Parametric optimization of aluminium alloy milling using Taguchi method for surface roughness

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Abstract-*The present work deals with the investigations of surface roughness of the machined parts during milling of Aluminium alloy using CNC Vertical machine. High speed steel Milling cutter is used for milling the Al alloy. The parameters considered for the optimisation are feed, depth of cut and speed. The taguchi's experimental design concept is used for optimizing the design parameters with three levels for better surface finish. Analysis of varience (ANOVA) technique and Signal-to-Noise ratios (S/N) functions are used in data analysis and to predict the optimum results.*
Keywords: **Milling, surface roughness, Taguchi method, ANOVA.**

I. INTRODUCTION

In the proposed research work, surface roughness of the product prepared by CNC end milling operation are studied experimentally and the results obtained are interpreted analytically for an Aluminium alloy. Milling is the machining process of using rotary cutters to remove material from a work piece advancing in a direction at an angle with the axis of the tool [7]. It covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. Milling is used in aerospace, die, machinery design and automobile as well as manufacturing industries [13]. After the advancement in the computer numerical control systems, Every industry now a days preferring CNC machines, CNC (Computer Numerical Control) is the general term used for a system which controls the functions of a machine tool using coded instructions processed by a computer. The application of CNC to a manual machine allows its operation to become fully automated [5]. Combining this with the use of a part program enhances the ability of the machine to perform repeat tasks with high degrees of accuracy.

Surface roughness is an important measure of product quality since it greatly plays a vital measure as it may influence frictional resistance, fatigue strength or creep life of machined components as well as production cost. In the present work surface roughness of the Aluminium alloy (AA5052) milling is determined; the parameters considered are speed, feed and depth of cut. Experiments are performed based on taguchi's L9 orthogonal array [9]. ANOVA technique and signal to noise ratio functions are used to identify the best influencing factor and optimising the parameter.

S.H. Tomadia, J.A. Ghanib [1] studied the effects of cutting parameters and the corresponding prediction model on the surface roughness in the machining of AlSi/AlN metal matrix composite (MMC). Experiments were conducted using uncoated carbide tool and PVD TiAlN coated carbide insert and conducted at different cutting parameters of cutting speed (240–400m/min), feed rate (0.3–0.5mm/tooth) and depth of cut (0.3–0.5mm) under dry cutting conditions. Taguchi's L18 orthogonal array was used for performing experiments, based on taguchi's signal to noise ratio functions and found the optimum parameter [1]. Emel kuram, babur ozcelik [2] carried out a study to understand micro milling of aluminium material with ball end nose mill, he performed the study in four stages (experimental work, modelling, mono and multi objective optimisation. On the first stage experiments are carried out using taguchi's orthogonal array and effect of parameters were studied. In second stage all data was gathered during the experimental work which is used to predict the responses in the process. In third and fourth stages using the data's of all the responses with the help of taguchi's signal to noise ratio functions, analysis of varience, they found that optimum parameters to obtain the best results [2].

A. Venkata Vishnu, K. B. G. Tilak [3] employed ANOVA technique to study the influence of cutting parameters (cutting speed, feed per tooth, axial depth of cut and radial depth of cut) during ball-end milling of Al2014-T6 under dry condition. Experiments were conducted based on face centred, rotary central composite design (RCCD) and analysis states that Radial depth of cut has significant effect on the cutting force components [3]. Takur premjit Mahesh and rajesh [4] applied fuzzy logic integrated with taguchi method for minimizing the surface roughness and maximizing the MRR in CNC end milling of AA7075 T6. The input parameters taken into consideration are speed, depth of cut, feed nose radius and radial depth of cut using S\N ratio functions and ANOVA technique shows that nose radius and radial depth of cut are best parameters contributing 31% of variance [4]. Venkata Vishnu and Tilak [5] investigated on the effect of cutting parameters on Surface Roughness of Aluminium Alloy 6351 by employing Taguchi techniques [5]. Kadirgamaa and Noora [6] said that optimization of milling is very useful to reduce cost and time for machining mould. The approach is based on Response Surface Method (RSM) and Radian Basis Function Network (RBFN). RBFN was successfully used by Tsoa and Hocheng in their recent research [6]. Siva Kumar and Bathina Sreenivasulu [7] found that Surface quality affects fatigue life of components and influences various mechanical properties. Optimization of cutting parameters in CNC End milling of Aluminium Alloy 6082 is done using taguchi technique [7].

