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Optimization of Process Parameters in Turning Operation of Aluminium (6061) with Cemented Carbide Inserts Using Taguchi Method and Anova

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ABSTRACT

This paper investigates the parameters affecting the roughness of surfaces produced during the turning process for the material Aluminium 6061. The surface roughness is considered as quality characteristic while the process parameters considered are speed, feed and depth of cut .Design of experiments were conducted for the analysis of the influence of the turning parameters on the surface roughness by using Taguchi design.. The results of the machining experiments for Aluminium 6061were used to characterize the main factors affecting surface roughness by the Analysis of Variance (ANOVA) method.. The feed and speed are identified as the most influential process parameters on surface roughness.

Keywords: *Aluminium (6061); ANOVA; Surface Roughness; Taguchi Method; Turning.*

1.0 Introduction

Surface roughness is mainly a result of process parameters such as tool geometry (i.e. nose radius, edge geometry, rake angle, etc). and cutting conditions (feed rate, cutting speed, depth of cut, etc).Surface roughness is harder to attain and track than physical dimensions are, because relatively many factors affect surface roughness. Some of these factors can be controlled and some cannot. Controllable process parameters include feed, cutting speed, tool geometry, and tool setup. Other factors, such as tool, work piece and machine vibration, tool wear and degradation, and work piece and tool material variability cannot be controlled as easily.

The important cutting parameters discussed here are cutting speed, feed and depth of cut. It is found in most of the cases surface roughness decreases with increase in cutting speed and decrease in feed and depth of cut. Since these cutting parameters will decide about the type of chips which we expect at the time of machining of a single constant material thus we have to analyze them for no such built-up edge chips formation.

The Taguchi method is statistical tool, adopted experimentally to investigate influence of surface roughness by cutting parameters such as speed, feed and depth of cut. Many researchers developed many mathematical models to optimize the cutting parameters to get lowest surface roughness by turning process.

The variation in the material hardness, alloying elements present in the work piece material and other factors affecting surface finish. Proper selection of cutting parameters and tool can produce longer tool life and lower surface roughness. Hence, design of experiments by Taguchi method on cutting parameters was adopted to study the surface roughness

2.0 Taguchi Method

Taguchi's parametric design is the effective tool for robust design it offers a simple and systematic qualitative optimal design to a relatively low cost.

The Taguchi method of off-line (Engineering) quality control encompasses all stages of product/process development. However the key element for achieving high quality at low cost is Design of Experiments (DOE). In this paper Taguchi's (DOE) approach is used to analyze the effect of process parameters like cutting speed, feed, and depth of cut on Surface Roughness of Aluminium 6061 work material while machining with cemented carbide insert type tool and to obtain an optimal

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setting of these parameters that may result in good surface finish. Steps of Taguchi method are as follows:

1. Identification of main function, side effects and failure mode.
2. Identification of noise factor, testing condition and quality characteristics.
3. Identification of the main function to be optimized.
4. Identification the control factor and their levels.
5. Selection of orthogonal array and matrix experiment.
6. Conducting the matrix experiment.
7. Analysing the data, prediction of the optimum level and performance.
8. Performing the verification experiment and planning the future action.

3.0 ANOVA (Analysis of Variance)

Since there are a large number of variables controlling the process, some mathematical models are required to represent the process.

However, these models are to be developed using only the significant parameters influencing the process rather than including all the parameters. In order to achieve this, statistical analysis of the experimental results will have to be processed using the analysis of variance ANOVA is a computational technique that enables the estimation of the relative contributions of each of the control factors to the overall measured response. ANOVA can be useful for determining influence of any given input parameter from a series of experimental results by design of experiments for machining process and it can be used to interpret experimental data.

Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes t-test to more than two groups. ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest.

The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations.

4.0 Experiment Set Up

4.1 CNC lathe

The CNC Lathe consists of the machine unit with a three jaw independent chuck, a computer numerically controlled tool slide, which cud move accordingly to two axis horizontal and vertical X and Z axis. X axis represents the vertical movement which gives the depth of cut where as Z axis represents the location of the cutting tool. Thus after deciding the machining zero at a certain point the command is given in the form of a part program. The machine is also provided with a automatic lubrication motor for its slides.

