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Experimental Investigation into Ball Burnishing Process of Brass Using Taguchi Approach

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Abstract— Burnishing is a chipless finishing process, which employs a rolling tool, pressed against the work piece, in order to achieve plastic deformation of the surface layer. The burnishing process increases the surface hardness of the work piece which in turn improves wear resistance, improves tensile strength, increases corrosion resistance, maintains dimensional stability and improves the fatigue strength by inducing residual compressive stresses in the surface of the work piece. In the experimental study, presented in this paper, ball burnishing of brass was done using standard L-18 array Taguchi's design of experiments. The aim of work was to find optimum burnishing parameters for enhancing the surface quality and surface hardness of the workpiece. In the experimental analysis, it is found that all the process parameters significantly affect the quality. The results revealed that the use of optimum burnishing parameters resulted in improvements in the surface finish and increase in the surface hardness.

Index Terms— Ball burnishing, Taguchi method, Surface finishing, Innova analysis, Main effect plot, SN ratio, Surface hardness.

1 Introduction

SURFACE quality is of great importance in the performance of mechanical components. Despite the best practices in the manufacturing processes used, surface roughness of different asperities usually exists in almost all surfaces of mechanical parts. As a result, more attention is paid to the finishing process during manufacturing. Methods that are commonly used to improve surface finish and produce low values of surface roughness include grinding, lapping, honing and polishing. Another important tool to improve surface finish is burnishing.

In this method, a large contact pressure is exerted on the surface of the workpiece by a smooth roller (roller burnishing) or a ball (ball burnishing) to cause plastic deformation of surface irregularities. The high burnishing pressure, exceeding the yield strength, causes roughness peaks to flow towards the valleys. This smears all the texture of the rough surface, resulting in smoother surfaces. This method of cold-working surface treatment is different from other surface treatments, such as shot peening and sand blasting. The burnishing process produces a good surface finish, increases dimensional and shape accuracy, enhances surface hardness and also induces residual compressive stresses at the metallic surface layers. Figure 1 shows the mechanism of burnishing process.

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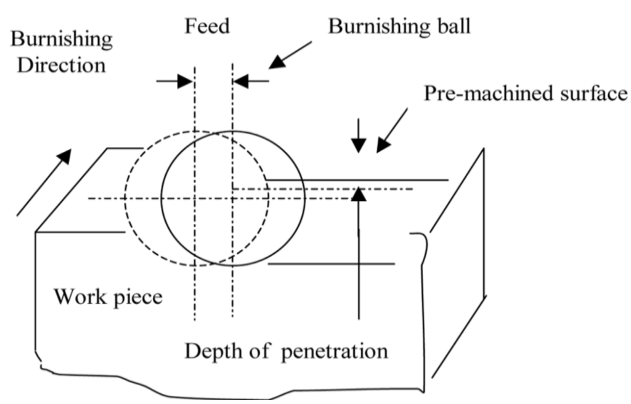

Fig 1. Mechanism of burnishing process

2 Previous Work

In burnishing process, a hard and highly polished ball or roller is made to press against the surface of a metallic work piece with high pressure. As a result of high pressure, the peaks of the metallic surface get plastically deformed to fill the valleys. The applied burnishing pressure must exceed the yield strength of the workpiece material [1]. The material is left with a residual stress which is compressive in nature due to the plastic deformation. As a result, the surface hardness, wear resistance, fatigue resistance, yield strength, tensile strength and corrosion resistance are improved. These results on the changes in surface characteristics due to burnishing, has been reported by many authors [2, 3, 4 and 5]. Several researchers have investigated the effect of burnishing on improving mechanical properties, and have concluded that proper design of burnishing process can lead to increased hardness [6], enhanced quality of surface finish, and increased maximum residual stress in compression [7]. The burnishing process also helps to prevent corrosion and stress corrosion cracking, and enhance the wear resistance and fatigue life of the workpiece [8]. Burnishing also produces a good surface finish and also induces residual compressive stresses at the metallic surface layers [9]. Burnishing leads to changes in the microstructure of the burnished surface. Also, burnishing is economically beneficial, because it is a simple and less costly process, requiring less time. Semi skilled operators can obtain a high-quality surface finish [10].

