Design and Development of Blow Mould Using Machining Optimization Parameters

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***Abstract:** This paper is concerned on the optimization of the surface roughness when milling mould aluminium alloys (AA6061-T6) with carbide coated inserts. Optimization of the milling is very useful to reduce cost and time for machining mould. The approach is based on Response Surface Method (RSM). In this work, the objectives were to find the optimized parameters and find out the most dominant variables (cutting speed, federate, axial depth and radial depth). The optimized value has been used to develop a blow mould. The first order model indicates that the feedrate is the most significant factors effecting surface roughness and cutting force.*

***Keywords:** response surface method, surface roughness, optimized, first order model*

I. INTRODUCTION

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. Although roughness is usually undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application.

Recent investigation performed by Alauddin *et al*. [1] has revealed that when the cutting speed is increased, productivity can be maximised and, meanwhile, surface quality can be improved. According to Hasegawa *et al*. [2], surface finish can be characterised by various parameters such as average roughness (Ra), smoothening depth (Rp), root mean square (Rq) and maximum peak-to-valley height (Rt). The present study uses average roughness (Ra) for the characterisation of surface finish, since it is widely used in industry. By using factors such as cutting speed, feed rate and depth of cut, Hashmi and his coworkers [3, 4] have developed surface roughness models and determined the cutting conditions for 190 BHN steel and Inconel 718. EI-Baradie [5] and Bandyopadhyay [6] have shown that by increasing the cutting speed, the productivity can be maximised and, at the same time, the surface quality can be improved. According to Gorlenko [7] and Thomas [8], surface finish can be characterised by various parameters. Numerous roughness height parameters such as average roughness (Ra), smoothening depth (Rp), root mean square (Rq), and maximum peak-to-valley height (Rt) can be closely correlated. The present study uses average roughness (Ra) for the characterisation of surface roughness, due to the fact that it is widely adopted in the industry for specifying the surface roughness. Mital and Mehta [9] have conducted a survey of the previously developed surface roughness prediction models and factors influencing the surface roughness. They have found that most of the surface roughness prediction models have been developed for steels.

II. RESPONSE SURFACE METHOD

Box-Behnken Design is normally used when performing non-sequential experiments. That is, performing the experiment only once. These designs allow efficient estimation of the first and second –order coefficients. Because Box-Behnken design has fewer design points, they are less expensive to run than central composite designs with the same number of factors. Box-Behnken Design do not have axial points, thus we can be sure that all design points fall within the safe operating. Box-Behnken Design also ensures that all factors are never set at their high levels simultaneously [10 - 12].

III. EXPERIMENTAL SET-UP

The 27 experiments were carried out on Haans machining centre with 6-axis as shown in Figure 1a and 90^0 tool holder as shown in Figure 1b. The water soluble coolant was used in these experiments. Each experiment was stopped after 90 mm cutting length. For the surface roughness measurement surface roughness tester was used. Each experiment was repeated three times using a new cutting edge every time to obtain accurate readings of the surface roughness. The physical and mechanical properties of the workpiece are shown in Table 1 and Table 2. After the preliminary investigation, the suitable levels of the factors are used in the statistical software to deduce the design parameters for Aluminium Alloys (AA6061-T6) as shown in Table 3. The lower and higher speed values selected are 100 m/s and 180 m/s, respectively. For the feed, the lower value is 0.1 mm/rev and the higher value is 0.2 mm/rev. For the axial depth, the higher value is 0.2 mm and the lower value is 0.1 mm and for the radial depth the higher value is 5 mm and lower value is 2 mm.

