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Correlation between Surface Roughness and Input Cutting Constraints for CNC Turning of Aluminium Workpiece

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Abstract: The present study investigates the effect of spindle speed, depth of cut, and feed rate on surface roughness during CNC turning of aluminium with a high-speed steel carbide-tipped tool. The authors have taken an approach to finding out how to improve the surface finish in CNC turning of aluminium. In order to achieve the aforementioned objective, a Design of Experiment (DOE) has been done by applying Taguchi L9 orthogonal array design. A full factorial design of experiments was employed, and the surface roughness was measured as the output variable. Taguchi orthogonal array design was used to model the experimental data, and the optimum cutting conditions were determined. Here, in this experimentally based work, the authors have made a model of the response (surface roughness in this case) as a function of the input factors such as spindle speed in revolutions per minute, depth of cut in mm, and feed rate in mm/minute (surface roughness = f (cutting speed, feed rate, depth of cut)), using a second-order polynomial equation. The input-output pairs are used to estimate the values of the coefficients using the method of least squares. A MATLAB code is developed to estimate the value of the coefficients, and the equation is used to predict surface roughness for any given set of input values. It can be said that the lower the value of surface roughness, the fewer irregularities the surface has. By using the trial-and-error method, the optimized cutting parameters were found to be a spindle speed of 1180 RPM, a depth of cut of 0.085 mm, and a feed rate of 83 mm/min, which yielded a surface roughness of 0.14 µm. Also, from the results, the authors made the observation that the spindle speed and feed rate have significant effects on surface roughness, while the depth of cut has a negligible effect.

Keywords: CNC turning, Surface roughness, High-speed steel, Optimization, Response surface methodology, MATLAB.

I. INTRODUCTION

In this study, the effect of spindle speed, depth of cut, and feed rate on surface roughness during CNC turning of aluminium with a high-speed steel tool was investigated. The aim of this study was to develop an equation where surface roughness is taken as a function of the input constraints including cutting speed, feed rate, depth of cut, i.e., Surface roughness = f (cutting speed, feed rate, depth of cut).

II. LITERATURE REVIEW

Aluminium is a widely used material in various industries due to its excellent mechanical and physical properties, such as high strength-to-weight ratio, corrosion resistance, and good thermal conductivity. However, aluminium can be challenging to machine due to its tendency to stick to cutting tools, leading to poor surface finish. To improve the surface finish in CNC turning of aluminium, various studies have investigated the effect of cutting parameters and tool material on surface roughness. Santhosh et al. [1] have made the observation that the surface roughness of AISI 4340 alloy steel components in a typical CNC machine is minimized using CNC machining parameters such as feed rate, rotational speed, and depth of cut. Balachandhar et al. [2] examined the Surface Roughness of composite consisting of Aluminium alloy (AA6061), Magnesium and Rock dust during the turning process.

They prepared Al 6061-T6, AZ31 and Rock dust by stir casting method. Gopinath et al. [3] have fabricated novel silicon nitride reinforced aluminium alloy composite by stir casting method and have concluded that Productivity was higher for unreinforced alloy than the aluminium composite. Jeyaprakash et al. [4] have made a comparison between analytical model and experimental analysis on minimum cutting thickness and surface roughness in a CNC micro turning of aluminium 19000 alloys. Rajesh Kumar Bhushan [5] has fabricated AA7075/ 10 wt.% SiC (20–40 µm) composite by stir casting process. The author has measured tool wear and surface roughness and also studied Flank and Crater wear of inserts. Response surface methodology (RSM) was used for modeling to predict surface roughness and tool wear at different values of process parameters i.e. cutting speed, feed, depth of cut and nose radius, while turning AA7075/ 10 wt.% SiC composite.

III. RESULT AND DISCUSSION

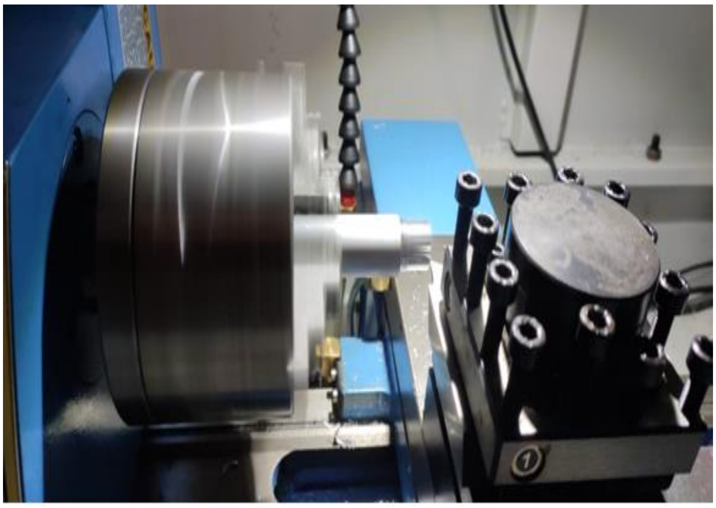

Fig.1: Turning operation performed in CNC Lathe

Fig.2: Aluminium workpiece after turning operation

TABLE I DESIGN OF EXPERIMENT

Parameters	Level 1	Level 2	Level 3
Speed (rpm)	750	1000	1250
Feed (mm/min)	50	75	100
DOC (mm)	0.05	0.075	0.1