In general, the two most frequently cited parameters affecting surface finish are the burnishing force and the feed rate. There are several controlling parameters that can have an effect on the workpiece surface properties [11]. These parameters include: burnishing speed, feed rate, force (or pressure), number of burnishing passes, workpiece material, ball material, ball size, and lubricant. The experimental investigation, presented in this paper, examined the use of a newly developed ball burnishing tool to give enhanced surface properties for a brass bar. In order to explore the optimum combination of burnishing parameters, several experiments were designed and performed on a machining centre based on Taguchi's L-18 design of experiments. The effects of burnishing parameters i.e., burnishing speed, feed rate, depth of penetration and number of passes, on the surface roughness and surface hardness were investigated. The output parameters are presented by the mean surface roughness (Ra) and Rockwell hardness number (HRB), respectively.

3 Experimental Planning

Taguchi method uses special design of orthogonal array to study the entire parameters space using only a small number of experiments. In selecting an appropriate orthogonal array, the prerequisites are (i) selection of process parameters and interactions to be evaluated (ii) selection of number of levels for the selected parameters, and (iii) evaluation of total degree of freedom based upon number of parameters and their levels. Experimental parameters and their levels selected for the study are tabulated in Table. 1. All other parameters were kept constant.

TABLE 1
Deflections at Various Loads

Factor Symbol	Parameter	Level 1	Level 2	Level 3
A	No. of passes	1	2	-
B	Burnishing speed (rpm)	683	1025	1535
C	Burnishing feed (mm/rev.)	0.067	0.083	0.100
D	Depth of penetration (mm)	0.01	0.04	0.08

It was decided to study the two factor interaction effects. For this purpose the selected interactions were: (i) between burnishing speed and burnishing feed (B×C) and (ii) between burnishing speed and depth of penetration (B×D). All other interactions were neglected. There were 7 degree of freedom owing to one two-level parameter and three three-level parameters and the degree of freedom of interactions selected were 8. The total degree of freedom was 7+8 = 15. A mixed orthogonal array L18 (21 37) was used for experimentation as it has degree of freedom 17 which is more than degree of freedom of selected machining parameters and interactions (7+8=15).

The loss function L_{ij} of the lower-the-better performance characteristic can be expressed as

$$L_{ij} = \frac{1}{n}\sum_{k-1}^{n}\frac{1}{y_{ijk}^{2}}$$

where L_{ij} is the loss function of the i^{th} performance characteristic in the j^{th} experiment, n the number of tests, and y_{ijk} is the experimental value of the i^{th} performance characteristic in the j^{th} experiment at the k^{th} test.

The loss function of the higher-the-better performance characteristic can be expressed as

$$L_{ij} = \frac{1}{n}\sum_{k-1}^{n} y_{ijk}^{2}$$

The loss function is further transformed into a signal to noise (S/N) ratio. In the Taguchi method, the S/N ratio is used to determine the deviation of the performance characteristic from the desired value. The S/N ratio n_{ij} for the i^{th} performance characteristic in the j^{th} experiment can be expressed as, $n_{ij} = -10\log(L_{ij})$ respectively.

4 Experimental Procedures And Parameters

The experiments were carried out on a standard Lathe machine; model LAXSHMI - 2009 of Lakshmi trade mark. The workpiece material selected for experimentation was brass having hardness 61 HRB and standard burnishing tool with a ball of high carbon high chromium steel having 80 HRC, was used.

The surface roughness (Ra value in microns) was measured on Telisurf roughness tester (model SE 1200, make Kosaka Laboratory Ltd., Japan). Experiments were performed as per L18 (21×37) Taguchi design and average value of each output parameter were statistically analyzed using Minitab 14 software.

