Optimization of Cutting Parameters When Machining of Magnesium AZ31 Using Box Behnken Design

[1]G.A. Ibrahim, A. Hamni[2], Y. Burhanudin[3] and W. Nadhira[4]

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 obtanied is $Vb = 0.3550 + 0.000797\, Vc + 0.3950\, f - 0.008159\, Vt + 0.000090\, Vt*Vt$.*

Key words: 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 many 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].

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 bock 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].

Box Behnken design has no axial or star runs in its design so this method is more efficient for designing because fewer experiments [7]. Kanlayasiri investigate the optimization of machining parameters on machining K460 tool steel, where this research using three factors studied are cutting speed, peak current, and offset distance. While the response is the accuracy of dimensions and surface roughness. The results show that peak current and offset distances have a significant effect on the dimensions of the specimen and only peak currents affect the surface roughness [8].

Based on research that has been done many 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.

METHODOLOGY

Research is done by using Surface Response Method (Box Behnken Design) to get the proper parameter so that the optimum condition for turned machining process of magnesium AZ31 using actively driven rotary tool is obtained resulting in minimal tool wear. Data retrieval was done based on experimental design of Box Behnken Design which then analyzed using MINITAB 17 software.

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 software MINITAB 17 or by using the equation [9]

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

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 machining process be done using rotary cutting tool with diameter of 18 mm. The cutting tool used in the experiment is carbide round insert with coating layer.
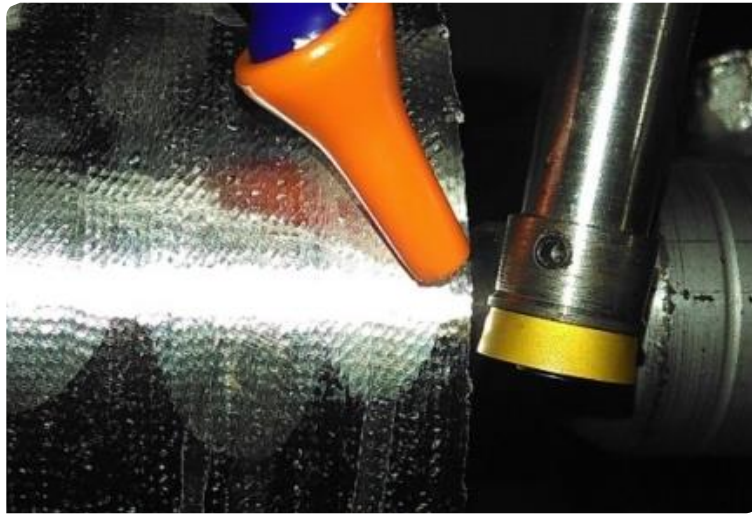

FIGURE 1. The machining process of magnesium AZ31 using rotary tool

Table 1. Machined factor with each levels

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

StdOrder	RunOrder	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 parameters. After one pass machining, the wear of tool (Vb) was recorded and following to next turning until the Vb reached 0.3 mm. cales on magnesium AZ31 lathe machining process.

Table 3. Data of measurement result of rotary tool wear

StdOrder	RunOrder	Vc	f	Vt	d	W
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 shown with p-value on 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 ≤ 0.05 then independent variables have a statistically significant effect on dependent variables, otherwise if p-value ≥ 0.05 then independent variable does not influence statistically to dependent variable [10].

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

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 cuting 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. Fron 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.

