibre Laser Technique

Siti Iriaty Sa Ismail[1,*], Mohd Khairol Anuar Mohd Ariffin[1], Mohd Idris Shah Ismail[1], Zaimah Hasan[1], Mohammadreza Lalegani Dezaki[2]

[1] Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[2] Department of Engineering, School of Science and Technology, Nottingham Trent University, Nottingham NG1 4FQ, United Kingdom

ABSTRACT

This study aims to design and analysed the structure of the frame of a 3D metal printer. First, this work calculates the static stress on a frame structure. Second, as vibration could affect the effectiveness and performance of a 3D metal printer, this study also concentrates on building a frame structure with minimum vibration. SolidWorks is the software used in this study to sketch and simulate designed 3D models. Finite element analysis (FEA) was used for the simulation part to assess the frame's static and vibration motion analyses. In the analysis using the aluminium 6061 alloy material on the frame design, the result analysed the value at a three-point location. Based on simulation results, the yield strength of the structure is 55.1 x 106 N/m2. The maximum value of von Mises stress does not exceed the yield strength at points 1, 2, and 3. Accordingly, point 2 (365 mm) was selected as the location for the fibre laser head since it had the least amount of vibration. The design is, therefore, capable of withstanding the applied load. In conclusion, a new 3D metal printer's frame design has been analysed to demonstrate its sturdy structure and minimal vibration

ARTICLE INFO

Keywords:
3D metal printer; Fused deposition modelling; Fiber laser

1. Introduction

The process of fabricating a component via additive manufacturing (AM), sometimes called three-dimensional (3D) printing, is based on a geometric model of the part created using a computer-aided design system. Huang *et al.,* [1] reported AM is a highly potential method for creating intricate and valuable parts in various sectors, particularly aerospace and automotive industries. The AM built components in stages, starting at the base and successively stacking each layer on top of one another to complete its full geometry. According to researchers, 3D printing provides low material waste, lower costs, and ease of manufacturing complicated geometric objects are all benefits of 3D printing. With 3D printing, product design flexibility is acknowledged. Accordingly, these factors contribute to the widespread use of this technology was also reported by

* *Corresponding author.*
E-mail address: iriaty.ismail@gmail.com

https://doi.org/10.37934/araset.59.1.255264

Armstrong *et al.,* [2] and Abilgaziyev *et al.,* [3] study.

Christodoulou *et al*., [4] introduces a novel Fused Filament Fabrication (FFF) 3D printer capable of operating at significantly higher speeds. This advanced printer demonstrates a more than fivefold increase in printing velocity compared to traditional FFF systems while maintaining the same level of product quality and structural integrity. Oluwajobi *et al*., [5] excellently created a Fused Filament Fabrication (FFF) 3-D printer utilizing locally obtained materials, showcasing impressive performance and reliability.

Fused deposition modelling (FDM) is one of the material extrusion processes. It extrudes a wax/thermoplastics polymer filament onto the existing part surface from a work head to complete each new layer. Sargini *et al.,* [6] mentioned that FDM technology typically applies a variety of thermoplastics for 3D printing plastic components. Furthermore, FDM technology now uses many high-strength composite filaments, including metal-polymer composites. Hence, this opens the way for producing metal components at far lower prices than the expensive selective laser melting (SLM) AM technique was reviewed by Cano *et al.,* [7] . Ahmad *et al.,* [8] in his study reported that by comparing to other rapid prototyping techniques, the FDM method offers several key benefits. These include simplified accessibility, reduced equipment expenses, and the ability to produce items in multiple colours. Furthermore, this approach is more economical and cost-efficient than alternative Rapid Prototyping processes.

