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Modeling and Analysis of CNC Milling Process Parameters on Aluminium Silicate Alloy

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ABSTRACT

With the increasing demands of high surface irregularities and machining of alloys, conventional machining processes are now being replaced by high speed Computer Numerical Control (CNC) machines. In this paper aluminium silicate made from alloying aluminium and silicon oxide made from rice husk are used. The machining of the alloy on CNC machine is carried out. In addition to speed, feed and depth of cut, step over ratio also is taken as one of the input variables. The study of characteristics of aluminium silicate was carried out at high speed CNC milling machine over the speed of 6000 rpm. Nine experiments were conducted according to Taguchi L_9 orthogonal array. The machining of $AlSiO_2$ is done on high speed CNC milling machine using flat end mill of diameter10 mm. Linear regression models have been developed using ANOVA technique through Minitab 18 software and result is validated by conducting selected additional set of experiments.

Keywords

CNC Milling, Aluminium silicate, Flatness, ANOVA Technique.

1. INTRODUCTION

CNC Milling is the most common form of machining. It can create a variety of features on a part by cutting away the unwanted material. CNC milling is typically used to produce parts that are not axially symmetric and have many features, such as holes, slots, pockets, and even three dimensional surface contours [1].

Many researchers have worked in the area of machining of aluminium alloys. Baharudin et al. [2] applied Taguchi method to find the optimal surface roughness with AL6061 and applied HSS insert in face milling cutting operation. They have taken namely three variable spindle speed, feed rate and axial rake angle. They applied an orthogonal array L_9 (3^4), the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) and figure out the important factors that are influencing to the surface roughness. Krishnakant et al. [3] successfully applied Taguchi method to enhance the quality of manufacturing goods for turning process. They have done their analysis part in software Minitab 16.EN24 steel is taken as the work piece material for conducting the experimentation and optimize the Material Removal Rate.

Yigit et al. [4] proposed the multi-response optimization to obtain the minimum cutting forces and surface roughness for turning operation. They couples the Grey relational analysis (GRA) and the Taguchi method. Nine experimental runs based on an orthogonal array of the Taguchi method were performed to set objective functions to be optimized within the experimental domain. Yang and Chen [5] developed a systematic way of using Taguchi parameter design. They have done process control of individual milling machines. The Taguchi parameter design had been done to find out the optimum surface roughness performance with a suitable combination of cutting parameters in an end-milling operation.

Patel et al. [6] deployed the Taguchi's nested experimental design and optimize the surface quality of an end-milled surface. The author had analyzed two work piece material Aluminum alloy and Plain Carbon Steel and observed the influence of various machining parameters on surface roughness. They concluded that depth of cut was the most indispensible factor that affecting the surface roughness. Spindle speed and feed rate were the other two critical factors while machining aluminum alloy parts.

Alauddin et al. [7] used cutting speed, feed and depth of cut which are three important parameters to predict the surface roughness. Tolouei-Rad and Bidhendi [8] deployed an optimization methodology which estimates optimum machining parameters for milling operations. They applied method of feasible direction for optimization and considered maximization of profit rate as an objective function in milling operation. Dhavamani et al. [9] Studied the drilling of Aluminum silicon carbide composite. In this paper a comprehensive mathematical developed for correlating the interactive and higher order influences of different machining parameter. Taguchi method with an L_{27} fractional factorial design were used and applied GA based multi objective optimization technique with objective was minimum surface roughness and maximum MRR. ANOVA was also performed to check the feasibility of model. They considered drilling speed, feed and diameter of cut as input parameters.

2. DETAIL OF EXPERIMENTATION

2.1 SELECTION OF MATERIAL, EQUIPMENT & TOOLS

Selection of material, equipment & tools are playing a very vital role in machining.In industries aluminium alloys are widely used parent material because of their variety of applications and light weight. Aluminium silicate is aluminium based alloy which is used as work piece material for research work. Aluminium is predominant metal in aluminium silicate alloy having approximately 84.50%. Coordinate measuring instruments (CMM) [10] is used for the flatness measurement having least count of 1μm. It is an articulated type of coordinate measuring machine.

In this paper, high speed CNC milling machine from the institute is used with different process parameter for machining of $AlSiO_2$ (25mm x 45mm x 4mm) with End Mill cutting tool. It is Siemens coded CNC milling having 20 tool magazine developed by MTAB MaxMill Plus. Selection of tool materials for CNC milling process is plays a very important role. It is mainly depends on type of work piece and tool wear. It also depends on the work material that can be easily machined so that different complex shapes can be made in order to obtain the required design of the product. For the machining of aluminium silicate alloywhich is a soft material, Stainless steel is used as tool material. End Mill tool of M2 grade & four fluted having helix angle 45^0 and 10mm diameter (density 8138 kg/m^3) has been used for the machining of aluminium silicate.