4.2 Cutting tool material

The cutting tool which provided with the CNC lathe Trainer was a 30 mm square tool with 60 mm length having the same tool angles as for a normal turning tool. The tool used was cemented carbide insert type. The geometry of tool is: Rake angle 60(+ve), 50 (+ve) clearance angle, 600 (+ve) major cutting edge angle, 600 (+ve) included angle and 00 cutting edge inclination angle. All the three elements-tungsten, molybdenum and cobalt help in achieving high hot hardness; the first two do so by forming complex carbides and the cobalt forms an alloy by going into solid solution in the ferrite matrix and thus raising the recrystallisation temperature. Vanadium in high speed steels increases the wear resistance of tool at all operating temperatures. Vanadium also helps to inhibit grain growth at the high temperatures required in heat treatment.

4.3 Work piece material

CNC Lathe made LMW was available for turning only Non-ferrous materials. The chuck holding the work piece diameter was only limited to 120 mm and the maximum work piece length was limited to about 250 mm length. Standardized material were selected to ensure consistency of the alloy, which was a common wrought alloy used in industry 6061 Aluminum HINDALCO made in the form of bars with the size of diameter 22 mm 120mm length so as to fit under the chuck.

Table 1: Chemical Composition of Aluminum Alloy

Element	Weight%
Cu	0.15-0.4
Mg	0.7-1.2
Si	0.4-0.8
Fe	0.7 max
Mn	0.2-0.8
Other	0.4

The aluminum we have chosen for turning is actually a Heat Treatable Alloy manufactured in the form of bars by HINDALCO. The inputs which were fed in the form of part program include dimensions ofthe work piece, cutting parameters depth of cut in mm, Speed available was 50-3500 rpm and feed in mm/min.This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables.

Alloy 6061 has excellent corrosion resistance to atmospheric conditions and good corrosion resistance to sea water. This alloy also offers good finishing characteristics and responds well to anodizing. Alloy 6061 is easily welded and joined by various commercial methods. (Caution: direct contact by dissimilar metals can cause galvanic corrosion). For screw machine applications, alloy 6061 has adequate machinability characteristics in the heat-treated condition. The different alloying elements present in a work piece are shown in the Table 1.The control factors and their levels are illustrated in Table 1. The cutting parameters ranges were selected based on machining guidelines provided by manufacturer of cutting tools

Table 2: Cutting Parameters and Levels

Code	Cutting Parameter	Level 1	Level 2	Level 3
A	Speed „s' (rpm)	1700	1900	2100
B	Feed „f „ (mm/rev)	0.1	0.125	0.15
C	Depth of cut „d' (mm)	0.2	0.3	0.4

The surface roughness of machined surface has been measured by a Surface Roughness Measuring instrument, the Surtronic 3+, is a portable, self-contained instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory. Parameters available for surface texture evaluation are: Ra, Rq, Rz (DIN), Ry and Sm.

The parameters evaluations and other functions of the instrument are microprocessor based. The measurements results are displaced on an LCD screen and can be output to an optional printer or another computer for further results.

The dependent variable is surface roughness. Table 3 shows standard L27 (33) orthogonal array designed by Taguchi with experimental results. The left side of the Table 3 includes coding values of control factors and real values of cutting parameters.

The right side of the Table 3 includes the results of the measured values of the surface roughness and calculated values.

The left side of the Table 3 includes coding values of control factors and real values of cutting parameters. The right side of the Table 3 includes the results of the measured values of the surface roughness and calculated S/N ratio and Residuals.

The different units used here are: speed – rpm, feed mm/ rev, depth of cut – mm and surface roughness Ra - µm. Design – MINTAB software was used for Taguchi's method and for analysis of variance (ANOVA).

4.4 Surface roughness

Surface properties such as roughness are critical to the function ability of machine components. Increased understanding of the surface generation mechanisms can be used to optimize machining process and to improve component function ability.

