# Perpendicular Hole During Drilling of Magnesium Alloy AZ31

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**Abstract,** Magnesium is one of important materials light weight, which is used world widely, especially in the field of the automotive, sport, electronic and biomedical. Application of material magnesium and its alloy in the field of biomedical based on the magnesium characteristics which look very much like the nature of biocompatibility of bones in the body. Application material magnesium is also many developed by means of implanting in the body to replace the bone. Magnesium alloy have some advantages as like good strength-to-weight ratio, good biocompatible, good thermal conductivity and resistant to corrosion. However, magnesium known as flammable material, especially during the machining process at high cutting speed. The objective of paper is to optimize machining process and to maintain the chip is not burning. In this research, the point angle, lubricant and drilling parameter were analyzed to know their influence on the value of surface roughness, cylindricity and perpendicularity. On this research analysis support be done by using a Taguchi Method L18 consisting of 3 factors with 3 levels and 1 factors with 2 levels. The experimental results show that surface roughness is influenced by the significant contributions from the point angle 18.9 % and lubricant 14.5 %, where the point angle is $65^0$ with lubricant of synthetic oil. The nose radius of cutting tool tend to increase the force when cutting process. The drilling process effected on cylindricity of hole, mainly by point angle of $45^0$, however, especially if there is an interactions between the feeding of 0,2 mm/rev and synthetic lubricant. The value of perpendicularity of magnesium AZ31 in the drilling process however also carried out similar procedures are very much influenced by the cutting parameter of feeding that produces the significance of p = 0,044, while the strongest significance will be happened if there were an interaction between feeding of 0,1 mm/rev and synthetic lubricant to p = 0,041.

**Key words**: drilling,dmagnesium AZ31, perpendicular, ANOVA, significant

## INTRODUCTION

Drilling process is one of metal cutting process which is an importance that has been researched and analyzed by any researchers. One of researcher who was done experiment on drilling stated that the drilling process determine significantly the quality of machined surface, no exception to machine the difficult-to-cut material as like magnesium alloys (Shong and Shih, 2002). Magnesium and its alloys are categorized as difficult to machine because of flammable at machining temperature. However, some parameters influenced the surface quality depend on machining condition. One of them, as be done by Chen and Fuh (1996) that geometry of cutting tool has a significant effect on the surface quality of machined surface magnesium. With using split point drill, the force of cutting can be reducing to produce good machined surface. The drill used the coated cutting tool tend to increase the tool life and the quality of drilling hole (Chen and Tsao, 1999). Even using the hard coating layer on the cutting tool can give contribution significantly. The hard coating layer with fine grain structures reduced the friction between the cutting tool and work piece material.

Haan and Batzer (1997) also was done experiments to identify the effect of drilled geometry on the profile of machined surface. Even, torsion for each condition was measured to determine which parameter is more significant on the machined surface quality. Cutting speed, federate, depth of cut and type of cutting fluid are experimental parameters. It can be concluded that type of cutting fluid was the most significant factor in producing good profile of drill hole. Moreover, efficiency of the cutting fluid also depended on the built-up-edge formed. Increasing in point angle of drilling process can decrease torsion, but increase thrust force. Therefore, it can be stated that the factor of drill geometry and others parameters influenced significantly on drilling performance.

As known that magnesium is one of light alloy material which is used much more in field of manufacturing automotive components and biomedical material (Biermenn and Liu, 2014; Sitte, et.al., 2008). Application of magnesium and its alloy in the biomedical material based on magnesium characteristics of similar to the man bone, have biocompatible and degradable in the man body. Even magnesium was also developed and implemented for implanted material in the man body such as bone pin and dentist (Hofmann, 2009). Magnesium alloys have some advantages such as unique strength-to-weight ratio, very light material, resistance to corrosion and good conductivity. However, magnesium alloys were known as a flammable material (Ibrahim, et.al., 2014; Spicer et.al., 2014). Normally, process machining generated high temperature so that dangerous for machining flammable material like magnesium alloy. Machining at high cutting speed automatically increased the temperature by more than 1000 °C. Some attempts be done to control the generated temperature in order to the chip is not burn. Machining at high cutting temperature can impair the machined surface such as roughness value, hardness, texture and microstructure. Even, the high cutting temperature has impact on wear of the cutting tool (Kalpakjian an Schmid, 2006).

