# Development of Regression Model for Surface Roughness on Al 6061 Alloy

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*Abstract*— **Aluminium and its alloys have importance in automobile and aerospace applications due to their high strength to weight ratio. The emerging trend of machining to produce low cost and high quality products in least possible time has given a real challenge in machining aluminium and its alloys. Turning is one of the metal cutting operation, is most widely used manufacturing technique in the industry and there are lots of studies to investigate this complex process in both academic and industrial world.**

**The main objective of the paper is to optimize the process parameters namely- cutting speed, feed, depth of cut, and rake angle of tool, on machining of Al 6061 alloy using single point cutting tool for Surface roughness.**

*Index Terms*—**Al6061, Turning, Surface roughness.**

## I. Introduction

THE turning is the one most commonly employed operation in experimental work on metal cutting. This operation is one of the most basic machining processes. That is, the part is rotated while a single point cutting tool is moved parallel to the axis of rotation [1-4].

Cutting speed, feed depth of cut and tool life are the major influencing parameters in turning process. The cutting speed and feed of cutting tool is largely influenced by the following factors.

- Material being machined.
- Material of the cutting tool.
- Geometry of the cutting tool.
- Required degree of surface finish.
- Rigidity of the machine tool being used.

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## II. Work Material and Methodology

**Aluminium Alloy 6061:** Aluminium alloy 6061 is one of the most extensively used of the 6000 series aluminium alloys. It is a versatile heat treatable extruded alloy with medium to high strength capabilities.

Al6061 sheets of following composition were used in a research paper, and the same material is used for this experimentation. However, the properties of the specimen can vary due to induced anisotropy.

Typical applications for aluminium alloy 6061 include:

- Aircraft and aerospace components.
- Automobile and transport industry.
- Marine fittings.

TABLE I
Al6061 Mechanical Properties

| Component | Amount (wt. %) |
|---|---|
| Aluminium | 98.46 |
| Magnesium | 0.8 |
| Silicon | 0.4 |
| Iron | 0.05 |
| Copper | 0.15 |
| Zinc | 0.05 |
| Manganese | 0.05 |
| Chromium | 0.04 |

- Valves.
- Drive shafts.

**Tool material (HIGH –SPEED STEEL):**

The Cutting tool used in machining the work material is an uncoated High Speed Steel Tool available in market. High-speed tool steels are so named primarily because of their ability to machine materials at high cutting speeds. They are complex iron-base alloys of carbon, chromium, vanadium, molybdenum, or tungsten, or combinations thereof, and in some cases substantial amounts of cobalt. The carbon and alloy contents are balanced at levels to give high attainable hardening response, high wear resistance, high resistance to the softening effect of heat, and good toughness for effective use in industrial cutting operations.

**TAGUCHI'S METHODOLOGY:**

This study focuses on the optimization of process parameters and hence Taguchi's parameter design [6-8] is chosen. The actual steps in using Taguchi's method of parameter design are divided into three groups: planning the experiment, performing the experiment, and analyzing the data from the experiment.

The use of Taguchi's parameter design involves the following steps.

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- Planning the experiment.
- Identify the target response, side effects, and failure modes.
- Identify noise factors and testing conditions.
- Identify the quality characteristic to be observed and the objective function to be observed.
- Identify the control factors and their levels.

TABLE II
PROCESS PARAMETERS

| Process Parameter | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| Speed (rpm) | 414 | 483 | 640 |
| Feed (mm/rev) | 0.061 | 0.121 | 0.243 |
| Depth of Cut (mm) | 0.5 | 0.6 | 0.9 |
| Back Rake Angle (°) | 10 | 15 | 20 |

- Design the matrix for experimentation.
- Performing the experiment.
- Conduct the matrix experiment.
- Analyzing the results.
- Analyse the data to determine the optimum levels, and predict the product/process response under these optimum levels.

**DESIGN OF EXPERIMENTS:**

- Formulating the orthogonal array
- Identifying the testing conditions and quality characteristics
- Observable characteristic Surface roughness
- Workpiece material Al 6061
- Operating Equipment Lathe Machine.
- Identifying the process factors and their levels

**Selection of Orthogonal Array**

Orthogonal array is selected based upon the degrees of freedom.