Recently, there has been a notable escalation in the demand for metallic prototypes and tools. The incorporation of non-polymeric materials, encompassing metals, has seen extensive application within the realm of 3D printing. According to a Rosli [9] direct metal prototypes may be realized through methodologies such as selective laser sintering (SLS), direct metal deposition (DMD), shape metal deposition (SMD), electron beam melting, and the most contemporary plasma deposition manufacturing technique. Directed energy deposition (DED) is a subset of AM techniques wherein a substrate is exposed to an energy source, such as a laser beam, electron beam, or plasma/electric arc reported by Ahn *et al.,* [10]. This is all the while simultaneously delivering feedstock material in the form of powder or wire. Svetlizky *et al.,* [11] illustrated this process results in the formation of a small melt pool and the continuous deposition of material, layer by layer, onto the substrate. Since its introduction in 1960, significant progress has been made in the study of laser applications in manufacturing and remanufacturing. Gong *et al.,* [12] reported the advancements in laser technologies over the past 50 years have enabled the development of various direct-energy processes, many of which are now being considered for industrial use. Numerous scholars have researched the manufacture of 3D printers with varied designs and printing techniques. According to the Huang *et al.,* [1] laser additive manufacturing (LAM) offers a versatile and rapid production technique for creating intricate geometric designs with numerous variations. However, research on metal printing is rarer. Based on this table, most 3D printers were developed using the FDM method as per details in Table 1. Therefore, this study will apply AM techniques such as FDM and DED to the design and development of 3D metal printers to fabricate metal parts.

Note that the design and vibration analysis of a 3D metal printer frame were the main topics of this study. First, this work calculates the static stress on a frame structure. This is crucial since a major part of the 3D metal printer, the frame, is the part that is subjected to stress, strain, and vibration while printing. Second, as vibration could affect the effectiveness and performance of a 3D metal printer, this study also concentrates on building a frame structure with minimum vibration.

Table 1
The list of design and development of 3D printers from the previous study

Authors	Types of printers	Process
[14]	Large scale multi extrusion FDM printer	FDM
[15]	Innovative 3D printer containing a co-rotating twin screw extrusion unit	FDM
[16]	Low-Cost-High-Accessibility 3D Printing machine	FDM
[17]	Fused Filament Fabrication (FFF) 3D printer	FFF
[18]	Low-Cost Open-Source 3D printer	FDM
[9]	Low-Cost 3D metal printer	Wire arc
[3]	Multi nozzle Extrusion system for 3D printer	FDM
[19]	Design and development of large scale FDM based 3D printer	FDM
	High-Speed Fused Filament Fabrication 3D Printer	
	3D printer	
[4]	Low Cost 3-D Printer	FFF
[13]		FDM
[5]		FFF

2. Methodology

2.1 Design of 3D Metal Printer

Referring to Figure 1 below, the 3D metal printer comprises mechanical components, an electronic component, and supporting firmware and software. While a 3D metal printer's support structure and kinematics for the movement of various pieces are composed of mechanical components, electronic components provide the system's mobility and control mechanism. At the same time, firmware and assisting software enable the 3D printer to communicate with the user and execute their commands. In this work, the application of fibre laser is proposed. The 3D printer operates along three axes: the x-axis, y-axis, and z-axis. These axes control the movement of the print bed, which is converted from rotational to linear motion using a ball screw mechanism. Meanwhile, the nozzle for both the filament and wire remains static. The movement of printer and the translation of command from the printer’s server to host computer is controlled by firmware provided with an Adruino microcontroller.

1. Aluminium profile
2. L Bracket
3. Leadscrew
4. Bed
5. Stepper motor
6. Fibre laser head
7. Wire feeder
8. Holder
9. Single axis Actuators LX45
10. Coupler

