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# Experimental Analysis of Surface Roughness in CNC Turning of Aluminium Using Response Surface Methodology

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## ABSTRACT

*The main controllable parameters for the CNC turning machines are cutting tool variables, work piece material variables, and cutting conditions. The desired output is surface roughness, material removal rate and tools wear. Optimization of machining parameters needs to determine the most significant parameter for required output. Various techniques are used for optimization of machining parameters including Taguchi, RSM and ANOVA approach to determine most significant parameter. This work presents the findings of an experimental investigation into the effects of cutting speed, feed rate, and depth of cut in CNC turning of Aluminium KS 1275. Response surface methodology (RSM) is used to accomplish the objective of the experimental study. Face centered central composite design has been used for conducting the experiments. The result from RSM reveals that feed is the most significant factor followed by depth of cut.*

***Keywords:*** *Surface Roughness; CNC Turning; Experimental Analysis; Aluminium; Response Surface Methodology.*

## 1.0 Introduction

The turning process is one of the most fundamental metal removal operations used in the manufacturing industry. Surface roughness, used to determine and evaluate the quality of a product, is one of the major quality attributes of a turned product. Surface roughness of a machined product could affect several of the product's functional attributes such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating and resisting fatigue. Surface roughness being important quality aspects in turning operations there is a need to optimize the process parameters in a systematic way to achieve the output characteristics/responses in order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process takes place. As a starting point for determining cutting parameters, technologists could use the hands on data tables that are furnished in machining data handbooks. Previously trial and error approach was followed in order to obtain the optimal machining conditions for particular operations. In recent times, a Design of Experiment (DOE) is implemented to select manufacturing process parameters that could result in a better quality product.

Aman Aggarwal et. al. [1] presented the findings of an experimental investigation into the effects of cutting speed, feed rate, depth of cut, nose radius and cutting environment on the power consumption in CNC turning of AISIP-20 tool steel. C. X. (Jack) Feng and X. Wang [2] focused on developing an empirical model for the prediction of surface roughness in finish turning. The model considered work piece hardness (material); feed; cutting tool point angle; depth of cut; spindle speed; and cutting time as the working parameters. Hasan Gokkaya and Muammer Nalbant [3] investigated the effects of insert radii of cutting tools, depths of cut and, feed rates on the surface quality of the work pieces depending on various processing parameters. Ranganath M S et. al. [17] presented the findings of

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an experimental investigation into the effects of speed, feed rate and depth of cut on surface roughness in CNC turning of Aluminium. Ilhan Asilturk.et.al. [4], have presented a paper on optimizing turning parameters based on the Taguchi method to minimize surface roughness (Ra and Rz). Jakhale Prashant P. and Jadhav B. R. [5] investigated the effect of cutting parameters (cutting speed, feed rate, depth of cut) and insert geometry (CNMG and DNMG type insert) on surface roughness in the turning of high alloy steel. M. Kaladharet.al. [10] Focused on Taguchi method to determine the optimum process parameters for turning of AISI 304 austenitic stainless steel on CNC lathe. A CVD coated cemented carbide cutting insert was used. The influence of cutting speed, feed, depth of cut were investigated on the surface roughness and material removal rate (MRR).

M. Kaladhar et. al.[ll] published a multi-characteristics response optimization model based on Taguchi and Utility concept was used to optimize process parameters, such as speed, feed, depth of cut, and nose radius on multiple performance characteristics, namely, surface roughness (Ra) and material removal rate(MRR) during turning of AISI 202 austenitic stainless steel using a CVD coated cemented carbide tool. M. Kaladhar et. al.

[12] investigated the effect of process parameters on surface finish and Material Removal Rate to obtain the optimal setting of these parameters. M. Kaladhar et. al. [13] analyzed the optimization of machining parameters in turning of AISI 202 austenitic stainless steel using CVD coated cemented carbide tools. Ranganath M S and Vipin [19] carried out experimental investigation and parametric analysis of surface roughness in CNC turning using design of experiments.

Their work integrated the effect of various parameters which affect the surface roughness. The important parameters discussed were cutting speed, feed, depth of cut, nose radius and rake angle Experiments were carried out with the help of factorial method of design of experiment (DOE) approach to study the impact of turning parameters on the roughness of turned surfaces.

