Comparison between Taguchi Method and Response Surface Methodology (RSM) In Optimizing Machining Condition

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Abstract - **The application of Taguchi method and RSM to optimize the milling parameters when machining Aluminum silicon alloy (AlSic) matrix composite reinforced with aluminum nitride (AlN) with three types of carbide inserts is presented. Experiments were conducted at various cutting speeds, feed rates, and depth of cut according to Taguchi method using a standard orthogonal array L_9 (3^4) and RSM historical data. The effects of cutting speeds, feed rates, depth of cut and types of tool on the surface roughness in milling operation were evaluated using Taguchi optimization methodology by utilizing the signal-to-noise (S/N) ratio and RSM optimization. Surface finish produced is very important in determining the quality of the machined part is within the specification and permissible tolerance limit. The analysis of results using S/N ratio concludes that the combination of low feed rate, low depth of cut, medium cutting speed and uncoated tool give a remarkable surface finish. Desirability criterion in RSM shows the optimum condition is at combination of high feed rate, high depth of cut, medium cutting speed and uncoated tool. In this case, the optimum condition obtained using Taguchi method is more accurate than RSM. Therefore it can be concluded that Taguchi method requires less number of experiment than RSM to determine an accurate optimum machining condition.**

Keywords - **Taguchi method, Response Surface Methodology, Machining process, Surface roughness.**

I. INTRODUCTION

Design of experiment (DOE) is very important tool to significantly reduce the time required for experimental investigation, as it is effective in investigating the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence, which less [1,2]. The most important stage in the design of an experiment lies in the selection of control factors. Robust design is an engineering methodology for obtaining product and process conditions, which are minimally sensitive to the various causes of variation to produce high-quality products with low development and manufacturing costs [1]. Taguchi's parameter design is an important tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost. Two major tools used in robust design are [1, 3-4]:

- Signal to noise ratio, which measures quality with emphasis on variation, and
- Orthogonal arrays, which accommodate many design factors simultaneously.

Taguchi's approach is totally based on statistical design of experiments [1], and this can economically satisfy the needs of problem solving and product or process design optimization [2]. Some of the previous works that used the Taguchi method as tool for design of experiment in various areas including metal cutting are listed in the references [5-6].

As many factors as possible should be included, so that it would be possible to identify non-significant variables at the earliest opportunity. Taguchi creates a standard orthogonal array to accommodate this requirement. Depending on the number of factors, interactions and levels needed, the choice is left to the user to select either the standard or column-merging method or idle-column method, or etc. Two of the applications in which the concept of S/N ratio is useful are the improvement of quality through variability reduction and the improvement of measurement. The S/N ratio characteristics can be divided into three categories when the characteristic is continuous [1]:

Nominal is the best characteristic; $S/N = 10\log\frac{\bar{y}}{s_y^2}$

Smaller the better characteristics; $S/N = -10\log\frac{1}{n}\left(\sum y^2\right)$

Larger the better characteristics; S/N $= -10\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right)$.

Where, $\bar{y}$ is the average of observed data, s_y^2 is variance of *y, n* is number of observations, and *y* is the observed data. For each type of the characteristics, with the above S/N ratio transformation, the higher the S/N ratio the better is the result.

RSM can be defined as a statistical method that uses quantitative data from appropriate experiments to determine and simultaneously solve multivariate equations, it is a collection of mathematical and statistical techniques for empirical model building whose objective is to optimise the responses [7]. Initially, RSM was developed to model experimental responses, and then migrated into the modelling of numerical experiments [8]. The application of RSM in design optimisation is aimed at reducing the cost of expensive methods of analysis.

Surface roughness is generally known to be highly affected by feed rate, followed by cutting speed and axial depth of cut [9-10]. The geometrical shape of the insert is another factor considered in studies on surface roughness [11-12]. According to Iqbal, et al. [13], who conducted a study on tool steel, material inclination angle, followed by radial depth of cut, was found to be parameter that most significantly affects surface finish after machining.

II. EXPERIMENTAL DETAILS

Taguchi Method

In this experiment with three factors at three levels each, the fractional factorial design used was a standard L_9 (3^4) orthogonal array [14]. This orthogonal array was chosen because of its minimum number of required experimental trials. Each row of the matrix represented one trial. However, the sequence in which those trials were carried out was random. The three levels of each factor were represented by a '0' or a '1' or a '2' in the matrix.

The factors and levels were assigned in L_9 (3^4) orthogonal array as in Table I according to roughing and semi-finishing conditions for the said material.

TABLE I
FACTORS AND LEVELS USED IN THE EXPERIMENT

Experiment No.	Cutting speed *V*(m/min)	Feed rate *f* (mm/gigi)	Depth of cut *d*(mm)	Type of insert
1	230	0.4	0.3	Uncoated
2	230	0.6	0.4	TiN
3	230	0.8	0.5	TiB2
4	300	0.4	0.4	TiB2
5	300	0.6	0.5	Uncoated
6	300	0.8	0.3	TiN
7	370	0.4	0.5	TiN
8	370	0.6	0.3	TiB2
9	370	0.8	0.4	Uncoated

Factors A, B, C and D are arranged in column 1, 2, 3 and 4 respectively in the standard L_9 (3^4) orthogonal array.

