Surface Roughness Prediction for Roller Burnishing of Al Alloy 6061 Using Response Surface Method

Kiran A Patel, Dr. Pragnesh K Brahmbhatt

Abstract— In recent years, industries have aggressively been deploying the method to improve the quality of surface roughness due to its effect on fabricated components. Burnishing is one of the best chip less finishing process in which a material will undergo the plastic deformation by pressing the burnishing tool against the work piece. It is possible to achieve a surface roughness up to 0.1µm by recent developments. The burnishing process provides a good surface roughness in addition of mechanical characteristic improvement by uniform stress distribution into the surface layer. This paper will show the effect of various process parameters on the surface roughness for aluminium alloy 6061. Design of experiment techniques, i.e. response surface methodology, has been applied to accomplish the objective of the experimental study. The generated mathematical model can predict the value of surface roughness for all conditional value of variables and also check the accuracy of machine as well.

Index Terms— Al alloy, ANOVA, Burnishing, CCRD, Design of experiment, Mathematical model, RSM.

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1 INTRODUCTION

Burnishing, which is ordinarily used as a finishing process, the aspect of the generated surfaces is mainly evaluated by its roughness. Previous investigations have shown wide correlations between this characteristic and the other parameters characterizing the surface integrity, including fatigue life, strength and corrosion resistance [1], [3]. Burnishing process is carried out simply by applying a highly polished and hardened ball or roller subjected to external forces onto the surface of flat or cylindrical work piece as shown Figure 1.The ball or roller is fed in an appropriate direction according to the work piece surface [2], [4].

Aluminum alloy has been burnished using different burnishing parameters like speed, feed, force and number of passes with burnishing tool. Using the experimental results a model has been used to achieve the best parameters for the burnishing process to achieve better surface roughness and hardness. The model predictions suggest that the most suitable values for surface roughness are the pressure force of 200 N, and a feed of 0.1 mm/rev with two tool passes which are highly consistent with the experiments [5]. Surface roughness is a common indicator of the quality characteristics of machining processes. The machining process is more complex, and therefore, it is very hard to determine the effects of process parameters on surface quality in all turning operations. Mathematical models have been created for surface roughness, namely Ra, through response surface methodology (RSM). The results indicate that the most effective parameter is feed-rate on the surface roughness [6], [7].Response surface methodology (RSM) and central composite rotatable design (CCRD) is greatly felicitous for modeling and optimization of the influence of some operating variables on the performance of a manufacturing process. RSM and CCRD could efficiently be applied for obtaining the maximum amount of information in a short period of time and with the fewest number of experiments [8], [9], [10].

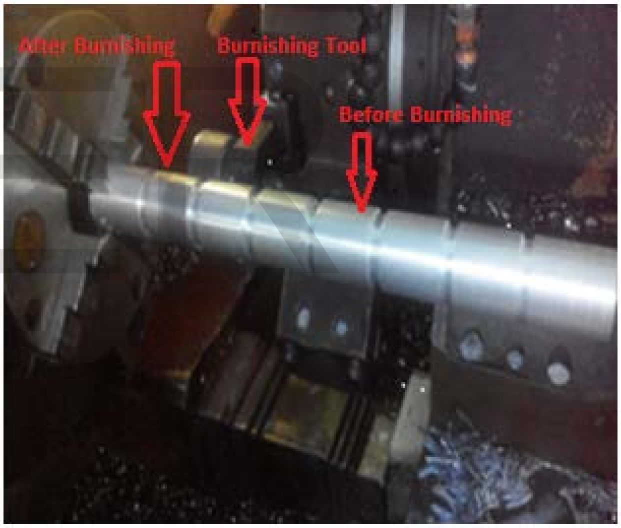

Fig.1 A part before and after burnishing

1.1 Objectives

In this unit, an effect of roller burnishing process parameter is evaluated on surface roughness for Al alloy 6061 work material. The objective of this exploration can be categorized into following different modules.

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- ✓ To investigate the working range and levels of Roller burnishing process parameters
- ✓ To determine the experimental results of the effects of various process parameters on the performance measure in Roller burnishing process
- ✓ To make a mathematical model of the performance measures using response surface methodology (RSM)

2 EXPERIMENTATION

2.1 Machine setup

A burnishing process test setup was developed to carry out the experimentation on Al alloy 6061. CNC Spin Flat Lathe with the specification as shown in Table 1, used to fulfill the requirement of objectives. To fulfill the objective, a Carbide roller burnishing tool having 40 mm diameter is used on Al alloy 6061 material.