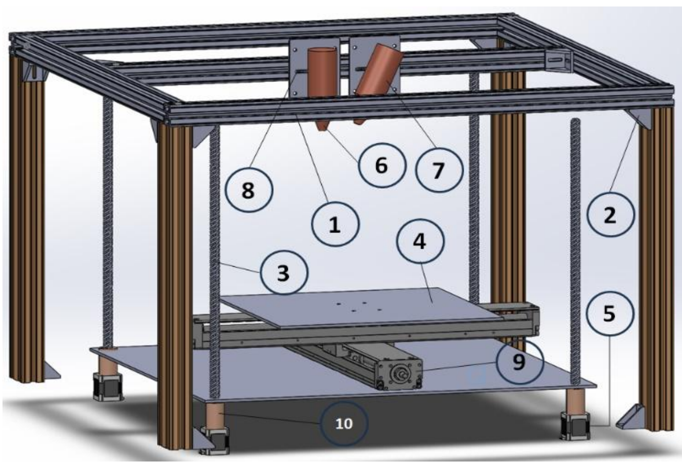


Fig. 1. The design of a 3D metal printer

2.2 Materials

The frame of the 3D metal printer utilized in this study comprises aluminium 6061 Alloy. The material has the ability to undergo precipitation hardening, with silicon and magnesium serving as its principal alloying elements. Additionally, this alloy exhibits robust mechanical characteristics, possesses weldability, and is frequently subjected to extrusion processes, Table 2 shows the Mechanical properties of Aluminium 6061 Alloy. The use of aluminium 6061 as a frame material for FDM 3D printers provides a robust and reliable foundation, contributing to the overall performance and quality of the printing process. Its durability, precision, consistency, and thermal conductivity make it a highly advantageous choice for FDM frame construction was reviewed by Hsu *et al.,* [20].

Table 2
Mechanical Properties of Aluminium 6061 Alloy

Mechanical Properties	Value	Units
Modulus of Elasticity	69	Gpa
Yield Strength	55.1×10^6	N/m^2
Density	2700	Kg/m^3
Poisson Ratio	0.33	

2.3 Modelling

SolidWorks software is used to create 3D models and conduct finite element analysis (FEA) in SolidWorks simulation. This frame was examined at three distinct locations: point 1 (40 mm), point 2 (365 mm), and point 3 (690 mm) as shown in Figure 2. 3-D modelling is created through the utilization of SolidWorks software. The objective is to visually present the preliminary design as a means to comprehend the final product. Mohd Jafri *et al.,* [21] reported the concept of the design must be articulated through the medium of technical illustration.

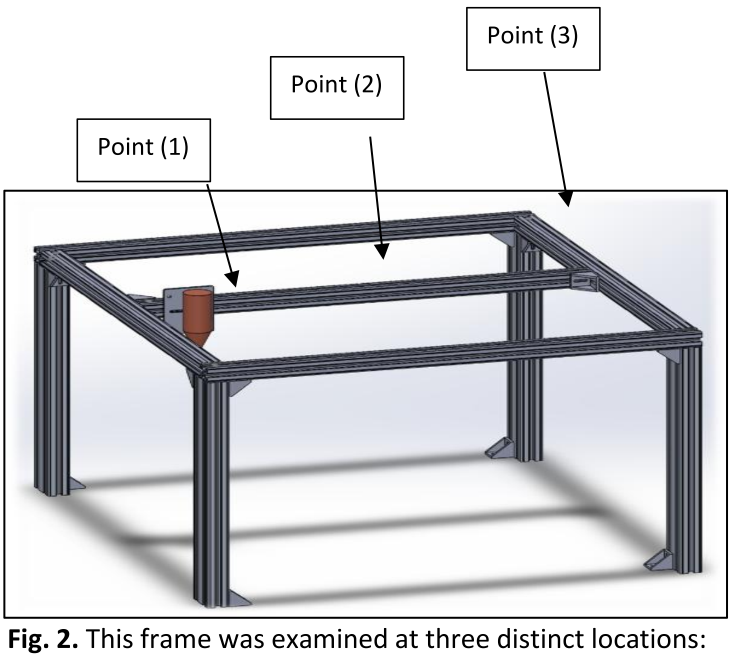


Fig. 2. This frame was examined at three distinct locations: point 1 (40 mm), point 2 (365 mm) and point 3 (690 mm)

2.4 Finite Element Analysis (FEA)

Putra *et al*., [22] illustrates that Finite Element Methods, a numerical methodology extensively employed for resolution of computer-related predicaments or strategies for carrying out an examination in engineering design, and used for accomplishing the process of Computer-Aided Design (CAD). Initially, FEM scrutinized the mechanical framework, but currently, it can be utilized for scrutinizing heat transfer, fluid flows, and vibration.

Finite Element Analysis (FEA) employs Computer-Aided Design (CAD) Simulation to create the frame based on measurement data obtained using aluminium material. Sani *et al*., [23] reported this software facilitates the implementation of FEA and allows users to examine structural characteristics such as stress, displacement, and natural frequency.

The flow chart illustrated in Figure 3 illustrates the process flow chart for conducting the frame's static and vibration motion analyses. Initially, the assembled drawing of the printer is prepared by connecting all the parts in the design. Then, the static test function is selected in order to start the new study. The material is chosen from the list provided in the database of the SolidWorks software.

