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# Experimental Investigation to Optimize Machining Parameters of Al 6061 Alloy

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***Abstract*:- Present day industries involved in mass production primarily look for higher productivity and better surface finish in machining operations. This depends upon optimum selection of process parameters for machining operations like turning, drilling, boring, milling etc. For turning and milling operations - spindle speed, feed, depth of cut etc. are influencing parameters. The use of aluminium alloys have been increased significantly in recent years. Aluminium alloys are widely used because of their complex metallurgical structure, machining characteristics and ability to combined lightness and high strength. Aluminium alloys of 6xxx series alloys have good formability, weldability, machinability, and corrosion resistance. Al 6061 heat treatable alloy of this series is used in transportation and structural applications. The aim of this research paper is to investigate the process parameters having significant effect on machining of Al 6061 alloy, so as to maximize material removal rate. In this context, Material removal rate is chosen as performance characteristic that is to be optimized by using control parameters such as speed, feed, depth of cut and Aluminum 6061 alloy is selected as a work material.**

## I. INTRODUCTION

Machinability governs the ease or difficulty with which the material can be machined under the given set of conditions. The most machinable material is one which permits the easy removal of material with good surface finish at lowest cost. Process parameters like spindle speed, feed rate, depth of cut are significant parameters for turning and milling operations.

Optimization of the machining parameters has been of great concern in manufacturing, where economy of machining operation plays a key role in competitiveness in the market. The machining parameters have been optimized by various researchers for turning, milling, drilling, boring etc. The aim of optimization is to find the most advantageous machining parameters to maximize material removal rate.

Aluminium with magnesium and silicon as alloys are commercial designated as Al 6xxx series alloys. Alloys of the 6xxx series contain silicon and magnesium approximately in the proportions required for formation of magnesium silicate (Mg2Si), thus making them heat treatable. The 6xxx series alloys have good formability, weldability, machinability and corrosion resistance. Some other alloys of this series are 6005, 6060, 6061, 6063, 6082. The alloy 6005 is used in structural applications, 6060 has better extrudability, 6061 is most versatile of heat treatable alloy having good corrosion resistance (which is used in transportation and structural applications) while 6063 is most popular extrusion alloy. Aluminum alloy 6061 is used for aircraft, missiles, space, ground and marine transportation, machine parts and architectural applications.

Aluminium alloy 6061 is commercially available in three forms 6061(O) type, 6061(T4) type and 6061(T6) type. The 6061(O) is annealed aluminium alloy and applied to products that are annealed to obtain the lowest strength temper. The 6061(T4) is solution heat treated and naturally aged alloy. The 6061(T6) denotes the temper of the material when it is solution heat treated, followed by quenching and artificial age hardening.

Table - 1: Chemical composition of Al 6061 – T6

| | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|
| % | 0.4 | 0.7 | 0.4 | 0.15 | 1.2 | 0.35 | 0.25 | 0.15 | 96.4 |

***Process Parameters:*** The following are some process parameters in turning and machining which affect performance of machining.

1. ***Cutting Speed (v):*** The cutting speed of a tool is the speed at which the metal is removed by the tool from the work material. In a lathe it is the peripheral speed of the work part in m/min.

$$\mathbf{V = \pi DN/1000} \qquad \text{(m/min)}$$

Where, D - Diameter of work piece (mm) and N - Cutting speed of spindle (rpm)

2. ***Feed (f):*** The feed of the cutting tool in lathe work is the distance, the tool advances for each revolution of the work piece in mm.

3. ***Depth of cut (d):*** The depth of cut is the perpendicular distance measured from the machined surface to the uncut surface of the work piece in mm.

***Performance Parameters:***

***Material removal rate (MRR)* -** MRR is the volume of material removed per minute. The higher is the cutting parameters, the higher will be the MRR**.**

Volume of material removed, $\mathbf{MRR = \pi\ D\ d\ f\ N}$ (mm $^3$/min)

Where, D – Diameter of workpiece, d – Depth of cut, f – Feed and N - Revolutions of spindle/min

## II. LITERATURE SURVEY

Kadigrama: et al [1] optimized surface roughness of Al 6061-T6 alloy during milling operation and developed prediction model to investigate the most dominant variable among the process variables as cutting speed, feed rate, axial and radial depth of cut, affecting surface roughness. It was concluded that feed was the most significant factor among all the factors.