Table 3: Machine Readings and Calculations of Roughness

Experiment.No	Control Factors			Speeds (s)	Feed (f)	Depth of cut (d)	Surface Roughness (µ)	Predicted Ra	Values got from Minitab	
	A (s)	B (f)	C (d)	(Rev/min.)	(mm per rev.)	(mm)			S/N Ratio	RESI1
1	1	1	1	1700	0.1	0.2	0.82	0.822465	1.71067	0.02963
2	1	1	2	1700	0.1	0.3	0.94	0.923216	0.61498	0.000741
3	1	1	3	1700	0.1	0.4	0.96	1.002099	0.16418	-0.04593
4	1	2	1	1700	0.125	0.2	1.12	1.044266	-0.69093	0.105185
5	1	2	2	1700	0.125	0.3	1.06	1.172187	-0.96497	-0.1037
6	1	2	3	1700	0.125	0.4	1.1	1.272344	-1.50581	-0.13037
7	1	3	1	1700	0.15	0.2	1.44	1.269214	-2.65349	0.116296

8	1	3	2	1700	0.15	0.3	1.54	1.424692	-3.42556	0.067407
9	1	3	3	1700	0.15	0.4	1.5	1.546424	-3.65622	-0.03926
10	2	1	1	1900	0.1	0.2	0.86	0.7976	1.62485	0.076296
11	2	1	2	1900	0.1	0.3	0.92	0.895305	0.84080	-0.01259
12	2	1	3	1900	0.1	0.4	0.76	0.971804	1.18614	-0.23926
13	2	2	1	1900	0.125	0.2	1.04	1.012696	-0.22666	0.031852
14	2	2	2	1900	0.125	0.3	1.2	1.13675	-1.35483	0.042963
15	2	2	3	1900	0.125	0.4	1.1	1.233879	-1.35523	-0.1237
16	2	3	1	1900	0.15	0.2	1.44	1.230843	-2.53892	0.122963
17	2	3	2	1900	0.15	0.3	1.6	1.381621	-3.49168	0.134074
18	2	3	3	1900	0.15	0.4	1.5	1.499672	-3.52088	-0.03259
19	3	1	1	2100	0.1	0.2	0.88	0.775869	1.62294	0.125185
20	3	1	2	2100	0.1	0.3	0.78	0.870913	1.65297	-0.1237
21	3	1	3	2100	0.1	0.4	1.16	0.945327	-0.49071	0.18963
22	3	2	1	2100	0.125	0.2	1.08	0.985105	-0.28740	0.100741
23	3	2	2	2100	0.125	0.3	1.14	1.105779	-1.00775	0.011852
24	3	2	3	2100	0.125	0.4	1.26	1.200262	-1.80159	0.065185
25	3	3	1	2100	0.15	0.2	0.58	1.197309	0.53069	-0.70815
26	3	3	2	2100	0.15	0.3	1.42	1.343978	-2.81338	-0.01704
27	3	3	3	2100	0.15	0.4	1.86	1.458814	-4.46206	0.356296

The present study has shown two purposes. The first was to demonstrate the use of Taguchi parameter design in order to identify the optimum surface roughness with particular combination of cutting parameters and a systematic procedure using Taguchi design in process design of turning operations. The second was to determine the optimum combination of process parameters more accurately by investigating the relative importance of process parameters using ANOVA. The obtained results are analyzed using Minitab software and all the values are shown in the Table 4.

Table 4: ANOVA Table for Surface Roughness

Source	**Speed(s)**	**Feed (f)**	**Depth of cut (s)**	**Error**
DOF	2	2	2	20
S.S	0.00643	1.29070	0.21923	0.88714
M.S	0.00321	0.64535	0.10961	0.04436
F Value	0.07	14.55	2.47	2.47
P Value	0.930	0.000	0.110	0.110

It can be seen from ANOVA table 4 that feed is the maximum contributing factor and other details of DOF - Degrees of freedom, S.S - Sum of Squares, M.S - Mean of Squares and Error are mentioned. Hence as a result the individual ranking of cutting parameters on the average value of mean on surface roughness are shown in Table 5:

Table 5: Ranking of Cutting Parameters

Level	**1**	**2**	**3**	**Rank**
Speed	2.786	2.236	2.855	3
Feed	2.066	2.266	3.544	1
Depth of cut	2.552	2.635	2.689	2