TABLE 2
layout Using Mixed Orthogonal Array L18 (21×37)

S. No.	No. of Passes (A)	Burnishing Speed (rpm) (B)	Burnishing Feed (mm/Rev) (C)	Depth of Penetration (mm) (D)
1	1	683	0.067	0.01
2	1	683	0.083	0.04
3	1	683	0.100	0.08
4	1	1025	0.067	0.01
5	1	1025	0.083	0.04

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6	1	1025	0.100	0.08
7	1	1535	0.067	0.04
8	1	1535	0.083	0.08
9	1	1535	0.100	0.01
10	2	683	0.067	0.08
11	2	683	0.083	0.01
12	2	683	0.100	0.04
13	2	1025	0.067	0.04
14	2	1025	0.083	0.08
15	2	1025	0.100	0.01
16	2	1535	0.067	0.08
17	2	1535	0.083	0.01
18	2	1535	0.100	0.04

5 Results And Discussion

These experiments were aimed to study the effect of burnishing parameters on surface roughness and surface hardness. The results will optimize the burnishing input parameter which has most significant effect on the output parameters which is obtained as a result of Taguchi analysis is discussed below.

5.1 Analysis of Surface Roughness (SR)

The average values of S/N ratios for surface roughness (SR) at different levels are plotted in Figure 2, keeping the objective as "smaller is better".

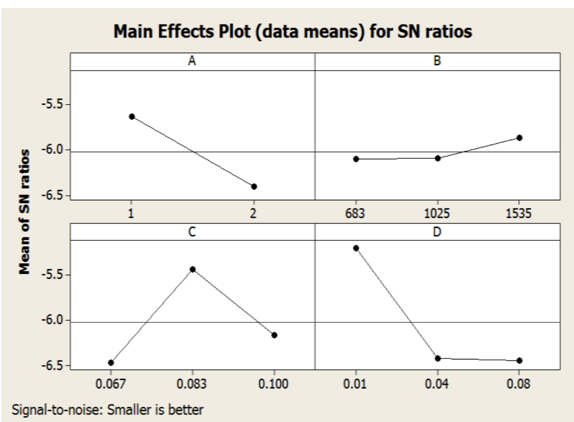

Fig. 2. Mean effect plot for S/N ratios for surface roughness (SR)

In order to study the significance of the parameters in affecting the quality characteristic of interest i.e. SR ANOVA was performed. The S/N ANOVA for SR is given in Table 3. The result of ANOVA indicates that burnishing speed, burnishing feed and depth of penetration affect the multiple performance characteristics.

Table 3: Analysis of variance table for average value of surface roughness (SR)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	1	2.681	2.6815	2.6815	4.38	0.171
B	2	0.214	0.2147	0.1074	0.18	0.851
C	2	3.349	1.6895	0.8448	1.38	0.420
D	2	6.080	4.8188	2.4094	3.94	0.203
B×C	4	1.862	1.3214	1.3214	0.54	0.731
B×D	4	4.712	4.7129	1.1782	1.92	0.370
Residual Error	2	1.224	1.2243	0.6121		
Total	17	20.12				

It is clear that surface roughness (SR) is minimum at the 1st level of parameter A, 3rd level of parameter B, 2nd level of parameter C and 1st level of parameter D. The S/N ratio analysis suggests the same levels of the parameters (A1, B3, C2 and D1) as the best levels for maximum SR. From the graph it is clear that with the increase in burnishing feed surface roughness increases and surface roughness is better at 0.083 mm/rev.

The interaction graph (shown in Figure 3) also reveals that B1, C1 and D3 are the best treatment combination to give minimum surface roughness.

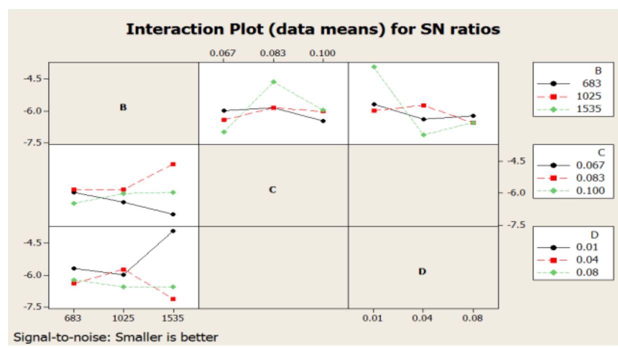

Fig. 3 Interaction Plot for S/N ratios of Surface roughness

These graphs show significant influence of number of passes on the output parameters. Surface roughness increases with the increase in burnishing feed for both the number of passes but it is less with 1 pass as compared to with 2 passes. This can be attributed to the crossing of roughness peaks to flow toward the valleys and thus smearing all the texture of the rough surface in the two dimensional planes on the burnished surface.