M. Nalbantet.al [14] investigated to find the optimal cutting parameters for surface roughness in turning using Taguchi method. RanganathM S et. al. [15] investigated the effect of the cutting speed, feed rate and depth of cut on surface roughness and material removal rate (MRR), in conventional turning of Aluminium (6061) in dry condition. Ranganath M S et. al. [16, 18, 21, 22] investigated the parameters affecting the roughness of surfaces produced in the turning process for the various materials studied by researchers. Ranganath M S and Vipin [20] have investigated the effect of rake angle on surface roughness in CNC turning of Aluminium (6061) while keeping other machining parameters as constant.

This paper presents the findings of an experimental investigation into the effects of cutting speed, feed rate, and depth of cut in CNC turning of Aluminium KS 1275. Design of experiment techniques, i.e. response surface methodology (RSM) have been used to accomplish the objective of the experimental study. Face centered central composite design has been used for conducting the experiments. The result of RSM reveals that feed is the most significant factor followed by depth of cut.

**2.0 Experimental Setup**

The work material selected for the study is Aluminium (KS 1275), used extensively for making pistons and other parts. The chemical composition of this material is given in the table 1.

Mechanical properties are: Thermal conductivity is 100 w/mk, Coefficient of thermal expansion at 3000C is 22.0 x 10-6 Kelvin, Hardness is 60-70 HRB. The aluminum alloy KS 1275 is used in automobile industry for piston manufacturing due to light weight. Piston is the heart of engine. Pure aluminum does not use for manufacturing pistons. Mechanical properties of aluminum are increased by adding various alloys like nickel, silicon, copper, magnesium, and zinc, tin.

In aluminum alloy KS 1275, every alloy play important role, Nickel reduces thermal conductivity because heat generation is more during engine working. Silicon increase fluidity and lower shrinkage during castings. Copper and magnesium increases strength. During machining of piston casting on shop floor, CNC Machines for turning to get required dimensions according to customer requirement. Customer requires different roughness on piston parts (groove, crown, outer diameter, bore), hence there is need of optimization of parametric values.

**Table 1: Chemical Composition of Work Material**

| Elements | Cu | Mg | Si | Fe | Mn | Ti | Zn | Ni | Al |
|---|---|---|---|---|---|---|---|---|---|
| Weight % | 2.5~3.5 | 0.7~1.3 | 10.5~11.5 | 0.4 max | 0.1 max | 0.2~0.3 | 0.1 max | 0.1 max | Rest |

The tool used was brazed diamond (VCMW) insert type. The geometry of tool was: Rake angle 0(+ve), 20(+ve) clearance angle, 600(+ve) major cutting edge angle, 60 (+ve) included angle and OOcutting edge inclination angle.

The experimental work was carried out at Sriram lab, on a CNC turning center. Canned cycle was used for machining and the machining was done in absolute mode. Cutting conditions were selected based on some preliminary investigations.

**Table 2: Details of Cutting Inserts**

| Nose Radius (mm) | Thickness (mm) | Cutting Edge Length | Feed Direction |
|---|---|---|---|
| 0.4 | 4.76 | 16.66 | Right Hand |

**Table 3: CNC Turning Machine Specification**

| CNC Machine Make | LT2 XL |
|---|---|
| Chuck size | 200/250 mm |
| max turning dia | 290 mm |
| Max swing over carriage | 290 mm |
| Max turning length | 400/500 mm |
| Spindle power (KW) | 11 KW |
| Axis motor N/M | 8 N/M |
| Weight of machine | 4000 kg |
| Cast bad | Yes |
| Type of spindle | A2-6 |
| Spindle RPM | 4000 |

The process was studied with a standard RSM design called a Central composite design (CCD). The factorial portion is a full factorial design with all factors at three levels, the star points are at the face of the cube portion on the design which correspond to value of -1. This is commonly referred to as a face centered CCD. The center points, as implied by the name, are points with all levels set to coded level 0, the midpoint of each factor range, and this is repeated six times. Twenty experiments were performed. For each experimental trial, a new cutting edge was used. The Minitab-17 was used to develop the experimental plan for response surface methodology. The same software was also used to analyze the data collected. The process parameters and their values at three levels are given in Table 4.

