INTERNATIONAL JOURNAL OF ENGINEERING TECHNOLOGY AND SCIENCES (IJETS)
ISSN: 2289-697X (Print); ISSN: 2462-1269 (Online) Vol.6 (1) June 2019
© Universiti Malaysia Pahang
DOI: http://dx.doi.org/10.15282/ijets.6.1.2019.1002

Optimization of Cutting Parameters on Tool Wear Using Box Behnken Design

G.A. Ibrahim[1*], A. Hamni[1], Y. Burhanudin[1] and W. Nadhira[1]

[1]*Department of Mechanical Engineering, Faculty of Engineering, University of Lampung*
**Email: gusri.akhyar@eng.unila.ac.id*

Abstract. Magnesium alloy is one type of metals that is currently widely used to replace various components in the biomedical field, but because of its low melting point. special attention is required during the machining process of magnesium alloy. This study aims to optimize machining parameters specifically cutting speed, feed rate and rotary tool speed. Analyze was done by using Response Surface Method of Box Behnken Design. The rotary turning of magnesium AZ31 was done to achieve minimum wear value on the cutting tool. The use of pressurized cold air was also applied to this study to reduce the temperature between work piece and rotary cutting tool. Based on the analysis using Response Surface Method of Box Behnken Design obtained, the optimum value for the minimum tool wear in the amount of 0,27728 mm at cutting speed of 80 m/min, feeding speed of 0,1 mm/rev and rotary tool speed of 45,7071 rotation/min. The mathematical modeling obtained is Vb = 0.3550 + 0.000797 Vc + 0.3950 f - 0.008159 Vt + 0.000090 Vt*Vt. In the model that cutting speed, feed rate and rotary tool are significant contribution and feed rate is the most one.

Keywords: magnesium AZ31, rotary tool, tool wear, Box Behnken Design

INTRODUCTION

Magnesium and its alloys are metals that have good cutting characteristics such as low specific cutting strength, short chip pieces, low tool wear and high surface quality. So this material is used as metal substitute components of steel and aluminum [1,2]. However, the weakness possessed by magnesium is its combustible character, especially at the time of cutting speed and high feeding speed [1]. So that proper machining parameters are needed to reduce the heat during machining process. Research conducted by Ibrahim (2010) states that turning process of lightweight material by using dry machining can reduce the temperature during machining process so as to reduce the wear rate in the edge of cutting tool [3]. Temperature is the most factor which contributed on the cutting tool failure. Therefore, to develop the machining performance need to control the machining parameters clearly.

To obtain optimum parameters in machining process can also be done by using statistical analysis. One of them is the Response Surface Method Box Behnken Design (BBD). The Response Surfce Method is a set of statistical and mathematical techniques that are very useful for modeling and analysis applications where the desired response by some variables and responses is to optimize the output response [4]. Box Behnken Method is an experimental design formed from a combination of two-level factorial and incomplete box design which can be used for 3 to 12 and 16 factors. In BBD, there are several repetitions that can be combined against all factor levels. In some experiments there is interaction between factors when there is a difference in response from a level on a factor that is not the same at each level in the other factor [5,6]. The interaction between one or more factors were done to compare the effect of one factor and some factors in the same time. It is possible that the effect more than one factor is better in the same time.

Box Behnken design has no axial or star runs in its design so this method is more efficient for designing because fewer experiments [7]. Results investigation shows that the optimization of machining parameters on machining super alloys material, where this research using three factors studied are cutting speed, feed rate and dept of cut. While the response is the accuracy of dimensions and surface roughness. The results show that feed rate and cutting speed have a significant effect on the surface roughness [8].

Based on research that has been done some finding can be concluded that Response Surface Method Box Behnken Design can be used to optimize parameters by using three variables. So, in this research Box Behnken Design is used to determine the optimum parameters on magnesium AZ31 rotary turning machining process so that the most suitable parameters are obtained for minimum tool wear that occurs in the machining process. Building of a mathematical model is needed to predict the optimum tool wear condition.