5.1 Analysis of Surface hardness (HRB)

The average values of S/N ratios for HRB at different levels are plotted in Fig.3 keeping the objective as "larger is better". In order to study the significance of the parameters in effecting the quality characteristic of interest i.e. HRB ANOVA was performed. The S/N ANOVA for HRB is given in Table 4. The result of ANOVA indicates that burnishing speed, burnishing feed and depth of penetration affect the multiple performance characteristics.

Table 4: Analysis of variance table for average value of surface hardness (HRB)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	1	2.6815	2.6815	2.6815	4.38	0.171
B	2	0.2147	0.2147	0.1074	0.18	0.851
C	2	3.3494	1.6895	0.8448	1.38	0.420
D	2	6.0803	4.8188	2.4094	3.94	0.203
B×C	4	1.8620	1.3214	1.3214	0.54	0.731
B×D	4	4.7129	4.7129	1.1782	1.92	0.370
Residual Error	2	1.2243	1.2243	0.6121		
Total	17	20.1251				

Figure 4 shows the mean effect plot for S/N ratios for HRB.

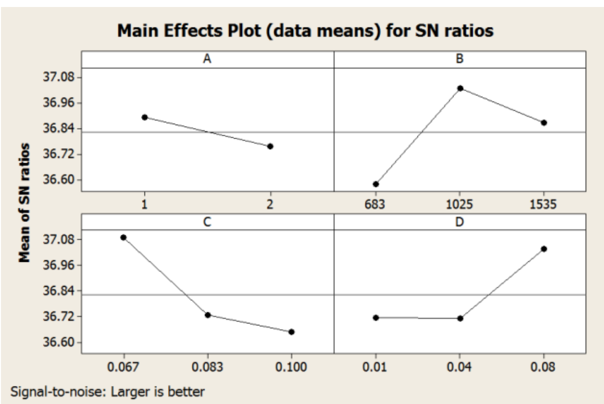

Fig 4. Mean effect plot for S/N ratios for HRB

It is clear from the Figure that HRB is maximum at the 1st level of parameter A, 2nd level of parameter B, 1st level of parameter C and 3rd level of parameter D. The S/N ratio analysis suggests the same levels of the parameters (A1, B2, C1 and D3) as the best levels for maximum HRB.

The interaction graph (shown in Figure 5) also reveals that B2, C1 and D3 are the best treatment combination to give maximum surface hardness. These graphs show significant influence of burnishing speed on the output parameters. Surface hardness increases with the increase in burnishing speed for both the number of passes but it is more with 2 passes as compared with 1 pass this can be attributed to the packing of crossing of roughness peaks to flow toward the valleys and thus hard the burnished surface.

Fig. 5 Interaction Plot for S/N ratios of Surface hardness

4 Conclusion

The Taguchi approach employed in this experimentation enabled the identification of significant factors and their associated levels on specific output measures. Selection of appropriate operating values from these data enabled preferred work piece characteristics to be achieved. During burnishing of brass it is found that burnishing speed, burnishing feed, penetration depth and no. of passes has significant effect on both the performance parameters. Best parameter selection within the experiment range for maximum Rockwell Hardness is with ball burnishing tool at 1 pass, 1025 rpm Speed, 0.01 mm/rev feed and 0.08 mm depth of penetration i.e. A1, B2, C1, D3 and for minimum surface roughness is with Ball burnishing at 1 pass, 1535 rpm Speed, 0.083 mm/rev feed and 0.01 mm depth of penetration i.e. A1, B3, C2, D1. After evaluating the optimum parameters again the experiments were performed which justified the above evaluated results with Taguchi approach.

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