**Table 4: The Process Parameters and Their Values**

| Levels | d | S | f |
|---|---|---|---|
| 1 | 0.25 | 1600 | 0.12 |
| 2 | 0.5 | 1900 | 0.18 |
| 3 | 0.75 | 2200 | 0.24 |

### 3.0 Analysis and Discussion

The results from the machining trials performed as per the experimental plan are shown in Table 5. These results were used as input in the Minitab Software for further analysis. The CCD details are given in Table 6.

**Table 5: Design Table**

| Std Order | Run Order | Pt Type | A | B | C | Ra |
|---|---|---|---|---|---|---|
| 16 | 1 | 0 | 1900 | 0.18 | 0.5 | 2.69 |
| 14 | 2 | -1 | 1900 | 0.18 | 0.75 | 4.73 |
| 17 | 3 | 0 | 1900 | 0.18 | 0.5 | 1.35 |
| 19 | 4 | 0 | 1900 | 0.18 | 0.5 | 2.69 |
| 20 | 5 | 0 | 1900 | 0.18 | 0.5 | 1.15 |
| 6 | 6 | 1 | 2200 | 0.12 | 0.75 | 1.55 |
| 4 | 7 | 1 | 2200 | 0.24 | 0.25 | 2.59 |
| 15 | 8 | 0 | 1900 | 0.18 | 0.5 | 2.67 |
| 3 | 9 | 1 | 1600 | 0.24 | 0.25 | 1.21 |
| 12 | 10 | -1 | 1900 | 0.24 | 0.5 | 2.69 |
| 13 | 11 | -1 | 1900 | 0.18 | 0.25 | 2.67 |
| 5 | 12 | 1 | 1600 | 0.12 | 0.75 | 4.78 |
| 8 | 13 | 1 | 2200 | 0.24 | 0.75 | 2.65 |
| 10 | 14 | -1 | 2200 | 0.18 | 0.5 | 2.69 |
| 9 | 15 | -1 | 1600 | 0.18 | 0.5 | 4.75 |
| 18 | 16 | 0 | 1900 | 0.18 | 0.5 | 1.74 |
| 2 | 17 | 1 | 2200 | 0.12 | 0.25 | 2.69 |
| 1 | 18 | 1 | 1600 | 0.12 | 0.25 | 5.092 |
| 7 | 19 | 1 | 1600 | 0.24 | 0.75 | 4.82 |
| 11 | 20 | -1 | 1900 | 0.12 | 0.5 | 2.69 |

**Table 6: Central Composite Design Details**

| | | | |
|---|---|---|---|
| Factors: | 3 | Replicates: | 1 |
| Base runs: | 20 | Total runs: | 20 |
| Base blocks: | 1 | Total blocks: | 1 |
| | | | |
| Two-level factorial: | Full factorial | | |
| Cube points: | 8 | | |
| Center points in cube: | 6 | | |
| Axial points: | 6 | | |
| Center points in axial: | 0 | | |
| Alpha: | 1 | | |

**Table 7: Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Model | 9 | 22.5767 | 2.5085 | 3.05 | 0.049 |
| Linear | 3 | 9.8323 | 3.2774 | 3.98 | 0.042 |
| A | 1 | 7.1944 | 7.1944 | 8.73 | 0.014 |
| B | 1 | 0.8077 | 0.8077 | 0.98 | 0.345 |
| C | 1 | 1.8301 | 1.8301 | 2.22 | 0.167 |
| Square | 3 | 4.1386 | 1.3795 | 1.67 | 0.235 |
| A*A | 1 | 1.1219 | 1.1219 | 1.36 | 0.270 |
| B*B | 1 | 0.4210 | 0.4210 | 0.51 | 0.491 |
| C*C | 1 | 1.0528 | 1.0528 | 1.28 | 0.285 |
| 2-Way Interaction | 3 | 8.6058 | 2.8686 | 3.48 | 0.058 |
| A*B | 1 | 2.9306 | 2.9306 | 3.56 | 0.089 |
| A*C | 1 | 2.3959 | 2.3959 | 2.91 | 0.119 |
| B*C | 1 | 3.2794 | 3.2794 | 3.98 | 0.074 |
| Error | 10 | 8.2380 | 0.8238 | | |
| Lack-of-Fit | 5 | 5.6383 | 1.1277 | 2.17 | 0.208 |
| Pure Error | 5 | 2.5997 | 0.5199 | | |
| Total | 19 | 30.8147 | | | |

