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# "Modelling and Optimization of turning process parameters on Aluminum 6061 alloy using Design of Experiments"

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**Abstract** – The experimental and analytical results of an analysis of the three key cutting parameters that determines surface roughness and cutting force —cutting speed, feed rate, and depth of cut—are presented in this paper. Design-of-experiment methods was used to plan a two-level, three-parameter experiment. Aluminum was used as the work material (Al 6061). The data was analyzed using the Pareto anova approach. Following that, regression analysis was used to create predictive models for each material.

**Keywords**: aluminum alloy; surface roughness, cutting speed, feed rate, depth of cut

## 1. INTRODUCTION

Quality and productivity play significant part in present's manufacturing demand. Every manufacturing assiduity aims at producing a large number of products within fairly lower time. But it's felt that reduction in manufacturing time may beget severe quality loss. In order to overcome similar issues numerous updates or developments have been done in this field which includes the use of mechanically clamped tools. Inserts are clamped through chromatic locking mechanisms. The advantage of inserts is that when one particular edge is worn out, it can be rotated to present a new slice edge. In certain cases, if the figure allows, after all similar edges have been used up; the insert can be removed, turned upside down and clamped again to reveal a fresh array of cutting edges.

The stylish parameter to judge the quality of turned product is face roughness which is veritably important for a product. Face roughness gives product a longer life, strength parcels & affects the functional parcels like disunion, heat transmission, light reflection parcels, etc. Product cost of an individual product is also get affected by face roughness. As we try to minimize the face roughness, we can negotiate towards the optimal parameters by optimizing some of the slice parameters.

The main motive of the trial is the evaluation of the face roughness of the crafted factors produced during turning operation. Turning tests are performed on a high severity HMT TL 20 lathe. Work pieces of an Aluminum amalgamation 6061 is used. They're 95 mm long with a periphery of 50 mm. A cutting tool with removable carbide inserts is used for machining Al6061 work pieces. Al 6061 is used in numerous operations in colorful fields of engineering where important mechanical parcels are in needed like construction, etc. The turning process parameters that may affect the machining characteristics of the crafted corridor have been decided on the base of the literature check.

However, it become found that no giant observe was accomplished into the floor roughness and slicing forces in turning AA 6061 alloy with special cutting gear. Therefore, this work targets to increase mathematical fashions of surface roughness (Ra) and cutting forces (Fc) within the turning AA 6061 alloy. In this context, turning checks were executed underneath dry reducing situations on an HMT LATHE. The slicing forces that occurred within the experiments performed beneath each reducing situation were measured via a KISTLER 9257A piezoelectric dynamometer. In addition, the roughness of the machined floor has been measured after each test. The evaluation of variance (ANOVA) has been carried out to outline the contribution of the turning parameters at the Ra and Fc. At the equal time, regression evaluation changed into finished to broaden the prediction equations of Ra and Fc. Finally, for the estimation of Ra and Fc, linear and quadratic mathematical models were evolved and tested with a validation test.

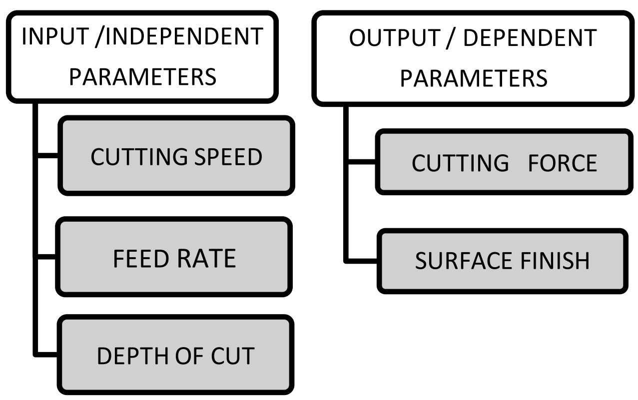


**Figure 1: Parameters of Aluminum 6061 Alloy**

## 2. OBJECTIVES

- To reduce time and fasten the movement
- Modelling and Optimization of turning parameters on Aluminum 6061 using DOE technique.