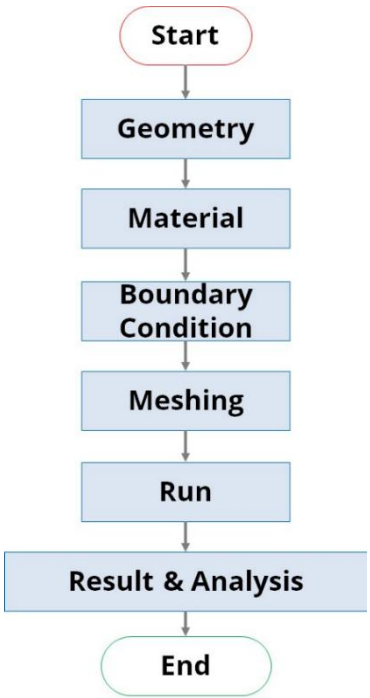
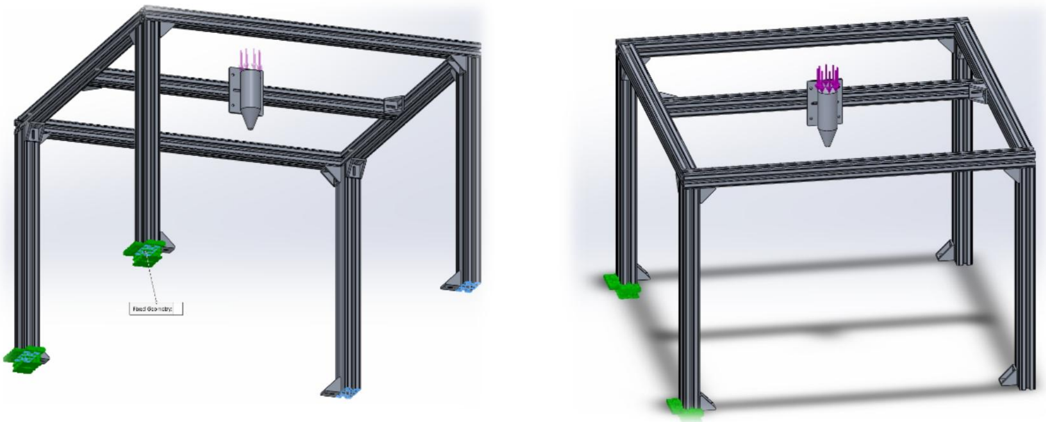


Fig. 3. Flow chart of static and vibration analysis

Then, the fixtures for the frame are applied. Afterwards, the force applied to the head laser is 30 N illustrated in Figure 4. Subsequently, the mesh is created, and the test continues until the result is generated.