TABLE 1

MACHINE SPECIFICATION

Sr.No.	Parameter	Specification
1	Swing Over Bed	700 mm
2	Std. Turning Dia.	400 mm
3	Max. Turning Dia.	480 mm
4	Rapid Feed	24 m/min.
5	Spindle Bore	50 mm
6	Spindle Speed Range	50-2200 rpm
7	No. Of Station	8
8	Accuracy	0.007 mm
9	Bar Capacity Through Spindle	65 mm
10	Tool Size (Cross-Section)	32 X 32 mm
11	Thrust Force	1000 kgf (Adjustable)
12	Spindle Motor	AC Servo

2.2 Process parameter and level selection

To investigate the effect of process parameters on the performance of output parameter which is surface roughness, the experiment was selected and conducted. In the following section the experimental results are discussed subsequently.

TABLE 2

PROCESS PARAMETERS AND THEIR LEVELS

Coded Factors	Factors	Levels				
		(-2)	(-1)	(0)	(+1)	(+2)
A1	Spindle Speed (m/min)	50	250	450	650	850
A2	Interference (mm)	2	3.5	5	6.5	8
A3	Feed (mm/rev)	0.024	0.044	0.064	0.084	0.104
A4	No. of Tool Passes	1	2	3	4	5

The selected process variables were varied up to five levels and central composite rotatable design was adopted to design the experiments [11]. Response Surface Methodology was used to develop a second order regression equation relating response characteristics and process variables [12]. The process variables and their ranges are given in Table 2.

3 EXPERIMENTAL RESULTS

The RBP experiments were conducted, with the process parameter levels set as given in Table 1, to study the effect of process parameters over the output parameter. Experiments were conducted according to the test conditions specified by the second order central composite design as shown in Table 3. Experimental results are given in the same table for surface roughness. Altogether 31 experiments were conducted using response surface methodology.

TABLE 3

CODED VALUES OF THE VARIABLES WITH THE RESPONSE

Sr.No	Coded				Ra
	A1	A2	A3	A4	(µm)
1	0	0	0	0	0.122
2	+2	-2	-2	+2	0.277
3	-2	-2	-2	-2	0.402
4	+2	+2	+2	+2	0.150
5	+2	+2	-2	-2	0.104
6	-2	-2	+2	-2	0.774
7	0	0	0	0	0.126
8	0	0	0	+2	0.100
9	-2	-2	+2	-1	0.639
10	0	0	0	0	0.136
11	-2	+2	+2	+2	0.134
12	-1	0	0	0	0.096
13	+2	-2	+2	-2	0.992
14	0	0	0	0	0.099
15	0	0	0	0	0.125
16	+2	+2	+2	-2	0.227
17	+2	-2	-2	-2	0.379
18	+1	0	0	0	0.115
19	-2	-2	-2	+2	0.335
20	+2	+2	-2	+2	0.350
21	0	0	0	0	0.117
22	-2	+2	-2	-2	0.214
23	0	-2	0	+1	0.312
24	+2	-2	+2	+2	0.540
25	0	0	0	0	0.095
26	0	0	0	0	0.120
27	0	0	0	+1	0.115
28	0	+2	-2	0	0.158
29	-2	0	+2	-2	0.311
30	0	+2	+1	0	0.107
31	-2	+2	-2	+2	0.450

A1, A2, A3, A4 represents coded values of various factors

3.1 Analysis and Discussion of Results

The experiments were designed and conducted by employing response surface methodology (RSM). The selection of appropriate model and the development of response surface models have been carried out by using statistical software, "Minitab 16". The regression equations for the selected model were obtained for the response characteristic which is surface roughness [13]. This regression equation was developed using the experimental data (Table 3) and were plotted to investigate the effect of process variables on response characteristic. The analysis of variance (ANOVA) was performed to statistically analyze the results.

3.2 Effect of Process Variables on Surface Roughness

The regression coefficients of the second order equation (Equation 1) are obtained by using the experimental data as shown in Table 4. The regression equation for the surface roughness as a function of four input process variables was developed using experimental data and is given below. The coefficients (insignificant identified from ANOVA) of some terms of the quadratic equation have been omitted [14].

Surface roughness = $0.110840 + 0.006024 * A1 - 0.070690 * A2 + 0.026662 * A3 - 0.019587 * A4 + 0.015689 * A1^2 + 0.035242 * A2^2 + 0.010256 * A4^2 - 0.006538 * A1 * A2 + 0.012052 * A1 * A3 - 0.026860 * A2 * A3 + 0.021932 * A2 * A4 - 0.019263 * A3 * A4$ (1)

The above response surface is plotted to study the effect of process variables on the surface roughness and is shown in Figures (2, 3, 4, 5, 6, and 7). It is observed from Figures that the surface roughness have an increasing trend with the increase of Feed and at the same time it decreases with the increase of No. of tool pass.