Response Surface Methodology (RSM)

In RSM the experiment were run according to the sequence in Table II as suggested in the Design expert software. The technique used was RSM historical data.

TABLE II
EXPERIMENTAL SEQUENCE USING CODING

Std	Run	Block	A:Vc m/min	B:fz mm/tooth	C:DOC mm	D:Tool
3	1	{ 1 }	-1	-1	-1	{ 1 0 }
6	2	{ 1 }	-1	0	0	{ 0 1 }
2	3	{ 1 }	-1	1	1	{ -1 -1 }
4	4	{ 1 }	0	-1	0	{ -1 -1 }
1	5	{ 1 }	0	0	1	{ 1 0 }
9	6	{ 1 }	0	1	-1	{ 0 1 }
5	7	{ 1 }	1	-1	1	{ 0 1 }
8	8	{ 1 }	1	0	-1	{ -1 -1 }
7	9	{ 1 }	1	1	0	{ 1 0 }

Materials and Milling Process

AlN reinforced Al-Si alloy matrix composite was fabricated by the method of stir casting which Al-Si alloy ingot, called matrix material, was reinforced with AlN particles of 10wt % reinforcement. The chemical chemical composition of Al-Si alloy was determined by Glow Discharge Profiler (Model-Horiba Jobin Yyon) as shown in Table III. The mean size of the reinforcement particles is <10 μm and the purity of >98%.

TABLE III
CHEMICAL COMPOSITION OF ALSi ALLOY

Elements	Fe	Si	Zn	Mg	Cu	Ni
Wt%	0.42	11.1	0.02	0.01	0.02	0.001
Elements	Sn	Co	Ti	Cr	Al	
Wt%	0.016	0.004	0.0085	0.008	Balance	

The experimental study was carried out in a DMC635V eco DMGECOLINE vertical milling machine fitted. Cutting inserts was attached in the tool body diameter ∅12mm. The surface roughness of the machined surface was observed using Roughness Tester Mpi Mahr Perthometer.

The surface roughness of the workpiece was measured at several locations along the length of the cut using a portable surface roughness tester model Mpi Mahr Perthometer. The length of each cutting path was 0.103 m.

III. RESULTS AND DISCUSSION

Experimental Results

Table IV shows the result of surface roughness. It is shown that, uncoated tool combined with high feed rate and medium depth of cut will produce high Ra i.e. rough machined surface. Previous study [15] also found that the feed rate was the most significant factor in controlling the surface finish. Martelotti [15] describes the chip thickness model as follows:

$t = s \sin b$, where s and b represent feed per tooth and tool angular position, respectively. Whereas the height of the tooth mark is given by the following:

$$h = \frac{s^2}{8[R + (s x N/\pi)]} \quad (1)$$

Where h is the height of tooth mark above point of lowest level, mm; s the feed per tooth, mm; R the radius of cutter, mm; N the number of teeth in cutter. The height of tooth mark can be reduced by increasing the radius of the cutter and by decreasing the feed per tooth until the tooth mark becomes scarcely distinguishable, particularly at the lower feed rates.

Coated tool normally will produce better Ra, since the coating material acts as dry lubrication. Similar results were found by previous researchers [16-17].

TABLE IV
RESULT OF SURFACE ROUGHNESS

No.	Cutting speed V(m/min)	Feed rate f (mm/tooth)	Depth of cut d(mm)	Type of insert	Surface Roughness, (μm)		*Ra*
1	230	0.4	0.3	Uncoated	0.57	0.74	0.5
2	230	0.6	0.4	TiN	1.13	1.05	1.05
3	230	0.8	0.5	TiB2	1.33	1.28	1.43
4	300	0.4	0.4	TiB2	0.35	0.33	0.39
5	300	0.6	0.5	Uncoated	1.28	1.59	1.26
6	300	0.8	0.3	TiN	1.5	1.47	1.48
7	370	0.4	0.5	TiN	0.75	1.09	0.93
8	370	0.6	0.3	TiB2	0.34	0.46	0.45
9	370	0.8	0.4	Uncoated	2.31	2.18	2.93

Optimization of Machining Condition Using Taguchi method

The objective of this study is to find the optimum condition for surface roughness when cutting AlSi/AlN using three types of cutting tools. One of the methods to analyze data for process optimization is the use SN ratio. Figure 1 shows the mean of SN ratio for smaller the better characteristic of surface roughness obtained using Minitab 14. From the slope of the graphs, it is observed that the feed rate is the most significant factor, followed by the type of coating material, depth of cut and cutting speed. Similar result is obtained from the Response Table for Signal to Noise Ratios Smaller is better in Table V The optimum condition is determined by the highest means SN values, and therefore the optimum condition is A1 (300 m/min), B0 (0.4 mm/rev), C0 (0.3 mm) and uncoated tool.

