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Ball Burnishing of Copper- A preliminary Experimental Study on Finishing

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Abstract. Ball burnishing is a finishing process, in which a ball burnishing tool is used to remove the surface flaws such as scratches, ploughing marks due to previous manufacturing/machining process, indentation, etc. The burnishing operation generates a reflective surface by plastically deforming the roughness peaks and filling the scratches. In the present research, the ball burnishing tool having a hard ball made of carbide has been used to finish the copper samples. Since copper is a soft material, it is very prone to scratch while finishing by most of the finishing processes employing bonded or loose abrasives. In the present study, the effect of different process parameters has been explored on the output performance i.e. Percentage change in surface roughness. From the experimental results it has been observed that in ball burnishing of copper, the maximum improvement in surface finish was about 94% when kerosene is used as a coolant.

Keywords. Ball burnishing, copper, finishing.

1. Introduction

Surface quality is crucial for the technological excellence of machined components. Material characteristics, form, and dimensional correctness are also significant considerations. Engineering components endure extreme strains, temperatures, and speeds. More investigation is required to comprehend and enhance the connection between the form and functionality of surfaces. The ideal surface specification depends on its intended application, necessitating the separation of surface geometry and function, particularly in tribological research. Surface roughness greatly influences qualities like wear resistance and fatigue strength in engineering parts [1]. It is impossible to achieve perfectly flat surfaces because they inherently contain imperfections in the form of peaks and valleys. Surface finishing processes vary in terms of their actions, thermal aand mechanical damage, residual tensions, and materials used. There are two categories into which these techniques can be classified based on their mechanisms: material loss methods like grinding, and plastic squeezing methods that redistribute material without loss, seen in processes like burnishing [2]. Ball burnishing, a chipless machining method involving superficial plastic deformation, focuses on surface polish and the creation of compressive residual stresses. When the burnishing is used as a final step after turning or grinding a workpiece, it can improve its ability to withstand wear, last longer under repeated stress, become stronger when pulled, and be more resistant to damage caused by corrosion [3]. It can serve as a viable alternative to grinding for achieving desired

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surface smoothness on hydraulic machine components such as piston rods. In this study, the burnishing operation was conducted on a lathe machine [4]. Ball burnishing is a mechanical finishing process that utilizes small, spherical balls to polish and enhance the surface quality of metal components. It improves appearance, texture, and functionality in various materials, including metals. The process, also known as ballizing, ball rolling, and ball polishing, excels at enhancing surface smoothness and texture. The rolling movement of balls on the workpiece surface removes flaws like burrs, roughness, and machining marks, resulting in a smoother and refined surface [5]. This is particularly advantageous for high-quality surface finishes in automotive parts, aircraft components, and medical equipment. Besides enhancing surface finish, ball burnishing induces compressive pressures that produce beneficial residual stresses, elevating the fatigue life, strength, and resistance to cracking and failure of the component. Thus, ball burnishing is an attractive solution for improving the mechanical performance and lifespan of metal products. It can be used on many different types of materials, including steel, aluminum, brass, copper, and various types of alloys [6]. It is a flexible and adaptable technique that can be applied to a wide range of substances. It can be employed on flat and curved surfaces, with the choice of ball size and type tailored to meet specific requirements for surface polish [7].

2. Experimentation

Copper was chosen as the experimental material due to its industry significance. It holds relevance for the study. A total of 60 Copper workpieces in a disc form with dimensions of [diameter = 25.4 mm] x [height = 12 mm] were prepared for the trials. Turning, Parting and Facing operations were performed on lathe machine to make the samples ready before doing the final operation i.e., Ball Burnishing. In surface finishing procedures, a ball burnishing tool is employed to enhance the workpiece's quality and appearance. It is formed of a spherical ball of carbide, which is noted for its hardness and durability. The ball burnishing tool is intended to be used in conjunction with a lathe machine. Its function is to apply pressure and roll over the workpiece's surface, causing plastic deformation and surface refinement. The burnishing tool's shank is designed such that mounting it to the tool holder of the lathe machine is simple. The lathe machine's three-jaw chuck holds the workpiece. During operation, the carbide ball comes into liaison with the workpiece surface. The applied pressure and rolling action of the ball create plastic deformation of the material. The roughness of the surface (Ra) is examined using a surface roughness profilometer both before and after the burnishing procedure. The bulk of the samples in this investigation has an initial surface roughness (Ra) that ranged from 2.18 to 3.13 µm. Before performing the ball burnishing procedure, the workpieces are cleaned with acetone. To stop hard particles from getting onto the contact surface between the tool and the workpiece, continuous ball cleaning is done. On the polished surface of the workpiece, such hard particles frequently cause significant scratches. This technique smoothes out any surface abnormalities like as roughness or tool marks, resulting in a more consistent and polished surface finish.

