

Optimization of Surface Roughness of Brass by Burnishing

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Abstract—Cylindrical components are important in several industrial applications. The surface quality plays a role in part performance. Non-ferrous surfaces are difficult-to-finish due to several issues encountered in grinding that is optimum for ferrous metals. Burnishing process, as a metal deformation process, is believed to be more suitable since it eliminates sticking, wheel dulling and overheating. The main objective of this work is to optimize the burnishing process that can be used to finish the surface of machined parts. To achieve this, burnishing tool was designed and constructed in such a way that it can be simply mounted or fixed onto the tool holder of the CNC lathe machine. Experiments are made according to the response surface methodology (RSM), in order to improve the reliability of results and to reduce the size of the experimental plan without loss of accuracy. In this work, four burnishing parameters, namely, burnishing speed, feed, depth of penetration and number of passes were selected in order to study their effects on the surface roughness. Mathematical models, which depend basically on the utilized experimental design, have been developed. Variance of analysis was conducted to determine the prominent parameters and the adequacy of the models. The results showed that good surface roughness can be obtained with minimum cost by transferring the CNC lathe machine from machine tool to super-finishing machine using the proposed burnishing tool. From an initial average roughness of about Ra (4-5 μm), the specimen could be finished to average roughness of 0.09 μm .

Index Terms: burnishing, surface roughness, brass, CNC, DOE.

I. INTRODUCTION

Conventional machining processes such as milling and turning produce a surface with inherent irregularities, which affect the surface properties and service behavior of the component. These irregularities are considered as imperfection which impair the function of components, such as bearings or scaling surface, cause wear, high level of noise, reduce both load carrying and fatigue strength. Finishing processes such as grinding, lapping, polishing and honing are commonly employed to improve the surface finish of the machined components. In engineering industries, grinding is the most common technique used to improve the surface finish of many metals and alloys. Ordinary grinding of some metals and alloys such as aluminum, copper and brass is difficult.

Wheel clogging on grinding of such metals causes rapid wheel breakdown and frequent dressing of the wheel is required.

During recent years, considerable attention being paid to the post-finishing processes. Burnishing forms an important member in the family of these post-finishing processes. Burnishing, as a metal deformation process, is believed to be more suitable since it eliminates sticking, wheel dulling and overheating. Burnishing processes has several advantages that are lacked in other processes. One of the advantages of burnishing processes is the cost reduction. That is because this process can be performed on any machine that is capable of rotating either the tool or workpiece. On the contrary, other processes need special equipment [1]. The second advantage for burnishing is increasing the surface hardness, which can improve the wear resistance, increase corrosion resistance, improve tensile strength, maintain dimensional stability and improves the fatigue strength by inducing residual compressive stresses in the surface and subsurface of the workpiece [2]. Nevertheless, the prime advantage of the burnishing process is the improvement of surface roughness and the minimization of out of roundness. Burnishing process is widely applied in industry. It is used in fine finishing inner and outer diameters of hydraulic cylinders, pistons for hydraulic systems or bearing seatings, bushes, and Housing connecting rods. The process of burnishing 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 workpiece. The work is usually driven positively and a burnishing tool rotates as a result of frictional engagement. Plastic deformation of micro irregularities starts with deformation of the crests and then as the contact pressure of the burnishing tool increases the crests are gradually flattened. The ball or roller is fed in an appropriate direction according to the workpiece surface. The main objective of this work is to use the ball burnishing process to improve surface quality (Ra) of 70/30 Cu-Zn alloy using CNC lathe machine. To explore the optimum combination of burnishing process parameters in an efficient and quantitative manner, the experiments were designed based on the response surface methodology, with central composite rotatable design and mathematical model for surface roughness (Ra) was developed to give the production Engineers more details about the produced surfaces.

The surface quality of mechanical parts is significant design specification that is known to have considerable influence on properties such as wear resistance and

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fatigue strength. High equality surface finish is especially crucial for optical and prosthetic products and in the aerospace industry. Nowadays, about 50% of the energy supplied is lost in the friction elements in relative motion [3].