Dodda Patter: et al [2] made an attempt to access effect of various cutting parameters (cutting speed, feed rate, depth of cut and tool nose radius) on surface roughness during turning operation of Al 6061-T6 alloy. It was concluded that feed was the most influential single factor significantly affecting the surface roughness and interaction between feed and speed was statistically most influential.

Zeelan Basha: et al [3] optimized the CNC turning process parameters of Al 6061 using genetic algorithm. RSM in design expert software 8.0 was used to develop mathematical models and genetic algorithm was used to find the optimal solution of the cutting conditions.

Venkata Ramaiah: et al [4] obtained optimum turning parameters for minimum cutting forces and cutting temperature by using Fuzzy Logic for Al 6061 work material under dry conditions with CNMG cutting tool. The experimental responses like cutting temperature and cutting force were measured for different influential parameter combinations. The experimental data was analyzed using fuzzy Logic and optimum parameters combination was determined. The influence of spindle speed, feed and depth of cut on cutting temperature and cutting forces in turning operation was studied.

Ali Abdallah: et al [5] applied response surface methodology and taguchi methods to find optimal process parameters namely feed, cutting speed and depth of cut to maximize material removal rate and minimize surface roughness during turning of Al 6061.

Devkumar: et al [6] developed mathematical model for analysis of machining response such as surface roughness and tool wear while turning Al 6061 alloy using spindle speed, depth of cut and feed rate for the purpose of analysis and predicted the optimum level.

Najiha: et al [7] investigated effects of coated carbide cutting tool on the surface roughness of aluminum alloy 6061-T6 during end milling operation using the minimum quantity lubrication (MQL) technique. Process parameters including the cutting speed, depth of cut and feed rate were selected. The analysis of variance method was utilized to validate the experimental data and response surface method was used to develop the mathematical models. It was concluded that the surface roughness depends significantly on depth of cut and feed rate, followed by spindle speed.

Sohail Akram: et al [8] investigated the residual stresses in an aluminum alloy Al-6061 work piece after machining. The sensitivity of residual stresses to cutting speed and feed rate was determined using finite element method. Tensile residual stresses at the surface of components were generally undesirable as they contribute to fatigue failure, quench cracking and stress-corrosion cracking. It was concluded that residual stresses were insensitive to change in cutting speed, however, residual stresses were clearly affected by the change in feed rate.

E. Yahya: et al [9] first-time included the tool flutes in addition to cutting speed, depth of cut and feed rate as independent input variables. Firstly, a set of machining tests were conducted using AA6061 aluminum alloy as work piece material to provide original data, and Response Surface Model (RSM) was adopted to establish the relationship model between the surface roughness and the process parameters using Minitab 16. Then, based on analysis of variance (ANOVA), the sensitivities of the surface roughness to the parameters were analyzed. It was concluded that cutter flutes has high significant influence on surface roughness followed by feed rate and depth of cut, while cutting speed has less significant influence.

Devendra Singh: et al [10] investigated the effect of nose radius on surface roughness, during turning of Aluminium (6061) in dry condition. The effect of cutting conditions (speed, feed and depth of cut) and tool geometry (nose radius) on surface roughness were studied and analysed. Design of experiments were conducted for the analysis of the influence of the turning parameter on the surface roughness by using Response Surface Methodology (RSM) and then followed by optimization of the results using Analysis of Variance (ANOVA) to minimize surface roughness. The nose radius was identified as the most significant parameter followed by feed. Surface roughness value decreased with increase in nose radius. Small decrease in nose radius within the specified range deteriorates surface finish to a large extent. Hence, increasing nose radius improves surface finish.