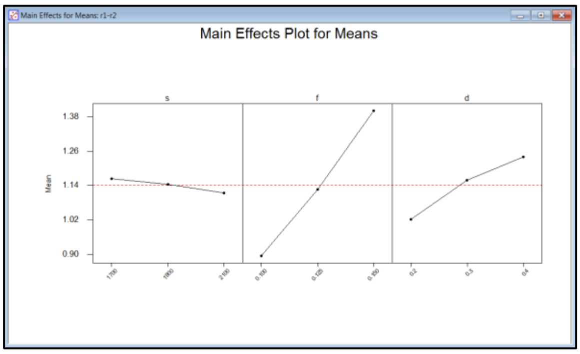
5.0 Mathematical Modeling

A regression model was developed for surface roughness using Minitab software. The predictions are speed, feed and depth of cut. Regression equation for surface roughness is $Ra = 1.564\ s^{-0.276}\ f^{1.07}\ d^{0.285}$

5.1 Main effect plots analysis

The analysis is made with the help of software package MINITAB. The main effect of plot is shown in Fig. 1 .They show the variation of individual response with three parameters i.e. speed, feed and depth of cut separately. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of the response.

Fig 1: Effect of Turning Parameters on Surface Roughness



The main effect plots are used to determine the optimal design conditions to obtain the optimal surface finish. According to this main effect plot, the optimal conditions for minimum surface roughness are speed at level (2100 RPM), feed rate at level 1 (0.1 mm/rev) and depth of cut at level 1 (0.2mm). Interaction plot for S/N ratios of the Surface roughness for data means is shown in Fig .3 Signal-to-Noise ratio of common interest for optimization for surface roughness is smaller the better.

The diagnostic checking has been performed through residual analysis for the developed model.

The residual plots for surface roughness are shown in Fig. 4. These are generally fall on a straight line implying that errors are distributed normally.