There are many processes that can be used to produce internal and external fine surfaces; grinding, honing, lapping, superfinishing and burnishing. The first four processes always leave a surface with geometrical defects in topography and metallurgical defect in physical structure. These conditions are the result of heat caused by speed and pressure of bonded abrasive. Another defect is that the abrasive points do not accumulate large volumes of metallic material pushing a head of abrasive grain making deep scratches in the base metal surface. Although considerable improvement in Ra value was realized for non-ferrous metal after finish-cuts, surfaces had problems with tribological performance features and this was attributed to the relative non-uniformity of cutting action compared with burnishing [4].

During recent years, considerable attention has been paid to the post-finishing processes such as burnishing which improves the surface characteristics by plastic deformation of the surface layer [5].

The burnishing process gives an improved surface finish besides increased hardness, corrosion resistance and fatigue life as result of the produced compressive residual stress. These advantages together with, the simple construction of tooling, the economy, the possibility of using typical machine tools in the process and work parts of various types made of various materials, make the burnishing process attractive in comparison with abrasive-methods such as grinding, honing, super-finishing and polishing.

The previous work in this area showed that considerable attention has been paid towards studying the influence of various parameters on characteristics of surfaces produced by burnishing process. The forth coming is a brief review on the effect of burnishing process variables; such as burnishing speed, feed, force, number of passes, tool diameter, and initial roughness on final surface roughness.

II. EXPERIMENTAL WORK

A. Workpiece Material

In this study 70/30 Cu-Zn alloy was used as workpiece material. This material was selected because of its importance in industry and its susceptibility to degradation when burnished, through surface and subsurface damage. The chemical composition, in weight percent, and the mechanical properties of this material are shown in Table 1 [6].

Table1. Chemical Composition of the Workpiece Material

Element	Ni	Fe	Cu	Mn
Weight %	29	1.5	Rem.	1.0

B. Tool Set-up

A simple tool was designed for the external ball burnishing process. The main parts of this tool and their assembly are shown in Figure. 1 and Figure. 2. An 8 mm diameter ball was used for burnishing.

With this arrangement the ball was free to rotate in conjunction with the specimen when the ball is set-in contact with the surface of the specimen during burnishing process, due to the frictional forces developed.

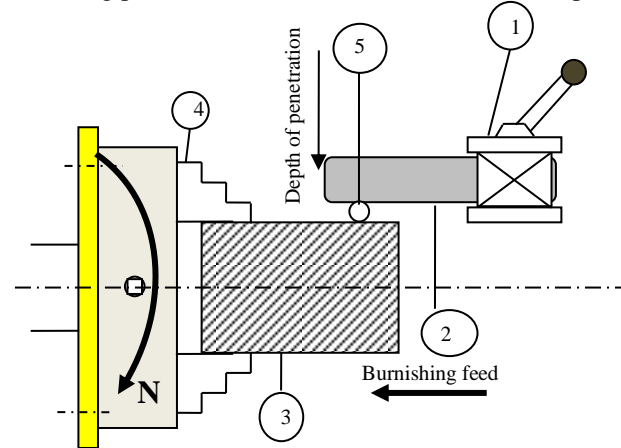


Figure 1. A Schematic Representation of the Experimental Setup: (1) Tool holder. (2) Shank. (3) Workpiece. (4) Lathe Three-Jaw Chuck. (5) Burnishing Ball.

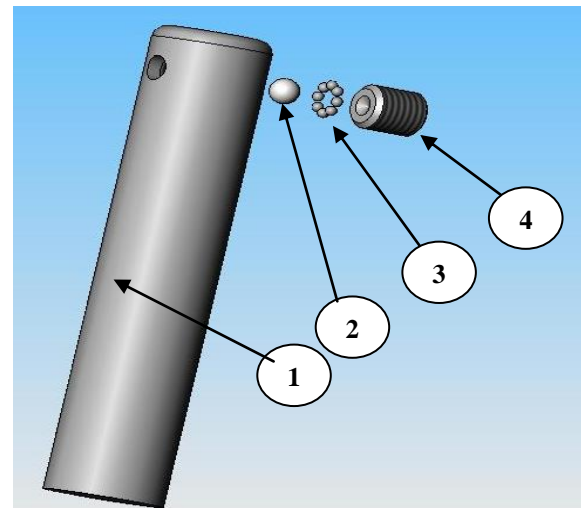


Figure 2. (1) Shank. (2) Burnishing ball. (3) Back-up balls. (4) Stud.