Experimental Design and Analysis: Examining how the parameters of the ball burnishing process affect the characteristics of the work material is the main objective of this work. Response surface methodology (RSM), a simple and acceptable experimental design, ended up being suitable for our study. A total of 60 experiments were performed. The ball burnishing parameters for the finishing action are shown in Table 1.

Table 1: Selected parameters and their values

Factor	**Name of parameters**	**Units**	**Type**	**Sub Type**	**Minimum level**	**Maximum level**
A	Speed	rpm	Numeric	Continuous	150	400
B	Feed	mm/min	Numeric	Continuous	0.100	0.50
C	Infeed	mm	Numeric	Continuous	0.15	0.45
D	Lubricant	–	Categoric	Without Lubricant	Paraffin	Kerosene

Table 2: Fit Summary

Source	**Model p-value**	**Lack of Fit p-value**	**Adjusted R^2**	**Predicted R^2**	
Design Model	<0.0001	0.3933	0.8986	0.7396	Recommended
Linear	<0.0001	0.0007	0.6260	0.5666	
2FI	0.0038	0.0042	0.7289	0.6409	
Quadratic	<0.0001	0.0483	0.8280	0.7319	Suggested
Cubic	0.0009	0.7602	0.9197	0.7710	Aliased

In our experimental analysis, we have utilized the Quadratic Source of the model to formulate our linear regression equation, as per table 2. The adjusted and predicted R^2 values of the model are in good agreement, indicating a reasonable fit. Additionally, the p-value for lack of fit is considerably larger than the threshold, indicating that the model is not overfitting and has adequate generalization capability.

Table 3: Fit Statistics

Std. Dev.	0.0381	R^2	0.9028
Mean	0.7464	Adjusted R^2	0.8634
C.V. %	5.11	Predicted R^2	0.7905
		Adeq Precision	20.3123

- The predicted R^2 value of 0.7905 and the adjusted R^2 value of 0.8634 are quite close to each other, with a difference of less than 0.2, table 3. This means that they are in reasonable agreement, indicating that the prediction made by the model is fairly accurate and reliable.
- Adeq Precision is a measure that tells us how clear the important information (signal) is compared to the unwanted noise. It is desirable to have a ratio greater than 4, as it indicates a strong and clear signal. In your case, with a ratio of 20.312, the signal is more than adequate, table 3. This means that the model provides a clear and reliable understanding of the data, and it can be confidently used to explore and make decisions within the design space.

Final equation in terms of coded factors:

$$Ra = 0.7617 - 0.0710 \times A + 0.0329 \times B + 0.01543 \times C + 0.0043375 \times D[1] - 0.0748 \times D[2] - 0.0239 \times AB + 0.0212 \times AD[1] - 0.0323 \times AD[2] + 0.0496 \times CD[1] - 0.0033 \times CD[2] + 0.0275 \times A^2 - 0.0790 \times B^2 + 0.0209 \times C^2 - 0.0504 \times A^2D[1] + 0.0566 \times A^2D[2] + 0.0533 \times C^2D[1] - 0.0617 \times C^2D[2] \quad (1)$$

The equation 1, which employs coded factors, allows predictions about the response variable to be produced based on precise levels of each factor. In this context, the high levels of the components are frequently labeled as +1 and the low levels as -1. By comparing the coefficients of the elements, the coded equation can be used to determine the respective importance of the components.