Degrees of freedom are computed to select the appropriate orthogonal array. The same is given below:

*Degrees of Freedom:(N-1)P+1*

*Total Degrees of Freedom: 9*

*N=Number of levels*

*P=Number of Parameters*

The most suitable orthogonal array for experimentation is L9 array for the total degrees of freedom are 9. Therefore, a total nine experiments are to be carried out.

TABLE III
L9 ORTHOGONAL ARRAY

| Trial | Speed | Feed | Depth of Cut | Back Rake Angle |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | **1** |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 2 | 1 | 2 | 3 |
| 5 | 2 | 2 | 3 | 1 |
| 6 | 2 | 3 | 1 | 2 |
| 7 | 3 | 1 | 3 | 2 |
| 8 | 3 | 2 | 1 | 3 |
| 9 | 3 | 3 | 2 | 1 |

## III. EXPERIMENTATION

Grooving is the process of cutting a narrow groove on the cylindrical surface of the workpiece. It is often done at end of a thread or adjacent to a shoulder to leave a small margin. The groove may be square, radial or beveled in shape. The cutting of grooves often requires high levels of precision. Grooving is done on work piece for conduct of trails(Fig. 1).

Fig. 1. Workpiece before experimentation

**TOOL MATERIAL:**

We have grinded the three tools to the side rake angle of 15° ,the Side relief angle of 10° by varying the three back rake angles to 10° ,15° and 20°.

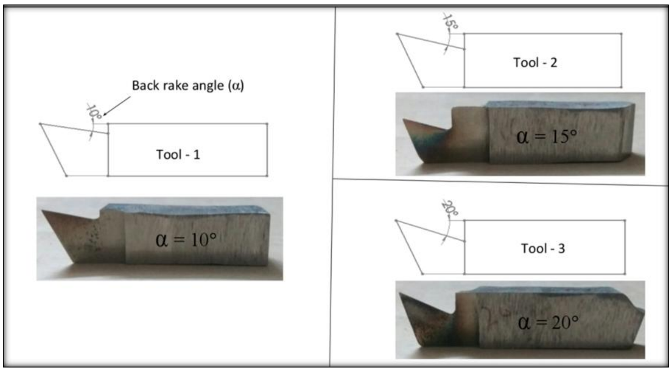


Fig.2. 2D - Drawings of Tools with Varying Back Rake-Angles

**EXPERIMENTAL SETUP:**

The various equipment used in performing the tests are listed below.

1. Lathe Machine
2. Work materials
3. Tool materials
4. Surface roughness tester

**SURFACE ROUGHNESS TESTER:**

Surface texture is the repetitive or random deviation from the nominal surface that forms the three dimensional topography of the surface. Surface texture includes (1) roughness (nano- and micro-roughness), (2) waviness (macro-roughness), (3) lay, and (4) flaws.

TABLE IV
SPECIFICATIONS OF THE SURFACE ROUGHNESS TESTER MODEL NO. SJ-210

| Drive unit type | Standard |
|---|---|
| Detector type | 4mN measuring force, 5µm stylus tip radius |
| Standards met | JIS (1982, 1994, and 2001), ISO 1997, VDA, and ANSI |
| Measuring range | X-axis: .69 inches (17.5mm); Z-axis 14200 µin (-7900µin ~+6300µin)/360µin /.08µin |

| | |
|---|---|
| Resolution | (25µm / 0.002µm) 14170µin /.8µin (360µm / 0.02µm), 4000µin /.2µin (100µm /0.006µm), 1000µin /.08µin (25µm / 0.002µm) |
| Assessed profile | Primary profile (P), roughness profile (R), DIN4776 [Primary profile (P), Roughness profile (R), MOTIF (R): M-type |
| Parameters | Rv, Rsk, Rku, Rc, RPc, RSm, Rmax, Rz1max, RzJIS, Rppi, RΔa, RΔq, Rlr, Rmr, Rδ, ς, HSC, Rpm, tp, Htp, Ra, Ry, Rz, Rq, S, Sm, Pc, R3z, mr ©, Rt, Rp, Rk, Rpk, Rvk, Mr1, Mr2, A1, A2, Vo (customizable)(R, AR, Rx: M-type) |
| Overall dimensions | 52.1 x 65.8 x 160 mm / 2.05 x 2.6 x 6.3 inches (H x W x D) |
| Weight | 1.1 lb (500g) including display unit, drive unit, and detector |