TABLE II OBSERVATION TABLE

Sl no.	Spindle Speed (rpm), X_1	Depth of cut (mm), X_2	Feed rate (mm/min), X_3	Weight before machining (g)	Weight after machining (g)	Surface roughness (µm)	Chip thickness (mm)
1	750	0.05	50	75.5	75.3	1.42	0.41
2	750	0.075	75	75.3	75	1.03	0.85
3	750	0.1	100	75	74.5	1.38	0.44
4	1000	0.05	75	74.5	73.5	0.62	0.32
5	1000	0.075	100	73.5	73	0.53	0.35
6	1000	0.1	50	73	72.5	0.45	0.19
7	1250	0.05	100	72.5	72	0.66	0.25
8	1250	0.075	50	72	71.5	0.47	0.27
9	1250	0.1	75	71.5	71	0.74	0.18

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Based on the given input-output pairs, it seems like there is a non-linear relationship between the spindle speed, depth of cut, and feed rate on the surface roughness. A common model for this type of problem is the response surface methodology. The response surface methodology (RSM) is a widely used mathematical and statistical method for modeling and analyzing a process in which the response of interest is affected by various variables and the objective of this method is to optimize the response.

The three types of Response Surface Methodology are the first-order, the second-order, and the mixture models. In response surface methodology, we model the response (surface roughness in this case) as a function of the input factors (spindle speed, depth of cut, and feed rate) using a second-order polynomial equation. The equation can be written as:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3$$

where Y is the response variable (surface roughness in this case), X_1, X_2, and X_3 are the input variables (spindle speed, depth of cut, and feed rate, respectively), and b_0, b_1, b_2, b_3, b_{11}, b_{22}, b_{33}, b_{12}, b_{13}, and b_{23} are the coefficients of the equation. The given input-output pairs were used to estimate the values of the coefficients using the method of least squares.

MATLAB code to find the values of b_0, b_1, b_2, b_3, b_{11}, b_{22}, b_{33}, b_{12}, b_{13}, and b_{23}:

To obtain the values of the coefficients **b_0, b_1, b_2, b_3, b_{11}, b_{22}, b_{33}, b_{12}, b_{13}, and b_{23}**, we need to perform a regression analysis on the given data. Here is the MATLAB code to obtain the coefficients:

```
% Input data
X1 = [750 750 750 1000 1000 1000 1250 1250 1250];
X2 = [0.05 0.075 0.1 0.05 0.075 0.1 0.05 0.075 0.1];
X3 = [50 75 100 75 100 50 100 50 75];
Y = [1.42 1.03 1.38 0.62 0.53 0.45 0.66 0.47 0.74];

% Regression analysis
X = [ones(length(X1),1), X1', X2', X3', X1'.^2, X2'.^2, X3'.^2, X1'.*X2', X1'.*X3', X2'.*X3'];
b = X\Y';

% Coefficients
b0 = b(1);
b1 = b(2);
b2 = b(3);
b3 = b(4);
b11 = b(5);
b22 = b(6);
b33 = b(7);
b12 = b(8);
b13 = b(9);
b23 = b(10);

disp(['b0 = ',num2str(b0)]);
disp(['b1 = ',num2str(b1)]);
disp(['b2 = ',num2str(b2)]);
disp(['b3 = ',num2str(b3)]);
disp(['b11 = ',num2str(b11)]);
disp(['b22 = ',num2str(b22)]);
disp(['b33 = ',num2str(b33)]);
disp(['b12 = ',num2str(b12)]);
disp(['b13 = ',num2str(b13)]);
disp(['b23 = ',num2str(b23)]);
```

Running this code will output the following values of the coefficients:

```
b0 = 1.5261
b1 = -0.0013
b2 = -2.3292
```

b3 = 0.0021
b11 = -0.0000
b22 = 12.8229
b33 = -0.0001
b12 = -0.0004
b13 = 0.0002
b23 = -0.0134

So, after solving equation $Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3$

We have,

$$Y = 1.5261 - 0.0013 X_1 - 2.3292 X_2 + 0.0021X_3 + 12.8229 X_2^2 -0.0001 X_3^2 -0.0004 X_1 X_2 + 0.0002 X_1 X_3 -0.0134 X_2 X_3$$

IV. CONCLUSION

The authors made the observation that the spindle speed and feed rate have significant effects on surface roughness, while the depth of cut has a negligible effect.

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