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Application of RSM Method in Biocomposite Materials (Polymethyl-Methacrylate/Hydroxyapatite) Tension Strength Optimization ~~of~~ by 3D Printing Machine Process ~~Parameters Using Biocomposite Materials (PMMA/Hydroxyapatite) to Get the Highest Tension Strenght~~

Abstract

It is necessary to develop optimization methods to improve synthetic bone structure for application in human bone implants.~~Solution developed to improve the structure of human bone in synthetic bone~~. Synthetic bone made of ~~Composites manufactured from~~ polymethyl-methacrylate (PMMA) composites are frequently employed in the medical field ~~(PMMAPure~~ .PMMA, on the other hand, has restricted mechanical qualities, as well as being less compatible, rigid, and non-bioactive. This research ~~will~~ mixed PMMA material with hydroxyapatite (HA) material. The material's composition is PMMA: MMA = 1: 1, with a hydroxyapatite (HA) to PMMA powder ratio of 0.50: 1 (w/w). The material will be printed through a 3D Printing machine which has a 1.5 mm nozzle. This 3D Printing machine undergoes periodic development, but the results obtained are not in accordance with the needs, especially the tensile strength of the specimen. Therefore, it is necessary to conduct research to ~~determine the ability of the 3D Printing machine printing process by~~ optimizing the printing parameters of the 3D Printing machine. Experimental results and analysis using the RSM method show ~~the~~ that ~~machining~~ printing parameters of the 3D printing machine on PMMA/HA material to get the highest ~~optimal~~ tensile strength was at the point of 13,670 mm/s for the perimeter speed parameter, 76,330 mm/s for the infill speed parameter and 33,670% point for the fill density

***Keywords**: RSM, Tensile Strengthht, PMMA*

1. INTRODUCTION

Autograft and allograft are alternative solutions for repairing ~~of~~ damaged human bone structures. Autograft is a bone replacement from human bone structure, while allograft is a bone replacement from materials other than human bones. Developments that cause changes in the structure of human bones that are damaged by accidents and trauma [1]. The material of hydroxyapatite (HA) includes osteoblast linkages that can build new bone tissue and is biocompatible, bioresorbable, bioinert, bioactive, non-toxic, and osteoconductive, making it an alternative bone implant material [1]. The substance of polymethyl-methacrylate (PMMA) is extensively used in the orthopaedic sector as an implant to replace damaged bone, but it can also be developed as an alternative material for prosthetics [2].

Polymethyl-methacrylate (PMMA) and hydroxyapatite (HA) materials are printed using two methods: manually and ~~with the aid of~~by 3D printing machines. 3D Printing technology

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is ~~causing~~ driving ~~a~~ big changes~~s in the globe right now~~, particularly in the material development ~~industrial~~ industry~~area~~. Since the 1980s, this ~~method~~ technology has been known as Additive Layer Manufacturing. This technology is well-known among academics and the manufacturing industry since it has a significant economic impact [3], [4]. Fused Deposition Modeling (FDM) technology is a well-known, low-cost 3D printing technique with additive features [5]. FDM was first introduced in the early 1990s by the American company Stratays Inc. FDM technique works by extruding thermoplastic material through a nozzle at a specific heat temperature, then building the product layer by layer.

Rapid prototyping refers to materials that are printed using a CAD application on a 3D printing equipment. Rapid prototyping printing is used to create complicated product or part models that can be processed quickly [6], [7]. Rapid prototyping can also help ~~you~~ to save time during the manufacturing process [8]. The 3D Printing machine process parameters must be optimized for printing composite materials made of polymethyl-methacrylate (PMMA) and hydroxyapatite (HA). Air gap, raster angle, raster width, interior style part, layer thickness, part fill style, part x, y, z shrinkage factor, and contour width are all factors that affect the quality and strength of printed specimens [5].