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•To find optimum range of input parameters on AL6061 like depth of cut, feed rate, cutting speed, to get maximum surface Roughness.

## 3. LITERATURE REVIEW

The surface roughness and cutting force of the machined components produced by the adhesive bonded tools are significantly less than that with brazed tools and hence adhesive bonded tools is a better alternative with distinct advantages in the field of tool manufacturing.

**Shrikant Jachak, Jayant Giri, G.K. Awari, A.S. Bonde**. "Surface finish generated in turning of medium carbon steel parts using conventional and adhesive bonded tools" 2021; 2882–2887

**Palanikumar K**. Modeling and analysis for surface roughness in milling glassfiber reinforced plastics using response surface methodology, Materials Design 2007; 28:2611-2618.

**Muthu Krishnan N, Paulo Davim J**. Optimization of machining parameters of Al/ SiC-MMC with ANOVA and ANN analysis, Journal of Materials Processing Technology.

**Suleyman Neseli, Suleyman Yaldız, Erol Turkes**, "Optimization of tool geometry parameters for turning operations based on the response surface methodology" Measurement.
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**Prabakaran MP, Kannan GR**. "Parametric Modeling of GTA Welding Process for Dissimilar Metals through Response Surface

## 4. MATERIAL METHOD

DoE with an extensive range of turning parameters was planned and the cylindrical components were turned in three environmental modes including DRY, MQL and WET. The arithmetic average surface roughness ($RRaa$) and the maximum height of the profile ($RRtt$) were measured for all the components in each mode.

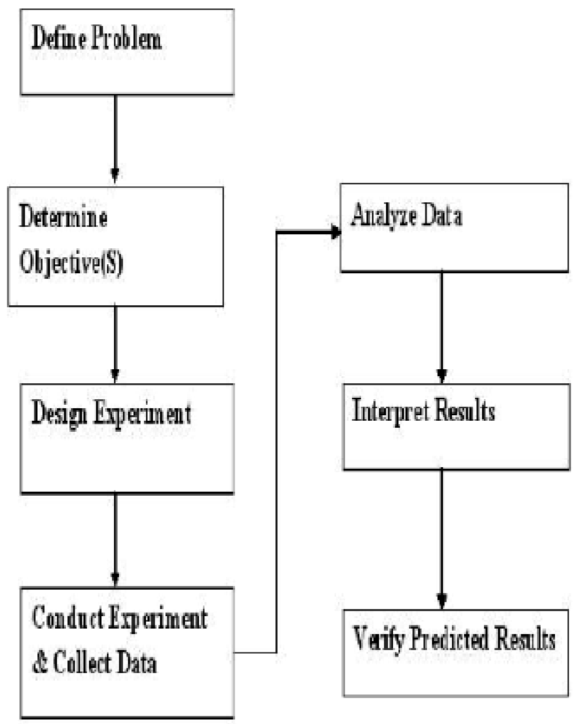


**Figure 2: Block Diagram**

RSM was used to develop predictive regression models, which were then validated using extra cutting conditions different from the design of experiment. The most effective turning parameters in each mode were identified based on ANOVA. Finally, these models were utilized in the optimization Process to obtain the optimal values of cutting.

## 5. MACHINING

**5.1 Material.** Aluminium-6061 is a precipitation-hardened alloy, containing silicon and magnesium as its major alloying elements. It has good mechanical properties and it exhibits good weld ability. Al6061 is used in modern manufacturing industries due to its inherent excellent properties.

| Si % | Fe% | Cu % | Mn% | Mg % | Cr % | Ni % | Zi % | Ti % | Aluminium |
|---|---|---|---|---|---|---|---|---|---|
| 0.40-0.8 | 0.7 | 0.15-0.40 | 0.15 | 0.8-1.2 | 0.04-0.35 | - | 0.25 | 0.15 | Balance |

**5.2 HMT Lathe.** A lathe is a machine tool that rotates a work piece approximately an axis of rotation to carry out various operations such as cutting, sanding, knurling, drilling, deformation, going through, and turning, with tools which can be carried out to the work piece to create an object with symmetry approximately that axis.

