Investigation of Roller Burnishing Process Parameters on Surface Roughness of Al-Alloy 6351 T6 by Response Surface Methodology

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Abstract— These study deals with investigation and mathematical modelling of roller burnishing process parameters in CNC lathe machine using response surface methodology. Here the work piece material used is Aluminium Alloy 6351 T6 and tool material used is carbide single roller burnishing tool. The input parameters during process are Interference, Tool feed, Burnishing speed and Number of tool passes. The output parameter is surface roughness.

Key words: Single Roller burnishing, Response surface method, Surface roughness

I. INTRODUCTION

Machining of any materials like turning and milling have inherent irregularities and defects like tool marks and scratches that cause energy dissipation (friction) and surface damage (wear). To overcome these limitations, conventional finishing processes such as grinding, honing, and lapping have been traditionally employed. However, since these methods essentially depend on chip removal to attain the desired surface finish, these machining chips may cause further surface abrasion and geometric tolerance problem especially if conducted by unskilled operators. Accordingly, burnishing process offers an attractive post-machining alternative due to its chip less and relatively simple operations.

Burnishing is a very simple and effective method for improvement in surface finish, surface roughness and surface hardness. It is widely used for increase the surface quality and imparting the physical and mechanical properties to any type of work materials.

J. N. Malleswara Rao et al. [1] [2014] developed work on varying various optimization parameters of burnishing and examined which parameter is optimizing for better improvement of surface quality. K Saraswathamma et al. [2] [2014] concluded that Optimization of surface roughness in the roller burnishing process using response surface methodology and desirability function. They have founded that at higher speeds Ra value decreases and at higher feeds Ra value increases. Prof. Ghodake A. P et al. [3] [2013] studied Effect of Burnishing Process on Behaviour of Engineering materials. They have founded that Burnishing force and number of burnishing tool passes are the important parameters to improve the ductility of materials. Dionizy BIAŁO et al. [4] [2013] investigated Improvement of Tribological Properties of Metal Matrix Composites By Means Of Slide Burnishing. Experiment was performed on CNC lathe machine with AlMg1SiCu Aluminum matrix composite material and Alsic. They have founded that surface roughness decreases from 1 μm to 0.15 μm.

II. EXPERIMENTAL SET-UP

A number of experiments were conducted to study the effects of various burnishing parameters on CNC lathe machine. These studies were undertaken to investigate the effects of various burnishing parameters on Surface roughness. The selected work piece material for the research work is Al-Alloy 6351 T6 was selected due to its emergent range of applications in the field of aerospace industries.

Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.

The Ra value, also known as center line average (CLA) and arithmetic average (AA) is obtained by averaging the height of the surface above and below the centre line. The Ra will be measured using a surface roughness tester from Mitutoyo, Model: SJ 201P.

In this investigation, experimental design was established on the basis of 2k factorial, where k is the number of variables, with central composite-second-order rotatable design to improve the reliability of results and to reduce the size of experimentation without loss of accuracy. Thus, the minimum possible number of experiments (N) can be determined from the following equations:

$$N = n_c + n_a + n.......$$

$$n_c = 2^k$$

$$n_a = 2 \times k$$

In this case k = 4 and thus nc = 2k = 16 corner points at ±1 level, na = 2 X k = 8 axial points at γ = ±2, and a center point at zero level repeated 7 times (no). This involves a total of 31 experimental observations. The Level and factors are depicted in table 1.

	-2	-1	0	+1	+2
Burnishing Speed (rpm)	50	250	450	650	850
Interference (mm)	2	3.5	5	6.5	8
Tool Feed (mm/rev.)	0.024	0.044	0.064	0.084	0.104
Tool Passes	1	2	3	4	5

Table I: Process Parameters and their Levels for CCD.

III. RESPONSE SURFACE METHODOLOGY:

RSM is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which the response of interest is influenced by several variables and objective is to optimize this response. In order to study the effects of the burnishing parameters on the above mentioned machining criteria, second order polynomial response surface mathematical models can be developed. In the general case, the response surface is described by an equation of the form:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j=2}^{2} \beta_{ij} x_i x_j + \varepsilon_r$$

Where Y is the corresponding response, X_i is the input variables, X_i^2 and $X_i X_j$ are the squares and interaction terms, respectively, of these input variables. The unknown regression coefficients are $\beta_0, \beta_i, \beta ij$ and β_{ii}. Using CCD various 31 number of experiments to be conducted as shown in Table: 2.