3. Results and Discussions

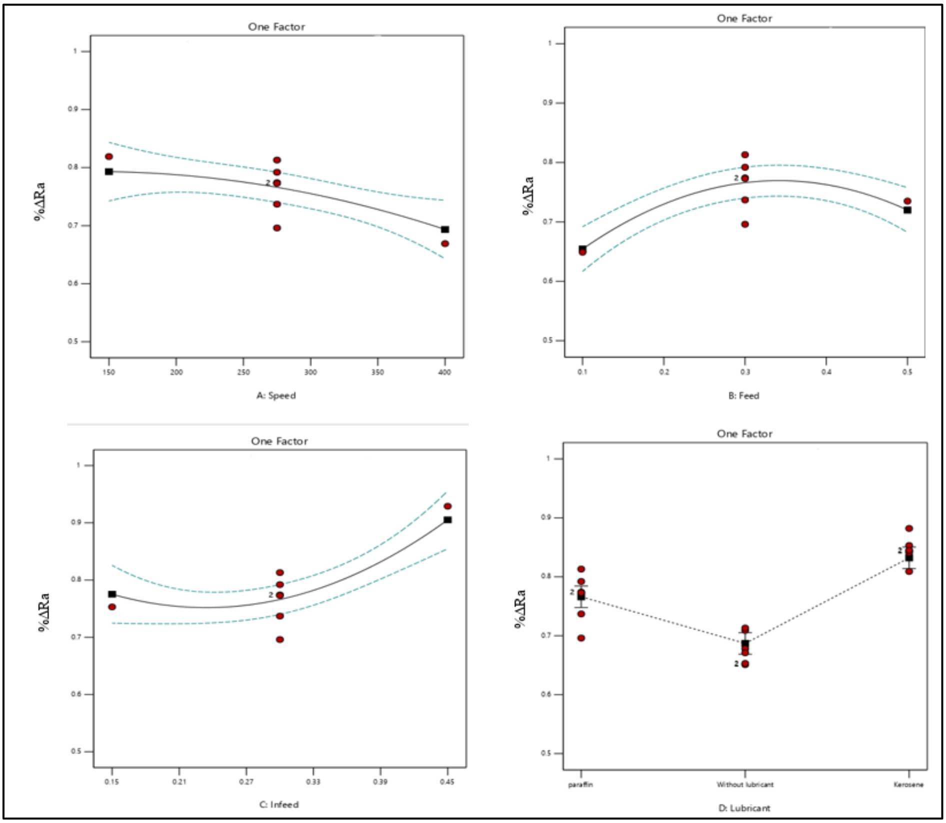

Figure 1. Effects of speed , feed, infeed and lubrication on % ΔRa.

Effect of speed on the % change in surface roughness (%ΔRa): According to the final model analyzing the link between the input ball burnishing parameters and change in surface roughness, lower speeds result in higher reduction in surface roughness. In contrast, as speed increases, the change in surface roughness steadily decreases, figure 1. This is because, slower ball movement allows for more time per unit area of the surface, improving its smoothness by continuous plastic deformation.

Effect of feed on the % change in Surface Roughness ($\%\Delta Ra$): The reduction in surface roughness is clearly affected at the lowest feed rate, according to the final model that links the input ball burnishing parameters with the change in surface roughness. However, as the feed rate rises from 0.1mm to 0.3mm, the reduction in surface roughness increases, peaking at 0.3mm. Beyond this point, as the feed rate climbs to 0.5mm, the change in surface roughness starts to decrease. The graph shows a peak value at 0.3mm, indicating that the highest reduction in surface roughness can be obtained at this feed rate, figure 1. It is worth noting that an excessively high feed rate results in a decrease in the change in surface roughness. A lower feed rate allows the ball of ball burnishing tool to work for a longer time on the roughness peaks and causes them to deform plastically in the repetitive action of the ball, whilst a larger feed rate may cause the ball of ball burnishing tool to be in contact for less time that results in a decrease in the change in surface roughness ($\%\Delta Ra$).

Effect of infeed on %change in Surface Roughness ($\%\Delta Ra$): It is evident from the graphs of figure 1 that initially as the infeed increases, the change in surface roughness decreases because at the higher infeed, higher forces act at the contact of ball and workpiece that results in taking out the embedded chips at the surface of the workpiece. But at higher infeed beyond a certain limit, the forces become so high at the contact of ball and workpiece that all the roughness imperfections suppress and deform plastically to give an increase in percent change in surface roughness value.

Effect of Lubricant on %change in surface roughness ($\%\Delta Ra$): Based on the data, different lubricants have different effects on the surface finish. Kerosene as the lubricant produces a surface polish that is noticeably superior. Similar to how the surface finish is of intermediate quality when using paraffin as the lubricant. However, the surface finish deteriorates greatly when no lubricant is used. From the graphs of the effects of lubricants on the percent reduction in surface roughness, it is evident that the change in surface roughness is higher when paraffin or kerosene is used as the lubricant and it falls drastically when no lubricant is used figure 1. At no lubricant condition, the roughness peaks and other imperfections are likely to adhere to the carbide ball and may result in a decrease in $\%\Delta Ra$.

4. Conclusion

The ball burnishing tool can successfully be employed to finish the surface of nonferrous metals that are difficult to grind with traditional grinding. From this study it can be concluded that slower ball movement allows for more time per unit area of the surface, improving its smoothness by continuous plastic deformation. an excessively high feed rate results in a decrease in the change in surface roughness. An excessively high feed rate results in a decrease in the change in surface roughness due to contact of the carbide ball with the roughness peaks for a lesser time. Higher infeed increases the forces on the roughness peaks and other surface defects and smoothens them. No lubrication condition causes a reduction in the percentage change in surface roughness due to the sticky nature of copper with the carbide ball at no lubrication condition. The model's predicted R^2 and adjusted R^2 indicate that model is fairly accurate and reliable.

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