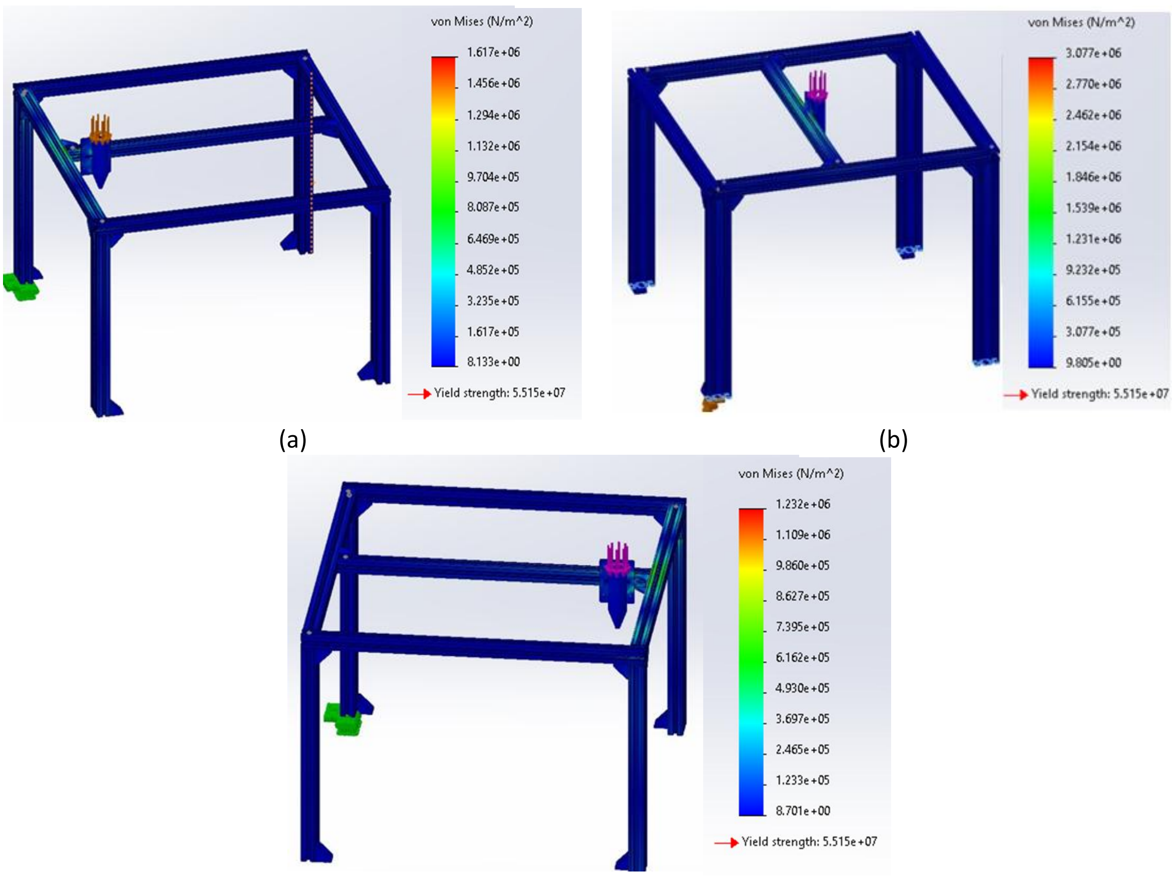
(a) (b)

Fig. 4. (a) 4 areas of fixed points were selected for Boundary Condition (b) Applied load of 30 N

3. Results and Discussion

3.1 Static Analysis

The inclusion of static analysis in the design and manufacturing processes of 3D printers is of crucial significance in ensuring their reliability and durability. It also enhances the 3D printer's overall quality and performance and helps avoid structural failures and related safety risks.



(a) (b)

(c)

Fig. 5. Result of simulation von Mises stress at (a) point 1, (b) point 2 and (c) point 3

Based on the simulation results as illustrated in Figure 5, the yield strength of the material is 55.1 x 10^6 N/m^2. The maximum value of von Mises for point 1 was 1.617 x 10^6 Nm^2, and the maximum value of von Mises for point 3 was 1.232 x 10^6 Nm^2. The point of the maximum stress was on the nozzle holder that connected to the frame. This was because the nozzle holder supported the load given (fibre laser head) with 30 N. Conversely, the maximum value of von Mises for point 2, which was 3.077 x 10^6 Nm^2, the highest compared with points 1 and 3 since the nozzle holder is located in the centre, which lacks support from the right and left frame as details in Table 3. Syehan *et al.,* [24] mentioned that the magnitude of the maximum von Mises stress remains below the yield strength of the material consequently, the design can be considered proficient in withstanding the simulated loads.

Table 3
Result of Static Analysis

Location	Maximum N/m^2	Minimum N/m^2
Point 1	1.617 x 10^6	8.133
Point 2	3.077 x 10^6	8.701
Point 3	1.232 x 10^6	9.805

3.2 Frequency Analysis

In the framework of a 3D printer, frequency analysis refers to assessing the printer's natural frequencies and vibration modes in addition to its dynamic response to different vibration and oscillatory forces. Understanding how the printer's parts react to dynamic loads and vibrations is crucial, as these factors might impact its performance and print quality.