The ~~factors~~ parameters of the 3D printing machine process that have been ~~utilized~~ noticed to ~~see~~ analyze the ~~influence~~ performance of the 3D printing machine~~'s printing process~~, such as layer thickness, temperature, and raster angle, have also been carried out in earlier research [9]. The parameters employed in this study are perimeter speed, infill speed, and fill density. These parameters were chosen because they are thought to have an impact on mechanical strength, and they have been used in prior studies [7]. Because these ~~characteristics~~ parameters have not been ~~tuned~~set, ~~more~~ further studies are needed to determine the optimum printing parameters to produce printed materials with the highest tensile strength~~study is needed to get the highest tensile strength~~. Some ~~of the~~optimization approaches methods, including ~~used for parameter optimization include the taguchi~~ Taguchi technique, genetic algorithms (GA), artificial neural networks (ANN), factorial design, and the response surface method (RSM) are commonly used [5].

The response surface method (RSM) was chosen ~~for this investigation~~in this study because it gives accurate predictions and can explain the influence of variable interactions. Figure 1 depicts previous research on the composition ratio of polymethyl-methacrylate (PMMA) with hydroxyapatite (HA) concentrations.

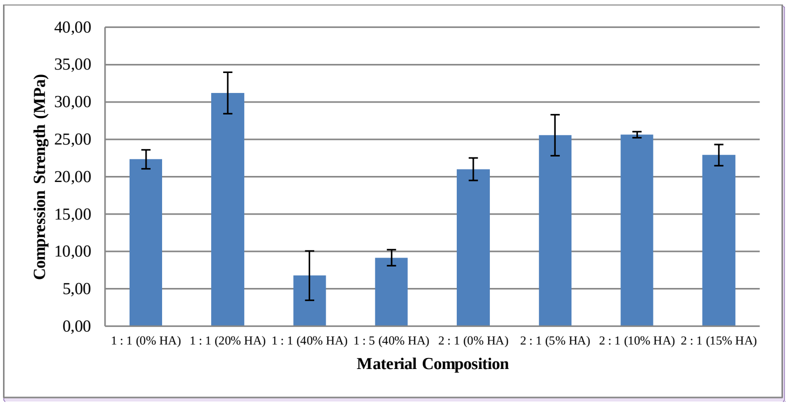

Figure 1: ~~Graph of~~ Compressive ~~Strength~~ strength of hydroxyapatite materials with varied composition (Sekarjati & Tontowi, 2018)

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According to research result by Sekariati & Tontowi (2018), ~~T~~the composition with ~~the~~ maximum compressive strength was found in the PMMA:MMA ratio ~~is~~ of 1: 1 (w/v), and with addition of 20% hydroxyapatite (HA) ~~content of 20%~~from ~~of the~~ overall mixture, as shown in Figure 1. When the hydroxyapatite (HA) concentration is replaced by PMMA powder, the ratio becomes 0.50:1 (w/w) [7]. The goal of this research is to find the best 3D printing machine parameters based on the composition of PMMA: Using the response approach, MMA = 1:1 (w/v) with a hydroxyapatite (HA) to PMMA powder ratio of 0.50:1 (w/w). To produce the best tensile strength, use the surface technique (RSM).

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2. METHODS

PMMA powder and MMA liquid (ISO 1567 type 1 class 1, acrylic denture materials, heat curing type) and HA powder material are used to make ASTM D638 Type 1 specimens (Bio-nano carbonate, BATAN). The specimens in this study were created with the Inventor 2017 software and saved in *stl format so that they could be translated to G-code for use on a 3D printer. The 3D printing machine will produce a specimen with a length of 165 mm, a width of 19 mm, and a thickness of 3 mm~~, and a nozzle of 1.5 mm~~. Three parameters were chosen to produce the best results: perimeter speed (the speed of the outer printing process), infill speed (the speed of the inner printing process), and fill ~~speed (the speed of the inner printing process)~~ density (the density between the perimeter speed and infill speed patterns). These settings were chosen because they have an impact on the printing process [7]. With a length of 20 mm, the extrusion speed of the 3D printing machine is 60 mm/min and 80 mm/min, flowing homogeneously and constantly. Heat treatment at 70°-80°C for 2 hours was applied to the extruded specimens. Following the heat treatment, the specimens were put through a mechanical test (tensile strength).