The ball could be removed easily from the tool for changing, readjusting or cleaning by unscrewing the adapter. The shank of this burnishing tool is designed in such manner that it can be simply mounted or fixed onto the tool holder of the used CNC lathe machine.

C. Burnishing Conditions

In this work, ball burnishing tests were performed. All of the burnishing tests were performed under dry conditions on CNC lathe machine [Model, Biglia B56/1 CNC]. In order that the effect of each parameter on the surface characteristics of workpiece can be thoroughly investigated, only four burnishing parameters were

chosen namely; burnishing speed (V), depth of penetration (ap), burnishing feed (f) and number of passes (n), other parameters such as ball diameter and lubrication were held constant throughout the work.

The first independent parameter chosen was the burnishing speed (V). In industry, the cost of burnishing depends strongly on the speed, the cost can be reduced by increasing the speed. In this study five burnishing speeds in the range of (25 to 85 m/min) were used. Because of its great effect on the produced surface characteristics, the burnishing feed was the second independent parameter used in this work; the range of burnishing feed is from (0.1 to 0.5 mm/rev). The third parameter chosen was depth of penetration which can significantly affect the produced surface characteristics depending on the workpiece material. Five burnishing depths were used in this study ranging from (10 to 50 μm).

Finally the number of burnishing passes is used as the fourth parameter. Five burnishing passes range from (1 to 5) were used. A constant ball diameter of (8 mm) was used in all experiments conducted in this work.

D. Measurements of Surface Profile Parameters

Most of previous investigators have studied the effect of some parameters on average roughness, Ra as the main parameter on the surface profile. It is very clear that information concerning surface profile parameters of the burnished surface will be very valuable in the part manufacturing. In this work, A Surtronic 3+ Instrument, Figure. (3) was used to measure five different surface profile parameter, Ra of unburnished and burnished parts of each workpiece. The average values of three measurements were reported for each part.



Figure 3 surtronic 3+ Instrument

III. DESIGN OF EXPERIMENTS

Traditional experimentation involves a considerable effort and time, especially where complex processes are involved. A very efficient way to enhance the value of research and cut down the process development time is through designed experiments. The designed experiment ensures less error in determining the effects of interest than an orthodox method could afford.

Generally, when the experimenter plans his experiments, he achieves results in a much more economical manner. As a rule, the experiment designed to find the optimum conditions of a process is described adequately by a second order polynomial.

In this work, experiments were designed on the experimental design technique that has been proposed by Box and Hunter [7, 8] A 2^k factorial, where K is the number of variables, with central composite-second-order rotatable design was used to improve the reliability of results and to reduce the size of experimentation without loss of accuracy. The main objective of experiments consists of studying the relationship between the response as dependent variable and the parameter levels. This approach helps to understand better how the changes in the levels of application of a group of parameters effect the response. A combination of levels of the parameter that leads to certain optimum response can also be located through this approach. It has been reported [8] that the factorial experiments provide an opportunity to study not only the individual effects of each factor but also their interactions. When experiments are conducted by a factor while changing the level of each factor, the effect of interaction cannot be investigated. The factorial experiments have the further advantage of making experiments more economical.

Designs having a “spherical” or nearly “spherical” variance function are preferable because such design insures that the estimated response has a constant variance at all points which are the same distance from the center of the design. Designs having this property are called rotatable designs. The main idea is to run a simple experiment over a small area of the response surface, where, for all practical purposes, the surface may be regarded as a plane. The equation of this plane is then determined, this will guide the user towards obtaining the optimum conditions of the surface.

In the general case, the response surface is described by an equation of the form;

$$y = f(x_1, x_2, \dots, x_k) \quad (1)$$

Where Y is response, and the $x_1, x_2, \dots, \dots, x_k$ are coded levels of k quantitative variables.