B. Balamugundan: et al [11] performed end milling operation on pre and post thermally treated AA6061-T6 aluminum alloys. Heat treatment with aging time of 8 hour was used to vary the mechanical properties of the AA6061-T6 alloy. The variation of material properties such us tensile strength, yield strength, hardness and ductility having significant effects on the burr formation. The burr formation was due to the transition of materials when the toll passes over the material. The material transition in the lateral direction with higher cutting speed and depth of cut was negligible for materials with higher hardness and yield strength leading to reduced burr height. The burr height of post heat treated materials was lesser than the parent material because of higher yield strength, hardness and lesser ductility.

Sonali Priyadarshini: et al [12] analyzed the machining parameters using Taguchi design in turning of aluminium alloy under dry conditions with carbide tipped tools. Spindle speed, feed rate and depth of cut were the controlling parameters. The effect of these controlling parameters on average surface roughness was studied and it was concluded that for machining aluminium alloy feed rate was the most significant controlling factor and average surface roughness decreases with increasing cutting speed.

From the literature survey it is concluded that, surface roughness is considered by a large number of researchers but very few of them have used Material removal rate for their study. Material removal rate is chosen as performance characteristics that is to be optimized by using control parameters namely the speed, feed, depth of cut for aluminium alloy 6061.

## III. EXPERIMENTAL SETUP AND METHODS

The following plan of experiment is executed in the present work:

a) Cutting Aluminum round bars by power saw and performing initial turning operation by Centre Lathe to get desired dimension of the work pieces.

b) Performing straight turning operation on specimens in various cutting environments involving various combinations of process control parameters on CNC lathe machine (XLTURN - MTAB Make), by considering spindle speed, feed and depth of cut as process parameters.

c) Optimization of machining parameters using Taguchi approach and ANOVA followed by final confirmation of experimental results.

***Process variables and their Limits:*** The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. The process variables (with their units and notations) are listed in Table - 2**.**

Table - 2: Process variables and their limits

| Values in coded form | Process Variables | | |
|---|---|---|---|
| | Spindle Speed (N) (RPM) | Feed (f) (mm/rev) | Depth of cut (d) (mm) |
| **1** | **48** | **0.06** | **0.8** |
| **2** | **76** | **0.08** | **1.0** |
| **3** | **104** | **0.10** | **1.2** |

***Design of Experiment:*** Experimental work is carried out using Taguchi's L9 Orthogonal Array (OA) experimental design which consists of 9 combinations of spindle speed, longitudinal feed rate and depth of cut. According to the design catalogue [Peace, G., S., (1993)] prepared by Taguchi, L9 Orthogonal Array design of experiment has been found suitable in the present work. It considers three process parameters (without interaction) to be varied in three discrete levels. The experimental design has been shown in Table - 3.

Table - 3: Taguchi's L9 Orthogonal Array

| SI. No. | Cutting speed | Feed | Depth of cut |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

## IV. RESULTS AND DISCUSSION

This section includes the analysis and interpretation of the experimental results to improve the performance characteristics of the turning process. The decisions are made with the assistance of following analytical techniques:

1. Column effect method
2. Plotting by levels method
3. Analysis of variance

### *1. Analysis using column effects method:*

This approach is used to subjectively point out column which has large influence on the response. Data associated with first, second and third levels are noted and difference of largest and smallest of the three levels represent “delta”. The magnitudes of differences are compared to each other, to find out the relatively strong control factors. The relative magnitudes (the plus or minus sign shows positive or negative correlation with level numbers, respectively) indicate the relative power of the factors affecting the result as shown in Table – 4.