Sr. No.	Ra
1.	0.191
2.	0.277
3.	0.402
4.	0.150
5.	0.104
6.	0.774
7.	0.126
8.	0.100
9.	0.639
10.	0.136
11.	0.134
12.	0.096
13.	1.504
14.	0.099
15.	0.125
16.	0.170
17.	0.317
18.	0.115
19.	0.508
20.	0.350
21.	0.175
22.	0.214
23.	0.080
24.	0.540
25.	0.095
26.	0.120
27.	0.115
28.	0.111
29.	0.204
30.	0.107
31.	0.128

Table II: Observed Values for Performance Characteristics

Term	Coef	SE Coef	T	P
Constant	0.865	0.297	2.914	0.011
Spindle Speed	0.001	0.001	0.814	0.428
Interference	-0.007	0.075	-0.091	0.928
Tool Feed	-30.899	20.235	-1.527	0.148
Tool Passes	0.108	0.117	0.924	0.370
Spindle Speed*Spindle Speed	-0.000	0.000	-0.744	0.468
Interference*Interference	-0.001	0.007	-0.080	0.937
Tool Feed*Tool Feed	309.521	155.913	1.985	0.066
Tool Passes*Tool Passes	-0.014	0.018	-0.745	0.468
Spindle Speed*Interference	-0.000	0.000	-2.208	0.013
Spindle Speed*Tool Feed	0.010	0.002	6.539	0.000
Spindle Speed*Tool Passes	-0.000	0.000	-4.023	0.001
Interference*Tool Feed	-1.544	0.208	-7.422	0.000
Interference*Tool Passes	0.029	0.004	6.773	0.000
Tool Feed*Tool Passes	-1.743	0.327	-5.329	0.000
R-Sq = 95.79% R-Sq(adj) = 91.87%				

Table III Estimated Regression Coefficients for SR:

The regression equation for SR is described below.

$$SR = 0.865 + 0.001 \times SS - 0.007 \times IF - 30.899 \times TF + 0.108 \times TP - 0.001 \times IF^2 + 309.521 \times TF^2 - 0.014 \times TP^2 + 0.010 \times SS \times TF - 1.544 \times IF \times TF + 0.029 \times IF \times TP - 1.743 \times TF \times TP$$

The Coefficient of determination R^2 as 95.79% for SR, which signifies that how much variation in the response is explained by the model. The higher of R2, indicates the better fitting of the model with the data.

Source	Df	Seq SS	Adj SS	Adj MS	F	P
Regression	14	2.39388	2.39388	0.170991	24.40	0.000
Linear	4	1.08404	0.07046	0.017614	2.51	0.046
Square	4	0.43413	0.54715	0.136788	19.52	0.000
Interaction	6	0.87571	0.87571	0.145952	20.82	0.000
Residual Error	15	0.10514	0.10514	0.007009		
Lack of Fit	8	0.09712	0.09712	0.012140	10.60	0.003
Pure Error	7	0.00802	0.00802	0.001145		
Total	30	2.49901				

Table IV: Analysis of variance for SR

It is important to check the adequacy of the fitted model, because an incorrect or under-specified model can lead to misleading conclusions. By checking the fit of the model one can check whether the model is under specified. The model adequacy checking includes the test for significance of the regression model, model coefficients, and lack of fit, which is carried out subsequently using ANOVA on the curtailed model (Table-IV). The P value indicates the significance of regression analysis.

The Coefficient of determination R^2 as 91.87% for SR, which signifies that how much variation in the response is explained by the model.

IV. RESULT AND DISCUSSIONS:

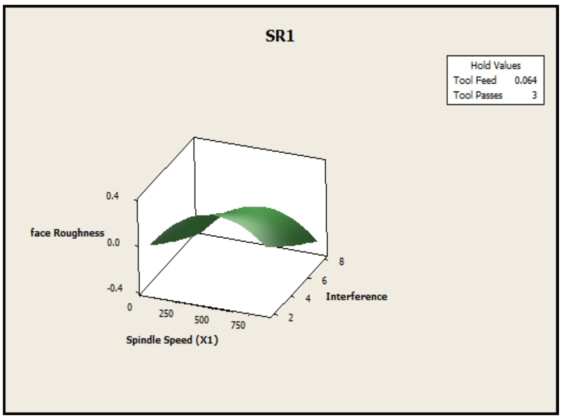

Fig. 1: Effect of speed and interference on SR

From Figure 1 the SR is found to have an increasing trend with the increase of spindle speed. SR is decreasing nonlinearly with the interference.

From figure 2 we know that how variables, Tool Passes and Tool Feed are related to the Surface Roughness while the other factors, Speed and Interference are held constant at mean level. SR is increases with speed and decreases with passes.