Suppose that there are k variables $x_1, x_2, \dots, \dots, x_k$ and we want to fit them to a polynomial of degree d=1, then the simplest surface is a plane given by

$$y = b_0 + b_1x_1 + b_2x_2 + \dots + b_kx_k \quad (2)$$

Where, y is the observed response, b_0 is the free coefficient and b's can be estimated by the method of least squares which minimizes the sum of the errors. Such an equation is referred to as a first-order equation.

As a rule, the experiment designed to find the optimum conditions of process is described adequately by a second-order polynomial [8]. For this polynomial, the number N of observations included in the design should not be less than the number of estimated coefficients of second-order equation for k factors.

In order to determine the equation of the response surface, several special experimental designs have been developed which attempt to approximate this equation using the smallest number of experiments possible. The N sets of conditions at which the response is observed will then correspond to N points in the space of variables called experimental points. According to A 2^k factorial with central composite-second-order rotatable design [14]

the total number N of experiments is estimated by the following.

$$N = n_c + n_a + n_o = 2^k + 2k + n_o \quad (3)$$

Where; $n_c = 2^k$, are factorial points or corner points in which all possible combinations of the factors at all levels involved in the experiment are used. In the dimensionless coordinate system, the upper and lower level starts at +1 and -1, respectively. The group $n_a = 2k$, are called axial points or star points which are positioned on the coordinate axes of factorial space $(\gamma, 0, \dots, 0)$, $(0, \gamma, \dots, 0)$, $(0, 0, \dots, \gamma)$, where $\gamma = k^{1/2}$, is the distance from the center point of the design to a star point.

The group $n_o = \frac{\lambda n(k+2) - kn}{k}$ is called the center points, $n = n_c + n_a$ and λ is constant which depends on the number of independent variables. More details about this constant and its values corresponding to number of variables are given by Box and Hunter [7]. In a dimensionless system, the coordinates of the center point of the design are zero. Figures 4 and 5 illustrate these three kinds of experimental design points of the composite design; for $k = 2$ in (Fig. 4) and for $k = 3$ in (Fig. 5) for example.

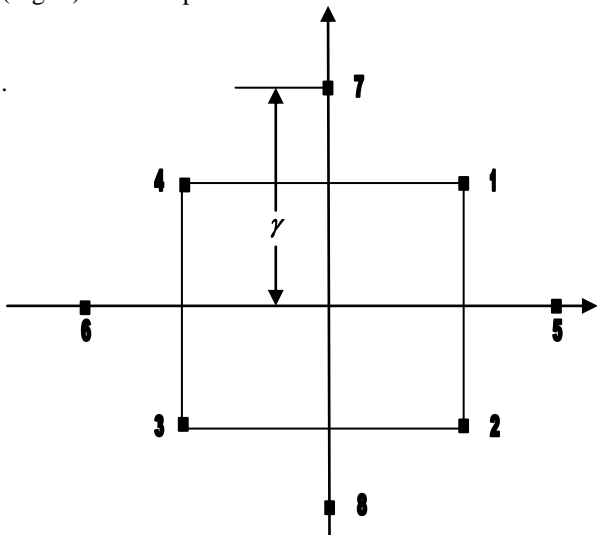
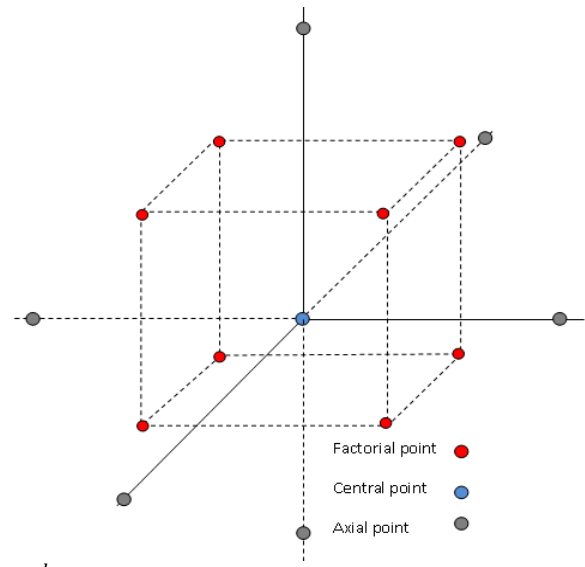