Table - 4: Analysis of MRR

| S No | Cutting Speed N(rpm) | Feed rate f (mm) | Depth of Cut d (mm) | MRR(mm$^3$/min) | S/N Ratio (db) |
|---|---|---|---|---|---|
| 1 | 48 | 0.06 | 0.8 | 289.38 | 49.2294 |
| 2 | 48 | 0.08 | 1.0 | 578.76 | 55.2500 |
| 3 | 48 | 0.10 | 1.2 | 844.03 | 58.5272 |
| 4 | 76 | 0.06 | 1.0 | 687.28 | 56.7427 |
| 5 | 76 | 0.08 | 1.2 | 1069.11 | 60.5804 |
| 6 | 76 | 0.10 | 0.8 | 763.65 | 57.6579 |
| 7 | 104 | 0.06 | 1.2 | 1223.85 | 61.7545 |
| 8 | 104 | 0.08 | 0.8 | 932.45 | 59.3925 |
| 9 | 104 | 0.10 | 1.0 | 1748.35 | 64.8526 |

### 2. *Analysis using Plotting by levels method:*

In this method, the average result for each level is calculated to plot the effect of influential factors. The sum of data associated with each level in the orthogonal array (OA) column divided by numbers of test (data point) for that will provide the appropriate averages. The factor strengths are directly proportional to the slope of the graphs.

Table - 5: S/N ratio response table for MRR (Larger is better)

| Factors/Levels | Level 1 | Level 2 | Level 3 | Delta | Rank |
|---|---|---|---|---|---|
| N | 54.34 | 58.33 | 62.00 | 7.66 | 1 |
| f | 55.91 | 58.41 | 60.35 | 4.44 | 3 |
| d | 55.43 | 58.95 | 60.29 | 4.86 | 2 |

The analysis was made using popular software specifically used for the design of experiment applications known as MINITAB 15.

Main effect plot for the MRR are shown in Figure - 1 which shows the variation of MRR with the input parameters.

