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# Optimization of Stroke Rehabilitation Hand Component of 3D Printing With Taguchi Method Approach

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## ABSTRACT

3D Printing commonly is known as additive manufacturing. It works by adding layer by layer resulting in a three dimensional shape. Using color change filament materials are safe to use for medical purposes. The parameters used in this study are layer height, print speed and print temperature. The most percentage of contributions is affected in the taguchi experiment of dimensional accuracy namely; layer height (51.196%), and Brinell Hardness Number namely; print speed (61.097%). The optimal parameters resulting of the taguchi experiment's dimensional accuracy are layer height (0,10 mm), print speed (40 mm/s) and print temperature (195°C). The optimal parameters resulting of Brinell Hardness Number are layer height (0,10 mm), print speed (20 mm/s) and print temperature (205°C).

**Keywords:** 3D Printing, layer height, print speed, dimensional

## 1 | INTRODUCTION

The causes of stroke are different among the countries, however, the largest are developed countries, especially Russia, Eastern European countries, and East Asian countries in 2013. The ranging is from 11.6% to 12.7% in North Korea, Macedonia, Bulgaria, and Georgia, while from 8.4% to 9.7% in China and Indonesia [1]. Stroke patients are required to follow rehabilitation programs, which consist of repetitive task practice (RTP) in order to restore their hand function [2]. Rehabilitation is a program set to people with physical disabilities or chronic diseases, so they can live or work with their capacity [3]. Therefore, robotic devices such as exoskeletons are use to assist with repetitive hand movements as an alternative to physiotherapist assisted program [4]. These devices do not only to reduce the therapist workload, but also help to improve therapy conditions for the patients. Experimental studies have confirmed that the used of robotic systems for post stroke and post trauma physical therapy under doctor supervision improves motor functions of the patients [5].

The 3D printing is used produce the part with different way compare with the traditional. It can be considered as the best possible method to the

manufacturing process. It can the physical realization of a 3D computer aided design (CAD) model by implementing the layer by layer addition of materials, thus producing a 3D physical object with the same structure as the digital model [6]. The 3D printing technology is attractive for many applications: namely; the research field for prototyping or for a limited production of prototypes; (ii) in medicine to create 3D biomedical structures using digital models obtained with different medical imaging techniques ie. computer tomography, magnetic resonance imaging, ultrasound, prototyping industry and automotive part manufacturing [7]. Material of 3D printing is used additive processing, that are control with computer control. These objects is produced with a 3D modelling or other electronic data source. The Poly Lactic Acid (PLA) is most common 3D printed filament used in FDM machine. It is generally produced from PLA and a bio degradable filament. It is also very easy to print which doesn't require heated bed [8] then, it is also one of the semicrystalline thermoplastic that has been a growing potential in FDM filament material [9].

Before, we produce part that should know the parameters and the number of experiment needed can be considered as the best possible method to the

problem in industrial [10]. The parameter design is an optimized part of the Taguchi method and is often used to improve the product and process design [11, 12] and the Taguchi method also is one of a design of experimental (DOE) that is to calculate a set of design variables in such a manner, then analyzed result with superior to all other possible design variants [13 and 14]. The purpose of this research is to obtain 3D printing product that is better in a size according to the design and strong structural.

## 2. PART DESIGN AND ANALYSIS

The material color change filament is used in this study that have performance similar with PLA. It is non-toxic, environment-friendly, and excellent printing performance. Then, printed into components using The 3D Printer Fused Deposition Modeling (FDM) with Cartesian type is used in this study. The shape and dimensions of the part are shown in figure 1.