**DESIGN MATRIX:**

The experiment was carried out in accordance to the following design matrix:

TABLE V
DESIGN MATRIX

| Trial | Speed | Feed | Depth of Cut | Back Rake Angle |
|---|---|---|---|---|
| 1 | 414 | 0.061 | 0.5 | 10 |
| 2 | 414 | 0.121 | 0.6 | 15 |
| 3 | 414 | 0.243 | 0.9 | 20 |
| 4 | 483 | 0.061 | 0.6 | 20 |
| 5 | 483 | 0.121 | 0.9 | 10 |
| 6 | 483 | 0.243 | 0.5 | 15 |
| 7 | 640 | 0.061 | 0.9 | 15 |
| 8 | 640 | 0.121 | 0.5 | 20 |
| 9 | 640 | 0.243 | 0.6 | 10 |

## IV. Results and Discussion

The following observations were made during the experimentation.

**Surface Roughness:**

The Surface Roughness was measured using a surface roughness tester for all the nine trails and the observations are recorded is shown below.

TABLE VI
SURFACE ROUGHNESS MEASUREMENTS

| Trial | Surface Roughness (µm) |
|---|---|
| 1 | 3.812 |
| 2 | 3.554 |
| 3 | 7.717 |
| 4 | 2.019 |
| 5 | 5.038 |
| 6 | 7.741 |
| 7 | 2.342 |
| 8 | 9.832 |
| 9 | 10.438 |

Fig. 3. 2D Surface Roughness Measurements

Fig. 4. 2D Surface Roughness Measurements

**THE LINEAR REGRESSION MODEL**

Regression analysis was performed using the observed Surface Roughness from the previous section. It was done using LASSO [9] with the 'right-fit' was chosen to fit the data.

An equation with the right fit is paramount for regression analysis. The 'right fit' can be understood by plotting the learning and the training curves for the training data by changing the regularization parameter and the degree of the polynomial.

TABLE VII
TRAINING DATA FOR REGRESSION ANALYSIS OF SURFACE ROUGHNESS

| P1 (Speed) (rpm) | P2 (Feed) (mm/rev) | P3 (Depth of Cut) (mm) | P4 (Back Rake Angle) (°) | Surface Roughness (µm) |
|---|---|---|---|---|
| 414 | 0.061 | 0.5 | 10 | 3.812 |
| 414 | 0.121 | 0.6 | 15 | 3.554 |
| 414 | 0.243 | 0.9 | 20 | 7.717 |
| 483 | 0.061 | 0.6 | 20 | 2.019 |
| 483 | 0.121 | 0.9 | 10 | 5.038 |
| 483 | 0.243 | 0.5 | 15 | 7.741 |
| 640 | 0.061 | 0.9 | 15 | 2.342 |
| 640 | 0.121 | 0.5 | 20 | 9.832 |
| 640 | 0.243 | 0.6 | 10 | 10.438 |

Lasso has substantially reduced the complexity of the equation by turning some insignificant coefficients to zero. An equation with fourteen variables is now reduced to an equation with seven variables.

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TABLE IX
REGRESSION COEFFICIENTS

| Variable | Value |
|---|---|
| Intercept | -1.61 |
| P1 | 0.0076 |
| P2 | 0 |
| P3 | 0 |
| P4 | 0 |
| P1P2 | 0 |
| P1P3 | 0.0073 |
| P1P4 | 0.0002 |
| P2P3 | 0 |
| P2P4 | 0 |
| P3P4 | 0 |
| P1P2P3 | 0 |
| P1P2P4 | 0.0044 |
| P1P3P4 | -0.0011 |
| P2P3P4 | 0 |

Final Equation for Surface Roughness

- Regularization constant = 5
- Maximum iterations = 5000
- Iterative algorithm = Coordinate descent
- Equation with third-order interaction terms

**Y = – 1.64 + 0.0076P1 + 0.073P1P3 + 0.0002P1P4 + 0.0044P1P2P4 – 0.0011P1P3P4**

Here, Y=Surface Roughness,
P1=Speed,
P2=Feed,
P3=Depth of Cut,
P4=Back Rake Angle.