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Commented [A5]: Please explain more detail about the heat treatment. What the equipment that be used (type)? What is the purpose of doing heat treatment?

Figure 2: Specimen according to ASTM D638 Type 1.

Figure 3: ASTM D638 Type 1 3D Printing Tool. Specimen Printing

This study yielded data in the form of 3D printing machine parameter setting data and ~~tensile~~ tension strength test data. Furthermore, the data is processed with Minitab 19 software, which employs the response surface method (RSM) to optimize the printing process ~~settings~~ parameters and properly predict the material printed's tension strength, as in prior studies [5], [9]. First-order regression modeling, which is expressed in a first-order polynomial linear equation, is one of two stages of analysis for the response surface approach. The first-order model was created using ~~minitab~~ Minitab 19 software and regression analysis. The first-order model's output was calculated using the following equation:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \quad (1)$$

A polynomial's degree is increased by using second order. If the regression analysis fails, the analysis is repeated in the second order, ~~this time~~ with data from the axial point. The second-order model's outcomes are calculated using the following equation:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 \quad (2)$$

3. Result and Discussion

3.1 Order One Data Analysis

Using the RSM approach, tensile strength testing was performed on PMAA and HA specimens to determine their tensile strength. Table 1 summarizes the results of the first-order experiment.

Table 1 Responses to the Results of the First Order Experiment

Coded Variable			Actual Variable			Tensile Strength
X1	X2	X3	PS	IS	FD	(N/mm^2)
1	-1	1	40	50	60	6,53
-1	1	-1	20	70	40	8,78
0	0	0	30	60	50	1,66
0	0	0	30	60	50	3,6
0	0	0	30	60	50	2,58
-1	-1	-1	20	50	40	8,18
-1	1	1	20	70	60	8,59
0	0	0	30	60	50	11,45
1	-1	-1	40	50	40	6,15
1	1	-1	40	70	40	10,37
-1	-1	1	20	50	60	7,94
1	1	1	40	70	60	9,2

The tensile strength response regression model was created using Minitab 19 software using the data in Table 1. Table 2 shows the results of the regression model calculations.

Table 2 Tensile Strength Response Regression Model

S	R-sq	R-sq(adj)	R-sq(pred)
2,886	1,33%	0,00%	0,00%

The coefficient of determination is 0.0133~~, according to~~ (~~~~Table 2). ~~(1.33%).~~ This value indicates that the independent variables (perimeter speed, infill speed, and fill density) have a very low influence on the response variable (tensile strength), as evidenced by the fact that the higher the R2 value, the greater the independent variable's influence on the response variable [10]. The F-value and P-value were subjected to an analysis of variance of the lack of fit test using ~~minitab~~ Minitab 19 software to reinforce the validity of the study's findings.

Table 3. Response Tensile Strength on Order One: Analysis of Variance

Source	*DF*	*Adj SS*	*Adj MS*	*F-value*	*P-value*
Model	4	1,681	0,4202	0,05	0,995
Blocks	1	0,030	0,0301	0,00	0,953
Linear	3	1,651	0,5502	0,07	0,977
Perimeter Speed	1	0,353	0,3534	0,04	0,840
Infill Speed	1	1,186	1,1855	0,14	0,711
Fill Density	1	0,112	0,1116	0,01	0,909
Error	15	124,899	8,3266		
Lack-of-Fit	11	61,942	5,6311	0,36	0,920

Commented [A6]: There is no identification, what are PS, IS and FD? Explain more detail about the parameter. What is unit for perimeter speed, infill speed and fill density?

Commented [A7]: All decimal number in English use full stop, rather than comma. Please revise **all decimal** numbers in **all tables**.