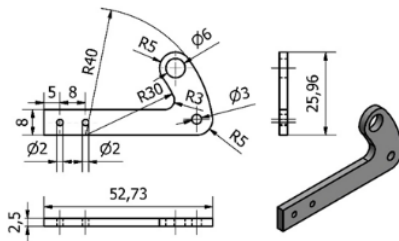


Figure 1. Dimensions of part

### 2.1. Processing Window

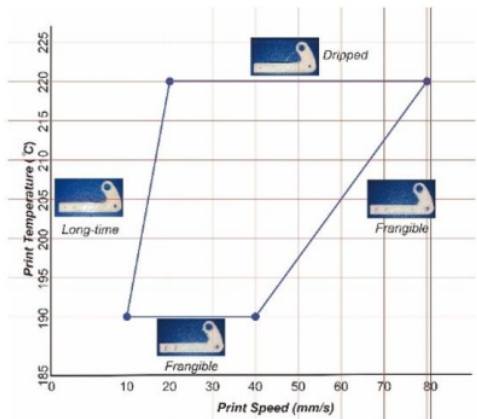


Figure 2. Print Temperature vs Print Speed

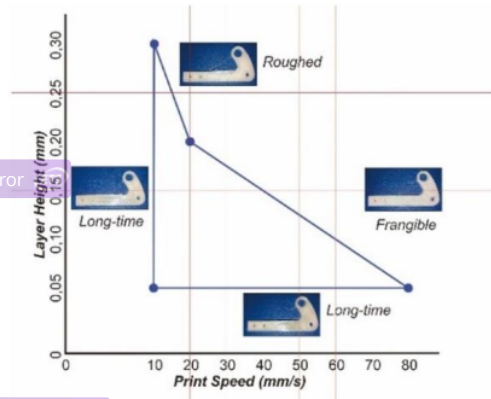


Figure 3. Layer Height vs Print Speed

By using a series of trial experiment is created processing window (Figure 2 and 3), that the result of is used to select parameters and level of Taguchi experiment. In this study we choose; Layer heights (LH) are 0.05 mm, 0.10 mm, 0.15 mm; Print Speeds (PS) are 20 mm/s, 30 mm/s, 40 mm/s; and Print Temperature (PT) 195°C, 210°C, 215°C.

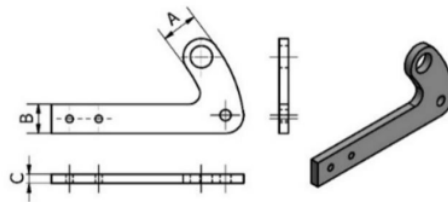


Figure 4. Dimensional accuracy

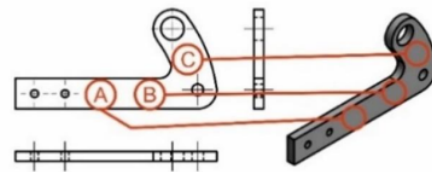


Figure 5. Hardness test area

The dimension accuracy (DA) is measured with the actual part reduced design part. The location of measurement shown in Figure 4. The dimension accuracy (DA) of each dimension can be calculated by the following equation:

$$DA = \frac{\text{Actual Part} - \text{Design Part}}{\text{Design Part}} \times 100\% \quad (1)$$

where Design Part (mm) is the design dimension and Actual Part (mm) is the dimension measured from the specimen or printing result from 3D Printer. The averaged dimensional accuracy of the measurements is calculated. Then, the hardness test is determined to get the strength of the structure of product. The Brinnell Hardness Number (HBN) is used in this study, then the position of measurement can be seen in Figure 5. The Brinnell Hardness Number (BHN) can be calculated by the following equation:

$$BHN = \frac{2P}{\pi \times D(D - \sqrt{D^2 - d^2})} \quad (2)$$

Where Brinnell Hardness Number (BHN), P (kg) is a load of indenter, D (mm) is diameter of indenter and dr (mm) is result of indenter diameter and surface. The

averaged brinell hardness number of the measurements is calculated. Sp.

### 3. RESULT AND DISCUSSION

#### 3.1 Dimensional Accuracy (DA) Result

Dimensional Accuracy (DA) were considered as the performance quality characteristics with the concept of smaller the better. The dimensional accuracy of the nine runs can be seen in Table 1. The results indicated that the sixth run demonstrated the best performance.