TABLE 4
ESTIMATED REGRESSION COEFFICIENTS FOR SURFACE ROUGHNESS

Term	Coef	SE Coef	T	P-value
CONSTANT	0.110840	0.006493	17.071	0.001
A1	0.006024	0.002859	2.107	0.049
A2	-0.070690	0.002943	-24.02	0.000
A3	0.026662	0.002823	9.445	0.000
A4	-0.019587	0.003112	-6.294	0.000
A1*A1	0.015689	0.00686	2.287	0.036
A2*A2	0.035242	0.004045	8.712	0.000
A3*A3	0.002324	0.007214	0.322	0.752
A4*A4	0.010256	0.004597	2.231	0.040
A1*A2	-0.006538	0.001567	-4.173	0.001
A1*A3	0.012052	0.001454	8.291	0.000
A1*A4	-0.002549	0.001589	-1.604	0.128
A2*A3	-0.026860	0.001515	-17.73	0.000
A2*A4	0.021932	0.001543	14.215	0.000
A3*A4	-0.019263	0.001589	-12.12	0.000
R-Sq = 99.46% R-Sq(pred)= 95.01% R-Sq(adj)= 98.99%				

TABLE 5
ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS

Source	DF	SS	Mean square	F-value
Model	14	1.4508	0.103630	212.07
Linear	4	0.5382	0.101113	206.92
Square	4	0.5060	0.096197	196.86
Interaction	6	0.4065	0.067765	138.68
Residual Error	16	0.0078	0.000489	
Lack-of-Fit	9	0.0064	0.000719	3.74
Pure Error	7	0.0013	0.000192	
Total	30	1.4586		

