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Application of Central Composite Design for Optimization Machining Parameters When Machine Magnesium AZ31

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Abstract: ***Magnesium AZ31 are widely used for industrial manufacturing such as manufacturing aircraft components, automotive, biomaterials and sports. The interests of manufacturing industries for machining Magnesium AZ31 are to obtain high accuracy, high precision and high tool life. The purpose of this experiment is to achieve optimum cutting parameter for tool life and quality of surface finish. A mathematical model for tool life can be computed from this experiment. Magnesium alloy AZ31 as work piece material consist of 3% of aluminium and 1% of zinc. The parameters used for experimental trials were cutting speed (v) of 22, 32 and 42 m/min, depth of cut (d) of 1, 2, and 3 mm and feed rate (f) of 0.15, 0.20, and 0.25 mm/rev. Minitab software was used to analyze the data obtained. The maximum actual tool life was 96.7 minutes or longer than 9.36% from the Central Composite Design prediction, which was 85.78 minutes. This maximum value achieved at cutting speed (v) of 42 mm/min, cutting depth (d) of 1 mm, and feed rate (f) of 0.15 mm/rev. Whereas the mathematical modeling for the magnesium AZ31 in the milling process is Y = 34.7 + 7.69v - 0.426f - 61.5d - 0.0688 v*v + 0.000539 f*f + 1.06 v*d + 0.0363 f*d.***

Keywords: RSM, CCD, magnesium AZ31, optimization, machining, parameters

1. Introduction

The quality of magnesium AZ31 as the raw material for the machining process, especially the milling machining, can be seen by optimizing the value using Central Composite Design (CCD) Response Surface Method by calculating several variables in milling process which influences the optimization of the machinery itself such as cutting depth, feeding and tool rate [1]. Some statistical and mathematical techniques are often used in order to gain an optimal conditions of a machining process, without requiring too much data. Among the frequently used methods is the Central Composite Design (CCD) response surface method. Simple use by composing a mathematical model, the researcher can detect the value of independent variables that have more influence to the response value to be optimal [2]. Compared with other methods such as full factorial used to find interaction relations using 3 factors requires 27 data samples, while using the Central Composite Design (CCD) only requires 20 data samples, and with the same success rate of research, the Central Composite Design (CCD) is more appropriate to be used in this research.

The number combination of factors is set up by the response surface method of the Central Composite Design (CCD) on the machining process for magnesium AZ31 with a total sample of 23 + 6 + 6 = 20. So that the results obtained material cutting more subtle and precision [3]. The factors used in this research are tool rate (v), cutting depth (d) and feeding (f) using 3 stratified variables for each factor [4]. Thiagarajan's research in 2012 shows that the Central Composite Design (CCD) method used to find out the optimal value of drill machining in steel as a composite matrix, takes 95% confidence level on all graphic results close to +1 or there is a positive relationship between variable and response.

2. Literature Study

Magnesium AZ31 is a mixture of magnesium with aluminum and zinc. Magnesium is a good nonferrous metal vibration damper so often used in structural and non-structural applications where weight of the material is preferred in the transportation industry because the weight or absence of the vehicle structure affects the amount of fuel consumption [5].

Table 1: Physical properties of magnesium

Physical Properties	Magnesium Alloy
Liquid Point, K	922 K
Boiling Point,K	1380 K
Ionization Energy, I	738 KJ/mol
Ionization Energy, II	1450 KJ/mol
Mass Density (ρ)	1.74 g/cm^3
Atomic Radian	1.60 A
Heat Capacity	1.02 J/gK
Ionization Potential	7.646 Volt
Conductivity of Heat	156 W/mK
Evaporation Entalpy	127.6 kJ/mol
Forming Entalpy	8.95 kJ/mol

The magnesium manufacturing industry requires several product characteristics that correspond to the properties of magnesium itself, which are lightweight, and are readily given machining treatment. The machining process itself has requirements that must be met to achieve the desired quality, the requirements to be considered include:
1) The machining is able to remove material from workpiece
2) Intended to create components