However, one of machining processes which is developed in Medical Engineering Field is drilling process because the drilling need high precision hole. As mention above that many factors which caused defects on machined components. Therefore, controlling generated temperature during drilling is needed in a way setting parameters. Chong and Shih (2002) recommended that to prevent the chip burned use point angle of twist drill of 70° - 118°. Other parameters which were controlled to reduce temperature were cutting speed, federate, and drilled technique.

The objective of this paper is to analyze perpendicular and cylindrical drilled hole during machining magnesium AZ31 by using design of Taguchi Method with orthogonal array of $L_{18}$. To get the optimal machining condition which produce the best perpendicular and cylindrical hole. Analysis variance used to build mathematic model as representative for machining condition.

## EXPERIMENTAL METHOD

Machining process was done by using Vertical Machining Center (VMC) and material used is magnesium alloy AZ31 with composition of aluminium of 3% and zinc of not more than1%. Magnesium alloy AZ31 prepare in block with dimension of length of 100 mm, wide of 50 mm and high of 40 mm. Twist drill cutting tool used is High Speed Steel with diameter of 12 mm. For drilling process, selected parameters are tool rotation 405 rpm and federate of 0.1 mm/rev. Figure 1 shows material and equipment used in drilling magnesium AZ31 are setting drilled hole for one set experiment trials (a), magnesium block, (c) CNC drilling of Vertical Machining Center and (d) Minimum Quantity Lubrication unit attach in the machine.

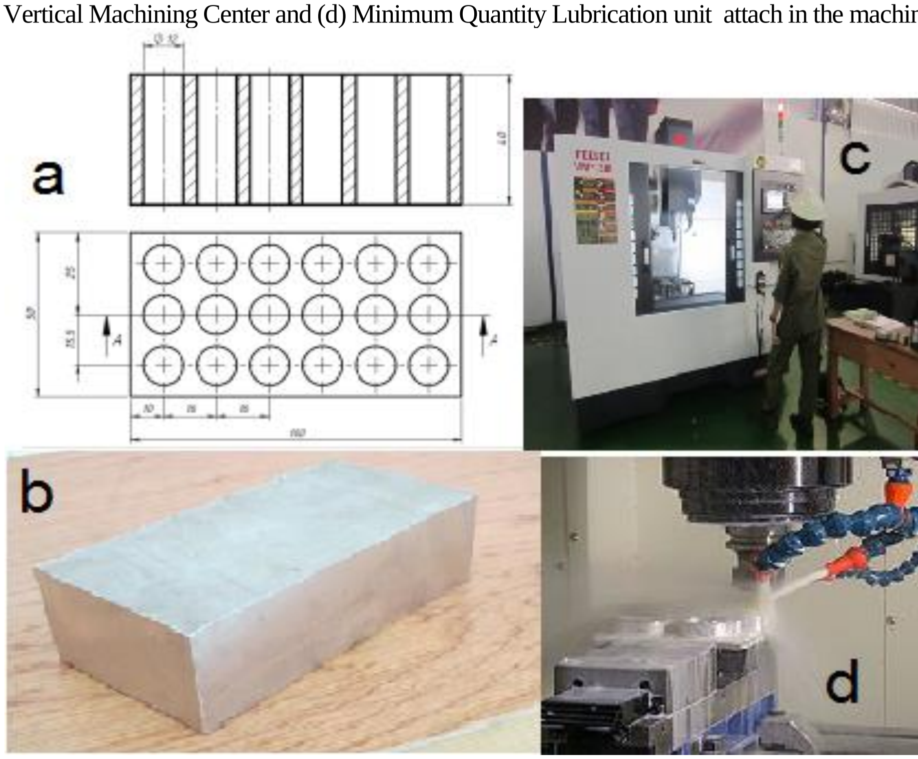

**FIGURE 1.** Material and equipment used in this experiment drilling of magnesium AZ31.

Perpendicular and cylindrical of the hole was measured by using Coordinate Measuring Machine (CMM). Every hole was measured three times to get average value. Eight teen holes produced in one set experiment, in which refer to Taguchi Method Design experiment with $L_{18}$. The drilling was done in deep of 40 mm and diameter of 12 mm. The cutting trials using four factors that are consist of three factors three levels each and one factor two levels. Their factors are tool rotation, feed rate, point angle and type of lubricant. Detailed factors and levels selected as shown in Table 1.