**5.3 Carbide Inserts**. are replaceable and usually indexable bits of cemented carbide used in machining process. high temperature alloys, and nonferrous materials. Carbide inserts allow faster machining and leave better finishes

**5.4 Selection of Process Parameters and Their Ranges**. The process parameters that may affect the machining characteristics of the parts machined by HMT lathe has been identified based on the literature review. The identified process parameters are as follows:

• Machining parameters: cutting speed, feed rate, depth of cut. The ranges of process parameters for the experiment were decided on the basis of literature survey and the results of pilot experiments conducted using one parameter at a time approach.

**5.5 Selection of the Levels of Parameters Based on Preliminary Investigation**. Results of the pilot experiments were utilized for deciding the levels of parameters for the cutting speed, feed, and depth of cut for conducting design of experiments on HMT lathe of 6061 Al.

## 6. DESIGN OF EXPERIMENTS

Design of Experiments (DOE) is a data analytics method that helps you plan, conduct, analyze and interpret controlled tests to determine which factors exert influence over your product quality, stability or other key process attributes. Rather than experimenting with one parameter at a time, DOE speeds up the process and helps you identify important interactions by manipulating multiple factors at the same time.

### 6.1 Response Surface Methodology:

RSM incorporates a series of mathematical / mathematical strategies for the construction of the test model and the application model. Through the use of appropriate design and test analysis, RSM seeks to associate feedback on the levels of the number of input variables or influential factors.

### 6.2 ANOVA: Analysis of Variance

Differential Analysis (ANOVA) is a mathematical formula used to compare variability across all methods (or measurements) of different groups. The scenario uses it to determine if there are any differences between the methods of the different groups.

The effect of ANOVA is ‘F’ numbers. This ratio shows the difference between the internal group differences and the group differences within, which ultimately produces a figure that allows for the conclusion that the null hypothesis is supported or rejected. If there is a significant difference between the groups, the null hypothesis is not supported, and the F value will be large.

### 6.3 Formation of Text Matrix:

For $2^3$ Full Factorial Design of Experiments the no. of factors selected are:

- Cutting speed (X1), m/min.
- Feed rate (X2), mm/rev.
- Depth of cut (X3), mm.

As for $2^3$ full trials a series of trials taken in an orderly fashion. Two levels of objects referred to as low (-1) and high (+1). Typical design $2^3$ item test matrix with corresponding values the Surface roughness and Cutting Force of the Material is shown in Table 1.

During this project, the outcomes of numerous machining parameters including feed fee, slicing speed and intensity of cut on surface roughness have been experimentally observed at some point of dry turning technique using CNMG inserts. Aluminum 6061alloy is machined the usage of CNMG 120408 EN-TM (H20TI) CNC turning inserts. Response Surface Methodology (RSM) is used to design the experiment, to get regression equation and for optimization of the enter parameters. Surface plots and Contour plots have been generated via the usage of RSM to test the interaction of enter parameters on the surface roughness of the thing. From the analysis of the experimental end result it was found that feed price has maximum impact on floor roughness and cutting velocity and depth of reduce has minimum effect on floor roughness. The variety of machining parameters are 0.1-0.2 mm/rev,124-207 m/min and zero.05-zero.8 mm for feed price, reducing speed and intensity of cut respectively. Best values of parameters are 0.1 mm/rev, one hundred sixty-five.5m/min and 0.85mm for feed fee, cutting pace and intensity of cut respectively.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 04 | April - 2022 Impact Factor: 7.185 ISSN: 2582-3930