2.2 MACHINING PARAMETERS

The machining process in CNC milling is greatly affected by a number of input and output
variables [11].

2.2.1 INPUT PROCESS PARAMETERS

Machining process input variables are the process-independent variables and these input variables are:

1. **Spindle Speed (N):** The spindle speed is the rotational frequency of the spindle of the machine, measured in revolutions per minute (rpm). The spindle speed used in this research work is in the range of 4000rpm to 6000 rpm.
2. **Feed Rate (f):** Feed rate is the relative velocity at which the cutting tool is advanced along the work piece. Its vector is perpendicular to the vector of cutting speed. The feed rate selected in the range of 250mm/min to 350mm/min.
3. **Depth of Cut (d):** It is cutting depth along Z- direction. It is also known as axial depth of cut. The depth of cut used for this research work is in the range of 0.6mm to 1.0mm.
4. **Step over Ratio (sr):** It is defined as the depth of cut in radial direction. It is measured in percentage of overlapping. The range of step over ratio lies in between 40% to 60%.

$$\text{Step Over Ratio} = \frac{\text{Width of overlap}}{\text{Width of end mill cutter}} \times 100$$

2.2.2 OUTPUT PROCESS PARAMETER

Machining output process parameter is the process-dependent parameter and it is defined as:

Flatness: Flatness can be analysed by quantifying deviations from a plane known as least squares (LS) reference plane. A least squares (LS) reference plane is a plane where the areas above and below the plane are equal and kept to a minimum separation. Flatness is measured as the highest peak to valley height normal to this reference plane. In this research work the flatness of the machined aluminium based alloys is measured by coordinate measuring Machine (CMM).

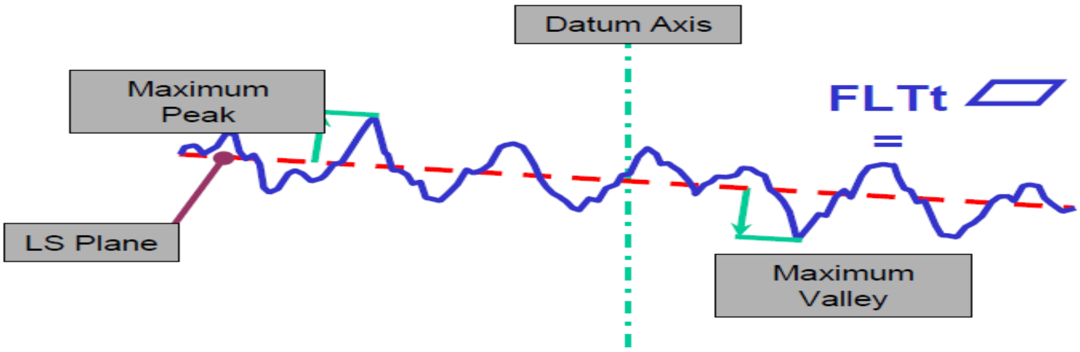

Fig. 1 Flatness Definition

2.3 EXPERIMENTATION

For experimental work on CNC Milling machine, CNC programmes have been developed with different levels of input parameters as per objective of research work. The levels of input

parameters selected are given Table 1:

Table 1: Input Process Parameter and their levels

Input Parameters	Level 1	Level 2	Level 3
Spindle Speed, N (rpm)	4000	5000	6000
Feed, f (mm/min)	250	300	350
Depth of Cut, d (mm)	0.60	0.80	1.00
Step over Ratio, sr (%)	40	50	60

Here there are four variable with three levels of input process parameters. So for conducting the experiments with these variables there are nine experiments needed according to Taguchi L_9 Orthogonal Array which give about 95% of confidence level [12, 13].

2.4 DEVELOPMENT OF PREDICTION MODEL

To predict the values of the selected response parameters, prediction models for and Flatness have been developed using linear regression with the help of ANOVA technique through MINITAB 18 software. The response variables have been taken as dependent variables and input process parameters (speed, feed, depth of cut and step over ratio) are taken as independent variables. It is important to test the significance of relations using F-test and p-test, and these values have been obtained from the MINITAB 18 software.