3) Accuracy
4) Getting a precise form
5) Short cutting time
6) Long life of cutting tool
7) High quality components
8) Low production costs
9) Environment support

In the manufacturing industry the machining process is one way to produce the product in large quantities with a relatively short time. Many different types of machines are used, this means leading to different processes for each form of product. In the process of milling machining, the workpiece is a type of material with certain mechanical properties that are cut continuously by cutting tool to produce the shape as required, therefore it is necessary to adjust the material of the cutting tool. Because of this, the age of the cutting tool itself becomes one of the most important machining requirements to be concerned to observe as it is directly related to other requirements such as low production costs and high component quality [6].

There are three main parameters that affect the cutting force, the increase of heat and integrity of the workpiece surface produced. The three parameters are cutting velocity (v), feeding (f) and cutting depth (d). The cutting velocity is the speed around the workpiece with the unit (m / min), feeding is the movement or distance of the cutting tool per unit of motion of the work piece with unit (mm / rev), the cutting depth is the thickness of the waste material in the feeding direction by unit (mm).

The success of cutting with the milling machine is influenced by the cutting ability of the cutting tool and the machine. The cutting capability involves cutting and feeding speeds. The cutting speed of the milling machine can be defined as the length of the waste that is cut off by one eye cutting the blade in one minute. The cutting speed for each material is not the same. Generally the harder the material, the smaller the price of cutting speed and to the contrary. The cutting speed in milling process is determined based on the price of the cutting speed according to the material and the diameter of the blade.

In response surface methodology, independent variables are defined as X1, X2, ..., XK and assumed as continuous variables, whereas the response is defined as the dependent variable Y which is a random variable [7]. The mathematical relationship describes the experimental response and the unknown free variables, so the first step to do is to determine the approximate corresponding to the mathematical connection. If a mathematical connection is already known, then it can be used to determine the most efficient operating conditions. According to Garsperz (1992), usually the initial stage formulated models of polynomial regression with a low order, eg first order which is nothing but a linear regression model, with the following equation:

$$Y = \beta 0 \neg + \beta 1x1 + \beta 2x2 + \ldots + \beta 0x\neg k + E$$

Using the central composite design (CCD), to have a better quality than not using it, the design must have an orthogonal property and also be adjustable if the range of response variables is completely unknown. In other words, the variety of response variables that are allegedly the same for all points provided that the points have the same distance from the center of the design (center runs). Three dimensional curves (Three dimensions response surface and contour plot) are used to test the true effect of experimental variables on the results obtained. The coefficients in the empirical model are estimated by using multi-regression analysis. The suitability of the empirical model with the experimental data can be determined from the coefficient of determination (R2). To test whether or not the empirical model produced is used ANOVA (Analysis of Variance). In simple correlation analysis, it is possible to find that two variables are positively correlated, negative, or uncorrelated.

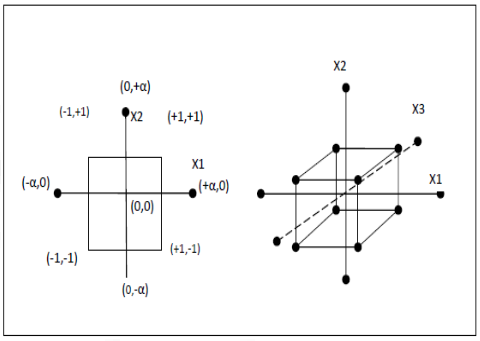


Figure 1: Central Composite Design in a box

3. Research Methodology

Place of research conducted at the laboratory of Production Department of Mechanical Engineering University of Lampung for data retrieval. The test is at room temperature condition varies from 27 °C to 35 °C. The cutting tools used for this research are high speed steel. The material used in this research is magnesium AZ31.The first step is to set the value of the increase the variables, with the table as follows:

Table 2: Variable value of central composite design

Cutting Speed (v) (mm/min)	Feed rate (f) (mm/rev)	Depth of Cut (d) (mm)
22	0.15	1
32	0,2	2
42	0,25	3

After that, do the machining using the AZ31 magnesium test material. With the test format according to the coding table for the Central Composite Design method:

Table 3: Design parameters of central composite design

Number	Run Order	Variable Coding		
		Cutting Speed (v) (m/min)	Feeding (f) (mm/rev)	Depth of Cut (d) (mm)
1	5	-1	-1	-1
2	9	1	-1	-1
3	16	-1	1	-1
4	8	1	1	-1
5	11	-1	-1	1
6	4	1	-1	1
7	14	-1	1	1
8	6	1	1	1
9	15	-1	0	0

10	18	1	0	0
11	3	0	-1	0
12	13	0	1	0
13	12	0	0	-1
14	20	0	0	1
15	2	0	0	0
16	1	0	0	0
17	7	0	0	0
18	17	0	0	0
19	19	0	0	0
20	10	0	0	0

The tool wear was measured progressively. Each experiment or run was stopped when the tool wear reached at the rejection criteria which is 0.2 mm. The tool then was replaced by the new tool and followed by new run. The tool life is obtained according to the machining time taken for the wear reached at this rejection criteria. All these data were analyzed using Minitab software in order to compute the mathematical model for the tool life.

4. Results and Discussions

Table 4: Results obtained

Run Order	Cutting Speed v, mm/m	Feeding *f*, mm/rev	Depth of Cut d, mm	Tool life, minutes	Tool Wear, Vb
1	32	0.2	2	13.38	0.2
2	32	0.2	2	13.38	0.2
3	32	0.15	2	32.6	0.2
4	42	0.15	3	37	0.2
5	22	0.15	1	40	0.2
6	42	0.25	3	4.4	0.2
7	32	0.2	2	17	0.2
8	42	0.25	1	4	0.2
9	42	0.15	1	96.7	0.2
10	32	0.2	2	13.38	0.2
11	22	0.15	3	64.2	0.2
12	32	0.2	1	50.1	0.2
13	32	0.25	2	6.48	0.2
14	22	0.25	3	11.4	0.2
15	22	0.2	2	6.34	0.2
16	22	0.25	1	9	0.2
17	32	0.2	2	13.38	0.2
18	42	0.2	2	5.45	0.2
19	32	0.2	2	13.38	0.2
20	32	0.2	3	15	0.2

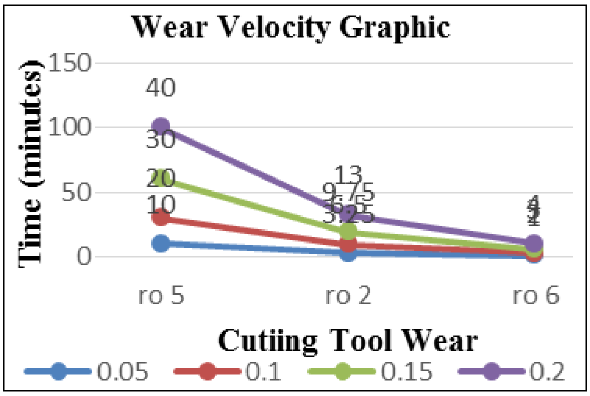
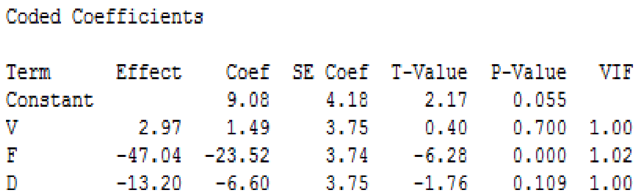


Figure 2: Tool wear progression at variance of feedrate

RO 5 is a combination of all lowest value variables (-1, -1, -1), RO 2 is a combination of all the middle value variables (0, 0, 0) and RO 6 is a combination of all highest value variables (1, 1, 1) . From tool life of low variable age of cutting tool for 40 minutes, to use of variable value of middle produce tool life for 13 minutes mean age of cutting tool decreased 67,5%, and from middle variable to low variable value with value 4 minute 24 second, decreased as much 68% . That is, the average decline in tool life value at each increase in the variation level is 67.75%.