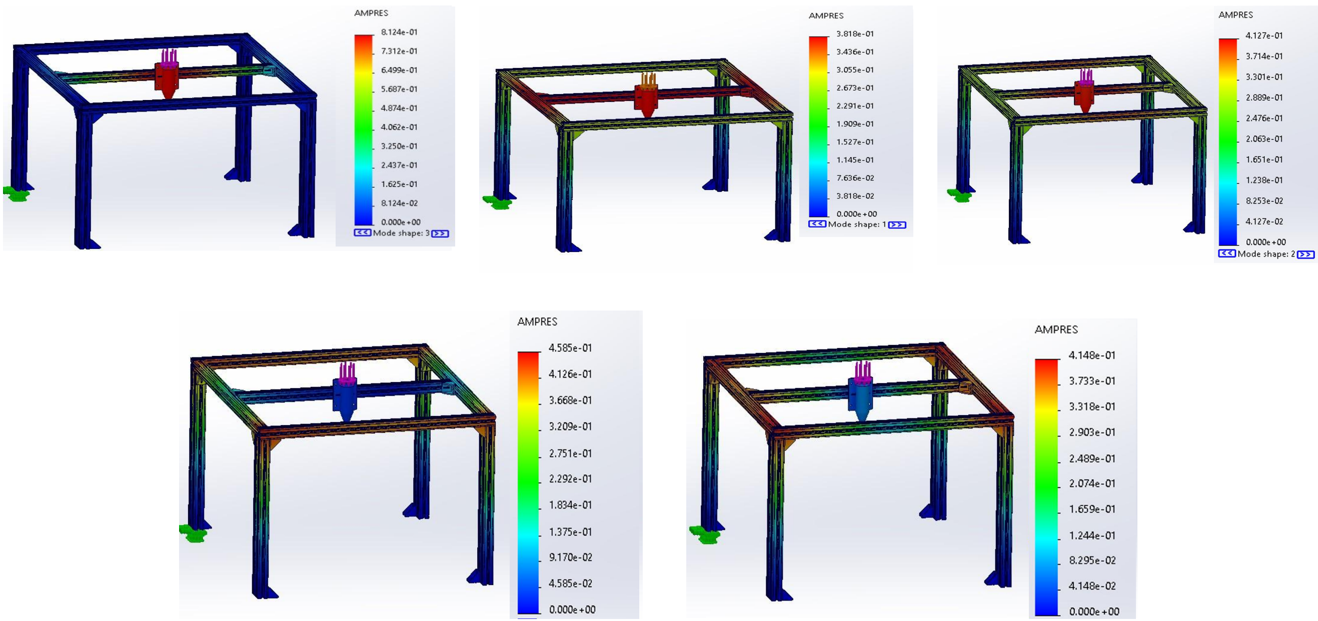


Fig. 6. 5 amplitudes of frequency analysis at point 2 (365 mm)

Table 4 summarises the frequency analysis of a structure at three different points. The frequency is the number of vibrations per second, and the period is the time it takes for one vibration to complete. Note that the lower the frequency, the less vibration there is. In this case, point 2 (365 mm) demonstrated less frequency compared to point 1 (40 mm) and point 3 (690 mm).

Table 4
Result of Frequency Analysis

Mode No.	Frequency (Hertz)	Period (Seconds)
Point 1 = 40 mm		
Mode No.	Frequency (Hertz)	Period (Seconds)
1	54.99	0.018185
2	87.20	0.011468
3	91.15	0.010971
4	112.52	0.008873
5	125.22	0.007986
Point 2 = 365 mm		
Mode No.	Frequency (Hertz)	Period (Seconds)
1	54.96	0.018192
2	86.30	0.011587
3	88.33	0.01132
4	90.16	0.011091
5	134.36	0.007442
Point 3 = 690 mm		
Mode No.	Frequency (Hertz)	Period (Seconds)
1	55.02	0.018174
2	87.18	0.01147
3	91.91	0.010879
4	120.00	0.008327
5	125.29	0.007981

4. Conclusions

In the present study, a new design of a 3D metal printer's frame has been analysed to demonstrate its sturdy structure and minimal vibration. The maximum value of von Mises stress does not exceed the yield strength at points 1, 2, and 3. In the entire simulation, when employing various materials, the magnitude of the highest von Mises stress remains below the yield point of the material. Consequently, it can be concluded that the design is capable of withstanding the loads simulated. Accordingly, point 2 referred to Figure 6, was selected as the location for the fibre laser head since it had the least amount of vibration. The design is, therefore, capable of withstanding the applied loads.