**Table 8: Model Summary**

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 0.907634 | 73.27% | 49.21% | 0.00% |

**Regression Equation:**

**Ra = 40.8 - 0.0322 A - 50.8 B - 2.0 C + 0.000007 A*A -109 B*B +9.90CC + 0.0336 A*B - 0.00730 A*C**

**+ 42.7B*C**

Without performing any transformation on the response, examination of the fit summary output revealed that the quadratic model is statistically significant for all the conditions and therefore, it has been used for further analysis. An ANOVA table is commonly used to summarize the tests performed. It is evident that speed, depth of cut and feed are significant at 95% confidence level and thus affects mean value and variation around the mean value of the Ra. The feed is most significant in ANOVA for and thus affects the mean value of the Ra followed by depth of cut.

The value of "P >F" for models less than 0.05 indicates that the model is significant, which is desirable as it indicates that the terms in the model have a significant effect on the response. The value of P < 0.0001 indicates that there is only a 0.01% chance that a "model F-value" could occur due to noise. Values greater than 0.1000 indicate the model terms are not significant. Some of the model terms were found to be significant. However, the main effect of feed was found to be the most significant factor followed by depth of cut.

**Fig 1: Residual Plots for Ra**

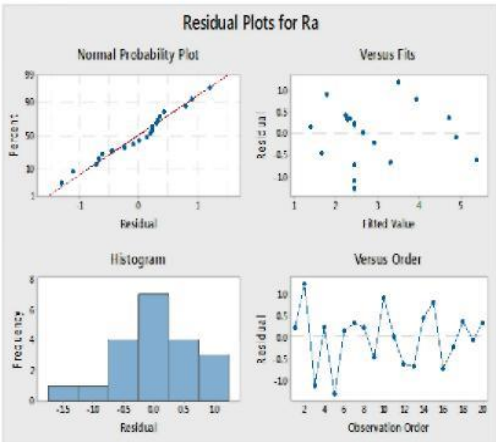
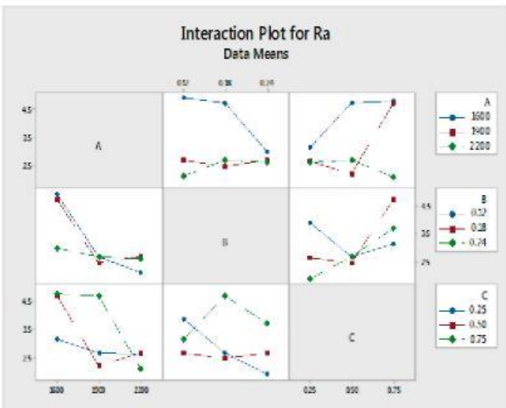



**Fig 2: Interaction Plot of Ra**



The normal probability plots of the residuals for Ra reveals that the residuals generally fall on a straight line implying that errors are distributed normally. Also in Fig. 1 showing residuals vs order for Ra reveals that they have no obvious pattern and unusual structure. This implies that the models proposed are adequate and there is no reason to suspect any violation of the independence or constant variation assumption. Fig.2 shows the interaction plots of Ra for three parameters.

**Fig 3: Main Effects Plot for Means**

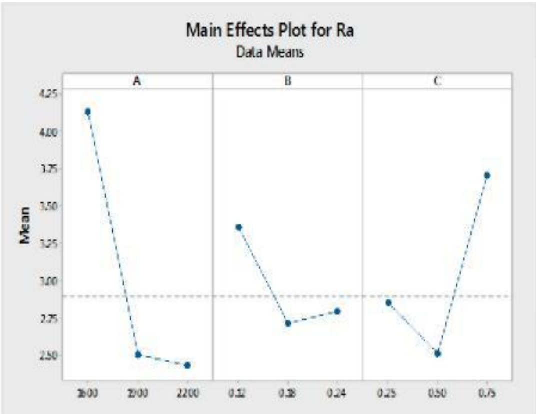
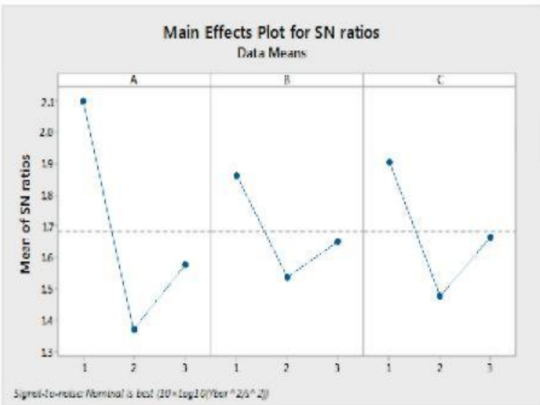