Cutting tool will experience wear and abration after being used for cutting, the greater the wear of cutting tool then the cutting tool condition will be more critical and the age of the cutting tool is getting shorter. If the cutting tool continues to be used then the wear of the cutting tool will be faster because the cutting edge will be damaged and lead to shorter cutting tool life, fatal damage should not occur on the cutting tool because a large cutting force will damage cutting tools, machine tools and workpieces and may endanger the operator as well as influence great on the geometry tolerance and surface quality of the product. The linear combination of cutting variables in Figure 2 shows a negative correlation, because the purpose of this study is the maximum cutting tool life. The negative correlation in question is when the cutting variable value is raised and used in the machining process of the frais, the value of the life of the cutting tool decreases or accelerates faster than if it uses a low cutting variable value [8].



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Coded Coefficients

Term      Effect    Coef  SE Coef  T-Value  P-Value   VIF
Constant            9.08     4.18     2.17    0.055
V           2.97    1.49     3.75     0.40    0.700  1.00
F         -47.04  -23.52     3.74    -6.28    0.000  1.02
D         -13.20   -6.60     3.75    -1.76    0.109  1.00
```

Figure 3: Regression coefficient

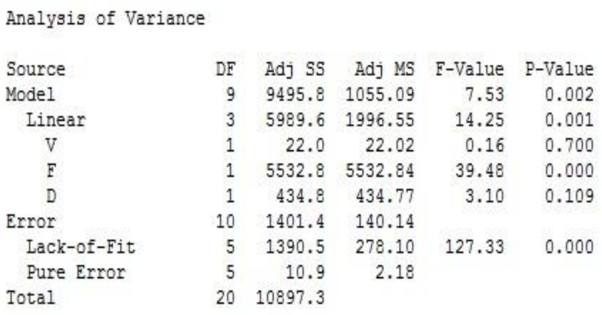
Figure 3 showed the result of the regression coefficient model in stage I. The value of the obtained coefficient shows the constant value of 9.08. So we get the following equation:

$Y = 9.08 + 1.49v – 23.52f – 6.60d$, or

$T \text{ (tool life)} = 9.08 + 1.49v – 23.52f – 6.60d$

According to the equation of linear regression line can be explained that:

1) The coefficient value v = 1.49 means that, if the velocity value (v) increases by one point, and the other independent variable remains, then the life of the tool will be added as the coefficient multiplier is 1.49.
2) The coefficient value f = -23.52 means that, if the value of the feeding motion (f) increases by one point, and the other independent variable is fixed, then the lifespan is reduced by 23.52% according to the coefficient multiplier value because the value of the coax is negative.
3) The coefficient value d = -6.60, means that if the depth of cut (d) value increases by one point, and the other independent variable is fixed, then the life of the tool (T) will decrease by 6.60 percent.



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Analysis of Variance

Source            DF   Adj SS   Adj MS  F-Value  P-Value
Model              9   9495.8  1055.09     7.53    0.002
  Linear           3   5989.6  1996.55    14.25    0.001
    V              1     22.0    22.02     0.16    0.700
    F              1   5532.8  5532.84    39.48    0.000
    D              1    434.8   434.77     3.10    0.109
Error             10   1401.4   140.14
  Lack-of-Fit      5   1390.5   278.10   127.33    0.000
  Pure Error       5     10.9     2.18
Total             20  10897.3
```

Figure 4: Result of ANOVA (Analysis of variance)

The hypothesis for this model is H_0 = the effect of the variable value on the response. H_1 = absence of influence of variable value to response. Possible data error (α) = 5% = 0.05 From the data above shows that the value of P-value of feeding motion variable (f) 0.000 and P-value of cutting depth (d) of 0.019 is smaller than when α = 0.05, meaning that the feeding motion and the depth of the cut affect the wear of cutting tool.

