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Determination of Surface Roughness by Ball Burnishing Process Using Factorial Techniques

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***Abstract*—**Burnishing is a method of finishing and hardening machined parts by plastic deformation of the surface. Experimental work based on central composite second order rotatable design has been carried out on a lathe machine to establish the effects of ball burnishing parameters on the surface roughness of brass material. Analysis of the results by the analysis of variance technique and the F-test show that the parameters considered, have significant effects on the surface roughness.

***Keywords*—** Ball burnishing, Response surface Methodology.

I. Introduction

BURNISHING is one of the methods of finish machining, yielding significant improvements in the service properties of machined parts. It provides efficient machining of machined parts made of most of the engineering metallic materials, including the high-strength alloys of practically any hardness. The method is used in machine production, especially for finishing of precision and critical parts. The plastic deformation of the processed surface is accomplished by the pressure of a sliding tool (burnisher) with a working surface. During burnishing, the surface roughness caused by the previous machining is flattened and leveled, and the surface acquires a mirror like finish. The surface layer strength increases and compressive residual stresses are generated. After burnishing, the surface becomes smooth and clear of metallic splinters or abrasive grains that usually occur during machining. Combination of properties of the burnished surface determines its high working specifications including wear resistance, fatigue resistance etc.

Traditional finishing processes such as grinding, lapping, polishing and honing are commonly employed to improve the surface finish. A smooth surface alone is insufficient; however, to protect the component against the wear and tear of regular usage, surface enhancement is to be carried out. Since all machined surfaces consist of a series of peaks and valleys of regular height and spacing, the plastic deformation created by ball burnishing (Fig. 1) is a displacement of the material in the peaks which cold flows under pressure into the valleys. This process improves surface finish, hardness, and wear and corrosion resistance.

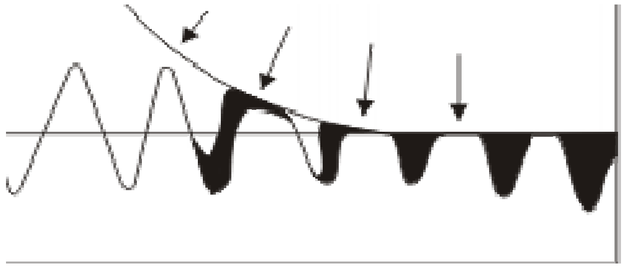

Fig. 1 Burnishing Process

When the burnishing pressure exceeds the yield strength of the component, localized plastic deformation at the surface will take place. This action leads to the spreading out of the valleys; causing an improvement of surface roughness. The grain structure is condensed, producing a hard surface with superior load-carrying and wear-resistance characteristics.

A through review has been made of previous work concerning the effects of burnishing on the surface roughness on the surface characteristics of a material [5]. The general objective of this work is to determine, in a comprehensive manner, the effects of the burnishing parameters, namely speed, force, ball diameter, no of tool passes and feed on the surface finish while burnishing brass material. The study is made through mathematical model and it is postulated by F test.

The ball burnishing process has the following advantages over other machining processes:

- A combination of high surface finish and accuracy.
- Increase surface hardness and fatigue life. The greater depth of work-hardening and beneficial compressive stresses on the surface will improve fatigue strength.
- Improved service properties.
- Simplicity and stability of the process characteristics, thus making it suitable for automation.
- Sometimes, burnishing is the only method by which the technical requirements can be satisfied.

Work on burnishing process have been investigated by various researchers on lathes [2]-[6] and on milling machine for wide range of materials like, mild steel [1]-[6] and non ferrous alloys.

II. Experimental Work

Burnishing can be performed on standard universal and special machine tools—turning, boring, planning, milling, etc.—with normal and high precision. Higher precision is required for burnishing with rigid fixing of a burnisher to the

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machine. Burnishing on lathes is most common. At this point, particular attention paid to the value of the spindle's radial concentricity (not more than 0.01-0.02mm run out), the rigidity of the support, and vibration resistance. A number of feeds, beginning with about 0.06mm/rev, provided on a machine tool.

The experimental work is conducted on a simple Lathe machine. The main advantage of using such a machine is its flexibility. It enables the machining and burnishing operations to be accomplished easily in a sequential order. Any change in the burnishing conditions (such as speed, force, ball diameters, number of tool passes and feed) can be easily adjusted.