Figure 4 Experimental design points of the composite design for k=2

Figure 5. Experimental Points of the Proposal Technique for k=3

The present experimental investigation studied the results of the effects of burnishing speed (V), burnishing feed (f), burnishing depth of penetration (ap), and number of passes (n) on surface profile parameters



A 2^k Factorial with central composite –second –order rotatable design was used (in this case $k=4$). This consists of $n_c = 2^k = 16$ corner points at ± 1 level, $n_a = 2k = 8$ axial points at ± 2 and a center point at zero level repeated 7 times (n_o) to estimate the pure error, where, the value of constant λ at four independent variables is 0.86, this involves a total of 31 experimental observations. The values of the coded variables are listed in Table (2).

Table 1 Coding of burnishing process parameters

Parameters	Sym-bol	Levels				
		-2	-1	0	1	2
Speed, (m/min)	x_1	25	40	55	70	85
Feed, (mm/rev)	x_2	0.1	0.2	0.3	0.4	0.5
Depth, (mm)	x_3	.01	.02	0.03	0.04	0.05
No. of passes	x_4	1	2	3	4	5

E. Postulation of Mathematical Model:

A functional relationship between the response (surface profile parameters) of the workpiece produced by ball burnishing and independent variables (burnishing speed, feed, depth of penetration, and number of passes) can be fitted into the following polynomial response equation of second-order [13].

$$y_u = b_0 + \sum_{i=1}^k b_i x_i + \sum_{i=1}^k b_{ii} x_i^2 + \sum_{j \geq 1} b_{ij} x_i x_j \quad (4)$$

Where; y_u is the response and $x_i(1,2, \dots, k)$ are coded levels of k quantitative. The coefficient b_0 is the free term, the coefficients b_i are the linear terms, the coefficients b_{ii} are the quadratic terms, and the coefficients b_{ij} are the interactions terms. Applying the least squares technique the values of these coefficients can be estimated by using the observations collected, y_1, y_2, \dots, y_N through the design points (N). This equation can be rewritten according to the four variables in the coded form:

$$y_n = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 \quad (5)$$

Where; x_1, x_2, x_3 and x_4 are the coded values of the variables V, f, ap and n, respectively. V_0, f_0, ap_0 and n_0 are the values of the burnishing speed, feed, depth of penetration, and burnishing passes, at zero level. $\Delta V, \Delta f, \Delta ap$ and Δn , are the units or intervals of variation in V, f, ap and n respectively. These variables are coded for convenient identification and for easy calculation.

The regression coefficients $b_0 + b_1 + b_2 \dots$ etc in equation (5) can be calculated by the method of least squares using the following equations:

IV. ANALYSIS OF VARIANCE (ANOVA):

The relationship between each response and the burnishing process parameters were quantitatively determined using empirical equations (the proposed model). The evaluation and the analysis of the experimental data were made by adopting polynomial response of second-order equations in terms of the process variables by establishing their interactions. Using the values of each response observed, a system of simultaneous equations is obtained. The 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. To check the adequacy of model, the analysis of variance was carried out using the F-ratio test.

The calculated (t) value for any regression coefficient can be computed from the following equation [9];

$$t = \frac{\text{Regression coefficient}}{\text{Standard error of the regression coeff.}} \quad (6)$$

The standard error for any regression coefficient is usually determined by

$$S = \sqrt{V_1} \quad (7)$$

Where V_1 is the variance of the regression coefficient.

In the present work the variance for each of the regression coefficient is given by the following equations [13]:

$$V(b_0) = 2A\lambda^2(k+2)\sigma^2/N \quad (8)$$

$$V(b_i) = C\sigma^2/N,$$

$$V(b_{ii}) = A(k+1)\lambda - (k-1)C^2\sigma^2/N, \text{ and}$$

$$V(b_{ij}) = C^2\sigma^2/N$$

Where;

$$\sigma^2 = \frac{1}{n_0 - 1} \sum (y_0 - \bar{y}_0)$$

It should be noted that the parameters which are non significant were omitted from the second-order response equation.

The F-ratio for each term can then be determined from the variance analysis. In such analysis, it is of interest to partition the sum of squares of the Y's into the contribution due to the first-order (linear) term, an additional contribution due to the second-order (quadratic and interaction) terms, lack-of-fit terms (which measure the deviation of the response from the fitted surface), and the experimental error obtained from the replicated points at the center.