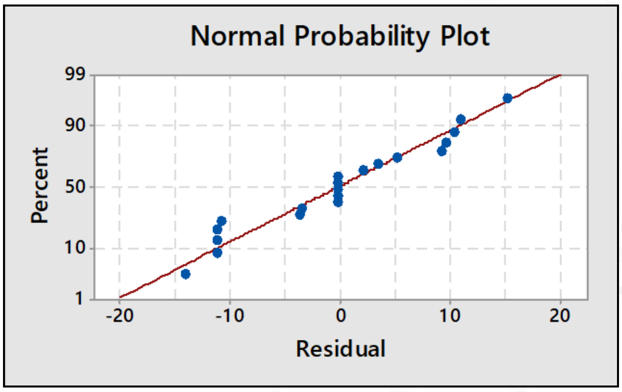
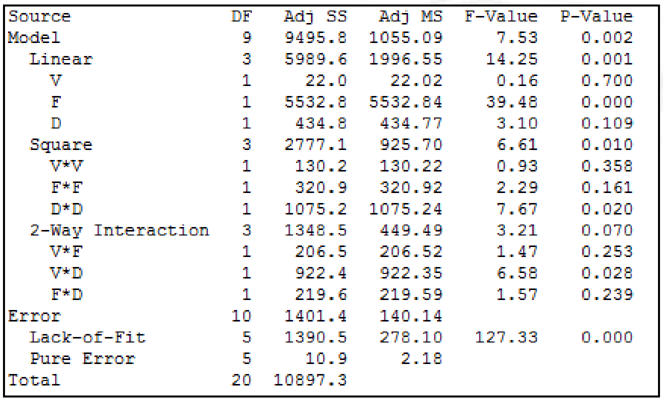


Figure 5: Normal probability plot

At the 20 sample points used, it shows the normal residual distribution close to the red line. The farthest drift from the normality test chart above is run order 20 with residual percentage reaching 23.03%.