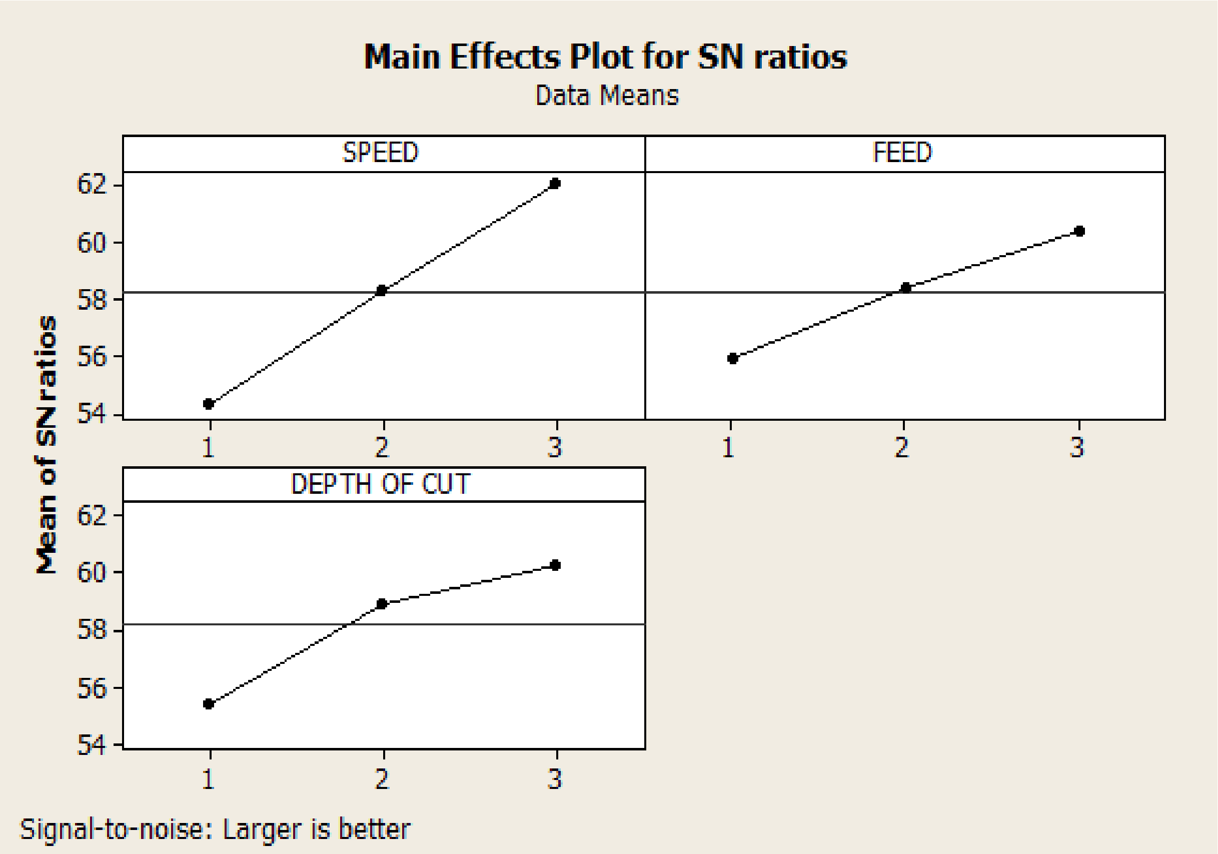

Figure - 1: Main effect plot for the MRR

Analysis of the result, in Figure -1, leads the conclusion that the factors at level $N_3$, $f_3$, $d_3$ gives the maximum MRR.

### *3. Analysis of Variance (ANOVA):*

ANOVA is a statically based, objective decision making tool for detecting any differences in average performance of groups of items tested. In this experiment, both the allocation of the experimental material and the order in which the individual trials of the experiment are to be performed and randomly determined because ANOVA requires that the observations or error be independently distributed random variables. Confidence level of 95% was used throughout analysis of the experiment. From the statistical point of view, it is highly recommended to examine these residuals for normality and constant variance when using ANOVA.

***Normal plot of residual*:** A typical check for normality assumption is made by constructing a normal probability plot of the residuals. Each residual is plotted against its expected value of normality. If the residual distribution is normal, this plot will be a straight line. If the points on the plot depart from a straight line, the normality assumption may be invalid. The normal probability plots of residuals are shown in Figure-2 for MRR. The normal probability curve is straight line. The result show the agreement between the normality assumptions used in the experiment.

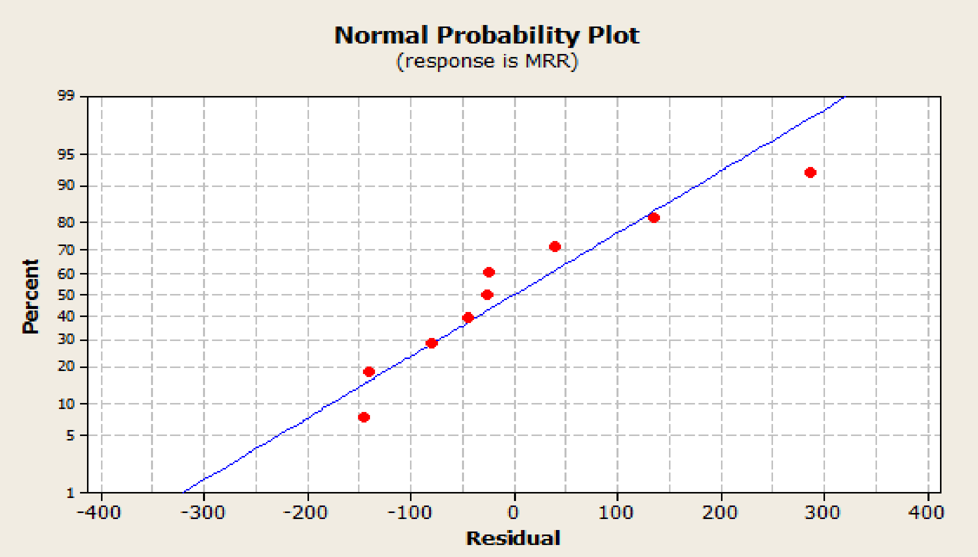

Figure - 2: Normal probability of residuals plot for MRR

***Residuals versus fits:*** The assumption of constant variance is typically checked by plotting residuals versus predicted values (fits). This plot should show a random pattern of residuals on both sides of 0. If a point lies far from the majority of points, it may be considered as lying outside. If the assumption is satisfied, there should not be any recognizable patterns in the residuals plot. Figure-3 shows that assumption of constant variance is satisfied.