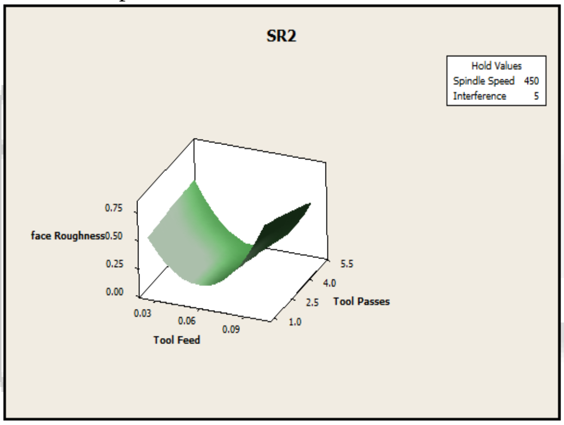

Fig. 2: Effect of feed and passes on SR

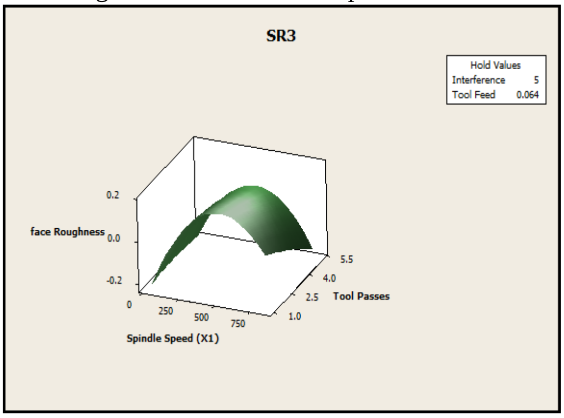

Fig. 3: Effect of speed and passes on SR

From figure 3 we know that how variables, Tool Passes and Speed are related to the Surface Roughness while the other factors, Feed and Interference are held constant at mean level. SR is decreases with increases of speed and feed.

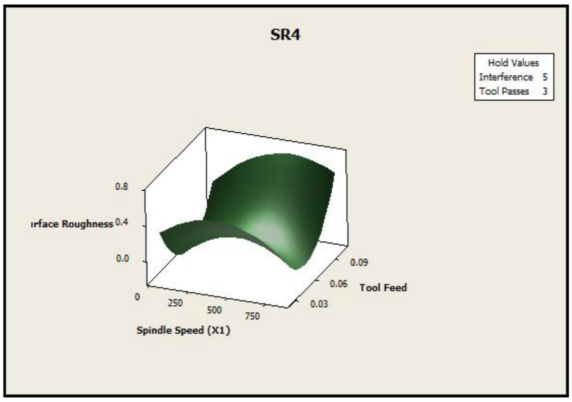

Figure 4: Effect of speed and feed on SR

From figure 4 we know that how variables, Tool Feed and Speed are related to the Surface Roughness while the other factors, Interference and Tool passes are held constant at mean level. SR is decreases with speed and increases with feed.

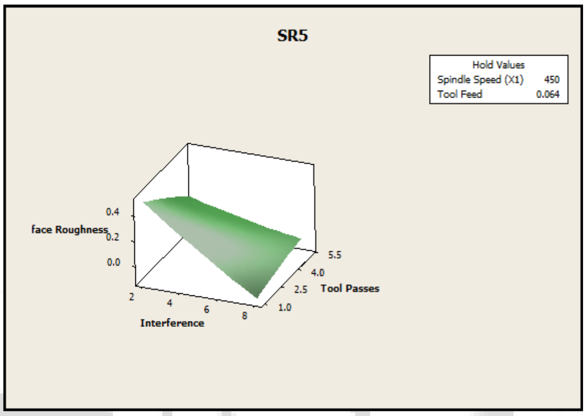

Fig. 5: Effect of interference and passes on SR

From figure 5 we know that how variables, Interference and Tool Passes are related to the Surface Roughness while the other factors, Feed and Speed are held constant at mean level. SR is decreases with interference and increases with tool passes.

From figure 6 we know that how variables, Interference and Tool Feed are related to the Surface Roughness while the other factors, Spindle Speed and Tool passes are held constant at mean level. SR is decreases with increases of interference and increases with increases of tool feed. At initial with tool feed surface roughness decreases.

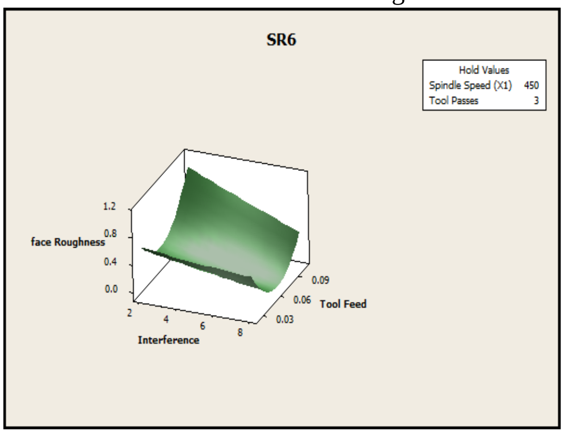

Fig. 6: Effect of interference and feed on SR

V. CONCLUSION

- It was identified the minimum surface roughness value 0.080 µm was obtained at values of 450 rpm, 0.064 mm/rev, 2 mm, 4 for Cutting Speed, Feed Rate, Interference and Number of Tool Passes respectively.
- From Main Effect Plots it was identified that surface roughness decreases with Burnishing Speed up to 250 RPM, Feed Rate up to 0.084 mm/rev, Interference 5 mm, and Number of Tool Passes 4, and then it starts to increase.
- From Main Effect Plots it was identified that surface roughness maximum with Burnishing Speed up to 850 RPM, Feed Rate up to 0.104 mm/rev, Interference 2 mm, and Number of Tool Passes 2.
- Mathematical Model for Surface Roughness is,
  $Ra = 0.865 + 0.001(X1) - 0.007(X2) - 30.899(X3) + 0.108(X4) - 0.001(X2^2) + 309.521(X3^2) - 0.014(X4^2) + 0.010(X1X3) - 1.544(X2X3) + 0.029(X2X4) - 1.743(X3X4)$

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