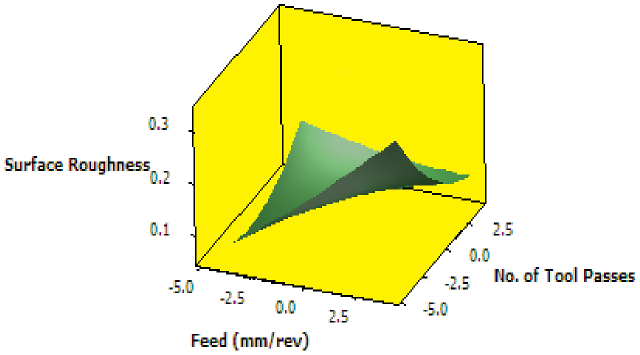


Fig.2 Combined Effect of feed and No. of tool pass on Surface Roughness

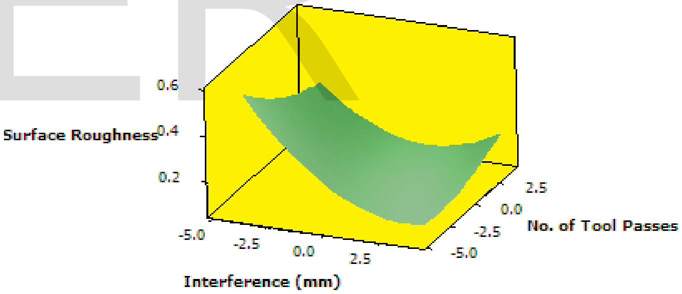


Fig.3 Combined Effect of interference and No. of tool pass on Surface Roughness

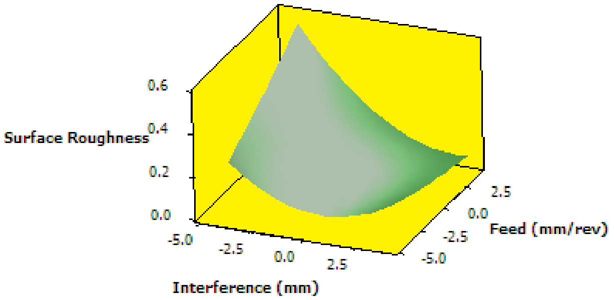


Fig.4 Combined Effect of interference and feed on Surface Roughness

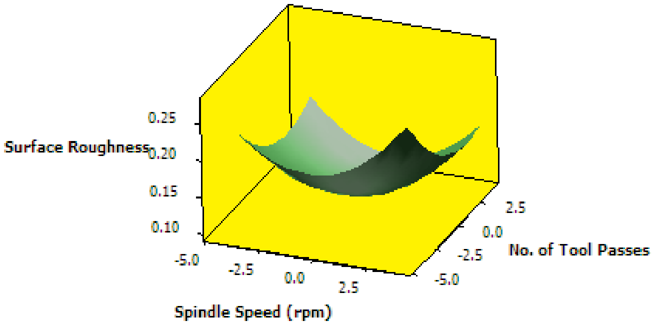
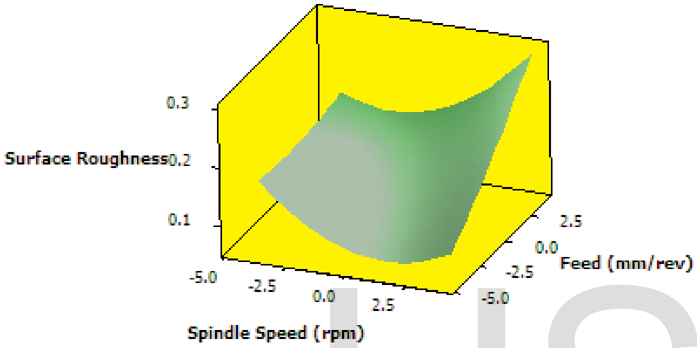


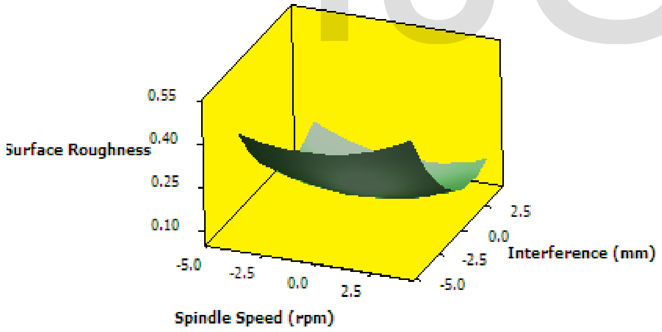
Fig.5 Combined Effect of spindle speed and No. of tool pass on Surface Roughness

Fig.6 Combined Effect of spindle speed and feed on Surface



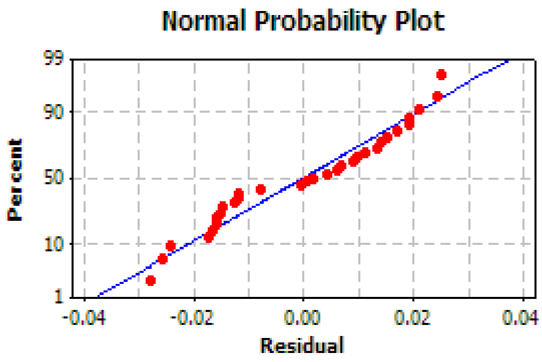
Roughness

Fig.7 Combined Effect of spindle speed and interference on



Surface Roughness

Fig.8 Predicted vs. Actual for Surface Roughness



The "Lack of Fit F-value" of 3.74 implies the Lack of Fit is not significant relative to the pure error.Non-significant lack of fit is good for the model.

Values of "P" less than 0.0500 indicates model terms are significant.HereA1,A2,A3,A4,A1*A1,A2*A2,A4*A4,A1*A2,A1*A3,A2*A3,A2*A4,A3*A4 are significant model terms. The "Pred R-Squared" of 0.9501 is in reasonable agreement with the "Adj R-Squared" of 0.9899 [18]."

4 CONCLUSIONS

The present work aimed to study the effect of various process parameters on surface roughness for Roller burnishing process. The effects of the process parameters viz. Spindle speed, Interference, Feed and No. of tool pass, on Surface roughness were studied.

Response surface methodology (RSM) was applied for developing the mathematical models in the form of multiple regression equations correlating the dependent parameters with the independent parameters (Spindle speed, Interference, Feed and No. of tool pass) in RBP of Al alloy 6061. Using the model equations, the response surfaces have been plotted to study the effects of process parameters on the performance characteristics.

From the experimental data of RSM, empirical models were developed and the confirmation experiments were performed, which were found within 95% confidence interval. There is a better visualization of the responses due to 3-D graphs in RSM. Moreover, it is possible to obtain regression equations correlating the dependent response with the independent variables through RSM which is not possible through some other technique.

Mathematical regression equation obtained for Surface roughness is:

Surface roughness $= 0.110840 + 0.006024 * A1 - 0.070690 * A2 + 0.026662 * A3 - 0.019587 * A4 + 0.015689 * A1^2 + 0.035242 * A2^2 + 0.010256 * A4^2 - 0.006538 * A1 * A2 + 0.012052 * A1 * A3 - 0.026860 * A2 * A3 + 0.021932 * A2 * A4 - 0.019263 * A3 * A4$

Apart of if, a derived mathematical equation is very useful to check the accuracy or durability of the machine.

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