METHODOLOGY

Trials experimental machining were done by using design experiment of Surface Response Method with Box Behnken Design. It is applied to get the proper parameters so that the optimum condition for turned machining process of magnesium AZ31 using actively driven rotary tool is obtained. Data retrieval was done based on experimental design of Box Behnken Design which then analyzed using variance analysis approach. It aims to achieve which parameter is the most significant contribution on variable response.

With the number of 3 parameters that each parameter has 3 levels obtained the number of test samples as much as 15 times, as shown in Table 1 and Table 2. Where the number of test samples can be known by entering directly the number of parameters to be used into the equation [9]

$$N = 2k(k-1) + C_0 \quad (1)$$

Where N is the number of test samples, k is the number of parameters to be used and C_0 represents the number of midpoints. Figure 1 shows that the machining process is done by using rotary tool with diameter of 18 mm. The cutting tool used in the experiment is carbide round insert with coating layer.

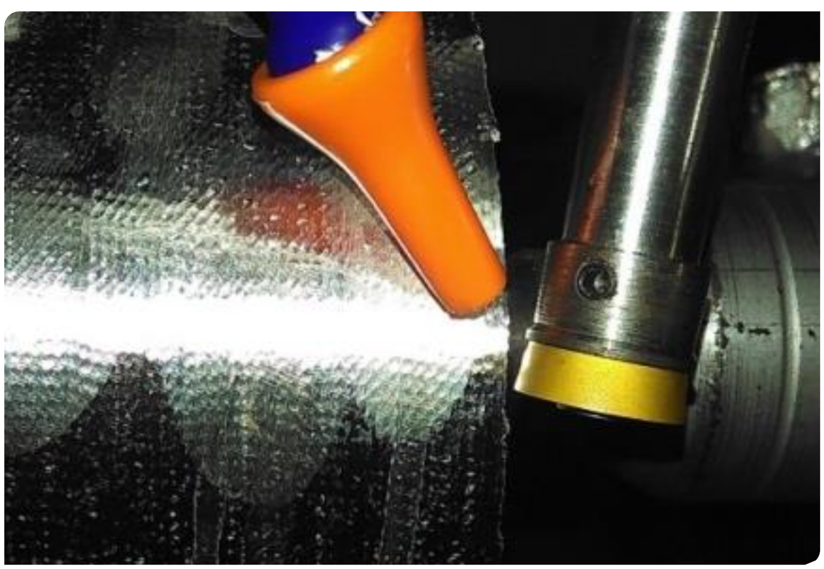


Figure 1: The machining process of magnesium AZ31 using rotary tool

Table 1: Machined factor with each level

Level	Cutting Speed, V_c (m/min)	Feeding, f (mm/rev)	Tool Speed, V_t (m/min)
Low	80	0,10	25
Mid	120	0,15	50
High	160	0,20	75

Table 2: Design experimental table

Std Order	**Run Order**	V_c	f	V_t	d
1	1	80	0,1	50	0,3
8	2	160	0,15	75	0,3
11	3	120	0,1	75	0,3
13	4	120	0,15	50	0,3
6	5	160	0,15	25	0,3
5	6	80	0,15	25	0,3
4	7	160	0,2	50	0,3
2	8	160	0,1	50	0,3
3	9	80	0,2	50	0,3
10	10	120	0,2	25	0,3
9	11	120	0,1	25	0,3
15	12	120	0,15	50	0,3
12	13	120	0,2	75	0,3
7	14	80	0,15	75	0,3
14	15	120	0,15	50	0,3

RESULTS AND DISCUSSIONS

Table 3 is one set of experimental result data when cutting by using rotary tool. The number of data are fifteen with each selected parameter. After one pass machining, the tool wear (Vb) was recorded and following to next turning until the Vb reached 0.3 mm. The wear on the cutting tool is measured by using toolmaker microscope with magnification scale. Detailly, measured data results can be shown in Table 3. The material which is used in the rotary machining process is magnesium AZ31 with specific physical properties.

