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Parameter Optimization of Fused Deposition Modeling Process for 3D Printed Prosthetic Socket using PCR-TOPSIS Method

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ABSTRACT

Prosthetic socket plays the most important role in lower limb prosthesis. The conventional fabrication process of prosthetic socket is labor intensive and time-consuming. The application of additive manufacturing technology may greatly simplify the process. One of the main concerns on the reliability of 3D printed prosthetic socket is its structural strength due to the various 3D printing parameters that may influence the strength of 3D printed products. Furthermore, most of the previous studies focused on single parameter and the effect on socket strength. Thus, this study aimed to examine the optimization of fused deposition modeling printing parameter of 3D printed prosthetic socket in term of strength, fabrication time and weight. Three FDM printing parameters were studied which included layer height, nozzle diameter and infill percentage. The data was analyzed using Taguchi and PCR-TOPSIS methods. Based on the result, it was concluded that the most effective combination of printing parameter is 1.0 mm nozzle diameter, 0.48 mm layer height and 30% infill percentage. In addition, infill percentage shown the highest influence towards the responsive values followed by layer height and nozzle diameter.

Keywords: Prosthetic socket, fused deposition modelling, 3D printing, PCR-TOPSIS

1. INTRODUCTION

Lower limb prostheses are crucial for amputees to regain their mobility and obtain better life quality. There are two common type of lower limb amputation (LLA) which are transfemoral (above knee) and transtibial (below knee) amputation [1]. The transtibial amputation represented the largest percentage of LLA which accounted for 39%[2–4]. A transtibial prosthesis comprised from three major components which are socket, pylon and foot as shown in Figure 1[5–6]. The socket plays the most important role to transfer the bodyweight from the amputee to the prosthetic leg [6–9]. Every prosthetic socket is customize based on an individual stump shape of amputee to achieve the best fit and comfortability [10]. The design and fit of a socket are important factors in the successful rehabilitation of amputees since every amputee stump is unique[11].

Conventional fabrication process of prosthetic socket is extensive labour intensive and time-consuming [12–13]. It is also highly dependent on the skill and experience of the prosthetist [14–15]. The application of additive manufacturing may greatly simplify the process to produce the prosthetic socket with better fitness using digitized data [16]. However, the strength and

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durability have become one of the main concerns of the three-dimensional (3D) printed prosthetic socket. The 3D printed prosthetic socket must comply with the ISO 10328 international standard where the principal structural strength of lower limb prosthesis is subjected to the required minimum ultimate force for safety assurance.

Figure 1. Prosthetic socket components.

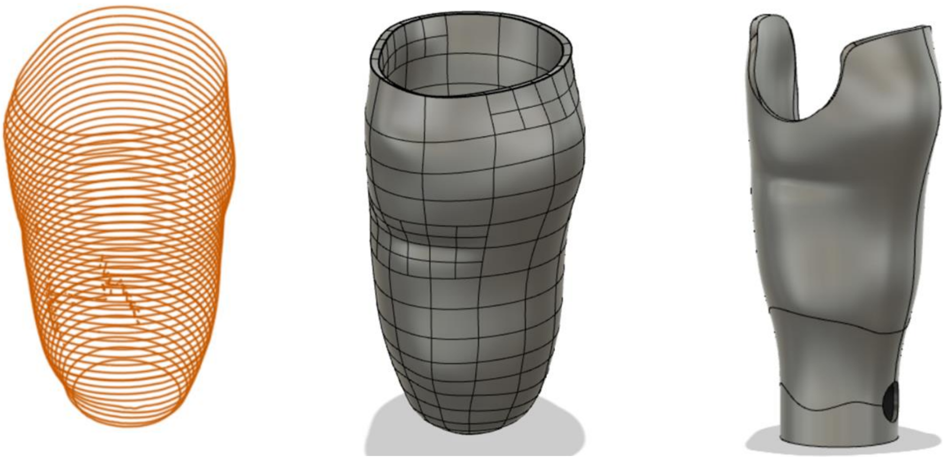
Recent advancement of 3D printing technology has gained increasing interest on 3D printed prosthetic socket. Studies have been conducted to evaluate and improve the strength of 3D printed prosthetic socket [16–18]. Owen *et al*. has evaluated the ultimate failure strength between 3D printed prosthetic socket and conventional prosthetic socket according to ISO 10328 where it was found that 3D printed prosthetic socket posed similar ultimate failure strength with conventional thermoplastic prosthetic socket with only 6% different [18]. In addition, Nickel *et al*. has studied methods to improve the strength of 3D printed prosthetic socket through iterative design process [17]. Nevertheless, the strength of the 3D printed socket is significantly influenced by the printing parameter particularly printing infill percentage [16, 19]. However, most of the previous studies focused on single parameter and the effect on socket strength. While the 3D printing process is influenced by series of parameter and there are also other important criteria for a 3D printed prosthetic socket such as fabrication time and socket weight. Thus, this research studied on the optimization of printing parameters including infill percentage, layer height and nozzle diameter to obtain satisfactory 3D printed socket in terms of strength, fabrication time and weight using PCR-TOPSIS method.