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Source                DF    Adj SS   Adj MS  F-Value  P-Value
Model                  9    9495.8  1055.09     7.53    0.002
  Linear               3    5989.6  1996.55    14.25    0.001
    V                  1      22.0    22.02     0.16    0.700
    F                  1    5532.8  5532.84    39.48    0.000
    D                  1     434.8   434.77     3.10    0.109
  Square               3    2777.1   925.70     6.61    0.010
    V*V                1     130.2   130.22     0.93    0.358
    F*F                1     320.9   320.92     2.29    0.161
    D*D                1    1075.2  1075.24     7.67    0.020
  2-Way Interaction    3    1348.5   449.49     3.21    0.070
    V*F                1     206.5   206.52     1.47    0.253
    V*D                1     922.4   922.35     6.58    0.028
    F*D                1     219.6   219.59     1.57    0.239
Error                 10    1401.4   140.14
  Lack-of-Fit          5    1390.5   278.10   127.33    0.000
  Pure Error           5      10.9     2.18
Total                 20   10897.3
```

Figure 6: Central Composite Design for second order

A mathematical model as below is obtained:
T = 34.7 + 7.69 v - 0.426 f - 61.5 d - 0.0688 v*v
+ 0.000539 f*f + 19.77 d*d - 0.00352 v*f - 1.074 v*d
+ 0.0363 f*d

Modeling shows the value of Y prediction is smaller than actual Y 85.7887 min compared with actual Y that reaches 96.7 min. With the value of the lack-of-fit test showing the result of 0 then the second order model can be accepted as the optimization model in the frais machining application.

The using of mathematical modeling according to the predicted Y result is as follows :

$$Y = 34.7 + 7.69\,(42) - 0.426\,(137) - 61.5\,(1) - 0.0688\,(42^2) + 0.000539\,(137^2) + 19.77\,(1^2) - 0.00352\,(42 \times 137) - 1.074\,(42 \times 1) + 0.0363\,(137 \times 1)$$
$$= 85.7887 \text{ minutes}$$

The prediction of tool life of the second order model results for 85.7887 minutes using the optimum point of each variable is v = 42 mm / min, f = 0.15 mm / rev, and d = 1 mm, while the actual test uses the combination of parameters similar to the optimum points of each variable yielded the lifetime of the length of 9.36% ie 96.7 minutes or 96 minutes 42 seconds.

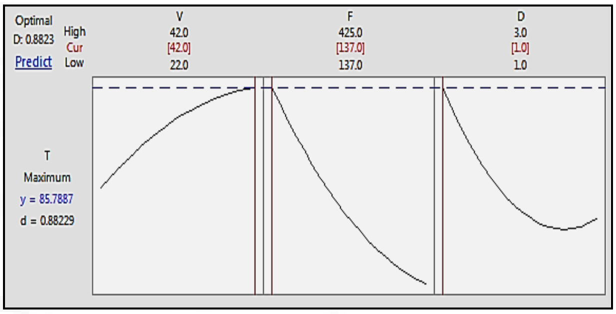

Figure 7: Optimization value of magnesium AZ31

The plot optimization shows the optimum point of the recommended milling machine based on this research, after the result of the research data is tabulated on the minitab software obtained the result as Figure 7 above. The picture shows that the optimum point for milling machining in this research used the variable value of cutting speed of 42 or using the highest variable value, low feeding variable is 0.15 mm / rev and low cut depth variable is 1 mm. The optimum point is obtained from the data table (Graphic 4), is run order 9.

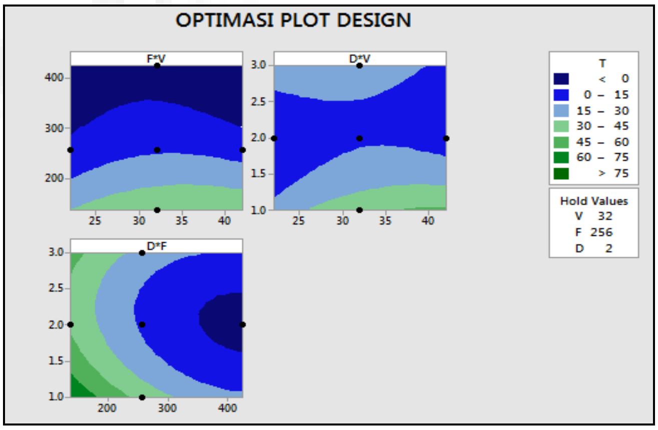

Figure 8: Plot contour

The green color is seen in all of the combining variable surface regions (f.v), (d.v), (d.f). The combined region shows that the area of maximum optimization is present in the feeding area of 0.15 mm / rev and the cutting depth of 1 mm for the contour of the combined plot (d.f). Meanwhile, for the other two combinations of factors (f.v) and (d.v) dark green or tool life above 75 min is very small at 42 mm / min cutting speed. This shows that the two most influencing variables on tool life with minimum variable value at milling machinary using AZ31 magnesium test material and HSS cutting tool are cut the variables of feed motion and cutting depth. That is, the greater the value of feeding motion and the depth of the cut then the more influential in reducing the life of the cutting tool. For variable speed cut, the value of the variable increasingly increasing the value of age response of it.