Figure 1: (a) Haans CNC milling with 6-axis, (b) 90^0 tool holder

Table 1: Physical properties for workpiece

Component	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
Wt %	95.8-98.6	0.04-0.35	0.15-0.4	Max 0.7	0.8-1.2	Max 0.15	0.4-0.8	Max 0.15	Max 0.25

Table 2: Mechanical properties for workpiece

Hardness, Brinell	95
Hardness, Knoop	120
Hardness, Rockwell A	40
Hardness, Rockwell B	60
Hardness, Vickers	107
Ultimate Tensile Strength	310 MPa
Tensile Yield Strength	276 MPa
Elongation at Break	12 %
Elongation at Break	17 %
Modulus of Elasticity	68.9 GPa
Density	2.7 g/cc

Table 3: Design Parameters

Cutting speed (m/min)	Feedrate (mm/rev)	Axial depth (mm)	Radial depth (mm)
140	0.15	0.1	5
140	0.15	0.15	3.5
100	0.15	0.15	5
140	0.15	0.15	3.5
180	0.15	0.2	3.5
180	0.15	0.15	2
100	0.2	0.15	3.5
140	0.15	0.15	3.5
180	0.15	0.15	5
100	0.15	0.2	3.5
140	0.2	0.1	3.5
180	0.1	0.15	3.5
140	0.15	0.2	2
180	0.15	0.1	3.5
140	0.1	0.15	2
140	0.15	0.2	5
100	0.15	0.1	3.5
140	0.2	0.15	2
100	0.15	0.15	2
140	0.2	0.15	5
140	0.1	0.1	3.5
140	0.2	0.2	3.5
140	0.15	0.1	2
100	0.1	0.15	3.5
180	0.2	0.15	3.5
140	0.1	0.2	3.5
140	0.1	0.15	5

IV. RESULTS AND DISCUSSION

The first order linear equation for predicting the surface roughness is expressed as:

$$y = 0.5764 + 0.0049x_1 - 3.5850x_2 + 1.5383x_3 - 0.016x_4 \quad (1)$$

Generally, reduction in cutting speed, axial depth of cut will cause the surface roughness to become larger. On the other hand, the increase in feedrate and axial depth will slightly cause a reduction in surface roughness. The feedrate has the most dominant effect on the surface roughness, followed by the axial depth, cutting speed and radial depth. Hence, a better surface roughness is obtained with the combination of low cutting speed and axial depth, high feederate and radial depth. The adequacy of the first order model was verified using the analysis of variance (ANOVA). At a level of confidence of 95%, the model was checked for its adequacy.

As it is shown in Table 4, indicates that the model is adequate since the P values of the lack-of-fit are not significant and F- statistics is 2.27. This implies that the model could fit and it is adequate. The optimum value for surface roughness is 0.4261 µm, which corresponds to design variables: Cutting speed (m/min) =100, Feed rate (mm/rev) = 0.2, Axial depth (mm) = 0.1 and Radial depth (mm) = 5.0. Figures 2 show the contour plots of the surface roughness in the cutting speed-feed rate plane for the lowest, middle and highest values of axial and radial depth of cut. Similar to the deduction from the linear model, the surface roughness decreases with the increasing of cutting speed and axial depth. For the other parameters, the cutting force exhibits proportional relationship. The final product of the blow mould has a surface roughness 0.45µm as shown in Figure 3. Eventually the time of machining has been reduced with the optimized method.

Table 4: ANOVA analysis

Source	Degree of freedom	Seq. sum of square	Adj. sum of square	Adj. mean of square	F-ratio	P-ratio
Regression	4	0.9309	0.9309	0.2327	0.78	0.552
Linear	4	0.9309	0.9309	0.2327	0.78	0.552
Residual Error	22	6.5937	6.5937	0.2997		
Lack-of-Fit	20	6.3151	6.3151	0.3158	2.27	0.351
Pure Error	2	0.2786	0.2786	0.1393		
Total	26	7.5246				