TABLE X
VALIDATION METRICS

| Metric | Value |
|---|---|
| Coefficient of Determination | 0.906 |
| Mean Squared Error | 0.847 |

With the coefficient of determination for the above model being 0.906 and the mean squared error being 0.847, the model is accurate and contains just enough scope of a decent generalized error.

**Variation of Surface Roughness with Respect to Process Parameters:**

The variation of Surface Roughness according to the process parameters is plotted using the regression equation generated .In the plots, Level-1 indicates that all the parameters other than the parameter under study are in the lowest level as per the orthogonal array. The same is the case with other two levels, with Level-3 having all parameters in the highest level.

All the graphs were plotted using Python Programming.

The plot between Surface Roughness and input parameters for various levels of the process parameters are outlined below:

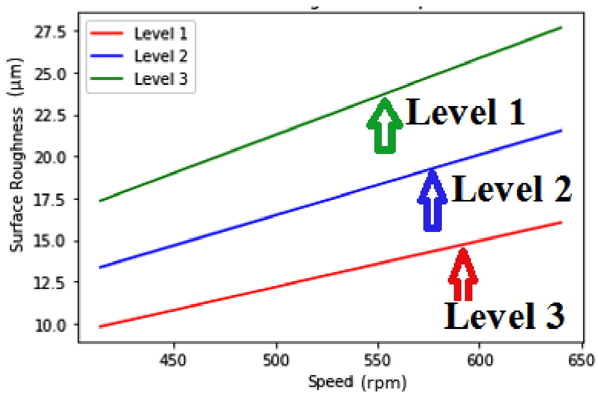


Fig.5. Surface Roughness vs Speed

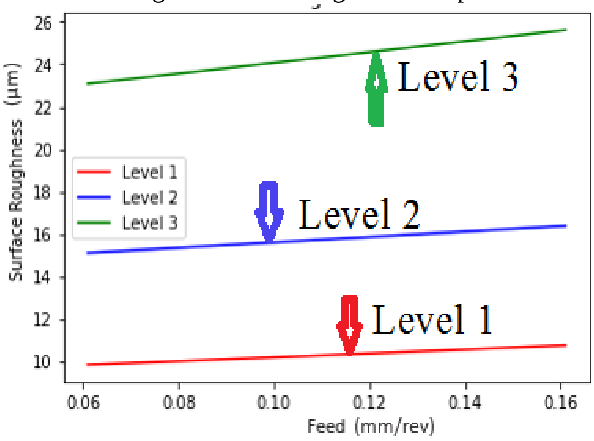


Fig.6 Surface Roughness vs Feed

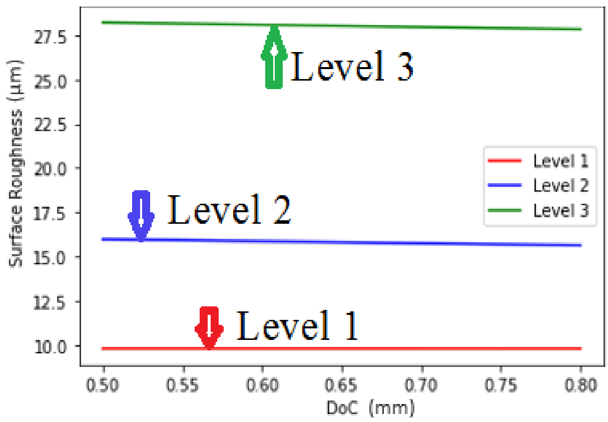


Fig.7. Surface Roughness vs Doc

## V. CONCLUSIONS

In the turning experiments, different cutting speed, feed rate, depth of cut and rake angle were used. Based on that, the following conclusions can be drawn for the turning operation:

1. Low value of the Surface Roughness is 2.019μm is obtained in trial - 4 at a spindle speed of 483rpm, tool feed of 0.061mm/rev, depth of cut of 0.6 mm and rake angle of 20°.

2. The feed rate has greater static influence followed by spindle speed and depth of cut on surface roughness.

3. The developed regression model with the Lasso reduces the complexity of the equation when compared to standard linear regression without regularization, and

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thereby offers a simple model.

4. An increase in the speed and the feed showed an increase in the surface roughness while the decrease in the two showed a decrease in the surface roughness in all three levels.

5. However, the surface roughness showed minimal variation with the change in depth of cut for all three levels.

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