**TABLE 1.** Factors and levels in design experiment of Taguchi Method

| Code | Factors | unit | Levels | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| A | Tool rotation ( n) | rpm | 405 | 890 | - |
| B | Feed rate (f) | mm/rev | 0,1 | 0,2 | 0,3 |
| C | Point angle | $^0$ | 45 | 55 | 65 |
| D | Lubricant | - | Synthetic oil ST) | Palm oil (MKS) | Soybean oil (MK) |

# RESULTS AND DISCUSSIONS

## *Analysis Variance*

Table 2 shows an analysis of variance for the perpendicular of drilling hole on magnesium alloy when machining at certain condition. There are individual factors analyzed and two interaction factors of AxC and BxD. There is not parameter contributes dominantly on the perpendicular value. All parameters, either individually or interaction factors, which are have significant value more than 0.05 % (significant value standard). The lowest perpendicular value is 0.078% for point angle factor (factor C). This value closes to the significant value standard. It means that factor of point angle gives more contribution than others factors. All interaction factors do not give contribution significantly because all significant values bigger than 0.05%.

**TABLE 2.** Analysis of Variance for SN ratios

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | C |
|---|---|---|---|---|---|---|---|
| A | 1 | 0.000014 | 0.000014 | 0.000014 | 1.20 | 0.334 | 3.22 |
| B | 2 | 0.000097 | 0.000097 | 0.000049 | 4.28 | 0.101 | 22.29 |
| C | 2 | 0.000037 | 0.000117 | 0.000059 | 5.15 | 0.078 | 8.51 |
| D | 2 | 0.000030 | 0.000025 | 0.000012 | 1.09 | 0.420 | 6.89 |
| AxC | 2 | 0.000056 | 0.000040 | 0.000020 | 1.75 | 0.284 | 12.88 |
| BxD | 4 | 0.000155 | 0.000155 | 0.000039 | 3.41 | 0.131 | 35.63 |
| Res. Err | 4 | 0.000046 | 0.000046 | 0.000011 | | | 10.57 |
| Total | 17 | 0.000435 | | | | | 100.00 |

In the drilling process using twist drill cutting tool, speed of rotation and point angle of cutting tool are two factors give more contribution than others. As done by Chong and Shih (2002) that in the drilling magnesium alloy, point angle give higher significance more than others factors. The significant value of point angle is 0.078. This value is very close to 0.05% (the standard of significant value). Perpendicular of drill hole becomes increase following the increase of point angle. If point angle increase becomes the contact area between cutting edge and work piece material also increases. It is potential to impair the wall of hole, furthermore decreasing the hole perpendicular.

Table 3 shows the factors ranking that contribute to perpendicular of drill hole. The most significant contribution of factor is feed rate (factor B) and followed by point angle (factor C), lubricant and then tool rotation. Generally, the feed rate has dominant effect on the hole perpendicular, however, the point angle is the most significant. Similar pattern also shows in Figure 2, in which, factor B (feed rate) give more contribution to the hole perpendicular compare to others factors.

**TABLE 3.** Response Table for Signal to Noise Ratios with characteristic of larger is better

| Level | A | B | C | D |
|---|---|---|---|---|
| 1 | 45.10 | 45.10 | 45.10 | 45.10 |
| 2 | 45.10 | 45.10 | 45.10 | 45.10 |
| 3 | | 45.10 | 45.10 | 45.10 |
| DELTA | 0.00 | 0.01 | 0.00 | 0.00 |
| RANK | 4 | 1 | 2 | 3 |

As it can be seen in Figure 2 that the graph of factor B (feed rate) has a slope of line bigger than three others graphs (factor A, C and D). It states factor which has a big slope contributes more on the response variable. More detail that factor B at level 1 to 2 has the most significant effect because the slope line is extreme. Deference with level 2 to 3, the its slope is little bit small.