Fig 2: Effect of Turning Parameters on Surface Roughness

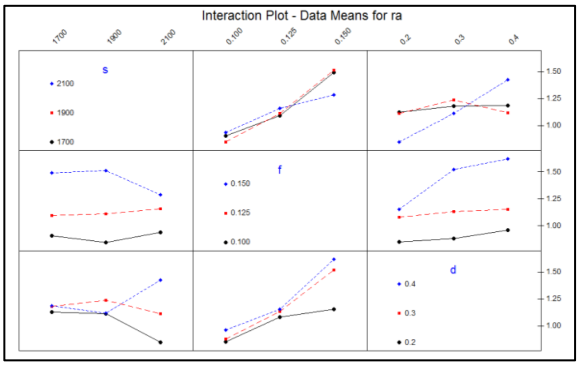


Fig 3: Interaction Plot for S/N Ratios of the Surface Roughness

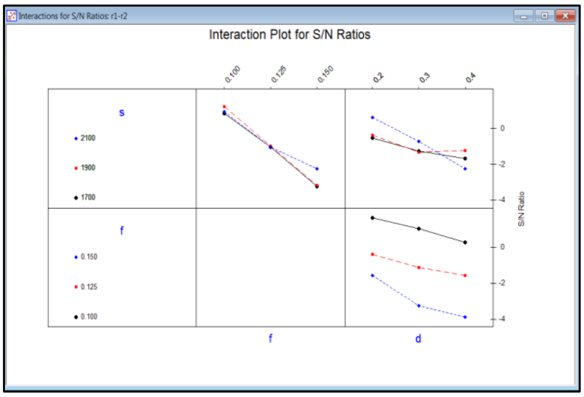


Fig 4: Residual Plot-Histogram

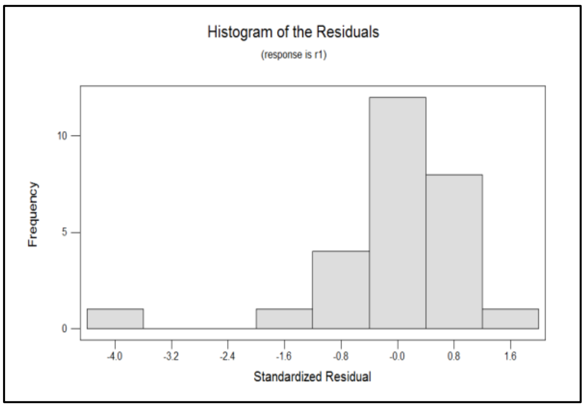


Fig 5: Residual Plot–Normal Probability

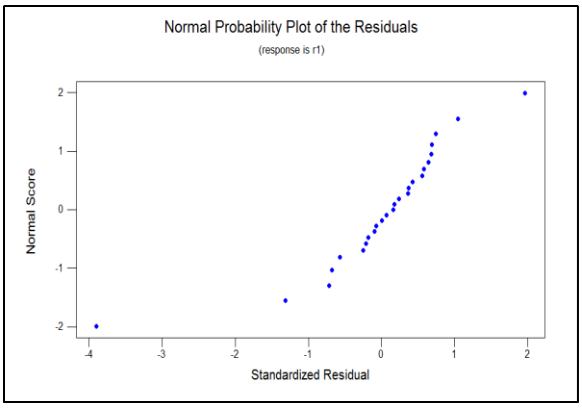


Fig 6: Residual Versus Order of Data

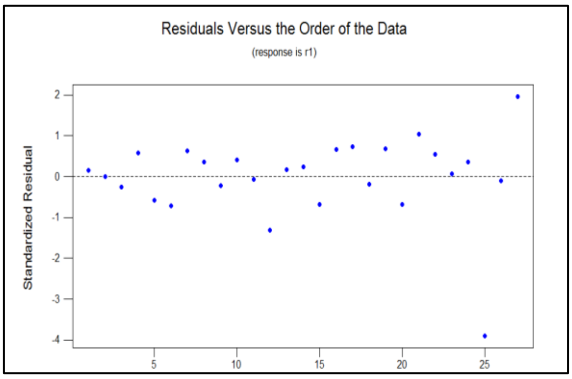
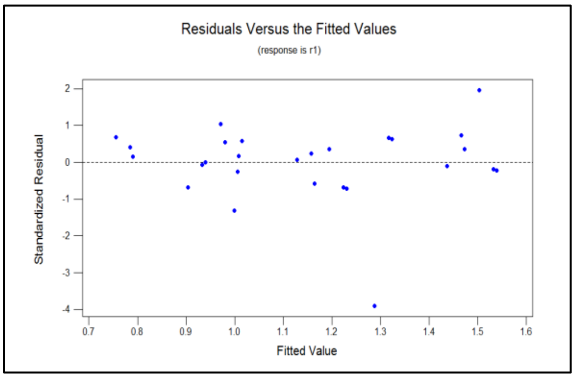


Fig 7: Residual Versus the Fitted Values



From Fig .4, 5, 6, 7, it can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy. Hence these values yield better results in future predictions.

6.0 Conclusions

This work presented an experimentation approach to study the impact of machining parameters on surface roughness. Strong interactions were observed among the turning parameters. Most significant interactions were found between work materials, feed and cutting speeds. A Systematic approach was provided to design and analyze the experiments, and to utilize the data obtained to the maximum extend.

The following are conclusions drawn based on the experimental investigation conducted at three levels by employing Taguchi technique to determine the optimal level of process parameters.

- From the data collection it has been observed that the increase in cutting speed tends to improve the finish, thus the average surface roughness value decreases.
- The increase in depth of cut influences the finish slightly, but greater depth of cut marks the finish poor.
- Feed rate is the most critical parameter when finish is the criterion.
- Finish gets poor as the feed increases, thus the average surface roughness value increases with increase in feed.
- The ANOVA and F-test revealed that the feed is dominant parameter followed by depth of cut and speed for surface roughness.
- The optimal combination process parameter for minimum surface roughness is obtained at 2100 rpm, 0.1 mm/rev and 0.2mm.
- A regression model is developed for surface roughness. The developed model is reasonably accurate and can be used of prediction within limits.
- Taguchi gives systematic simple approach and efficient method for the optimum operating conditions.

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