Although Taguchi method is the most common analysis method used in process parameter optimization. it was limited to one response value only and not suitable for multiple response analysis [20]. Hence, Liao had proposed a multi-response prediction model based on the process capability ratio (PCR) theory and the theory of order preference by similarity to the ideal solution (TOPSIS) to optimise the multi-response problem effectively using the Taguchi method. The method was acknowledged as PCR-TOPSIS method and has been widely applied in optimizing process parameter for various manufacturing process such as computer numerical control (CNC) and additive manufacturing process[21, 22]. Thus, the most effective combination of printing parameter to achieve the optimal strength, fabrication time and weight of 3D printed prosthetic socket was determined using PCR-TOPSIS method in this research.

2. MATERIAL AND METHODS

2.1 Sample Preparation

The digital geometrical data of an amputee stump was obtained from Tun Razak Rehabilitation Centre Malaysia (TRRC) using a hand-held 3D scanner. The mesh model of the amputee stump was then used to develop a 3D geometrical model of the stump and finally constructed a prosthetic socket using Autodesk Fusion 360 software as shown in Figure 2. Subsequently, the 3D model of prosthetic socket was exported to Cura 3D printing software in STL format. Ender 5 plus 3D printer was utilized to fabricate the socket using poly lactic acid (PLA) material with thickness ranging from 2 mm to 6 mm with an increment of 1 mm to determine the optimum thickness for the parametric study.



(a) (b (c)

Figure 2. (a) 3D mesh model (b) 3D model of stump (c) 3D model of socket.

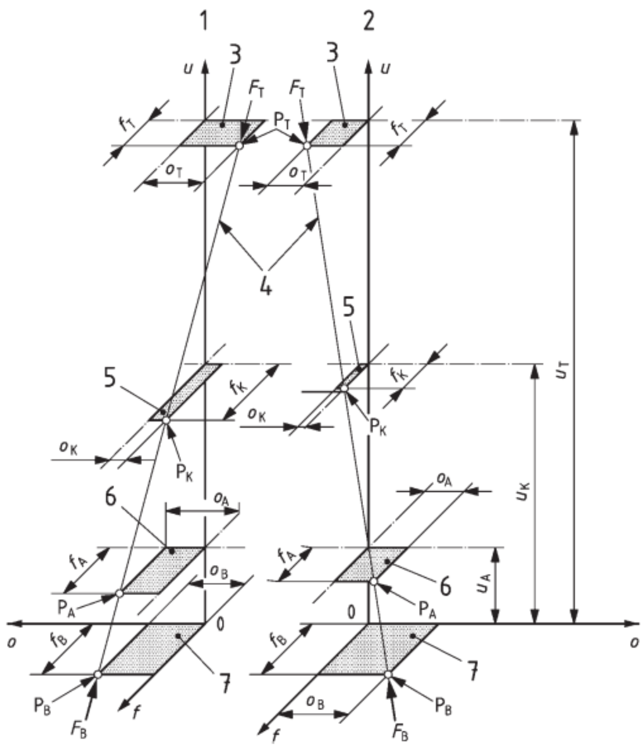
Based on the optimum thickness of the socket, nine sets of sockets with different printing parameter combination were prepared according to Taguchi method L9 orthogonal array as tabulated in Table 1. The fabrication time and weight of each socket was recorded using Cura 3D printing software.