The floor roughness of the test samples was measured using the DOE M1 version take a look at tool. The cutoff period turned into zero. Eight mm and the dimension duration turned into 12 mm. The floor roughness values had been decided from measurements taken at three distinctive points at the machined surfaces formed after each test. Then, the common surface rough nesses (Ra) become decided with the aid of calculating the average of the measurements.

| Factors | Basic Level | Upper Level | Lower Level |
|---|---|---|---|
| Cutting Speed(mm/min) | 89 | 112 | 66 |
| Feed Rate(mm/rev) | 0.09 | 0.13 | 0.05 |
| Depth of Cut (mm) | 1.0 | 1..5 | 0.5 |

Table 1: Machining parameter.

| Sr.no | Cutting Speed | Feed Rate | Depth of Cut | Surface Roughness | | |
|---|---|---|---|---|---|---|
| | | | | **Rep. 1** | **Rep. 2** | **Avg** |
| 1 | -1 | -1 | -1 | 14.7 | 15.5 | 15.1 |
| 2 | +1 | -1 | -1 | 10 | 10.2 | 10.1 |
| 3 | -1 | +1 | -1 | 17.3 | 16.7 | 17 |
| 4 | +1 | +1 | -1 | 13.8 | 14.2 | 14 |
| 5 | -1 | -1 | +1 | 16.2 | 16.8 | 16.5 |
| 6 | +1 | -1 | +1 | 7.2 | 8.2 | 7.7 |
| 7 | -1 | +1 | +1 | 22.3 | 20.3 | 21.3 |
| 8 | +1 | +1 | +1 | 18.2 | 18.4 | 18.3 |

Table2: Design matrix for a $2^3$ factorial experiment for Surface Roughness.

| Sr no | Cutting Speed | Feed Rate | Depth of Cut | Cutting Force (N) | | |
|---|---|---|---|---|---|---|
| | | | | **Rep. 1** | **Rep. 2** | **Avg** |
| 1 | -1 | -1 | -1 | 97.90 | 98.19 | 98.045 |
| 2 | +1 | -1 | -1 | 103.39 | 103.00 | 103.195 |
| 3 | -1 | +1 | -1 | 176.38 | 174.61 | 175.495 |
| 4 | +1 | +1 | -1 | 247.89 | 247.70 | 247.795 |
| 5 | -1 | -1 | +1 | 206.99 | 206.01 | 206.5 |
| 6 | +1 | -1 | +1 | 320.39 | 319.80 | 320.095 |
| 7 | -1 | +1 | +1 | 568.78 | 567.01 | 567.895 |
| 8 | +1 | +1 | +1 | 619.20 | 619.79 | 619.495 |

Table3: Design matrix for a $2^3$factorial experiment for Cutting Force.

## 7. RESULT

### 7.1 Calculation

Full Factorial Design

Factors: 3 Base Designs: 3, 8
Runs: 8 Replicates :1
Blocks: 1 Center point (total): 0

All terms are free from aliasing.

For CF
Regression Equation in Uncoded Units

CF = Constant Effect + Cutting Speed + FeedRate + Depth of Cut
CF = 292.3+30.3+110.4+136.2
CF = 569.2

For SF
Regression Equation in Uncoded Units

SR = Constant Effect + Cutting Speed + Feed Rate + Depth of Cut
SR = 15.000 - 2.475+2.650+0.950

SR= 16.125

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Model | 3 | 112.405 | 37.468 | 6.59 | 0.050 |
| Linear | 3 | 112.405 | 37.468 | 6.59 | 0.050 |
| Cutting Speed | 1 | 49.005 | 49.005 | 8.62 | 0.043 |
| Feed Rate | 1 | 56.180 | 56.180 | 9.88 | 0.035 |
| Depth of Cut | 1 | 7.220 | 7.220 | 1.27 | 0.323 |
| Error | 4 | 22.735 | 5.684 | | |
| Total | 7 | 135.140 | | | |