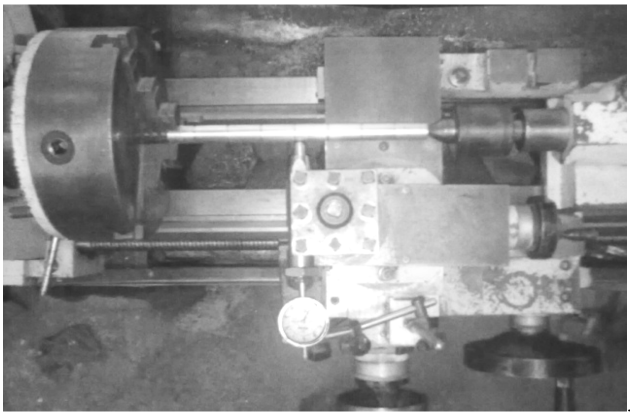

Fig. 2 Experimental setup for burnishing process on Lathe machine

The burnishing tool assembly consists basically of a burnishing ball that is held rigidly in the ball holder by means of an adapter and the work piece. The tool was designed to permit the use of balls with different diameters by changing the adapter. The assembly drawing of the tool is shown in Fig. 3. The ball is located inside an interchangeable adapter. The ball is free to rotate with the movement of the work piece due to the frictional engagement between their surfaces. When the ball is pressed against the surface of the metallic specimen, the adapter compresses a pre-calibrated spring (Fig. 4). This spring is used to reduce the possible sticking effect of the ball and also to measure the applied burnishing force. The balls used in present studies are High chromium high carbon having a hardness of 60HRC and Ra of 0.12µm.The shank of the burnishing tool is designed in a simple manner, so that it can be mounted easily onto the tool holder of a turning machine.

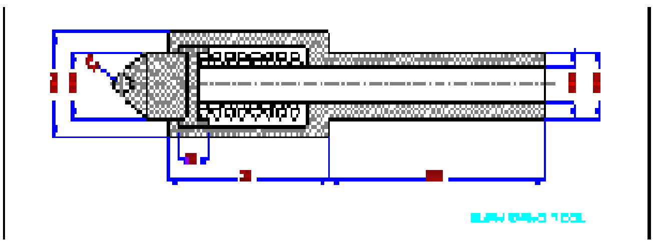

Fig. 3 Burnishing tool

CALIBRATION OF SPRING: Technical Specifications

1. Inside Diameter: 15mm
2. Outside Diameter: 21mm
3. Wire Diameter: 3mm
4. Free length Of Spring: 104mm
5. Stiffness Of Spring: 12.95N/mm

TABLE I
CALIBRATION OF SPRING

Force(N)	50	70	100	150	200
Mass(Kg)	5.10	7.13	10.20	15.13	20.40
Deflection (mm)	4	6	8.5	12.6	16.9

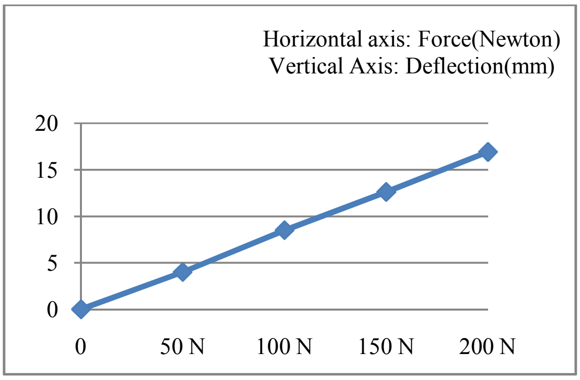

Fig. 4 Force Verses Deflection Graph

III. PLANNING OF THE EXPERIMENT

The experimental program was planned in accordance with the principles of experimental design suggested by Cochran et al using RSM with central composite design was used [7]. Response surface methodology is a collection of mathematical and statistical techniques useful for analyzing problems in which several independent variables (parameters) influence a dependent variable (Surface roughness), and the goal is to optimize this response.

The experimental program was planned using factorial design at ±2 levels. This involves 33 experimental observations. The levels for the variables are given in Table I. & the scheme of experimentation adopted in the present study is given in Table II.

TABLE II
LEVEL IN CODED FORM

Variables Designation	Description	Levels in coded form				
		2	1	0	-1	-2
X_1	Burnishing Speed, rpm	540	425	330	260	200
X_2	Ball diameter, mm	10	9	8	7	6
X_3	Burnishing force, N	200	150	100	70	50
X_4	No. Of Tool Passes	5	4	3	2	1
X5	Feed, mm per revolution	0.20	0.16	0.13	0.09	0.06

TABLE III
CODED DESIGN MATRIX

EXPT. NO.	X1	X2	X3	X4	X5	R_a, µm
1	-1	-1	-1	-1	1	0.39
2	1	-1	-1	-1	-1	0.57
3	-1	1	-1	-1	-1	0.35
4	1	1	-1	-1	1	0.37
5	-1	-1	1	-1	-1	0.51
6	1	-1	1	-1	1	0.49
7	-1	1	1	-1	1	0.41
8	1	1	1	-1	-1	0.47
9	-1	-1	-1	1	-1	0.61
10	1	-1	-1	1	1	0.39
11	-1	1	-1	1	1	0.22
12	1	1	-1	1	-1	0.43
13	-1	-1	1	1	1	0.49
14	1	-1	1	1	-1	1.00
15	-1	1	1	1	-1	0.21
16	1	1	1	1	1	0.34
17	0	0	0	0	0	0.40
18	0	0	0	0	0	0.62
19	0	0	0	0	0	0.43
20	0	0	0	0	0	0.89
21	0	0	0	0	0	0.26
22	0	0	0	0	0	0.29
23	-2	0	0	0	0	0.26
24	2	0	0	0	0	0.23
25	0	-2	0	0	0	0.35
26	0	2	0	0	0	0.25
27	0	0	-2	0	0	0.24
28	0	0	2	0	0	0.41
29	0	0	0	-2	0	0.82
30	0	0	0	2	0	0.35
31	0	0	0	0	-2	0.45
32	0	0	0	0	2	0.32
33	0	0	0	0	0	0.42