3 RESULTS AND DISCUSSION

In this section the evaluation of the experimental results after machining of the work material is done according to Taguchi L_9orthogonal array. The machining involves movement of end mill cutter (10mm diameter) from one end to other end in the direction of machining. Coordinate measuring machine (CMM) is used for measuring the value of flatness. This experimental result shows the flatness with the combination of different sets of input process parameters. The values obtained are given in Tables 2:

Table 2: Experimental Data of Alloy $AlSiO_2$

Exp. No.	N (rpm)	f (mm/min)	d (mm)	sr (%)	Flatness (μm)
1	4000	250	0.6	40	12
2	4000	300	0.8	50	10
3	4000	350	1.0	60	13
4	5000	250	0.8	60	11
5	5000	300	1.0	40	10
6	5000	350	0.6	50	12
7	6000	250	1.0	50	11
8	6000	300	0.6	60	10
9	6000	350	0.8	40	9

3.1 REGRESSION ANALYSIS

In the regression analysis, a statistical test is used to compute a probability, called a p-value, for the coefficients associated with each independent variable. It is important to have p-value less than or equal to 0.01 so it is statistically significant at the 99% confidence level and the associated variable is an effective and efficient predictor [14]. S is called the Standard Error or the Standard Error of the Estimate. It is the average squared difference of the error in the actual to the predicted values of the date (i.e. the square root of the mean squared error).Smaller the value of S, stronger the linear relationship [15].

The F value is the ratio of the mean regression sum of squares to the mean error sum of squares. Its value will range from zero to an arbitrarily large number. R-squared is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determinations for multiple regressions. R-squared is the ratio of Explained variation and Total variation. It is always between 0 and 100%. In general, the higher the R-squared, the better the model fits the data.

3.1.1 REGRESSION ANALYSIS OF ALUMINIUM SILICATE

The experimental results obtained are used to develop the linear equation. The regression equations obtained from linear regression analysis using MINITAB 18, are given below

Flatness = 19.56 - 0.001667 N- 0.02667 f + 4.17d – 0.1000sr ……………………. (1)

Also Analysis of variance (ANOVA) table is obtained which shows the p-value, F- value, coefficient of determination (R) and Standard Error (S) for the different input parameters are as shown in Table 3.

Table 3: Analysis of Variance of Flatness

Source	DF	Adj. SS	Adj. MS	F-Value	p-Value
Regression	4	37.500	9.375	7.94	0.035
N	1	16.667	16.667	14.12	0.020
f	1	10.667	10.667	9.04	0.040
d	1	4.167	4.167	3.53	0.133
sr	1	6.00	6.00	5.08	0.047
Error	4	4.722	1.181		
Total	8	42.222			
S= 1.08653 R-sq = 88.82% R-sq(adj) = 77.63% R-sq(pred) = 51.72%					

The above (Analysis of Variance) ANOVA table shows the model analysis of flatness. From this table it is observed that p-value is approximately less than 0.05 which means it is statistically significant at the 95% confidence level and the associated variable is an effective and efficient predictor. R-squared is approximately 89% which indicates that the model explains 89% the variability of the response data around its mean i.e. the better the model fits data. Here S, known as the Standard Error of the Estimate having smaller value which means stronger the linear relationship.

4 VALIDATION OF RESULT

In this section results are validated by conducting four separate set of experiments, and the data were recorded. The actual value of Flatness through CMM whereas predicted value of and Flatness is computed using Eqs.(1) and calculated the error. The validation results are presented in Tables 4. And it is observed that the maximum percentage of error was 13.3312 % for flatness. Thus it is observed that the error found between the experimental values and predicted values are less than 15%.

Table: 4 Validation of results for Flatness

Sr. No.	Speed N	Feed f	Depth of cut d	Step over ratio sr	Flatness (actual) µm	Flatness (Predicted) µm	Error (%)
1	4000	250	0.6	0.5	10	8.7765	12.2350
2	4000	350	0.8	0.4	8	6.9335	13.3312
3	5000	300	1.0	0.6	8	7.4540	6.8250
4	6000	250	0.8	0.5	7	6.2765	10.3357

5 CONCLUSION

This research work is aimed to modeling and analysis of CNC milling process parameters (speed, feed, depth of cut and step over ratio) using ANOVA technique. In this research it is observed that process parameters selected for the experiment have significant effects on the response parameters. Flatness value increases with increase in depth of cut whereas decreases with increase in speed and feed. The flatness value first decreases up to 50% of step over ratio and then increases with increase in step over ratio. For the validation of results, there are some additional set of experiments performed and find the experimental results. From the experimental results it is observed that the error found between the experimental values and predicted values are less than 15%. As it is less than 15%, the developed model is considered to validate the results [12].

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