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. Therefore, the residuals can be said to be not identical. Normality test was performed using the Kolmogrorov-Smirnov method. By looking at the Kolmogrorov-Smirnov and p-value values greater than 0.05, it can be said that the residuals are normally distributed (Figure 3).
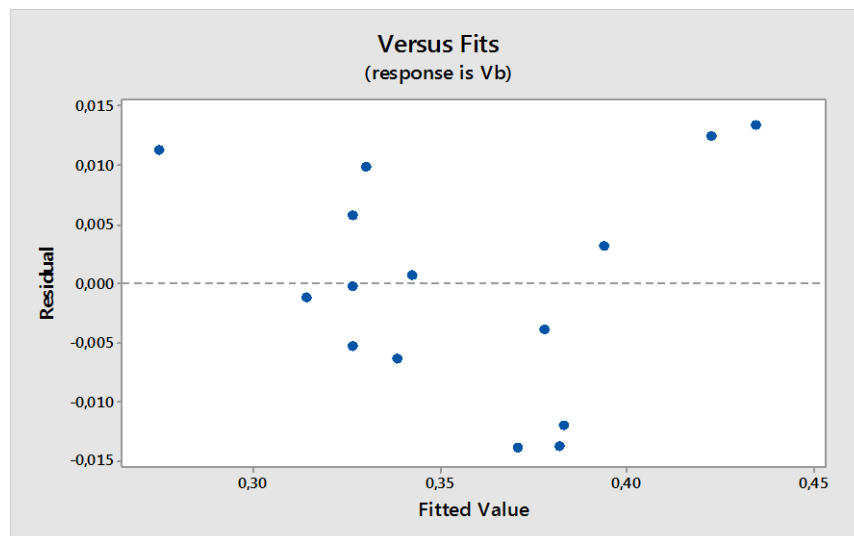
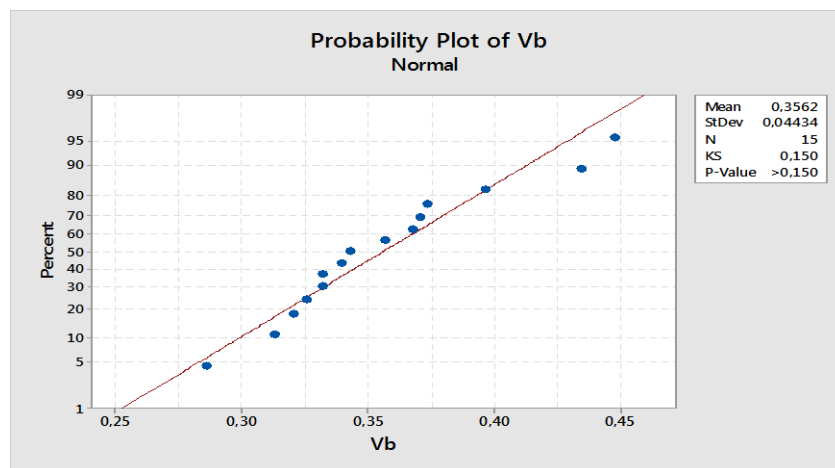**Figure 2. Graph for identical residuals**

Figure 3. Graph of residual test results normally distributed

Based on 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.
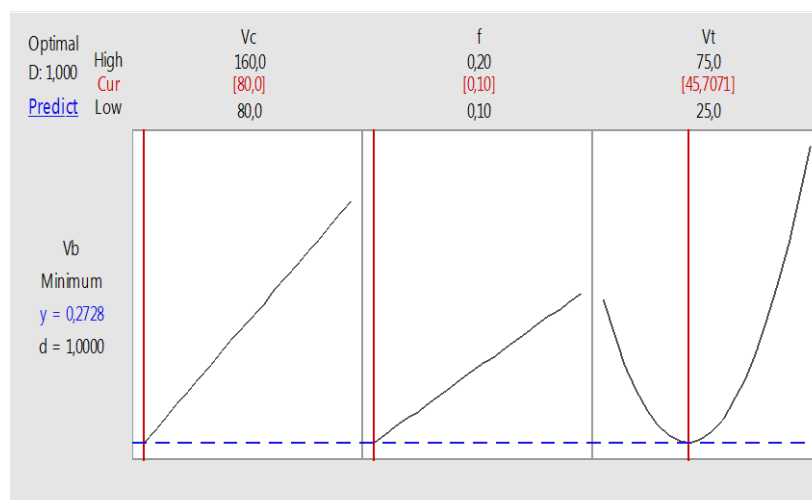

Figure 4. Plot of minimal tool wear optimization

CONCLUSIONS

Based on the analysis using Response Surface Method 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. The 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 paramter less than 0,05. A mathematical model that can be used to find tool wear value based on statistical analysis Response Surface Method Box Behnken Design on rotary tool process of magnesium AZ31 is following $Vb = 0.3550 + 0.000797\ Vc + 0.3950\ f - 0.008159\ Vt + 0.000090\ Vt*Vt$

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