Roughness and Hardness of 60/40 Cu-Zn Alloy

Pavana Manvikar, G K Purohit

***Abstract*—**The functional performance of machined components, often, depends on surface topography, hardness, nature of stress and strain induced on the surface, etc. Invariably, surfaces of metallic components obtained by turning, milling, etc., consist of irregularities such as machining marks are responsible for the above. Surface finishing/coating processes used to produce improved surface quality/textures are classified as chip-removal and chip-less processes. Burnishing is chip-less cold working process carried out to improve surface finish, hardness and resistance to fatigue and corrosion; not obtainable by other surface coating and surface treatment processes. It is a very simple, but effective method which improves surface characteristics and is reported to introduce compressive stresses.

Of late, considerable attention is paid to post-machining, finishing operations, such as burnishing. During burnishing the micro-irregularities start to deform plastically, initially the crests are gradually flattened and zones of reduced deformation are formed. When all the crests are deformed, the valleys between the micro-irregularities start moving in the direction of the newly formed surface. The grain structure is then condensed, producing a smoother and harder surface with superior load-carrying and wear-resistant capabilities.

Burnishing can be performed on a lathe with a highly polished ball or roller type tool which is traversed under force over a rotating/stationary work piece. Often, several passes are used to obtain the work piece surface with the desired finish and hardness.

This paper presents the findings of an experimental investigation on the effect of ball burnishing parameters such as, burnishing speed, feed, force and number of passes; on surface roughness (Ra) and micro-hardness (Hv) of a 60/40 copper/zinc alloy, using a 2-level fractional factorial design of experiments (DoE). Mathematical models were developed to predict surface roughness and hardness generated by burnishing in terms of the above process parameters. A ball-type tool, designed and constructed from a high chrome steel material (HR_C=63 and Ra=0.012 µm), was used for burnishing of fine-turned cylindrical bars (0.68-0.78µm and 145Hv). They are given by,

$$Ra = 0.305 - 0.005X_1 - 0.0175X_2 + 0.0525X_4 + 0.0125X_1X_4 - 0.02X_2X_4 - 0.0375X_3X_4$$

$$Hv = 160.625 - 2.37\,5X_1 + 5.125X_2 + 1.875X_3 + 4.375X_4 - 1.625X_1X_4 + 4.375X_2X_4 - 2.375X_3X_4$$

High surface microhardness (175H_V) was obtained at 400rpm, 2passes, 0.05mm/rev and 15kgf., and high surface finish (0.20µm) was achieved at 30kgf, 0.1mm/rev, 112rpm and single pass. In other words, surface finish improved by 350% and microhardness improved by 21% compared to as machined conditions.

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I. Introduction

THE properties of a machined component such as fatigue strength, load bearing capacity, etc depend to a large extent on the surface topography, hardness, nature of residual stress and strain induced on the surface region. In fact, the surfaces of components produced by conventional machining processes such as milling and turning consist of inherent irregularities produced by the cutting tool or a finer structure due to tearing of the material during machining [1]. There are many finishing processes used to produces surfaces with high quality textures. They are classified into chip-removal processes such as, grinding and chip-less processes such as, burnishing [2]. While grinding is a more popular process and has limitations in terms of special set-up, high machining speeds and is, often accompanied by deteriorated ground surfaces, considerable heat, etc; burnishing is a cold working process and is reported to improve surface roughness, surface hardness, fatigue resistance, corrosion resistance and introduce compressive stresses by way of smoothening the peaks and valleys on the surface [3], [4]. In addition, it is a very simple and cost-effective process; and can be carried out using existing machines, such as lathe [5]. During burnishing, the micro-irregularities on the surface of the components deform plastically at the crests and are gradually flattened, resulting in zones of reduced deformation. When all the crests are subjected to plastic deformation, the valleys between the micro-irregularities start moving in the direction of the newly formed surface, i.e. towards the surface in contact with the tool. The grain structure is then condensed, producing a hard surface with superior load-carrying capacity and wear-resistance [6]. Fig. 1 illustrates the principle of ball burnishing process.