Taguchi method and response surface methodology are used for optimisation of surface roughness for end milling of Aluminium alloy by considering the are speed, depth of cut and feed and some of the researchers found that radial depth of cut is the most significance factor [8-9,12-14]. Mithilesh Kumar Dikshit and Asit Baran Puri [10] employed response surface methodology for the study of cutting force on end milling of Al2014-T6 alloy and they concluded that radial depth of cut has most influential factor on cutting forces [10]. Sanjit Moshat and Saurav Datta [11] to build up a bridge between productivity and quality studied the optimization of CNC end milling process parameters to provide good surface finish as well as high material removal rate (MRR). The surface finish and material removal rate have been identified as quality attributes and are assumed to be directly related to productivity and to find the optimum parameter they used PCA and taguchi analysis.

II.TAGUCHI METHOD AND EXPERIMENTAL DETAILS

A. Taguchi method

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. Genichi Taguchi [7] developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. Taguchi method is applied in engineering, biotechnology, marketing and advertising etc.

B. Design of experiments

The first step for design the experiments is to identify the quality characteristics and to select the process parameters. In the machining processes, the most common controlled parameters are the cutting speed, feed rate and radial depth of cut. These are other parameters that could also be controlled, like insert radius or the geometry of tool. However, these parameters are more restricted and are associated to the properties of tools, which is not the goal of this study. The below table shows the process parameters and their levels taken for experimentation.

TABLE 1
CUTTING PARAMETERS AND THEIR LEVELS

Symbol	Cutting parameter	Level 1	Level 2	Level 3
A	Cutting speed(m/min)	1500	1750	2000

B	Feed rate(mm/rev)	50	75	100
C	Depth of cut(mm)	0.25	0.5	0.75

After defining the process parameters and the quality characteristic that will be controlled, it is necessary to designate the number of levels of experiments should be conducted. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect the product quality with a minimum amount of experimentation, thus saving time and resources. An L9 orthogonal array is used in this study for doing experiments, the below table shows the taguchi's L9 orthogonal array.

C. Experimental details

Experiments are carried on a CNC end milling machine with high speed steel(HSS) end mill cutter of diameter 10mm for the material AA5052 of dimensions (90mm x 30mm) based on the taguchi L9 orthogonal array. The following table 2 shows the chemical composition of the Aluminium alloy, fig.1shows the CNC end milling machine with the material inserted.

TABLE 2
CHEMICAL COMPOSITION OF AA5052

Material		Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
%wt		0.6	0.5	0.1	0.5	2.6	0.2	0.1	0.25	Balance