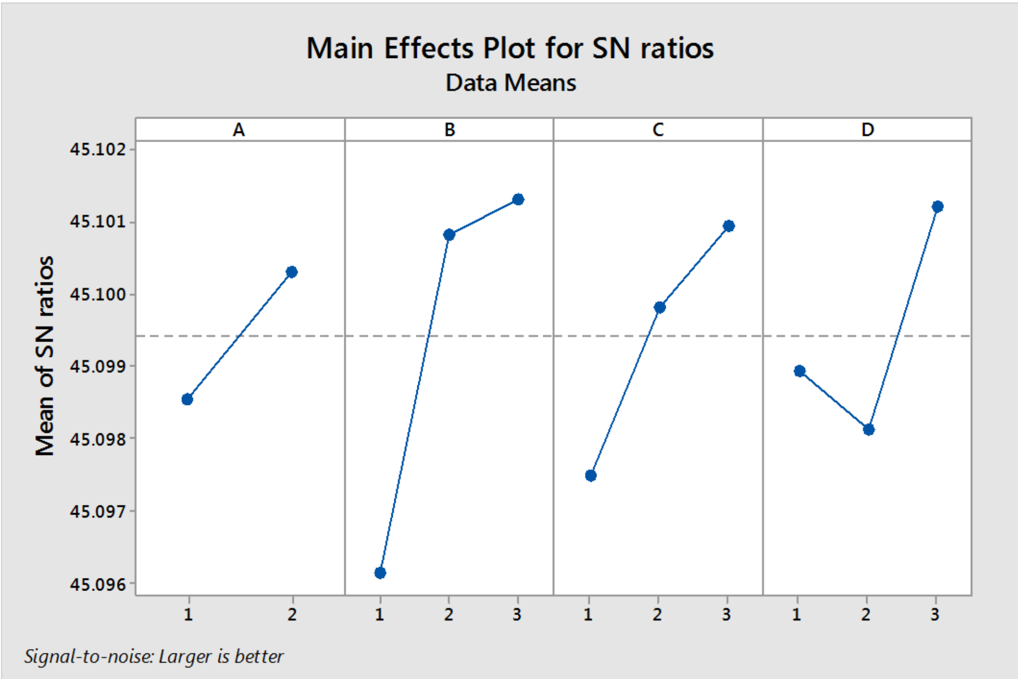


**FIGURE 2.** Graph of main effect plot of each factor for SN ratios with characteristic of larger is better

Figure 3 shows the interaction plot for SN ratios for each factor. Generally, almost all factors have interaction among them. There is an interaction between factor A and C at point of A1 and C2. It shows in the cross section between two lines. Similar phenomenon has at others factors. Factor B and C also has interactions. As shown in Table 4 that factor B and D has more significant effect than other factors. The interaction significant value of B1 and D1 of 0.041. This value is the most significant value for interaction. Factor B is feed rate and factor D is lubricant. Therefore, in theme of the surface roughness value that the interaction between feed rate and lubricant gave the best contribution.