Table 3: Data of measurement result of rotary tool wear

StdOrder	RunOrder	Vc	f	Vt	d	Vb
1	1	80.00	0.10	50.00	0.30	0.286
8	2	160.00	0.15	75.00	0.30	0.448
11	3	120.00	0.10	75.00	0.30	0.371
13	4	120.00	0.15	50.00	0.30	0.326
6	5	160.00	0.15	25.00	0.30	0.397
5	6	80.00	0.15	25.00	0.30	0.340
4	7	160.00	0.20	50.00	0.30	0.374
2	8	160.00	0.10	50.00	0.30	0.332
3	9	80.00	0.20	50.00	0.30	0.313
10	10	120.00	0.20	25.00	0.30	0.368
9	11	120.00	0.10	25.00	0.30	0.343
15	12	120.00	0.15	50.00	0.30	0.321
12	13	120.00	0.20	75.00	0.30	0.435
7	14	80.00	0.15	75.00	0.30	0.357
14	15	120.00	0.15	50.00	0.30	0.332

Table 4 shows that the cutting speed, feeding and speed of the rotary tool have a significant level for each parameter. In the engineering experimental case, the significant value selected is 5%. With a confidence level of 95%, the statistically significant parameters will have a p-value of less than 0.05, which means if p-value $\leq$ 0.05 then independent variables have a statistically significant effect on dependent variables, otherwise if p-value $\geq$ 0.05 then independent variable does not influence statistically to dependent variable [10]. It can be seen that cutting speed with significant value of 0.000 is the most significant factor with high contribution in affecting the tool wear values. Similar contribution is shown also by tool speed with significant value of 0.001. It can be state that the cutting speed gives a good contribution on the tool wear value [14].

Table 4 also shown the steps of analysis by backward method to get the significant values of each parameters. The stepping from 1 until 6 were done repetitively. At the step of 6, the significant values for all parameters are significant, because all values are lower the 0.05. So, based on Table 4 we get a mathematical model for magnesium AZ31 with turning by using rotary cutting tool as followed Vb = 0.3550 + 0.000797 Vc + 0.3950 f - 0.008159 Vt + 0.000090 Vt*Vt. From the mathematical model, it can be concluded that the single factor which gave significant contribution are feed rate, cutting speed and tool speed. Among them, the feed rate is the biggest contribution on the tool wear. The number of coefficient model is +0.3950. This value is bigger that others coefficient such as for cutting speed of 0.000797 and tool speed of 0.008159.

Table 4: Response surface regression of Vb vs Vc, f, Vt with Backward Elimination of Terms

	-------Step 1------		-------Step 2------		-------Step 3------	
	Coef	P	Coef	P	Coef	P
Constant	0.32633		0.32823		0.32629	
Vc	0.03188	0.000	0.3188	0.000	0.03188	0.000
f	0.01975	0.002	0.01975	0.001	0.01975	0.000
Vt	0.02037	0.001	0.02037	0.001	0.02037	0.001
Vc*Vc	0.00308	0.543				

f*f	-0.00317	0.532	-0.0034	0.476		
Vt*Vt	0.05608	0.000	0.05585	0.000	0.05609	0.000
Vc*f	0.00375	0.446	0.00375	0.418	0.00375	0.400
Vc*Vt	0.00850	0.120	0.00850	0.096	0.00850	0.082
f*Vt	0.00975	0.084	0.00975	0.065	0.00975	0.053
S	0.0090765		0.0086315		0.0083671	
R-Sq	98.50%		98.38%		98.22%	
R-Sq (adj)	95.50%		96.38%		98.22%	
R-Sq (pred)	79.09%		85.15%		88.26%	
Mallow' Cp	10.00		8.43		6.95	