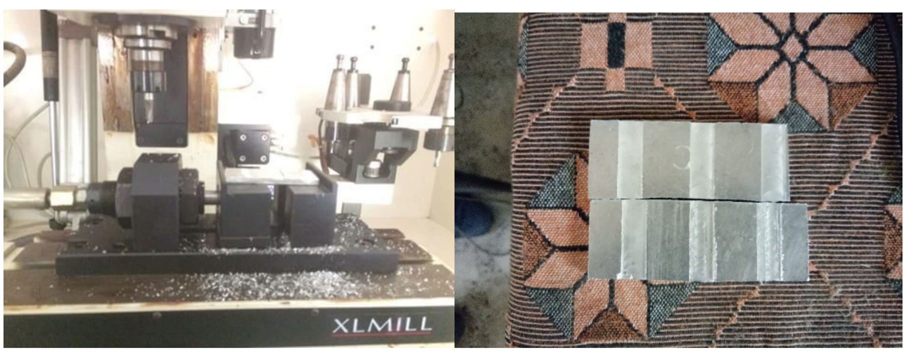

Fig.1 Milling machine and Work piece

III. RESULTS AND DATA ANALYSIS

The Taguchi analysis procedure can be described in four steps. In the first, is implemented the evaluation of signal-to-noise ratio and allows to define the level of variation for each parameter. This is followed by a comparison of arithmetic mean surface roughness among all the tests. The third is based on analysis of variance, which is used to define the influence of each parameter. Finally, is implemented the final test to validate the results [9].

TABLE 3
TEST RESULTS AND S/N RATIO

Speed	Feed	DOC	Surface roughness (µm)	S/N ratio

1	1	1	4.39	-12.8493
1	2	2	2.36	-7.45824
1	3	3	3.09	-9.79917
2	1	3	1.79	-5.05706
2	2	1	2.07	-6.31941
2	3	2	2.63	-8.39911
3	1	2	0.68	3.349822
3	2	3	1.65	-4.34968
3	3	1	1.12	-0.98436

A. S/N Ratio analysis

In Taguchi’s design method the design parameters (factors that can be controlled by designers) and noise factors (factors that cannot be controlled by designers, such as environmental factors) are considered influential on the product quality [12]. The Signal to Noise (S/N) ratio is used in this analysis which takes both the mean and the variability of the experimental result into account. The S/N ratio depends on the quality characteristics of the product/process to be optimized. Usually, there are three categories of the performance characteristics in the analysis of the S/N ratio, the lower-the-better, the higher-the-better and the nominal-the-better. In the present study smaller-the-better is chosen since the objective is to minimize the surface roughness of thee milling work piece. The following figure 2 shows the main effect plots for surface roughness. Thus, the optimized combination of levels for all the three control factors from the analysis which provides the lowest cutting force was found to be A3B1C3.

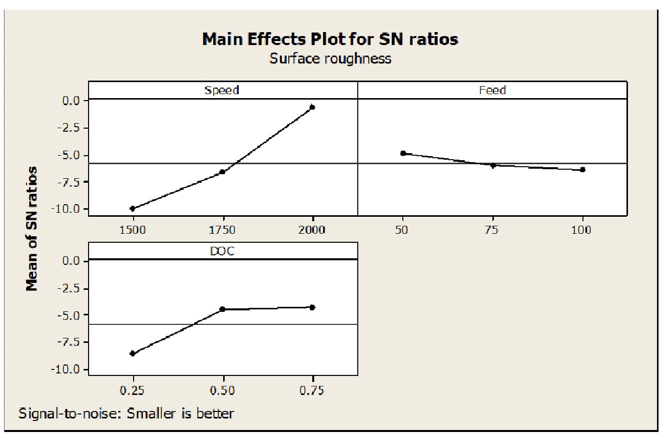

Fig.2 Main effect plot for S/N ratio for surface roughness

B. Analysis of Variance

The objective of ANOVA is to analyse the extent to which various parameters effect the response variables. This goal is achieved by splitting the variability of the S/N ratios that is measured by the sum of the squared deviations from the total mean S/N ratio, in the contributions of each cutting parameters and the error [4]. The F-Ratio test is statistic tool to verify which design parameters affect significantly in the quality characteristic. This is defined as the ratio of the mean squared deviations to the mean squared error. Generally, when show a value greater than four, it means the variation of the design or cutting parameter has an important effect in the quality characteristic [9]. Table 4 shows Analysis of Variance for Means and table 5 shows responses for means. The analysis of the F-Ratio values reveals that the speed and the depth of cut and feed are the most significant cutting parameters.