**Table 4**
Factorial Regression: Surface Roughness versus Cutting speed, Feed rate, Depth of Cut

| Term | Effect | Coeff | SE Coeff | T-Value | P-Value | VIF |
|---|---|---|---|---|---|---|
| Constant | 15.000 | 0.843 | 17.80 | 0.000 | | |
| Cutting Speed | -4.950 | -2.475 | 0.843 | -2.94 | 0.043 | 1.00 |
| Feed Rate | 5.300 | 2.650 | 0.843 | 3.14 | 0.035 | 1.00 |
| Depth of cut | 1.900 | 0.950 | 0.843 | 1.13 | 0.323 | 1.00 |

**Table 5:**
Coded Coefficients: Surface Roughness versus Cutting speed, Feed rate, Depth of Cut

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Model | 3 | 253151 | 84384 | 12.45 | 0.017 |
| Linear | 3 | 253151 | 84384 | 12.45 | 0.017 |
| Cutting Speed | 1 | 7360 | 7360 | 1.09 | 0.356 |
| Feed Rate | 1 | 97427 | 97427 | 14.37 | 0.019 |
| Depth of cut | 1 | 148364 | 148364 | 21.89 | 0.009 |
| Error | 4 | 27113 | 6774 | | |
| Total | 7 | 280263 | | | |

**Table: 6**
Factorial Regression: Cutting Force versus Cutting Speed, Feed Rate, Depth of Cut

| Term | Effect | Coeff | SE Coeff | T-Value | P-Value | |
|---|---|---|---|---|---|---|
| VIF | | | | | | |
| Constant | 292.3 | 29.1 | 10.04 | 0.001 | | |
| Cutting Speed | 60.7 | 30.3 | 29.1 | 1.04 | 0.356 | 1.00 |
| Feed Rate | 220.7 | 110.4 | 29.1 | 3.79 | 0.019 | 1.00 |
| Depth of cut | 272.4 | 136.2 | 29.1 | 4.68 | 0.009 | 1.00 |

**Table 7:**
Coded Coefficients: Cutting Speed versus Cutting speed, Feed rate, Depth of Cut

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## 8. DISSCUSSION

Although special parameters used to don't forget whilst machining tough to reduce substances such as SiCp/Al MMCs however the slicing parameters, device slicing attitude and tool fabric significantly affect the slicing process as well as reducing pressure. The effect of the work piece cloth SiC content percent deviation will produce a heavy impact at the slicing pressure. Therefore, the machining of the particle strengthened metallic matrix composite with unique possibilities of SiC debris such as SiC/Al 45 and SiC/Al 50% have been completed so that it will recognize the machining behavior on reducing force trend the effect of slicing parameters and SiC wt possibilities. The Factors of reducing forces including (Fx, Fz) of SiCp/Al 45 and 50p.Cwt are modeled and compared with one of a kind cutting parameters inside the turning technique using RSM.

In this experimental take a look at there are three reducing variables used which were divided into 4 tiers and other elements of SiC %. This look at is based totally on effect of three reducing parameters on each content of SiC % and their contrast so that it will better understand the impact of cutting parameters and content of SiC % on the slicing forces and machinability of tough to reduce materials SiCp/Al. The method parameters of turning SiCp/Al workpieces with this procedure. The experimental outcomes of MRR and Ra wherein the mixture of parameters for MRR and Ra are obtained from the Taguchi blended stage orthogonal array layout approach. It is glaring that feed and depth of reduce are sizeable elements for changing the MRR whilst final factors show the insignificant effect on MRR. Through this Table its miles observed that which parameter has higher effect and which has lower and is obtained by means of Taguchi evaluation. The feed and depth of reduce are great elements on Ra at the same time as remaining elements.