	-------Step 1------		-------Step 2------		-------Step 3------	
	Coef	P	Coef	P	Coef	P
Constant	0.32629		0.32629		0.32629	
Vc	0.03188	0.000	0.3188	0.000	0.03188	0.000
f	0.01975	0.002	0.01975	0.000	0.01975	0.000
Vt	0.02037	0.000	0.02037	0.000	0.02037	0.000
Vc*Vc						
f*f						
Vt*Vt	0.05609	0.000	0.05609	0.000	0.05609	0.000
Vc*f						
Vc*Vt	0.00850	0.074				
f*Vt	0.00975	0.046	0.00975	0.074		
S	0.0082637		0.0096339		0.0110252	
R-Sq	98.02%		96.97%		95.58%	
R-Sq (adj)	96.53%		95.28%		93.82%	
R-Sq (pred)	90.13%		90.58%		88.86%	
Mallow' Cp	5.63		7.14		9.75	
α to remove = 0.05						

Where if one of the independent variables increases as much as one percent and the other independent variable remains, then any one percent increase in the cutting speed will increase the value of the rotary tool wear by 0.000797%. Likewise, if the feeding increased in one percent will raise 0.3950% the value of rotary tool wear, if the speed of rotary tool increased one percent will decrease the tool wear value by 0.008159% and if the rotary tool speed is raised one percent then it will raise the value of rotary tool wear by 0.000090%. Some tests were done to see the suitability of the model that is coefficient of determination test (R^2), lack of fit and F test. The coefficient of determination test is done to see how big the prediction model influences the response variable [11]. The coefficient value of determination is 95.58%, so the linear model of cutting speed parameters, rotary tool speed, feeding and quadratic model of rotary tool speed affect the value of tool wear significantly by 95.58%.

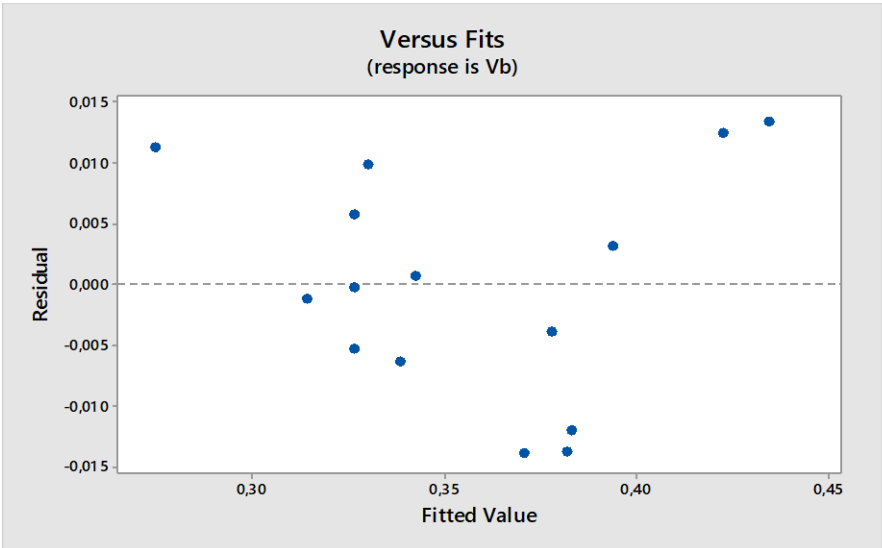
The test of lack of fit is performed to show the accuracy of the test result model. If the value of lack of fit is greater than the value of α then the model is acceptable [12]. The value of lack of fit occurs at 0.185, where the value is greater than α = 0.05 so it can be said that first order linear model is appropriate and appropriate to the given model. F test can also be done to find out whether the regression model of analysis result can be accepted or not. If the value $F_{count} > F_{table}$ then the regression model can be accepted [13]. Where F_{count} is 54.12 and for F_{table} is 3.89. Which means that the regression model of the results of the analysis made acceptable.