Table 1 Printing Parameter Combination According to Taguchi L9 Orthogonal Array

Parameter	Nozzle Diameter, mm	Layer Height, mm	Infill Percentage %
1	0.6	0.3	30
2	0.6	0.4	60
3	0.6	0.48	100
4	0.8	0.3	60
5	0.8	0.4	100
6	0.8	0.48	30
7	1	0.3	100
8	1	0.4	30
9	1	0.48	60

2.2 Prosthetic Leg Structural Test

The structural test of the prosthetic leg was conducted to examine the strength of the 3D printed socket according to ISO 10328:2016 standard. In the present study, loading condition II was applied since it produces larger moment at the distal end of the socket compared to loading condition I [17]. Based on the standard, the test was subjected to a specific configuration as shown in Figure 3.



Key

1	right leg	5	knee reference plane, K	P_T	top load application point
2	left leg	6	ankle reference plane, A	P_K	knee load reference point
3	top reference plane, T	7	bottom reference plane, B	P_A	ankle load reference point
4	load line			P_B	bottom load application point

Figure 3. Testing configuration in ISO 10328:2016 standard.

The structural static test was performed using Shimazu AGS-X universal testing machine to determine the ultimate failure force of the 3D printed socket. The load was applied between 100 N/s to 250N/s until socket failure was observed. Figure 4 shows the experimental test set-up for lower limb prosthetic leg according to ISO 10328:2016 standard.

Figure 4. Experimental set-up of lower limb prosthetic leg structural test.

2.3 Taguchi and PCR-TOPSIS Analysis

The Taguchi method was employed to compute signal-to-noise ratio (SNR) of the ultimate force, printing time and socket weight. SNR was used to identify the level of suitability for each factor that was calculated in different methods based on the type of characteristic such as larger-the-better and smaller-the-better [23]. Equation (1) and (2) were employed to compute the SNR value for smaller-the-better and larger-the-better respectively.

$$\eta_j^i = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{l} y_j^i\right], 0 \le y_j^i < \infty \quad (1)$$

$$\eta_j^i = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{l} \frac{1}{y_j^i}\right], 0 \le y_j^i < \infty \quad (2)$$

where y_j^i = observed data for the *j*th response at the *i*th trial.
n = number of replications

The optimum solution for multi-response of FDM printing parameter was then determined using the PCR-TOPSIS method. In PCR-TOPSIS method, the SNR was converted into dimensionless PCR value to examine the ability of printing parameters to produce product that meets specification [24]. The formula to calculate PCR of SNR in the *j*th response at the *i*th trial was demonstrated in Equation (3).

$$C_j^i = \frac{\eta_j^i - \bar{x}_{\eta_j}}{3s_{\eta_j}} \quad (3)$$

where $\bar{x}_{\eta_j}$ is the sample mean for SNR in the *j*th response and s_{η_j} is the sample standard deviation for SNR in the *j*th response given as

$$\bar{x}_{\eta_j} = \frac{\sum_{i=1}^{m} \eta_j^i}{m-1} \quad (4)$$

$$s_{\eta_j} = \sqrt{\frac{\sum_{i=1}^{m} (\eta_j^i - \bar{x}_{\eta_j})^2}{m-1}} \quad (5)$$

Subsequently, TOPSIS was calculated from the PCR of SNR to identify the relative closeness of each trial to the ideal solution. Equation (6) and (7) calculated the distance of *i*th trial from the positive and negative ideal solution respectively. The preferred alternative solution was the one which closest to the positive ideal solution and furthest away from the negative ideal solution [20].

$$d^{i^+} = \sqrt{\sum_{j=1}^{n}(C_j^i - C_j^+)^2} \; , for\ i = 1, \dots , m \tag{6}$$

$$d^{i^-} = \sqrt{\sum_{j=1}^{n}(C_j^i - C_j^-)^2} \; , for\ i = 1, \dots , m \tag{7}$$

provided that $C_j^+(C_j^-) = \max(\min)\{C_j^i, for\ i = 1, 2, \dots , m\}$

PCR-TOPSIS value was finally computed to determine the combination of optimum printing parameter defined in Equation (8). The main effect was then plotted through the connection of mean PCR-TOPSIS value of each level of parameters.