Pure Error	4	62,957	15,7393
Total	19	126,580	

The lack of fit F-value of 0.36 is below the F-table value of 9.01, and the lack of fit P-value of 0.920 is above the value of = 0.05, indicating that there is no variation between the model produced and the real model, allowing it to be characterized with a linear line. Figure 4 shows the results for the maximum tensile strength response values at perimeter speed 10 mm/s, infill speed 80 mm/s, and fill density 30%. These data are used to calculate the ensuing response when given at various levels, however it cannot be stated to be the best result because it is confined to only one response [11]

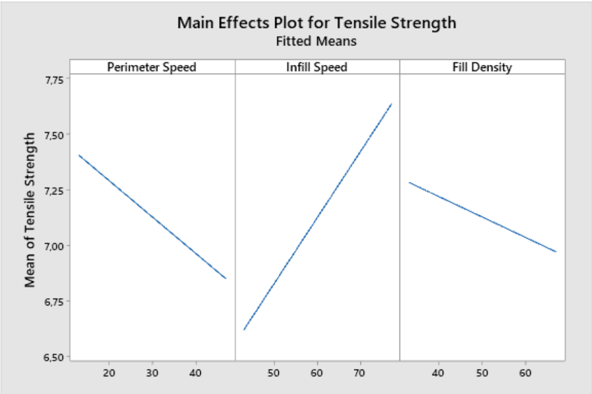

Figure 4: Response Tensile Strength Main Effect Plot

The model is well described by the experiment given in the first order, because it meets the constraints such as the F value being below the F table and the P value being above the value. However, the coefficient of determination (R2) is still quite ~~tiny~~low, resulting in a ~~low link~~weak relationship between the independent variable and the response variable in the regression model that is created. As a result, a second-order analysis is required to enhance the value of the coefficient of determination (R2).

3.2 Analysis of Second-Order Data

By adding six axial points and two central points to a central composite design, this second-order experiment uses a central composite design. Minitab 19 software was used to evaluate the outcomes of each second-order response. Table 4 shows the experimental data for the second order.

Table 4 shows the responses to the results of the second order experiment.

Coded Variable			***Actual Variable***			***Tensile Strength***
X1	**X2**	**X3**	**PS**	**IS**	**FD**	**(N/mm²)**
0	-1,633	0	30	43,67	50	8,29
0	0	0	30	60	50	6,67
0	0	1,633	30	60	66,33	6,65
1,633	0	0	46,33	60	50	9,16
-1,633	0	0	13,67	60	50	9,73
0	0	-1,633	30	60	33,67	6,65
0	0	0	30	60	50	4,43
0	1,633	0	30	76,33	50	5,74

Using the Minitab 19 program, the data in Table 4 was processed to create a tensile strength regression model. Table 5 shows the results of the second-order regression model calculation.

Table 5. Tensile Strength Response Regression Model

S	R-sq	R-sq(adj)	R-sq(pred)
2,877	41,16%	0,00%	0,00%

The coefficient of determination (R2) is 0.4116~~, according to~~(Table 5). ~~(41.16%).~~ This number indicates that the response variable (tensile strength) is influenced by the independent factors (perimeter speed, infill speed, and fill density) ~~(tensile strength)~~. This is demonstrated by the fact that the higher the R2 value, the stronger the independent variable's influence on the response variable [10]. The F-value and P-value were subjected to an analysis of variance of the lack of fit test using Minitab 19 software to reinforce the validity of the study's findings.

Table 6 Second-order analysis of variance for response tensile strength

Source	***DF***	***Adj SS***	***Adj MS***	***F-value***	***P-value***
Model	10	52,103	5,2103	0,63	0,760
Blocks	1	0,030	0,0301	0,00	0,953
Linear	3	1,651	0,5502	0,07	0,976
Perimeter Speed	1	0,353	0,3534	0,04	0,841
Infill Speed	1	1,186	1,1855	0,14	0,714
Fill Density	1	0,112	0,1116	0,01	0,910
Square	3	46,149	15,3829	1,86	0,207
*Perimeter Speed*Perimeter Speed*	1	37,498	37,4980	4,53	0,062
*Infill Speed*Infill Speed*	1	7,908	7,9076	0,96	0,354
*Fill Density*Fill Density*	1	5,358	5,3575	0,65	0,442
2-way Interaction	3	4,274	1,4245	0,17	0,913
*Perimeter Speed*Infill Speed*	1	3,976	3,9762	0,48	0,506
*Perimeter Speed*Fill Density*	1	0,016	0,0162	0,00	0,966
*Infill Speed*Fill Density*	1	0,281	0,2812	0,03	0,858
Error	9	74,477	8,2752		
Lack-of-Fit	5	11,520	2,3040	0,15	0,971
Pure Error	4	62,957	15,7393		
Total	19	126,580			