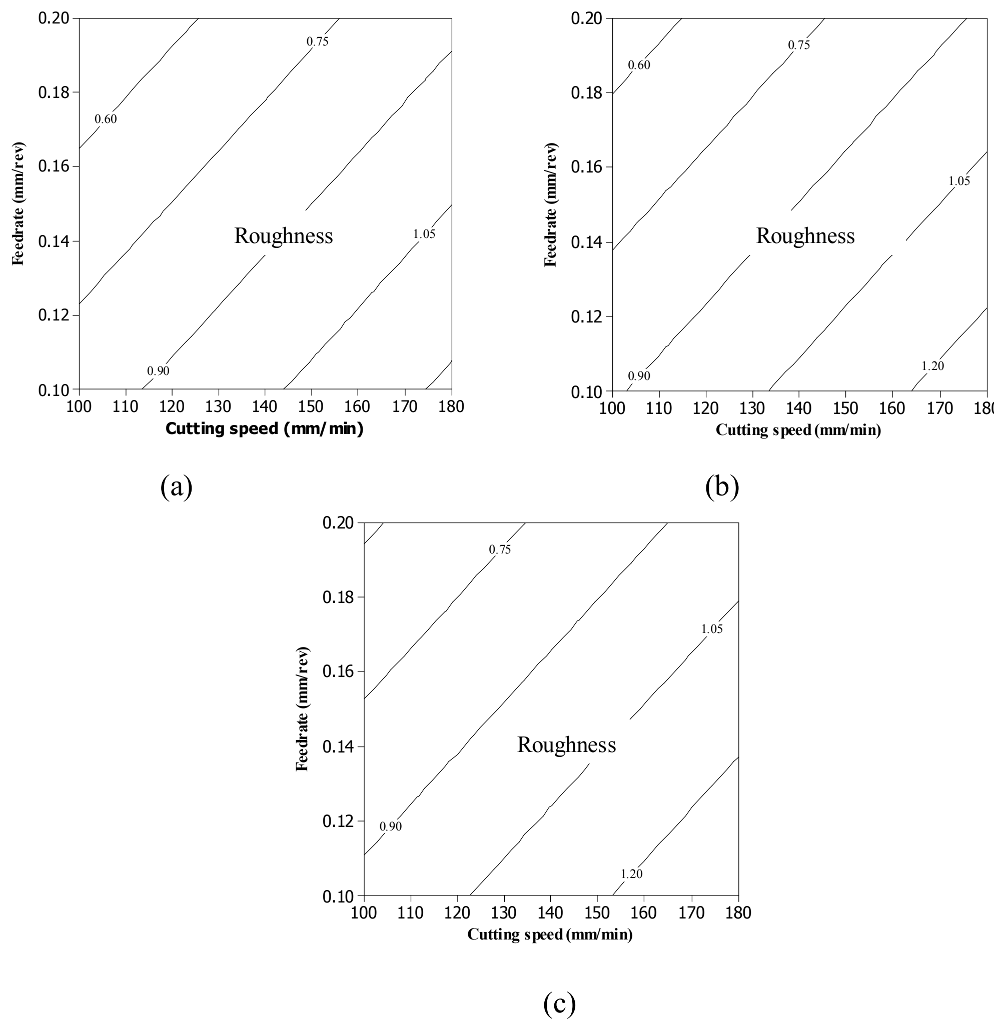

Figure 2: Surface roughness contours in the cutting speed-feed rate plane for (a) axial depth 1 mm, radial depth 2, (b) axial depth 1.5 mm, radial depth 3.5, (c) axial depth 2 mm, radial depth 5 mm

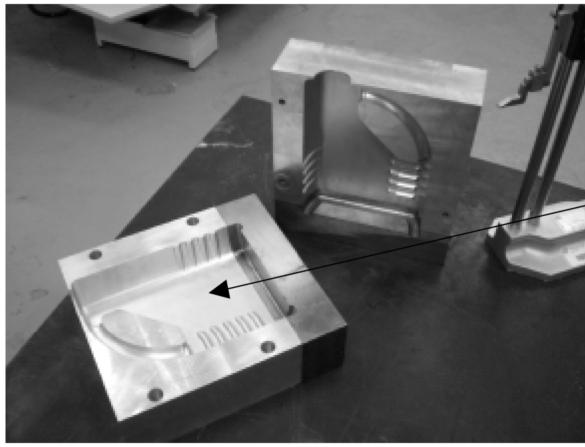

Figure 3: Blow mould

V. CONCLUSION

RSM has been found successful technique to perform trend analysis of surface roughness with respect to various combinations of four design variables (cutting speed, federate, axial depth and radial depth). The models have been found to accurately representing surface roughness values with respect to experimental results. RSM reveal that feedrate is the most significant design variable in determining surface roughness response as compared to others. With the model equations obtained, a designer can subsequently select the best combination of design variables for achieving optimum surface roughness. This eventually will reduce the machining time and save the cutting tools.

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