Table 1. Results of the sum average of dimensional accuracy and the S/N ratio

No. Eks	LH (mm)	PS (mm/s)	PT (°C)	Dimensional Accuration (%)			Ave.DA	S/N Ratio
				DA <sub>1</sub>	DA <sub>2</sub>	DA <sub>3</sub>		
1	0.5	20	195	1,525	1,633	1,192	1,450	-3,227
2	0.5	30	205	0,917	1,492	0,783	1,064	-0,539
3	0.5	40	215	0,750	1,050	1,008	0,936	0,574
4	0.1	20	205	0,475	0,758	0,550	0,594	4,519
5	0.1	30	215	0,767	0,875	0,825	0,822	1,699
6	0.1	40	195	0,392	0,258	0,375	0,342	9,328
7	0.15	20	215	1,100	1,033	1,050	1,061	-0,514
8	0.15	30	195	0,467	0,508	0,633	0,536	5,417
9	0.15	40	205	0,650	0,783	1,133	0,856	1,357

Table 2. The ANOVA for Dimensional Accuration (DA)

Factors		LH	PS	PT	Error	Total
Sum of Factor Levels	1	-3,192	0,778	11,517	-0,171	
	2	15,546	6,577	5,338	8,275	18,614
	3	6,260	11,260	1,759	10,511	
Sum of Squares of Differences		526,688	165,431	146,212	190,428	1028,759
Degrees of Freedom		2	2	2	2	8
Percentage Contribution Ratio		51,196	16,081	14,212	18,510	
Cumulative Contribution Ratio		51,196	67,277	81,490	100	
Optimum Levels		A2	B3	C1		

The contributions of the factors are Layer Height 51,196%, Print Speed 16,081% and Print Temperature 14,212% as shown in Table 2. Layer Height is the dominant factor in the measuring dimensional accuracy on product part.

From the response graph Figure 6, the best parameter combination is able to be calculated by choosing the level with the highest value of each factor, and that is LH2PS3PT1 which corresponds to the Layer height 0.10 mm, Print speed 40 mm/s, Print temperature 195°C.

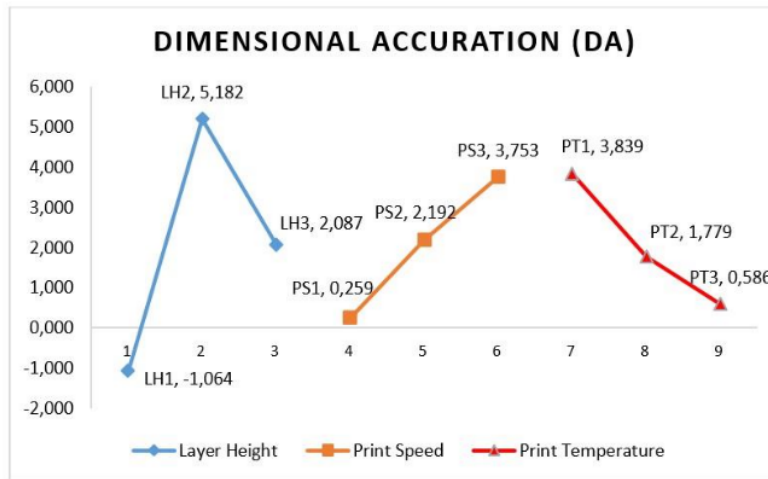


Figure 6. The Effect Plot for SN Ratios Dimensional Accuracy

### 3.2. The Brinell Hardness Number Test

The Brinell Hardness Number (BHN) were considered as the performance quality characteristics

with the concept of larger the better. The BHN of the nine runs are listed in Table 3. The results indicated that the fourth run demonstrated the best performance.

Table 3. Results of the sum average of hardness test and the S/N ratio

No. Eks	Frag.	LH (mm)	PS (mm/s)	PT (°C)	BHN (Kg/mm <sup>2</sup> )			Ave. BHN	S/N Ratio
					BHN <sub>1</sub>	BHN <sub>2</sub>	BHN <sub>3</sub>		
1		0.5	20	195	6,607	9,427	8,589	8,208	18,284
2		0.5	30	205	7,021	7,987	7,871	7,626	17,646
3		0.5	40	215	6,505	5,329	4,881	5,571	14,920
4		0.1	20	205	11,710	12,026	11,169	11,635	21,315
5		0.1	30	215	5,063	7,572	7,135	6,590	16,378
6		0.1	40	195	5,452	4,574	4,532	4,853	13,720
7		0.15	20	215	6,576	5,840	6,536	6,317	16,011
8		0.15	30	195	4,366	5,372	6,043	5,261	14,420
9		0.15	40	205	3,710	4,788	3,715	4,071	12,194

These results in Table 4 show that the layer height 27.07%, print speed 61.09%, print temperature 7.08% as the influence factor for BHN. This proves that print speed, layer height, and print temperature are the most

significant parameters contribute to improving BHN in the process while print temperature only have small effect towards the BHN.