The lack of fit F-value of 0.15 is below the F-table value of 5.05, and the lack of fit P-value of 0.971 is above the value of = 0.05, according to the results of the tensile strength response variance analysis ~~of the tensile strength response variance~~ (Table 6). ~~(~~H0 or null hypothesis was not rejected.~~)~~ This result indicates that the produced model ~~produced~~ and the actual model are identical. The response surface approach can provide a graph model with a 3D curve ~~(3D)~~ to show the ideal locations of each response for each parameter that impacts the response. Figure 5 shows the surface plot data for the tensile strength response.

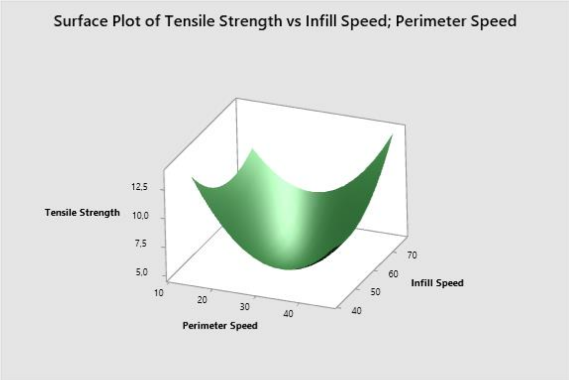

Figure 5: Tensile Strength of the Surface Plot

3.3 Response Parameter Optimization

The tensile strength response variable was optimized using ~~minitab~~ Minitab 19 software at this point. The goal of optimization was to find the independent variable point with the highest ~~percentage~~ value of tensile strength. The optimization results received are depicted in Figure 6.

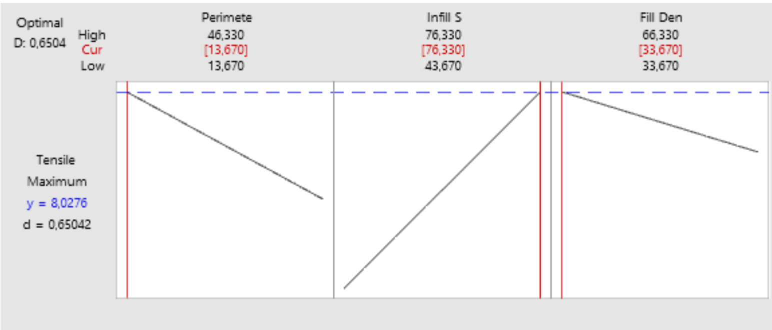

Figure 6. Tensile Strength Optimization Response

The perimeter speed parameter is 13,670 mm/s, the infill speed parameter is 76,330 mm/s, and the fill density parameter is 33,670 percent, according to the results of parameter optimization on the response variable. The composite desirability rating on the optimization plot indicates how optimal the combination of factors is for the overall response. The composite desirability value is a number between 0 and 1 that indicates how desirable something is. The composite desirability value in this experiment is 0.6504. This number is near to one, indicating that the resultant combination is excellent [12].

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4. CONCLUSION

The machining parameters of the 3D printing machine with PMMA/HA material ~~are~~ were obtained from the experimental results and analysis of the Minitab 19 software using the response surface method (RSM), then the optimal results are formed at the points of 13.670 mm/s for the perimeter speed parameter, 76.330 mm/s for infill speed parameter, and 33.670 percent point for fill density parameter.

Commented [A9]: Please rewrite the conclusion. This sentence is too long, so that the meaning is not clear.

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