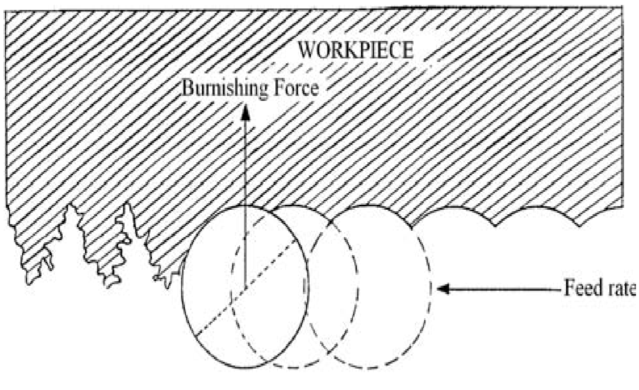

Fig. 1 Principle of ball burnishing process

II. Experimental Details

A. Test Equipment

A simple ball type tool was developed to carry out the burnishing of a cylindrical work piece made-up of a 60/40 Cu-Zn alloy. The burnishing tool is a spring-loaded chrome steel (HRC62.6) and surface roughness, Ra, of 0.012µm ball. The Ball holder was elastically supported by a pre-calibrated spring, which could apply the required force when it was pressed on the surface of the work piece. Fig. 2 gives the details of the burnishing tool and Fig. 3 shows the burnishing process in progress.

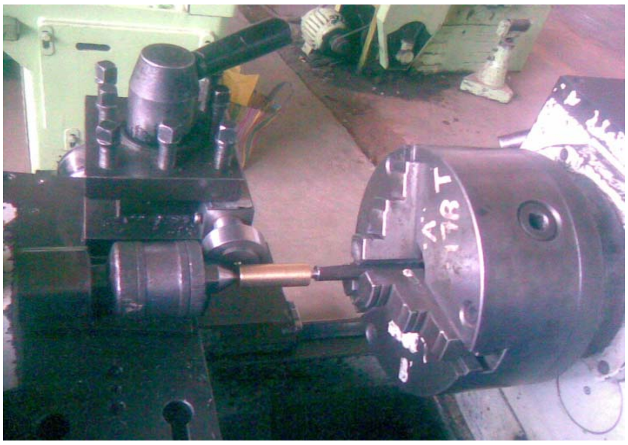

Fig. 2 Ball burnishing operation

Fig. 3 Ball burnishing tool

B. Material

The work piece was received in the form of cylindrical bars of 20mm diameter. The bars were turned to 17mm diameter and 60mm length. The chemical composition and mechanical properties of the work piece material are presented in Table I.

TABLE I
Chemical Composition and Mechanical Properties of the Work Piece Material

Material (Brass rod; IS 319-2007 Gr.1)	Cu %	Zn %	Pb %	Fe %	Tensile Strength MPa	Hardness Hv 10kgf
	57.94	Balance	2.62	0.24	407	128

TABLE II
Burnishing Parameters

Factors/Levels	Unit	Low Level (-1)	High Level (+1)
Burnishing speed (X_1)	rpm	112	400
Burnishing force (X_2)	kgf	15	30
Burnishing feed (X_3)	mm/rev	0.05	0.10
Number of passes (X_4)	--	1	2

C. Factorial Design of Experiments

It was decided to use a 2-level, half factorial design of experiments which meant the experimentation involved performing 2^{4-1} burnishing operations [7], [8]. Table II shows the upper and lower levels of the most influential process parameters, viz., burnishing speed, force, feed and number of passes. The design matrix of Table III shows the different combination of the selected parameters for conducting the experimental work. Thus, 8 experimental runs were performed (with 2 repetitions) following the design matrix so as to provide all possible treatment combinations of Table III. Randomization was employed for conducting the experiments to avoid entry of systematic errors [9].

The surface roughness (Ra) was measured using a stylus-type surface roughness tester (Mitutoyo, Japan made SJ-201) and the surface hardness was measured using a Vickers microhardness testing machine. A Kirloskar Turn Master T-400 lathe was used for burnishing the work pieces as it has a wide range of parameters settings. Table III gives experimental values of the four most influential burnishing parameters, viz. Burnishing speed, rpm, Burnishing force, kgf, Burnishing feed, mm/rev and Number of passes

TABLE III
Design Matrix and Responses

Trial Nos.	**X_1**	**X_2**	**X_3**	**X_4**	**Ra**	**Hv**
1	-	-	-	-	0.23	152
2	-	-	-	+	0.44	152
3	-	+	-	+	0.35	179
4	+	+	-	-	0.20	152
5	-	-	+	+	0.35	159
6	+	-	+	-	0.27	159
7	-	+	+	-	0.31	162
8	+	+	+	+	0.29	170

III. Results and Discussion

Mathematical models were deduced for the two responses by employing regression analysis and are presented in (1) and (2).