V. MATHEMATICAL MODELS

In today's complex and competitive economy there is a need to improve the efficiencies of burnishing process, such efficiencies may be attained by understanding the relationship between the outputs of the burnishing process and the burnishing variables.

This section presents a study of the development of response models for burnishing of 70/30 Cu-Zn alloy under dry conditions. These models are developed in terms of burnishing speed, feed, depth of penetration, and number of passes by utilizing Response Surface Methodology (RSM). It has been successfully applied in a wide variety of situations.

In this study, the variables are investigated using the experimental design matrix instead of the conventional one-variable at a time method. The evaluation and the analysis of the experimental data is made by adopting a polynomial response surface of second-order in terms of the process variables by establishing their interaction. The results of surface profile parameter for burnished specimen, which has been made according to the experimental design matrix used in this work, are used based on the statistical methodology mentioned above.

It should be pointed out here that surface profile parameters namely; roughness average (Ra), was measured. Using the results of the response, mathematical models that related burnishing responses, Ra to burnishing parameters have been proposed.

To check the adequacy of each model and the analysis of variance were carried out by using the F-ratio test.

Based on the experimental data, the model is as follows:

$$Ra = 0.5512 - 0.0968x_1 + 0.272x_2 + 0.083x_3 - 0.168x_3 + 0.03x_1^2 + 0.199x_2^2 - 0.015x_3^2 + 0.199x_4^2 + 0.044x_1x_2 + 0.092x_1x_3 + 0.143x_1x_4 - 0.03x_2x_3 + 0.212x_2x_4 - 0.007x_3x_4 \quad (4)$$

VI. RESULTS AND DISCUSSION

Figures (6)-(8) show three-dimensional curves for the effects of various combinations of the input ball burnishing parameters (burnishing speed, feed, depth of penetration, and number of passes) on average roughness. The graphs were constructed from the experimental results using response surface methodology (RSM) and the final equations (mathematical models) created above. In the following paragraphs, the burnishing results will be discussed in terms of each of the burnishing parameters.

A. Effect of Working Parameters on Average Roughness, Ra

The effect of burnishing speed on average roughness at various feeds, depth of penetrations, and number of passes can be assessed from Figures (6)-(8). It can generally be seen from these Figures that the surface average roughness decreases slightly with an increase in burnishing speed at any value of feed, depth of penetration and at low number of passes. This is may be due to the stability of the ball burnishing tool which is much better at high speeds within the range of speeds used in this study. The best results from these figures were obtained at the highest speed used in this work (85m/min). However, an increase in burnishing speed at high number of passes deteriorates the surface roughness because of the overhardening and consequent flaking of the surface layers.

Burnishing feed is one of the very important burnishing parameters that affect the results of this ball burnishing process. It can be seen from Fig. 6 and Fig.7 that for a given burnishing speed, and / or depth of penetrations the average roughness decreases with moderate burnishing feed, reaching a minimum value at burnishing feed of (0.25-0.35mm/rev). A further increase in burnishing feed causes an increase in average roughness. It is better, then, to select low feeds because the deforming action of the ball burnishing tool is greater and metal flow is regular at low feed.

The effect of depth of penetration on average roughness for different speeds and feeds can be assessed from Fig. 7. The general trend of the results reveals that an increase in depth of penetration, within the range used in this study, leads to an increase of the burnished surface roughness. Fig. 8 presents the effect of the burnishing number of passes on average roughness at various speeds. The results show that the number of passes is one of the most significant factors affecting the surface roughness. There are two interactions, the first is between number of passes and burnishing speed; as shown in Fig. 8. A combination of low burnishing speed with high number of passes leads to a substantial improvement in the burnished surface roughness. A combination of high burnishing speed with high number of passes deteriorates the burnished surface finish. It is believed that this occurs because of the over hardening and consequently flaking of the surface layers.