Acknowledgement
This research was not funded by any grant.

References
[1] Huang, Wenhao, Shujun Chen, Jun Xiao, Xiaoqing Jiang, and Yazhou Jia. "Laser wire-feed metal additive manufacturing of the Al alloy." *Optics & Laser Technology* 134 (2021): 106627. https://doi.org/10.1016/j.optlastec.2020.106627
[2] Armstrong, Mark, Hamid Mehrabi, and Nida Naveed. "An overview of modern metal additive manufacturing technology." *Journal of Manufacturing Processes* 84 (2022): 1001-1029. https://doi.org/10.1016/j.jmapro.2022.10.060
[3] Abilgaziyev, A., T. Kulzhan, N. Raissov, Md Hazrat Ali, WL KO Match, and N. Mir-Nasiri. "Design and development of multi-nozzle extrusion system for 3D printer." In *2015 International Conference on Informatics, Electronics & Vision (ICIEV)*, pp. 1-5. IEEE, 2015. https://doi.org/10.1109/ICIEV.2015.7333982
[4] Christodoulou, Ioannis, Vasiliki Alexopoulou, and Angelos P. Markopoulos. "Study and Development of a High-Speed Fused Filament Fabrication 3D Printer." In *2023 8th South-East Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM)*, pp. 1-6. IEEE, 2023. https://doi.org/10.1109/SEEDA-CECNSM61561.2023.10470706