TABLE 4
ANALYSIS OF VARIANCE FOR MEANS

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	6.8107	6.8107	3.40534	11.16	0.082
Feed	2	0.1318	0.1318	0.06591	0.22	0.822
DOC	2	2.2104	2.2104	1.10521	3.62	0.216
Residual error	2	0.6100	0.6100	0.30501		
Total	8	9.7630				

TABLE 5
RESPONSE TABLE FOR SURFACE ROUGHNESS

Level	Speed	Feed	DOC
1	3.28	2.287	2.89
2	2.163	2.027	1.757
3	1.15	2.28	1.947
Delta	2.13	0.26	1.133
Rank	1	3	2

The effect of milling parameters on surface roughness can be obtained using response table 5. Response table displays the average response characteristics for each level of each factor in the design. The rank orders the factors based on the delta values in the response table from the highest effect to the least effect depending on the characteristics of the response [15]. Table 4 shows the response table for surface roughness in which it is clearly visible that speed is the most influencing factor since it is ranked first followed by depth of cut and feed in minimizing the surface roughness.

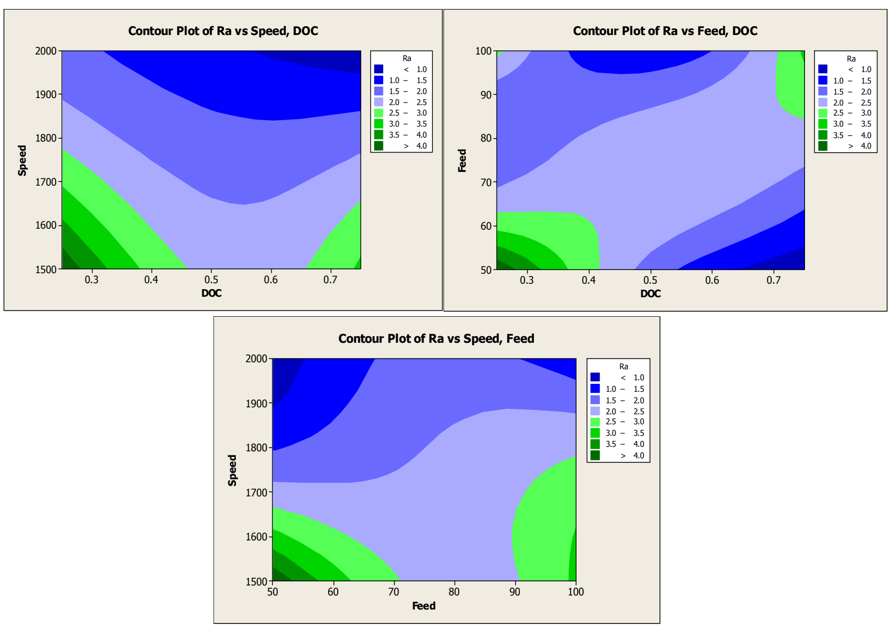

Fig.6 Contour plot of Speed, Feed and depth of cut

A contour plot presents a 2-dimensional view of the surface and plots are useful for establishing relationship between the response values and various levels of each process parameter. Figure 6 shows the Contour plot of the surface roughness versus Interaction between speed depth of cut and feed. Contour plot demonstrates that high spindle speed (2000 rpm) and low feed (50mm/rev) generated good surface finish by reducing the surface roughness of the turned parts. Further it is observed that from Contour plot intermediate depth of cut values gives the better surface roughness during milling process.

IV. CONCLUSION

In this paper optimisation of process parameters for end milling of AA5052 are studied and optimised parameter with the help of taguchi's S/N ratio functions, responses of means and ANOVA.

- From S/N ratio functions the optimal parameters for better surface roughness is speed-2000(m/min), feed-50(mm/rev) and radial depth of cut-0.75(mm).
- From ANOVA it is found that the most influential factor for surface roughness of AA5052 aluminium alloy is speed followed depth of cut and feed rate.
- From this analysis it is found that when speed increased, it decreases the surface roughness.

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