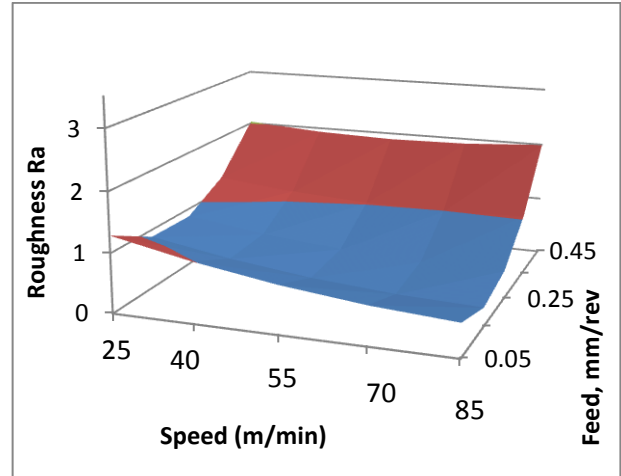


Figure 6 Effect of Burnishing Speed and Feed on Surface Roughness Average

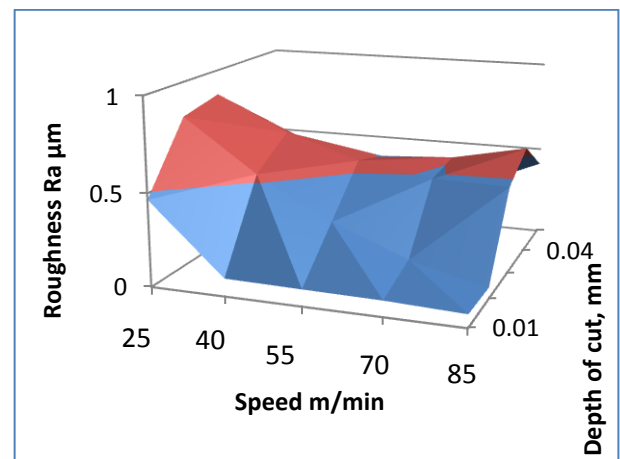


Figure 7. Effect of Burnishing Speed and Depth of Penetration on Surface Roughness Average

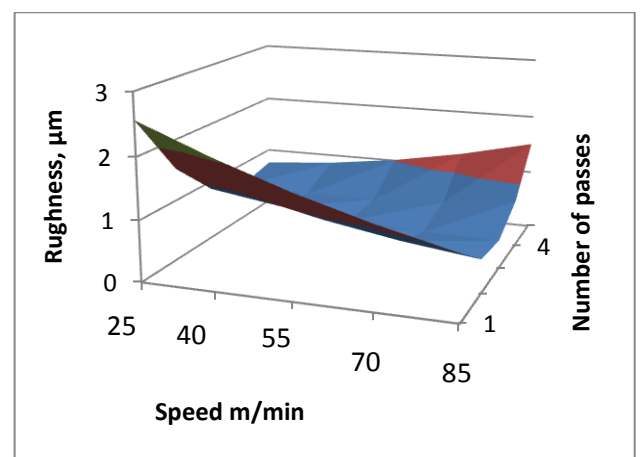


Figure 8. Effect of Burnishing Speed and Depth of Penetration on Surface Roughness Average

VII. CONCLUSIONS AND RECOMMENDATIONS

In this investigation the ball burnishing process was carried out. The effects of burnishing parameters using the proposed ball burnishing tool were studied. The following can be concluded:

- 1- A good correlation between the experimental and predicated results derived from the models was exhibited. Thus, using the proposed procedure, the optimum ball burnishing conditions should be obtained to control the surface response of other materials.
- 2- The results obtained from this work have shown that burnishing speed has different effect on the response studied. An increase in burnishing speed leads to a slight improvement in surface finish.
- 3- The recommended burnishing feeds that result in good surface finish are in the range from 0.25 to 0.35 mm/rev.
- 4- The best results for surface finish were obtained at depth of penetration in the range from 0.01 to 0.02 mm.
- 5- The best results for response were obtained in the range from 2 to 3 passes and higher speeds.
- 6- The principle factors which affect the results of the response studied in this work are the workpiece over hardening and the flaking which generally occur when using a combination of high depth of penetration with a high number of passes. Other factors include the great deforming action of the tool and the increase of structural homogeneity of the surface layers that occurs when using low burnishing feed.

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BIOGRAPHIES



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