Table 5 shows the analysis variance of tool wear on the cutting edge of the tool when machining of magnesium AZ31 using rotary cutting tool at various cutting parameter based on Box Behnken Design. From the Table 5, all P-value of each factor in the machining process are 0.000 (or lower than 0.05). it means that all factor give significantly contribution on the wear on the edge of the cutting tool. For individual factor, speed of work piece, feed rate, and speed to tool are significant contribution. Whereas, for interaction factor, quadratic of speed of cutting tool factor give significant effect on the tool wear. Therefore, cutting speed and tool speed are two factors which have more contribution than others factors including the interaction factor. The interaction that gave a significant contribution is the cutting speed square (Vt*Vt).

Table 5: Analysis Variance (ANOVA) for cutting tool wear (Vb)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	4	0.026315	0.006579	54.12	0.000
Linear	3	0.014570	0.004857	39.95	0.000
Vc	1	0.008128	0.008128	66.87	0.000
F	1	0.003121	0.003121	25.67	0.000
Vt	1	0.003321	0.003321	27.32	0.000
Square	1	0.011745	0.011745	94.62	0.000
Vt*Vt	1	0.011745	0.011745	94.62	0.000
Error	10	0.001216	0.000122		
Lack-of-fit	8	0.001155	0.000144	4.76	0.185
Pure error	2	0.000061	0.000030		
Total	14	0.027530			

The graph in Figure 2 shows the residuals that occur spreading around the zero line. The spreading data were not form a particular pattern and not assemble in one place. The analysis of tool wear data after doing machining showed random distribution spread at up and down of zero line. Therefore, the residuals can be said to be not identical. Normality test was performed using the Kolmogorov-Smirnov method. By looking at the Kolmogorov-Smirnov and p-value values greater than 0.05, it can be stated that the residuals are normally distributed (Figure 3). All points closed to normal line. However, there are two values which are far from normal line (below normal line). But this condition still assumed as a normal distribution.