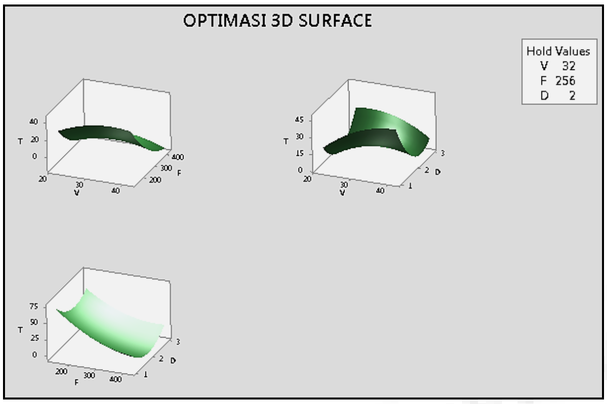

Figure 9: 3D Surface Plot

The above 3-dimensional surface illustrates how the combination of the three variables used affects the tool life. Surface number 1 shows that the longest life on the use of high cutting speed variable 42 mm / min and low feeding variable of 0.15 mm / rev. Surface number 2 shows the same thing, the age of the oldest cutting tool using high cutting speed value combined with low cutting depth. Number 3 using low feeding motion with low cut depth also results in the longest life of the cutting tool.

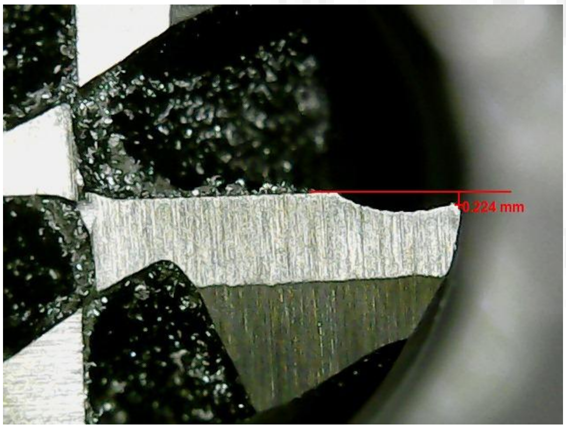

Figure 10: Cutting tool using optimization parameters

It can be seen that the wear of the tool itself occurs at the end of the edge of cutting tool. This is because at the end of the cut piece has a higher surface than the center of the cutting tool so that at the end of the cutting process will experience friction (cut) with the workpiece surface. Use of high cutting speed variable value at this optimum point in accordance with machining tolerance conditions for the finishing process on the milling machine. The cutting speed of 42 mm / min converted to 1280 rpm is the ideal cutting speed according to the HSS diameter tool usage guidelines for final machining process with mixed magnesium or AZ31 materials [9].

It is also revealed by some researchers that relatively large cutting and feeding depths will provide a large cutting load as well and a large contact surface will cause a rise in temperature resulting in a quick tool life due to abrasion and plastic deformation

5. Conclusions

From testing to the Central Composite Design application on the optimization of magnesium magnesium machining of AZ31, the following conclusions can be drawn:

1) The optimum value for AZ31 magnesium machining machining using HSS is using a variable cutting speed of 42 mm / min, a feeding motion of 0.15 mm / rev, and a cutting depth of 1 mm.
2) The equation of the mathematical model for AZ31 magnesium machining produced from the composite design surface reaction method is:
   $Y = 34.7 + 7.69 v - 0.426 f - 61.5 d - 0.0688 v * v + 0.000539 f * f + 19.77 d * d - 0.00352 v * f - 1.074 v * d + 0.0363 f * d$. With Y in response to tool life. With the estimated life of the cutting tool obtained from the calculation of modeling is over 85.7887 minutes.
3) The actual life score of the test using the optimum value increased by 9.36% from 85,7887 minutes to 96.7 minutes or 10,9113 minutes.
4) Residual value of 87.4% means response Y (tool life) has a strong relationship to the three variables.
5) The fastest tool life for 4 minutes using a variable combination of cutting speed 42 mm / min, feeding motion 0.25 mm / rev and cutting depth of 1 mm. While the longest tool life is 96.7 minutes using a combination of variables of the optimal value obtained from the second order mathematical modeling is cutting speed 42 mm / min, feeding motion 0.15 mm / rev and 1 mm cutting depth.

6. Acknowledgement

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