$$S^i = \frac{d^{i^-}}{d^{i^+} + d^{i^-}} \tag{8}$$

3. RESULTS AND DISCUSSION

3.1 Optimum Thickness of Prosthetic Socket

Figure 5 shows the ultimate failure force of the 3D printed sockets with different thickness from 2 mm to 6 mm. According to ISO 10328 standard, the minimum requirement of the ultimate force for a lower limb prosthetic leg is 5250 N. It was observed that the minimum 3 mm thickness was the minimum thickness to achieve the standard required with 5700 N ultimate force prior to failed and fractured. In the previous study, it was found that the prosthetic component may experience structural failure at loading above 6462 N with minimum socket thickness of 4 mm [18]. Thus, subsequent further experiment was carried out using 3 mm thickness of the 3D printed socket to perform printing parametric and optimization study.

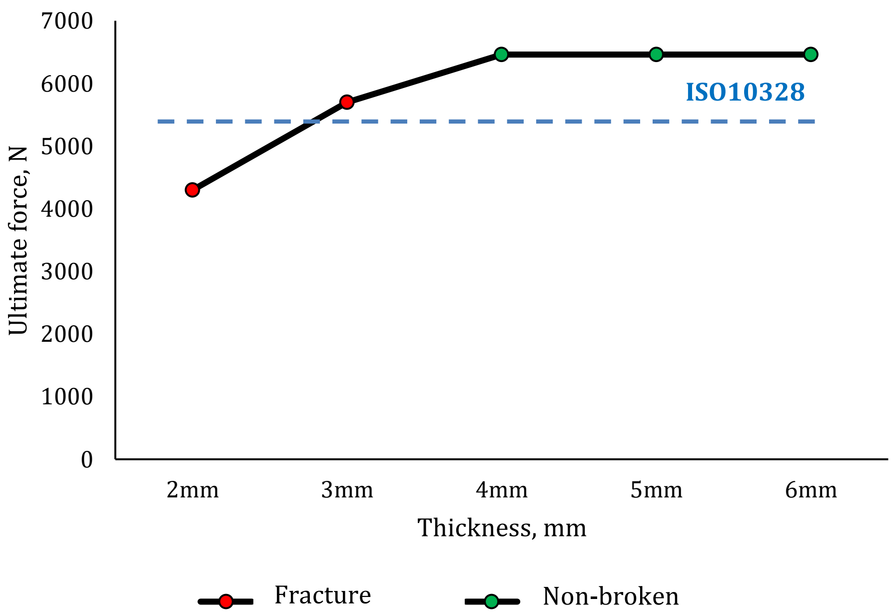


Figure 5. Ultimate force of 3D printed socket at different thickness.

3.2 3D Printing Parametric Study

The result obtained for the strength, fabrication time and weight were tabulated as shown in Table 2. The average ultimate force was 5.71 kN which was comparable with previous study with average force of 5.5 + 0.3 kN using the test loading condition II [25].

Based on the results, it was observed that for socket printed with same nozzle diameter, the ultimate strength of the product increased with the increase in infill percentage. Generally, the socket printed with 0.8 mm nozzle diameter shown higher ultimate force compared to socket that was printed with 0.6 mm nozzle diameter. This is due to the thicker and stronger extrusion using larger nozzle diameter which lead to the increase in product strength [26]. However, sockets that were printed with 1.0 mm nozzle diameter shows lower strength than sockets printed with 0.6 mm and 0.8 mm nozzle diameters. This may be due to the smaller number of shells and more voids were produced with 1 mm nozzle diameter compared to other nozzle diameters as shown in Figure 6. The red, green, and yellow line corresponded to outer shell, inner shell, and infill structure respectively. It was observed that the socket printed with 0.6 mm and 0.8 mm nozzle diameters constructed both outer shell and inner shells while the socket printed with 1 mm nozzle diameter has only outer shell. Similar findings was also found in previous study where the increment of shells will increase the strength of FDM product [27]. In addition, higher strength will be achieved for infill pattern that created less hole or void [26]. Since socket printed with 1 mm socket showed similar internal structure at different infill percentage level, it was observed that the socket strength decreased with the increased in layer height.