c

Figure 2: Graph for identical residuals

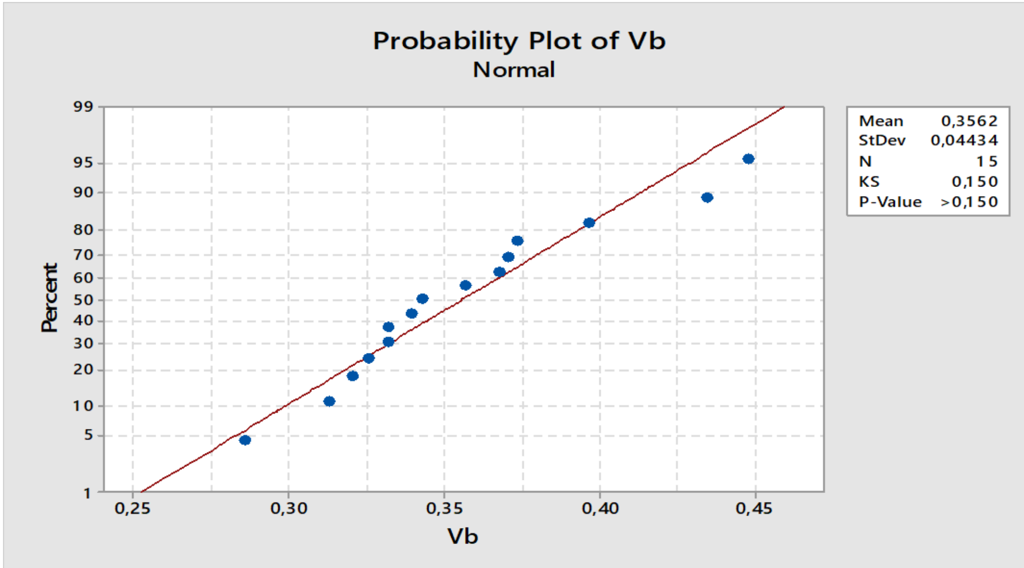


Figure 3: Graph of residual test results normally distributed

Based on the mathematical modeling, the optimum condition for turning of magnesium alloy AZ31 was done using rotary cutting tool with tool wear of 0.277 mm. Machining condition was took place at cutting speed of 80 m/min, feed rate of 0.10 mm/rev and rotary tool speed of 45.77 rotation as shown in Figure 4. The cutting speed which produced the optimum condition is 80 m/min, where it is at low level of cutting speed. The same condition shown also for factor of feed rate, in which the optimum value is low level of 0.10 mm.rev. Low level of cutting speed and low level of feed rate generated slow wear propagate as long as machining process. At low cutting speed, the friction between the cutting tool and workpiece is low, so that generated low temperature [15]. In some cases, the temperature is one of factors that dominant contribution on the tool wear.

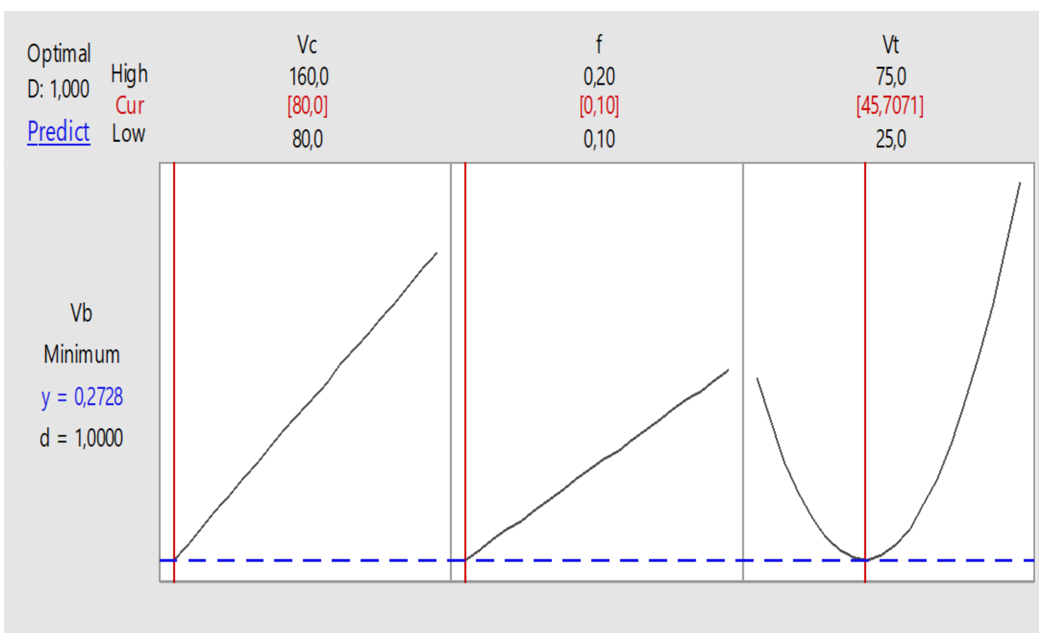


Figure 4: Plot of minimal tool wear optimization

CONCLUSION

Based on the analysis using Response Surface Method with Box Behnken Design for rotary tool turning process of magnesium AZ31, that the prediction of the optimum condition of the machining parameters is at the cutting speed of 80 m/min, the feed rate of 0.10 mm/rev and the rotary tool speed of 45.7071 rotation/min. At low level of cutting speed and low level or feed rate generated low cutting temperature as a result of the friction between cutting tool and workpiece material. At the optimum condition, prediction value of tool wear obtained is 0.27728 mm. Where cutting speed, feed rate and speed of rotary tool have statistically significant effect to tool wear an shown by coefficient of determination model of 95.58%. it has an effect on to response variable and p-value at each parameter less than 0,05. The most Signiant factor that contribute to tool wear is feed rate with the number of coefficient of 0.395. This value is bigger than cutting speed and tool speed significantly. A mathematical model that built in the machining process is $Vb = 0.3550 + 0.000797\ Vc + 0.3950\ f - 0.008159\ Vt + 0.000090\ Vt*Vt$. This model can be used to predict the tool wear progression as function of controllable factors.