Surface roughness is given by,

$$\mathbf{Ra = 0.305 - 0.005X_1 - 0.0175X_2 + 0.0134X_3 + 0.0525X_4 + 0.0125X_1X_4 - 0.02X_2X_4 - 0.0375X_3X_4} \quad (1)$$

Micro-hardness is given by,

$$\mathbf{Hv = 160.625 - 2.375X_1 + 5.125X_2 + 1.875X_3 + 4.375X_4 - 1.625X_1X_4 + 4.375X_2X_4 - 2.375X_3X_4} \quad (2)$$

where, X_1 = Burnishing speed, rpm, X_2 = Burnishing force, kgf, X_3 = Burnishing feed, mm/rev and X_4 = Number of passes

It is observed from the two equations that the responses are not only influenced by the main factors, but also by the 2-factor interactions. Equation (1) shows that burnishing speed and force effect the surface roughness negatively, while feed and number of passes effect it positively. However, the 2-factor interaction effect of burnishing speed and number of passes is negative; while that of burnishing force and number of passes, and feed and number of passes is negative. This indicates that the combination of higher speed and force, and lower values of feed and number of passes results in better surface finish.

Equation (2), on the other hand, indicates that burnishing speed has a negative effect on micro-hardness, while force, feed and number of passes effect it positively. As far as the interaction effects are concerned, the 2-factor interaction effects of burnishing speed and number of passes is negative, while that of burnishing force and number of passes effects positively. Hence, it is evident that the combination of higher speed and lower values of force, feed and number of passes results in results in better surface finish. Further, burnishing feed appears to be the most influential parameter.

Overall, it is imperative that there is an optimum value of each of the four process parameters and it is paramount to select them, judiciously, keeping in mind their main/individual as well as interaction effects, so that the desired responses can be obtained.

IV. Analysis of Variance

Analysis of variance was carried out to assess the significance of each parameter on the two responses. Tables IV and V show the results.

TABLE IV
ANOVA Results Ball Burnishing for Microhardness

Model/factor	Degrees of freedom (DoF)	Sum of Squares (SS)	Mean Square (MS)	Fisher's F-value
Linear Model	4	436.50	145.5	2.64
Lack of fit	3	219.38	54.8	

TABLE V
ANOVA Results Ball Burnishing for Surface Roughness

Model/factor	Degrees of freedom (DoF)	Sum of Squares(S.S.)	Mean Square(M.S.)	Fisher's F-value
Linear Model	4	0.025	0.0083	2
Lack of fit	3	0.016	0.004	

It is observed that the F-values determined from experimental results are higher than the corresponding tabulated values. Hence, the mathematical models are adequate and can be successfully used for predicting the two responses within the frame work of experimentation.

V. Conclusion

Following conclusions have been drawn from the present work.

1. Burnishing process can be used to finish a component instead of grinding or other secondary operations. It can effectively and economically on a conventional lathe with an appropriate burnishing tool. It can produce good surface finish and micro-hardness in both longitudinal and cross sections.
2. It was found that all of the parameters, namely, burnishing speed, force, feed rate, and number of passes have a significant effect on both roughness and surface microhardness. In addition to their main effect, 2-factor interaction effects must be considered while predicting the roughness and hardness of the burnished surface as they have significant effect on them.
3. Improved surface finish and micro-hardness can be obtained by employing optimum values of the process parameters. The most conservative value of surface roughness obtainable is 0.44µm and the least value of hardness obtainable is 152Hv.
4. A pre-machined surface roughness of around 0.75µm (by turning) can be finished up to 0.20µm by ball burnishing and micro-hardness of the order of 179Hv can be achieved compared to the original/machined part with 145Hv. In other words, the surface roughness decreased by around 390% and the improvement in micro-hardness was of the order 80%.
5. Factorial design of experiments can be successfully used to evaluate the performance of burnished components.

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