**Fig 4: Main Effects Plot for SN ratios**




The main effects plot for Ra and SN Ratios are shown in Fig 3 and 4. The optimal values obtained are at 2200 rpm speed, 0.18m/min feed and 0.5mm depth of cut. During Optimal Design of A, B, C the Response surface design selected is according to D-optimality. Number of candidate design points are 20, Number of design points in optimal design are 10 and Model terms are A, B,C, AA, BB, CC, AB, AC, BC. Initial design generated by Sequential method and Initial design improved by Exchange method. Number of design points exchanged is 1 .For Optimal Design Row number of selected design points are 7, 18, 19, 9, 12, 13, 2, 10, 14, and 17

Condition number:
15.0299
D-optimality (determinant of XTX):
1048576
A-optimality (trace of inv(XTX)):
5.625
G-optimality (avg leverage/max leverage):
1
V-optimality (average leverage):
1
Maximum leverage:
1

**Fig 5: Surface Plot of Ra vs C, A**

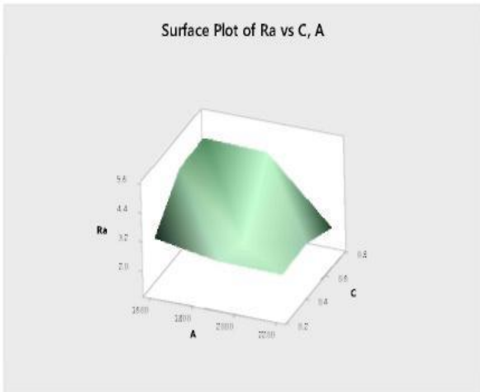
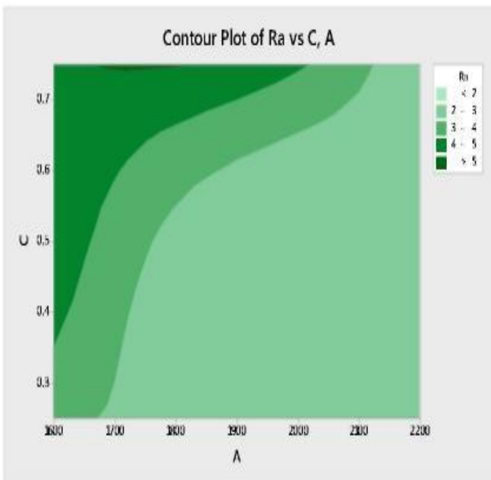



**Fig 6: Contour Plot of Ra vs C, A**



The entire 3D surface graph for surface roughness has curvilinear profile in accordance to the quadratic model fitted. Fig-5 shows 3D surface plot graph of the effect of speed and depth of cut on the surface roughness. It has a curve linear shape according to the model fitted. The contour plot for the response, surface roughness is shown in fig-6. The surface roughness increases with increase in feed.

## 4.0 Conclusions

The analysis of the results for surface roughness shows that the feed is the most significant factor followed by depth of cut. The 3D surface plots of Response surface methodology reveals that feed has very significant effect on surface roughness. The optimum value of surface roughness in the given range of parameters as depicted by graphs is 0.18 m/min (feed), 0.5 mm (depth of cut) and 2200 rpm (speed). The Response surface methodology shows significance of all possible combinations of interactions and square terms. 3D surfaces generated by Response surface methodology can help in visualizing the effect of parameters on response in the entire range specified, thus Response surface methodology is a better tool for optimization and can better predict the effect of parameters on response.

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