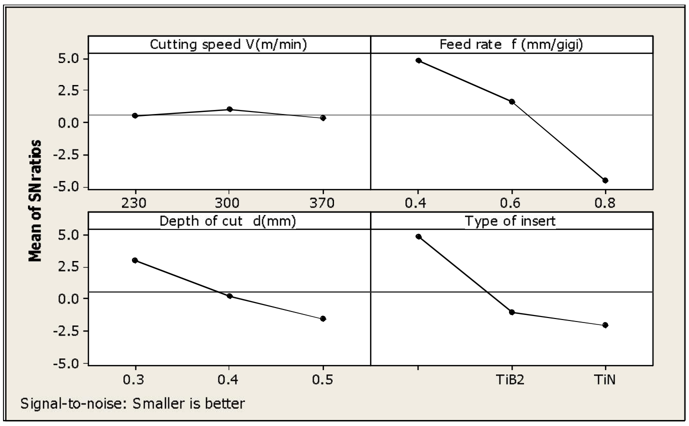

Fig 1 Mean of SN ratio for smaller the better characteristic of surface roughness

level	Cutting speed V(m/min) cut	Feed rate f (mm/tooth)	Depth of cut d(mm)	Type of insert
1	0.4357	4.7600	2.9968	4.8451
2	0.9930	1.5456	0.2257	-1.0896
3	0.2764	-4.6004	-1.5174	-2.0505
Rank	4	1	3	2

TABLE V
RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS SMALLER IS BETTER

Optimization of Machining Condition Using RSM

ANOVA was performed as shown in Table VI. R squared for this ANOVA and equation (2) is 0.98. This indicates that the mathematical model is significant, and factor A (cutting speed) is not significant on the surface roughness model.

TABLE VI
ANOVA TABLE FOR SURFACE ROUGHNESS

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	1.023840091	5	0.204768	31.481656	0.0085	significant
A	0.003192256	1	0.0031923	0.4907871	0.5340	
B	0.482645742	1	0.4826457	74.203419	0.0033	
C	0.145184167	1	0.1451842	22.321054	0.0180	
D	0.392817925	2	0.196409	30.196509	0.0103	
Residual	0.01951308	3	0.0065044			
Cor Total	1.04335317	8				

SQRT 1/Ra = 1.083 + 0.023 A - 0.283 B - 0.156 C - 0.156 D1 - 0.139 D2 (2)

Table VII shows the value of actual and predicted using equation (2), and the error was found less than 9%.

TABLE VII
VALUES OF ACTUAL AND PREDICTED SURFACE ROUGHNESS

No.	*V*(m/min)	*F*(mm/tth)	*d* (mm)	Type of insert	Average *Ra* (μm)	Predicted Ra (μm)
1	230	0.4	0.3	Uncoated	0.6	0.55
2	230	0.6	0.4	TiN	1.07	1.18
3	230	0.8	0.5	TiB2	1.34	1.19
4	300	0.4	0.4	TiB2	0.35	0.36
5	300	0.6	0.5	Uncoated	1.37	1.68
6	300	0.8	0.3	TiN	1.48	1.5
7	370	0.4	0.5	TiN	0.92	0.83
8	370	0.6	0.3	TiB2	0.4	0.41
9	370	0.8	0.4	Uncoated	2.47	2.25

Optimization is carried out by finding the desirability value using Design Expert software. Table VIII shows a part of the result generated. The optimum condition is when Ra equal 0.56 µmthat can be achieved when machining at cutting speed of 326 m/min, feed rate of 0.8, depth of cut of 0.47, and using uncoated tool. This optimum condition is not similar with the one obtained using Taguchi method. This may be due to a small number of data that caused the misleading of the result. Therefore it is recommended to use RSM CCD and Box Behkin to obtain an accurate optimization condition.

TABLE VIII
OPTIMIZATION USING DESIRABILITY CRITERION

No	Vc	fz	DOC	Tool	Ra	Desirability	
1	326.80	0.7	0.47	Uncoated	0.56	1	Selected
11	301.82	0.80	0.46	TiN	0.57	1	
21	308.03	0.80	0.50	TiB2	0.94	0.71	

IV. CONCLUSION

Two techniques of DOE has been compared i.e. Taguchi method and RSM. From the result obtained, the following can be concluded:

1. Taguchi method is found giving a better graphic visualization to determine the optimum condition by calculating SN ratio. But how big is the contribution of each factor need further investigated using ANOVA.
2. In RSM, the equation and ANOVA are the important elements to analyze the result. Therefore from this information, one can easily determine the degree of significant of each factor.
3. The desirability criterion available in the software for RSM will easily help user to determine the optimum condition. In order to avoid misleading result, user should ensure have enough data such as in CCD or Box Behkin arrays.
4. If user wants to use RSM, the steepest accent concept must be visualized to ensure the optimum condition is accurately determined, which requires more data.
5. Taguchi method requires less data to find the optimum condition than RSM. Therefore it is recommended to use Taguchi method if the experimental run is time consuming and costly.

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