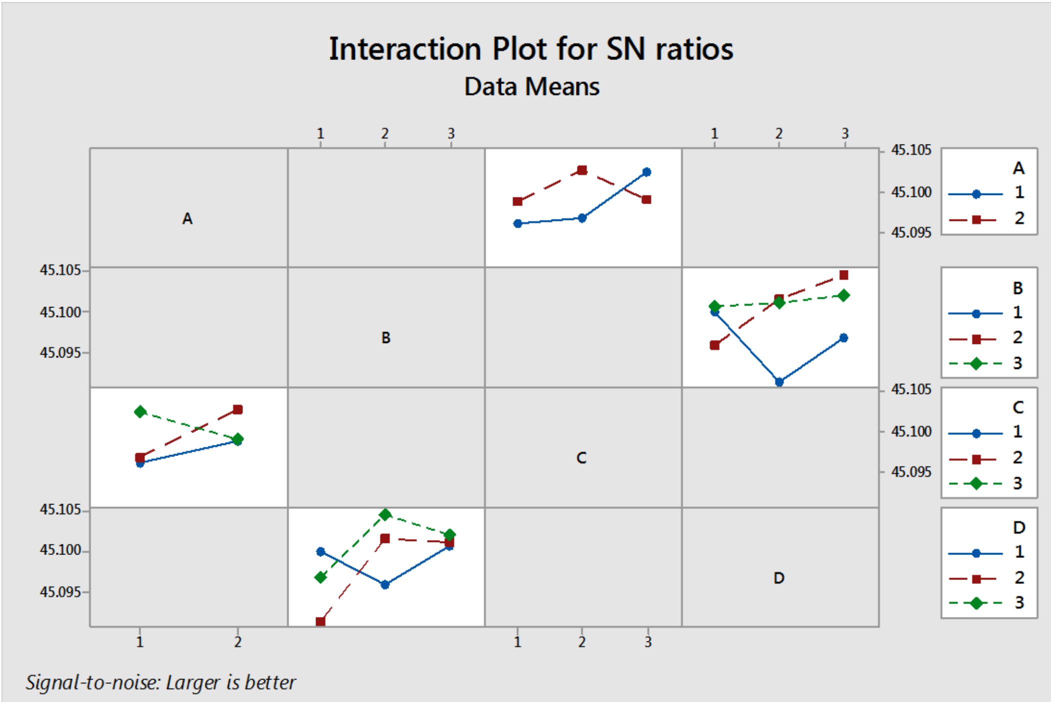


**FIGURE 3.** Graph of interaction plot of each factor for SN ratios with characteristic of larger is better

## *Mathematical Model*

Table 4 shows the coefficients of model for every parameter to build mathematical model for perpendicular drilling hole. Interaction between factor B and D (B1xD1) has the most significant factor contribute on the mathematical model, in which, the significant value (P) is 0.041. Following by individual factor B with the significant value is 0.044. Others factors are not significant contribution on to the perpendicular of hole generated. Observation and analysis indicated that the mathematical model built dominantly depend on feed rate either at individual factor or interaction setting. For individual factor, the significant factor value is 0.044 and for interaction factors are 0.041 (B1xD1) and 0.085 (B1xD2).

**TABLE 4**. Estimated Model Coefficients for SN ratios for perpendicular of drilled hole**.**

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 45.0994 | 0.000795 | 56717.601 | 0.000 |
| A1 | -0.0009 | 0.000795 | -1.097 | 0.334 |
| B1 | -0.0033 | 0.001125 | -2.914 | 0.044 |
| B2 | 0.0014 | 0.001125 | 1.231 | 0.286 |
| C1 | -0.0037 | 0.001377 | -2.662 | 0.056 |
| C2 | -0.0003 | 0.001377 | -0.223 | 0.835 |
| D1 | -0.0026 | 0.001778 | -1.465 | 0.217 |
| D2 | 0.0010 | 0.001778 | 0.591 | 0.587 |
| A1x C1 | 0.0019 | 0.002385 | 0.792 | 0.473 |
| A1xC2 | -0.0045 | 0.002385 | -1.866 | 0.135 |
| B1xD1 | 0.0053 | 0.001778 | 2.964 | 0.041 |
| B1xD2 | -0.0041 | 0.001778 | -2.280 | 0.085 |
| B2xD1 | -0.0020 | 0.002637 | -0.753 | 0.493 |
| B2xD2 | 0.0051 | 0.002637 | 1.936 | 0.125 |

It can be concluded that the feed rate has strong relation to perpendicular of drill hole. The perpendicular of drill hole also has correlation to the surface roughness or surface texture of machined surface. Therefore, the perpendicular and the surface roughness significantly influenced by the feed rate. As stated by Ibrahim et. al (2010) that the most dominant factor which contributed to surface roughness was the feed rate. Its contribution almost reached by 47.15%. But this result was achieved when machining titanium alloy with condition of dry machining.

On the analysis stages using the analysis of variance (ANOVA) with confident level of 95% or P-value less than 0.05 considered significant. In this analysis, where are all parameters gave contribution for the mathematical model but not all parameters contributed significantly. It can be built the mathematical model for the perpendicular value by using all parameters as followed.

Ra = 45.0994 – 0.0009A1 -0.0033B1 + 0.0014B2 – 0.0037C1 -0.0003C2 – 0.0026D1 + 0.0010D2 + 0.0019(A1xC1) – 0.0045(A1xC2) + 0.0053(B1xD1) + 0.0041(B1xD2) – 0.0020(B2xD1) + 0.0051(B2xD2)

However, to achieve efficiently the perpendicular value can be built the mathematical model by considering parameters which are contributing significantly, as shown in Table 5. And the mathematical model achieved as follow.

Ra = 45.0994 -0.0033B1 + 0.0053(B1xD1)

**TABLE 5.** Coefficients for parameters produced significant contribution

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 45.0994 | 0.000795 | 56717.601 | 0.000 |
| B1 | -0.0033 | 0.001125 | -2.914 | 0.044 |
| B1xD1 | 0.0053 | 0.001778 | 2.964 | 0.041 |

## CONCLUSIONS

1. Perpendicular of drill hole when machining of magnesium AZ31 was influenced significantly by feed rate, in which the significant value, P of 0.044.
2. There is an interaction cutting parameter between feed rate and synthetic lubrication that contribution significantly with P value of 0.041, in which machining process at feed rate of 0.1 mm/rev.
3. Decreasing of feed rate and lower synthetic viscosity resulted better perpendicular value.

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