Table 2 Experimental Result of Printing Parametric Study

Parameter	Nozzle Diameter, mm	Layer Height, mm	Infill Percentage, %	Ultimate Force, N	Fabrication Time, hours	Weight, g
1	0.6	0.3	30	5256.16	18.30	367
2	0.6	0.4	60	5556.45	18.08	489
3	0.6	0.48	100	6224.87	21.55	636
4	0.8	0.3	60	6352.75	19.87	518
5	0.8	0.4	100	6763.45	20.27	641
6	0.8	0.48	30	6073.81	11.40	432
7	1	0.3	100	5932.99	22.13	647
8	1	0.4	30	4817.21	12.30	482
9	1	0.48	60	4386.19	12.27	558

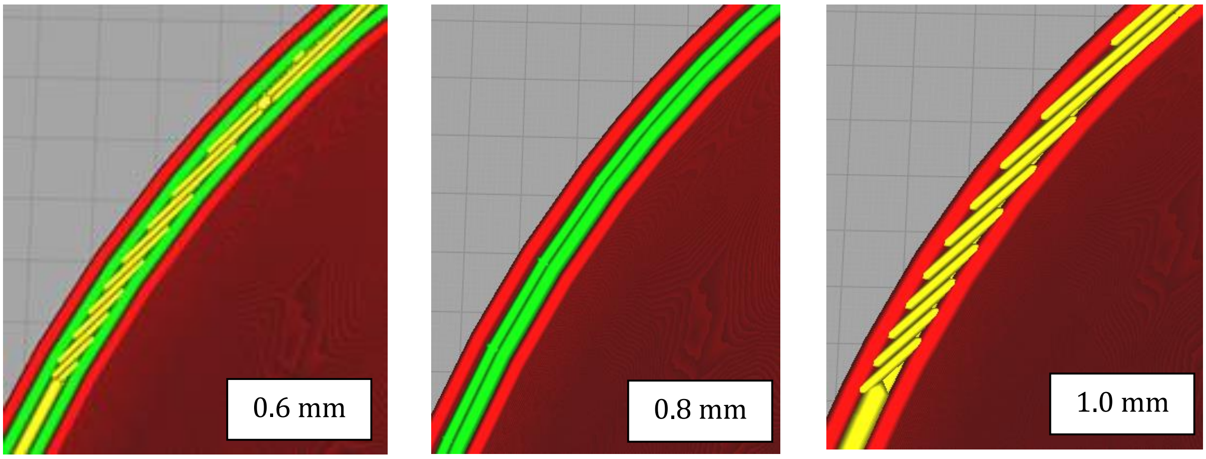


Figure 6. Internal structure for socket printed with different nozzle diameter.

A significant of 46% percentage difference was observed in the fabrication time of 3D printed prosthetic socket ranging from 11.40 hours to 21.30 hours. The shortest fabrication was attained by parameter 6 with minimum infill percentage of 30% and maximum layer height of 0.48 mm. Lower infill percentage may lead to shorter printing time as less material was deposited while greater layer height may decrease the total number of layers that have to be printed. The longest fabrication time was observed in parameter 3 with highest infill percentage of 100% and smallest nozzle diameter of 0.6 mm. The building time typically prolonged at higher infill percentage level due to increased amount of material deposited and total extrusion path length[28].

The infill percentage shown significant influence toward the weight of the socket. The weight of the sockets printed with 100% infill percentage were higher than 600 g. The lightest printed socket was observed in parameter 1 with minimal infill percentage, nozzle diameter and layer height. Generally, higher infill percentage may result in heavier 3D printed product due to the increased of density. In addition, the bigger nozzle diameter allowed for higher volume of molten material deposited per extrusion and enhance the product density which may contribute to the increase in product mass [26].