Result after analysis for Surface Roughness and Cutting Force are shown in following graph:

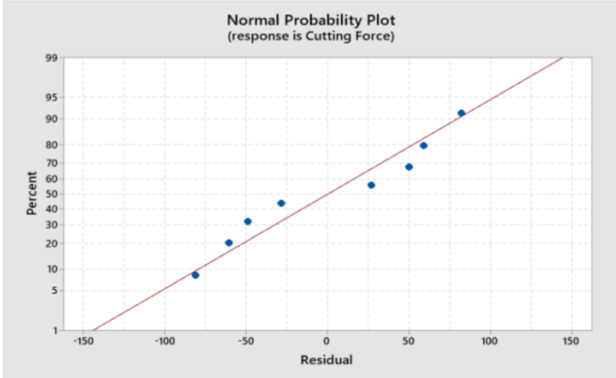


Figure 4: Normal Probability Plots for Surface Roughness.

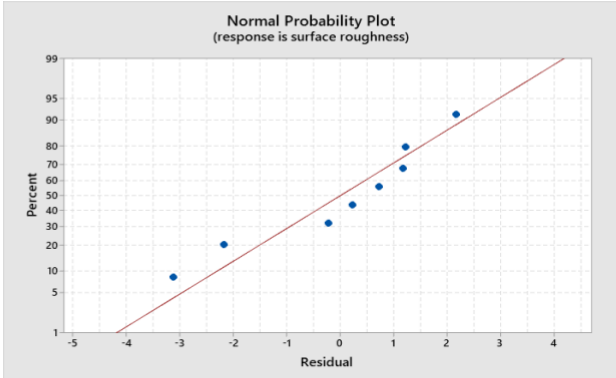


Figure 5: Normal Probability Plots for Surface Roughness.

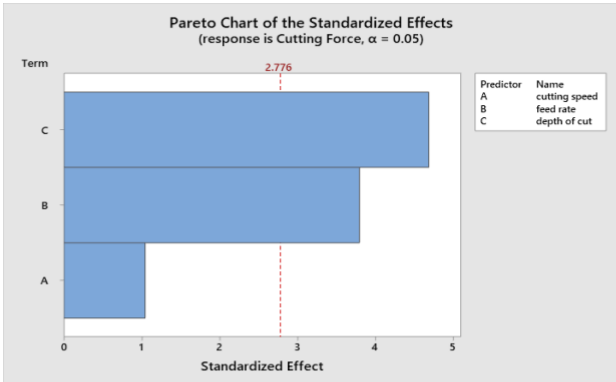


Figure 6: Pareto Chart of the Standardized effects for Cutting Force.

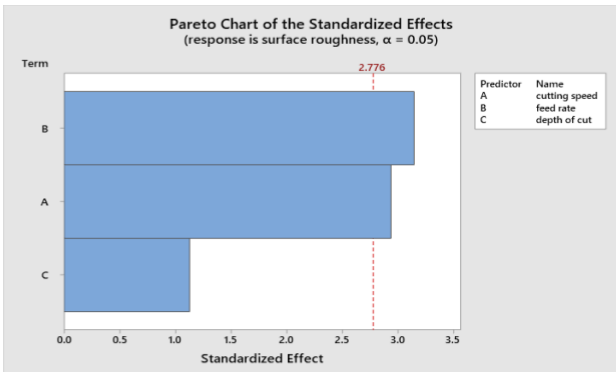


Figure 7: Pareto Chart of the Standardized effects for Surface Roughen

## 9. CONCLUSION

In this paper Response Surface Methodology turned into used to see the influence of the enter parameters on the surface roughness of the aluminum 6061 alloy during turning and to optimize the procedure. A mathematical quadratic equation is developed for surface roughness. The effects are as bellow:

1. Feed rate is the main great element for surface roughness. Depth of cut and reducing speed has less significant impact on surface roughness.

2. Contour and surface plots become used for determining the most efficient conditions to attain required surface roughness.

3. Response Surface Methodology indicates that optimal values for the lowest surface roughness are zero. Eighty-five mm for cutting velocity, feed rate and depth of reduce respectively.

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