[5] Oluwajobi, A. O., and F. O. Kolawole. "Development and evaluation of a Fused Filament Fabrication (FFF) 3-D printer." *Nigerian Journal of Technology* 40, no. 5 (2021): 829-836. https://doi.org/10.4314/njt.v40i5.8
[6] Sargini, M. I. M., S. H. Masood, Suresh Palanisamy, Elammaran Jayamani, and Ajay Kapoor. "Additive manufacturing of an automotive brake pedal by metal fused deposition modelling." *Materials Today: Proceedings* 45 (2021): 4601-4605. https://doi.org/10.1016/j.matpr.2021.01.010
[7] Cano-Vicent, Alba, Murtaza M. Tambuwala, Sk Sarif Hassan, Debmalya Barh, Alaa AA Aljabali, Martin Birkett, Arun Arjunan, and Ángel Serrano-Aroca. "Fused deposition modelling: Current status, methodology, applications and future prospects." *Additive manufacturing* 47 (2021): 102378. https://doi.org/10.1016/j.addma.2021.102378
[8] Ahmad, Mohd Nazri, Mohamad Ridzwan Ishak, Mastura Mohammad Taha, Faizal Mustapha, and Zulkiflle Leman. "Rheological properties of natural fiber reinforced thermoplastic composite for fused deposition modeling (FDM): a short review." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 98, no. 2 (2022): 157-164. https://doi.org/10.37934/arfmts.98.2.157164
[9] Rosli, N. A., M. R. Alkahari, F. R. Ramli, S. Maidin, M. N. Sudin, S. Subramoniam, and T. Furumoto. "Design and development of a low-cost 3D metal printer." *Journal of Mechanical Engineering Research and Developments* 41, no. 3 (2018): 47-54. https://doi.org/10.26480/jmerd.03.2018.47.54
[10] Ahn, Dong-Gyu. "Directed energy deposition (DED) process: state of the art." *International Journal of Precision Engineering and Manufacturing-Green Technology* 8, no. 2 (2021): 703-742. https://doi.org/10.1007/s40684-020-00302-7
[11] Svetlizky, David, Mitun Das, Baolong Zheng, Alexandra L. Vyatskikh, Susmita Bose, Amit Bandyopadhyay, Julie M. Schoenung, Enrique J. Lavernia, and Noam Eliaz. "Directed energy deposition (DED) additive manufacturing: Physical characteristics, defects, challenges and applications." *Materials Today* 49 (2021): 271-295. https://doi.org/10.1016/j.mattod.2021.03.020
[12] Gong, Na, and Hongfei Liu. "Laser-based Process Towards Advanced Manufacturing of Metal Alloys." In *Journal of Physics: Conference Series*, vol. 2510, no. 1, p. 012025. IOP Publishing, 2023. https://doi.org/10.1088/1742-6596/2510/1/012025
[13] Sarvajna Bhat, Madni Faruquee, Shweta Patil, Sudarshan Patil, Asst Prof. ShilpaKatre and Dr. Pradnya Maturkar. “Design And Development Of 3d Printer,” *International Journal of Scientific Research in Engineering and Management*, (2023).
[14] Ali, Md Hazrat, Syuhei Kurokawa, Essam Shehab, and Muslim Mukhtarkhanov. "Development of a large-scale multi-extrusion FDM printer, and its challenges." *International Journal of Lightweight Materials and Manufacture* 6, no. 2 (2023): 198-213. https://doi.org/10.1016/j.ijlmm.2022.10.001
[15] Netto, Joaquim Manoel Justino, Amir Ilkiu Sarout, Andre Luiz Grando Santos, Alessandra de Almeida Lucas, Marcelo Aparecido Chinelatto, Jorge Lino Alves, António Gaspar-Cunha, José António Covas, and Zilda de Castro Silveira. "Design and validation of an innovative 3D printer containing a co-rotating twin screw extrusion unit." *Additive Manufacturing* 59 (2022): 103192. https://doi.org/10.1016/j.addma.2022.103192
[16] Ajao, Kajogbola R., Segun E. Ibitoye, Adedire D. Adesiji, and Esther T. Akinlabi. "Design and Construction of a Low-Cost-High-Accessibility 3D Printing Machine for Producing Plastic Components." *Journal of Composites Science* 6, no. 9 (2022): 265. https://doi.org/10.3390/jcs6090265
[17] Soni, Shivam, and Mohammad Taufik. "Design and assembly of fused filament fabrication (FFF) 3D printers." *Materials Today: Proceedings* 46 (2021): 5233-5241. https://doi.org/10.1016/j.matpr.2020.08.627
[18] Sood, Rishabh, and Sharad K. Pradhan. "Design and development of a low-cost open-source 3D printer and its single response optimization using polylactic acid (PLA) material." *Materials Today: Proceedings* 27 (2020): 2981-2991. https://doi.org/10.1016/j.matpr.2020.04.905
[19] Brathikan, V. M., S. Balasubramanian, S. Kiranlal, and R. Ravi Ragul. "Design and development of large scale FDM based 3D printer." In *Journal of Physics: Conference Series*, vol. 2272, no. 1, p. 012016. IOP Publishing, 2022. https://doi.org/10.1088/1742-6596/2272/1/012016
[20] Hsu, Chang-Hsien. "Process performance analysis and improvement for the manufacture of 6063 aluminum alloy." *Metals* 10, no. 5 (2020): 605. https://doi.org/10.3390/met10050605
[21] Mohd Jafri, Mohamad Azri Haziq, Shahrul Hisyam Marwan, Muhammad Khairudin Mohd Lazim, and Nurul Damia Mohd Anuar. "Finite element analysis of go-kart chassis." *e-Academia Journal* 7 (2018): 127-132. https://doi.org/10.24191/e-aj.v7iSI-TeMIC18.5397
[22] Putra, Faris A., Dena Hendriana, and Hanny J. Berchmans. "Design Improvement and Vibration Analysis of Gantry System using Finite Element Method (FEM)." In *Proceedings of The Conference on Management and Engineering in Industry*, vol. 1, no. 1, pp. 17-21. 2019. https://doi.org/10.33555/cmei.v1i1.11
[23] Sani, M. S. M., N. A. Nazri, S. N. Zahari, N. A. Z. Abdullah, and G. Priyandoko. "Dynamic study of bicycle frame structure." In *IOP Conference Series: Materials Science and Engineering*, vol. 160, no. 1, p. 012009. IOP Publishing, 2016. https://doi.org/10.1088/1757-899X/160/1/012009

[24] Syehan, Aufar, Anjas Trihatmojo Pamungkas, and Danardono Agus Sumarsono. "Static simulation of E-bike tilting three-wheeled frame structure using the finite element method." In *IOP Conference Series: Materials Science and Engineering*, vol. 494, no. 1, p. 012088. IOP Publishing, 2019. https://doi.org/10.1088/1757-899X/494/1/012088