3.3 Taguchi and PCR-TOPSIS Analysis

The SNR was computed for each experiment as a quality indicator for the printing parameter. The SNR analysis for the ultimate force response was conducted such that higher value was always desirable. In contrary, the SNR analysis for the fabrication time and weight response was based on lower value was always preferable. Based on the SNR, PCR value was calculated for each experiment to determine whether the printing parameter was within the specification tolerance as shown in Table 3.

Table 3 Result of SNR and PCR-SNR

Parameter	SNR			PCR-SNR		
	Ultimate Force	Fabrication Time	Weight	Ultimate Force	Fabrication Time	Weight
1	74.41	-25.25	-51.29	-0.33	0.20	0.44
2	74.89	-25.15	-53.79	-0.32	0.21	0.33
3	75.87	-26.67	-56.07	-0.28	0.08	0.23
4	76.06	-25.96	-54.29	-0.28	0.14	0.31
5	76.60	-26.14	-56.14	-0.26	0.12	0.23
6	75.67	-21.14	-52.71	-0.29	0.54	0.38
7	75.46	-26.90	-56.22	-0.30	0.06	0.22
8	73.66	-21.80	-53.66	-0.36	0.49	0.34
9	72.84	-21.77	-54.93	-0.39	0.49	0.28

Further printing parameter evaluation was performed using PCR-TOPSIS as shown in Table 4. Based on the results, parameter 6 is the most ideal combination where lowest d^{i^+} and highest d^{i^-} values were observed where it indicated the closest with positive ideal solution and furthest away from negative ideal solution. The PCR-TOPSIS value was used as a reference to determine the optimal condition of parameter setting.

Table 4 Result of PCR-TOPSIS

Parameter	d^{i^+}	d^{i^-}	PCR-TOPSIS
1	0.35	0.27	0.43
2	0.36	0.20	0.35
3	0.51	0.10	0.17
4	0.43	0.16	0.27
5	0.47	0.14	0.23
6	0.07	0.52	0.88
7	0.53	0.09	0.14
8	0.15	0.44	0.74
9	0.21	0.43	0.67

Subsequently, the mean value of PCR-TOPSIS for each parameter level was calculated as shown in Table 5. The optimum condition was achieved at the combination of parameter levels with the highest average value. Based on the results, it was observed that nozzle diameter at level 3, layer thickness at level 3, and infill percentage at level 1 shown the highest mean value compared to other levels. Thus, the optimum condition to produce the 3D printed socket could be achieved at combination of 1.0 mm nozzle diameter, 0.48 mm layer thickness and 30% infill percentage.

Table 5 Optimum Condition

	Nozzle Diameter	Layer Thickness	Infill Percentage
Level 1	0.3173	0.2811	0.6837
Level 2	0.4600	0.4412	0.4316
Level 3	0.5173	0.5724	0.1794
Difference	0.2001	0.2912	0.5043
Ranking	3	2	1
Optimum level	3	3	1

The main effect was plotted based on the PCR-TOPSIS results as shown in Figure 7. The printing parameter with larger difference between maximum and minimum PCR-TOPSIS mean value shown higher influence toward the test result. Hence, infill percentage was found to be the most significant printing parameter as the steepest slope was observed. On the contrary, nozzle diameter was the least significant parameter due to the smallest difference between the peak and lowest value.