IV. MATHEMATICAL MODELING

A polynomial response surface of second order can be represented by

$$Y_u = b_0+\sum_{i=1}^{K} b_i x_i+\sum_{i=1}^{K} b_{ii} x^2_i +\sum_{i=<j} b_{ij} x_i x_j \quad (1)$$

where Y_u is the response and the x_i (i =1,2, k) are coded levels of k quantitative variables or factors. The Regression coefficients b_0, b1 etc in (1) were calculated by using Mat Lab by

$$b=(x^{'}x)^{-1}xy \quad (2)$$

where x is the matrix of independent variables in coded from and y is the column matrix of the observed response.

The adequacy of the model was checked from the Analysis of Variance and postulated by use of the F-test.

The second order mathematical model, which correlates the five process parameters to the response, Surface roughness (Ra µm) is of the following form as shown in (3) by using Minitab Software.

The regression equation is

Surface Roughness = 0.452 + 0.0356 x1 - 0.0790 x2 + 0.0321 x3 - 0.0443 x4 - 0.0527 x5- 0.0362 x11 - 0.0225 x22 - 0.0162 x33 + 0.0488 x44 - 0.0012 x55- 0.0049 x12 + 0.0511 x13 + 0.0343 x14 - 0.0414 x15 - 0.0517 x23- 0.0681 x24 + 0.0476 x25 + 0.0090 x34 + 0.0239 x35 - 0.0233 x45 (3)

V. T- TESTING SIGNIFICANCE OF REGRESSION

Using the observed values of each response, a system of simultaneous equations was obtained. This system of equations was solved to get the regression coefficients for each model, the less-significant coefficients were eliminated from further analysis by using Student's t test. It should be noted that if the computed t value is larger than the standard critical value, the parameter is significant, where as if it is smaller it means that the parameter is non-significant and it must be deleted from the regression equation.

It is calculated by using following steps:

1. Calculating variance-covariance matrix $s^2\{b\}$ by using (4)

$$s^2\{b\}= MSE(x'x)^{-1} \quad (4)$$

From $s^2\{b\}$, one can obtain $s^2\{b_1\}$, or whatever other variance is needed, or any needed covariance's.

2. Using the test static's:

$$t^* = b1/s\{b_1\}$$

and the decision rule: if $|t^*| \le t(1-\alpha/2;n-p)$, Conclude H_0 , Otherwise conclude H_a. For α =0.10, n-p=33-6=27, The standard critical value of the t test: $t_{0.10,27}$ = 1.314

TABLE IV
STUDENT'S T TEST

Coefficient	Coef	SE Coef	T	P
bo	0.45218	0.07353	6.15	0.000
b1	0.03565	0.04115	0.87	0.403
b2	-0.07898	0.04115	-1.92	0.079
b3	0.03213	0.04146	0.77	0.453
b4	-0.04426	0.04141	-1.07	0.306
b5	-0.05269	0.04115	-1.28	0.225
b11	-0.03620	0.03615	-1.00	0.336
b22	-0.02245	0.03615	-0.62	0.546
b33	-0.01620	0.03615	-0.45	0.662
b44	0.04880	0.03615	1.35	0.202
b55	-0.00120	0.03615	-0.03	0.974
b12	-0.00486	0.05083	-0.10	0.925
b13	0.05111	0.05647	0.91	0.383
b14	0.03431	0.05136	0.67	0.517
b15	-0.04139	0.05083	-0.81	0.431
b23	-0.05168	0.05644	-0.92	0.378
b24	-0.06806	0.05136	-1.33	0.210
b25	0.04764	0.05083	0.94	0.367
b34	0.00903	0.05079	0.18	0.862
b35	0.02389	0.05126	0.47	0.650
b45	-0.02332	0.05458	-0.43	0.677

VI. Results

Using the observations in Table III, the final form of the model is as follows:

Surface finish (Ra, µm):

$$Ra = 0.452 - 0.0790\,X2 - 0.0527\,X5 + 0.0488\,X44 - 0.0681\,X24$$

This mathematical model is used to study the influence of the process parameters and their interactions on the surface finish produced by the ball burnishing process.

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	20	0.64699	0.03235	0.82	0.663
Residual Error	12	0.47248	0.03937		
Total	32	1.11947			

VII. Conclusion

1. The analysis shows that a Second order Rot table design can be used to predict the performance characteristics of a burnished surface. The mathematical model developed can be used to correlate the burnishing parameters and their interactions with the response parameters for brass, were proposed which can easily be used in selecting the optimum process parameters for generating the desired controlled surface characteristics.
2. Optimum condition of a Surface finish is obtained at speed of 425rpm, ball diameter of 7mm and normal force of 70N and no. of tool pass was 4.
3. As per analysis of variance shown in Table III, the obtained fisher value is greater than the standard F value of 2.68 {from table for degree freedom (5, 21)}. Hence the model is validated with 95% significance level.

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