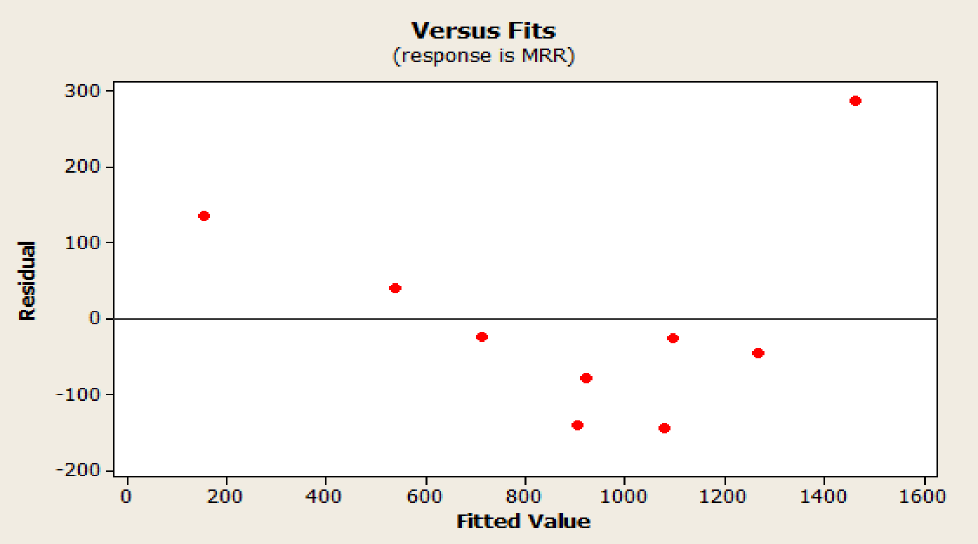

Figure - 3: Residual vs. predicted value plot for MRR

***Confirmation Experiment*:** A confirmation experiment is performed by conducting a test using a specific combination of the factors and levels previously evaluated. The final step of the Taguchi's parameter design after selecting the optimal parameters is to predict and verify the improvement of the performance characteristics with the selected optimal machining parameters. The predicted S/N ratio using the optimal levels of the machining parameters is calculated with the help of following prediction equation:

$$\eta_{opt} = \eta_m + \sum_{j=1}^{k} (\eta_j - \eta_m)$$

Here, $\eta_{opt}$ is the predicted optimal S/N ratio, $\eta_m$is the total mean of the S/N ratios, $\eta_j$ is the mean S/N ratio of at optimal levels and k is the number of main design parameters that affect the quality characteristics.

An experiment is performed with each combination of different factors for MRR and compared with the result obtained from the predicted equations as shown in Table - 6. As per calculations the error is 6.26% for S/N ratio of MRR, therefore it can be interpreted that the obtained MRR have reasonable accuracy.

Table - 6: Confirmation experiment result for MRR

| Exp no | Optimum machining parameters (333) | | | S/N ratio for MRR (db) | |
|---|---|---|---|---|---|
| | Speed ($N_3$) | Feed ($f_3$) | Depth of cut ($d_3$) | Predicted | Experiment |
| 1 | 104 | 0.1 | 1.2 | 66.1916 | 58.216 |
| | | | | Error % | 6.26 |

## V. CONCLUSION

Taguchi method is applied to find the optimal process parameters to maximize material remover rate for turning of Al 6061 alloy. Taguchi orthogonal array, S/N ratio and ANOVA are used for optimization of cutting parameters. The experimental results show that the order of priority, for performance characteristic MRR are: ***speed, depth of cut and feed*** in reducing order. It is concluded that $N_3$, $d_3$, $f_3$ gives the maximum MRR. An Experiment is also conducted to verify the effectiveness of Taguchi optimization method for Al 6061 alloy.

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