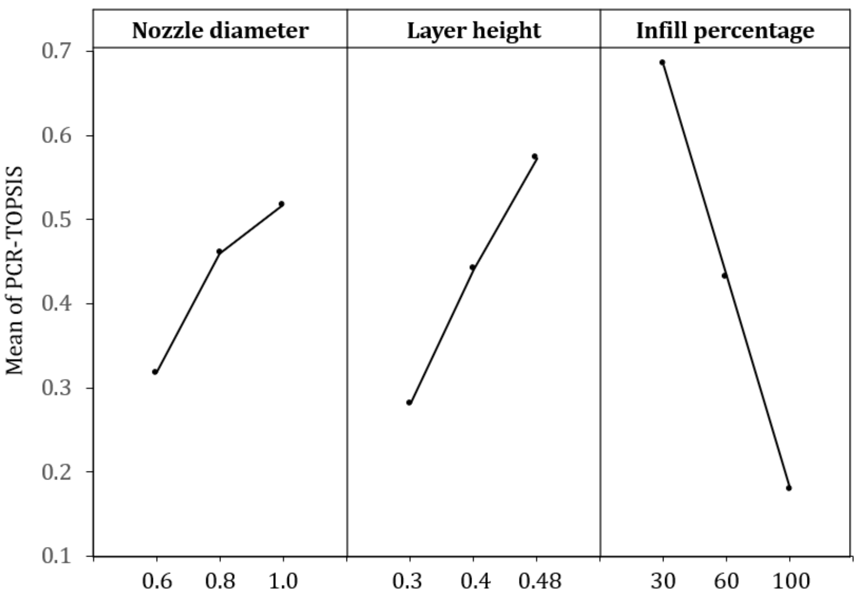


Figure 7. Main effect plot.

4. CONCLUSION

The present study has examined the effect of selected FDM parameter including nozzle diameter, layer thickness and infill percentage to produce a 3D printed prosthetic socket. The structural test of prosthetic leg or lower limb was conducted at loading condition II according to ISO 10328:2016 standard. The results were optimized using Taguchi and PCR-TOPSIS methods to examine the significance of each printing parameter. It was concluded that the optimum parameter combination is 1.0 mm nozzle diameter, 0.48 mm layer thickness and 30% infill percentage. In addition, infill percentage is the most significant parameter while layer thickness ranked the second and nozzle diameter is the least influential parameter.

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REFERENCES

[1] Allen, A., Bolton, W., Jalloh, M., Halpin, S., Jayne, D., Scott, J., "Barriers to accessing and providing rehabilitation after a lower limb amputation in Sierra Leone–a multidisciplinary patient and service provider perspective," Disability and Rehabilitation, (2020) pp. 1–8.

[2] M. Mahdi, A. Razak, M. Z. Tauhid, N. F. Yasin, A. Hanapiah, "Quality of life among lower limb amputees in Malaysia," in Procedia - Social and Behavioral Sciences, (2016) pp. 450–457.

[3] Esquenazi, A., "Amputation rehabilitation and prosthetic restoration. From surgery to community reintegration," Disability and Rehabilitation, vol **26**, issue 14/15 (2004), pp. 831–836.

[4] A. M. Takhakh, S. M. Abbas, and A. K. Ahmed, "A study of the mechanical properties and gait cycle parameter for a below-knee prosthetic socket," in IOP Conference Series: Materials Science and Engineering, (2018) pp. 1–8.

[5] Balioti, V., Tzimopoulos, C., Evangelides, C., "Multi-criteria decision making using Topsis method under fuzzy environment. Application in spillway selection," Proceedings, vol **2**, issue 637 (2018) pp. 1–8.

[6] M. J. Jweeg, Z. S. Hammoudi, B. A. Alwan, "Optimised analysis, design, and fabrication of trans-tibial prosthetic sockets," in IOP Conference Series: Materials Science and Engineering, (2018), pp. 1–13.

[7] Ballit, A., Mougharbel, I., Ghaziri, H., Dao, T., "Fast soft tissue deformation and stump-socket interaction toward a computer-aided design system for lower limb prostheses," IRBM, vol **41**, issue 5 (2020) pp. 276–285.

[8] Ahmed, M., Abd-alrahman, M., Abdallah, M., Zarog, M., "Materials investigation for lower limb prosthetic socket," International Journal of Mechanical and Industrial Technology, vol **6**, issue 1 (2018) pp. 18–22.

[9] Stevens, P., Depalma, R., Wurdeman S., "Transtibial socket design, interface, and suspension: A clinical practice guideline," Journal of Prosthetics and Orthotics, vol **31**, issue 3 (2019) pp. 172–178.

[10] Ballit, A., Mougharbel, I., Ghaziri, H., Dao, T., "Computer-aided parametric prosthetic socket design based on real-time soft tissue deformation and an inverse approach," Visual Computer, (2021) pp. 1-19.

[11] Keszler, M., Heckman, J. T., Kaufman, G., Morgenroth, D., "Advances in prosthetics and rehabilitation of individuals with limb loss," Physical Medicine and Rehabilitation Clinics of North America, vol **30**, issue 2 (2019) pp. 423–437.