Table 4. The ANOVA for Brinell Hardness Number (BHN)

Factors		LH	PS	PT	Error	Total
Sum of Factor Levels	1	50,850	55,610	46,424	46,856	144,888
	2	51,413	48,444	51,516	47,377	
	3	42,625	40,833	47,308	50,655	
Sum of Squares of Differences		145,197	327,641	37,971	25,454	536,264
Degrees of Freedom		2	2	2	2	8
Percentage Contribution Ratio		27,076	61,097	7,081	4,747	
Cumulative Contribution Ratio		27,076	88,173	95,253	100	
Optimum Levels		A2	B1	C2		

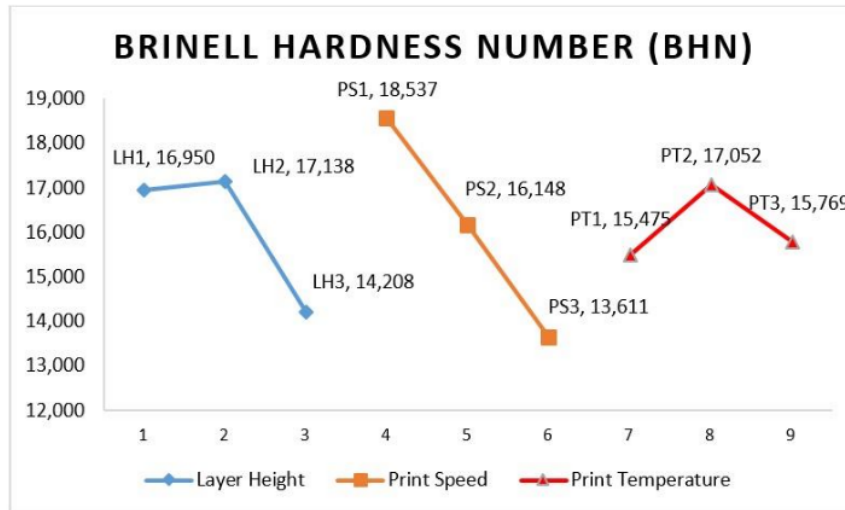


Figure 7. Main Effect Plot for SN Ratios Brinell Hardness Number

The best parameter combination is able to be calculated by choosing the level with the highest value of each factor, and that is LH2PS1PT2 which corresponds to the Layer height 0.10 mm, Print speed 20 mm/s, Print temperature 205°C as can be seen in the response graph figure 5.

Since, the result of the Taguchi experiment above is the optimal process parameters suggested from dimensional accuracy and brinell hardness number are shown in Table 5.

Table 5. Confirmation experiments for taguchi

Method	Responses	Optimum Levels	Average Experimental Values	
			DA (%)	BHN (Kg/mm <sup>2</sup> )
Taguchi	Dimensional Accuracy	A <sub>2</sub> B <sub>3</sub> C <sub>1</sub>	0,203	4,862
Taguchi	Brinell Hardness Number	A <sub>2</sub> B <sub>1</sub> C <sub>2</sub>	0,647	11,537

#### 4. CONCLUSION

In conclusion, dimensional changing occurs in all products 3D printing for many reasons. However, the question is how these defects can be reduced and which parameters are dominant in this process. However, it is significant to understand and calculate the cause and effect of these defects. Since, it will be improved

completely by optimizing some process parameters using the Taguchi method. The current studies have obtained considerable results to know the relationship between them. Layer height, print speed, and print temperature are some of the major molding parameters influence the product dimensional changing. During the printing process, the dimension of product is very small, therefore, it is hard to avoid to minimize the changing. Besides, measuring the BHN was not get accurate number, thus the error happens during the measuring process. The experimental results support the proposed approach which not only minimize the dimensional changing of the product of 3D printing process but also improves the quality of the hardness of product.

#### ACKNOWLEDGMENT

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