ACKNOWLEDGMENT

These authors acknowledge the financial support from Directorate General of Higher Education of Ministry of Research and High Education of Indonesia. The acknowledgment is also addressed to University of Lampung which facilitated the facilities to finish this experiment

REFERENCE

[1] K.S. Cristopher, K. Vince, K. Hodgson, "Biodegradable surgical implants based on magnesium alloys," *IOP Conference Series Materials Science and Engineering*, Vol. 4, No. 1, 2016.

[2] J. Su, "Characteristics of magnesium AZ31 alloys subjected, "Materials *Science & Engineering A*, pp. 582-592, 2015.

[3] G. A. Ibrahim, C. H. Che Haron, J. A. Ghani, "Tool Wear Mechanism in Continous Cutting of Difficult-to-Cut Material under Dry Machining," *Advance Materials Research*, Vol. 126-128, pp. 195-201, 2010.

[4] D. Montgomery, "*Statistical Quality Control: A Modern Introduction Seventh edition.* Singapore," Jhon Wiley and Sons, 2005.

[5] N. Nguyen, J. J. Borkowski, "New 3-level Response Surface Designs Costructed from Incomplete Block Designs," *Statistical planning and inference*, pp. 294-305, 2008.

[6] M. A. Tekindal, "Box - Behnken experimental design in factorial experiments: the importance of bread for nutrition and health," *Turkish Journal of Field Corps*, pp. 115-123, 2012.

[7] M. Xiao, X. Shen, Y. Ma, F. Yang, N. Gao, W. Wei, D. Wul, "Prediction of Surface Roughness and Optimization of Cutting Parameters of Stainless Steel Turning Based on RSM, "Mechanical *Problem in Engineering*, pp. 1-15, 2018.

[8] G. A. Ibrahim, C. H. Che Haron, J. A. Ghani, H. Arsyad, "Taguchi optization method for suface roughness and material removal rate in turning of Ti-6Al-4V ELI, "International *Review of Mechanical Engineering*, Vol. 4, No. 3, pg. 216-221, 2010.

[9] S. L. C. Ferreira, “Box-Behnken design: An alternative for the optimization of analytical methods, “Analytica *Chimicia Acta 597*, pp. 179-186, 2007.

[10] M. Balasubramanian, “Application of Box-Behbken desing of fabrication of titanium alloy and 304 stainless steel joints with silver interlayer,“ *Material and Design*, 2015.

[11] L. Rupesh, D. Abhijeet, M. Ashok, “Taguchi analysis of bonded single-lap joint in hemp fiber composite*, “International Journal of Engineering Technology and Science*, Vol. 5, No. 1, pp. 27-33, 2016.

[12] Winhaju, W. Setya,” Analysis variance and mathematical statistic,” *ITS, Surabaya*, 2013.

[13] D. D. Againa, S. Wimani, E. Supartini, “Application of overlaid contour plot method and desirability function on central composite design,“ *BIA Statistic,* Vol. 10, No. 1, pp. 17-30, 2016.

[14] R. Viswanathan, S. Ramesh, N. Elango, K. D. Kamesh, “Temperature measurement and optimisation in machining magnesium alloy using RSM and ANOVA, “ *Pertanika Journal of Science and Technology*, Vol.25, No.1, pp. 255-262, 2017.

[15] K. Chomsamutr, S. Jongprasithporn, “Optimization parameters on tool life model using Taguchi approach and Response Surface Methodology, “ *International Journal of computer Science Issues*, Vol. 9, No. 1, pp. 120-125, 2012.