[12] C. Nayak, A. Singh, and H. Chaudhary, "Customised prosthetic socket fabrication using 3D scanning and printing," in Additive Manufacturing Society of India, (2014) pp. 1–10.

[13] Ng, P., Lee, P., Goh, J., "Prosthetic sockets fabrication using rapid prototyping technology," Rapid Prototyping Journal, vol **8**, issue 1 (2002) pp. 53–59.

[14] Laing, S., Lythgo, N., Lavranos, J., Lee, P., "Transtibial prosthetic socket shape in a developing country: A study to compare initial outcomes in pressure cast hydrostatic and patella tendon bearing designs," Gait Posture, vol **58**, (2017) pp. 363–368.

[15] Rankin, K., et al., "Developing an analogue residual limb for comparative DVC analysis of transtibial prosthetic socket designs," Materials, vol **13**, issue 18 (2020) pp. 1–15.

[16] Pousett, B., Lizcano, A., Raschke, S., "An investigation of the structural strength of transtibial sockets fabricated using conventional methods and rapid prototyping techniques," Canadian Prosthetics & Orthotics Journal, vol **1**, issue 2 (2019) pp. 1–8.

[17] Nickel, E., Barrons, K., Owen, M., Hand, B, Hansen, A., Desjardins, J.," Strength testing of definitive transtibial prosthetic sockets made using 3D-printing technology," Journal of Prosthetics and Orthotics, vol **32**, issue 4 (2020) pp. 295–300.
[18] Owen M., Desjardins J., "Transtibial prosthetic socket strength: the use of ISO 10328 in the comparison of standard and 3D-printed sockets," Journal of Prosthetics and Orthotics, vol **32**, issue 2 (2020) pp. 93–100.
[19] Aifaa, W., Fadzil, W., Mazlan, M., Abdullah, A., Hanapiah, F., Pangesty, A., "Effects of infill density on 3D printed socket for transtibial prosthetic leg," Journal of Mechanical Engineering, vol **9**, issue 1 (2020) pp. 229–238.
[20] Liao, H., "Using PCR-TOPSIS to optimise Taguchi's multi-response problem," International Journal of Advanced Manufacturing Technology, vol **22**, (2003) pp. 649–655.
[21] S. P. Bhise, P. D. Pantanwane, B. Rajiv, "Optimisation of hard turning of M42 tool steel using PCR-TOPSIS method," in All India Manufacturing Technology, Design and Research Conference, (2014) pp. 3–8.
[22] A. Rinanto, A. Nugroho, H. Prasetyo, E. Pujiyanto, "Simultaneous optimization of tensile strength, energy consumption and processing time on FDM process using Taguchi and PCR-TOPSIS," in International Conference on Science and Technology, (2018) pp. 1–5.
[23] Subbaraj, P., Rengaraj, R., Salivahanan, S., "Enhancement of self-adaptive real-coded genetic algorithm using Taguchi method for economic dispatch problem," Applied Soft Computing Journal, vol **11**, issue 1 (2011) pp. 83–92.
[24] Prabhuswamy, P., Nagesh, M., "Process capability analysis made simple through graphical approach," Kathmandu University Journal of Science, Engineering and Technology, vol **1**, issue 3 (2007) pp. 1–10.
[25] Irawan A., Sukania, I., "Gait analysis of lower limb prosthesis with socket made from rattan fiber reinforced epoxy composites," Asian Journal of Applied Sciences, vol **3**, issue 1 (2015) pp. 8–13.
[26] Triyono, J., Sukanto, H., Saputra, R., Smaradhana, D., "The effect of nozzle hole diameter of 3D printing on porosity and tensile strength parts using polylactic acid material," Open Engineering, vol **10**, issue 1 (2020) pp. 762–768.
[27] A. J. Qureshi, S. Mahmood, W. L. E. Wong, and D. Talamona, "Design for scalability and strength optimisation for components created through FDM process," in International Conference On Engineering Design, (2015) pp. 1–12.
[28] Abbas, T., Othman, F., Ali, H., "Effect of infill parameter on compression property in FDM process," International Journal of Engineering Research and Application, vol **7**, issue 10 (2017) pp. 16–19.