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Investigations of Corrosion Resistance, Residual Stress and Conductance of Roller Burnished Component

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Abstract* – Burnishing is a very simple and effective method for improvement in surface finish and can be carried out using existing machines, such as lathe and milling machine. On account of its high productivity, it also saves more on production costs than other conventional processes such as super finishing, polishing, honing and grinding. Moreover, the burnished surface has a high wear resistance, corrosion resistance and better fatigue life. In conventional machining processes the tensile residual stresses are induced on the surface of material, which reduces the fatigue strength of material, this can be prevented by inducing residual compressive stresses on the surface of material. Burnishing is a cold working process in which initial asperities are compressed beyond yield strength against load. The surface of the material is progressively compressed, then plasticized as resultant stresses reach a steady maximum value and finally wiped a superfine finish. In the present paper, preliminary investigations for roller burnishing are specifically focused. It gives a thorough idea about the effect of roller burnishing parameters (such as feed, speed, burnishing force and number of passes) on corrosion resistance, residual stresses and electrical conductivity on AISI 4340 steel (EN24 steel).

Keywords: Roller Burnishing, Corrosion Resistance, Residual Stresses and Electrical Conductivity.

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1. INTRODUCTION

Technological revolution in the recent years increased in the expectation from the manufacturing industry. The expected service-life of the components has taken a long-leap, without increasing the production cost. So the engineers had to come up with improvised and versatile manufacturing processes that address these expectations. The service behavior and life of the components depend mostly on the surface properties. For this reason, significant attention has been paid to the post-machining operations, because the conventional machining processes like turning, milling etc produce surfaces with inherent irregularities and imperfections. So there is need for a surface finishing operation that nullifies these irregularities and also improves other surface properties like hardness, corrosion resistance, wear resistance and fatigue life. These properties can be increased by utilizing surface plastic deformation (SPD) process, which does not involve material removal, but improves the surface properties by deforming the surface plastically, under compressive loads. Under this external load, the surface of the component is subjected to cold working. One such SPD process that has gained increasing acceptability in the manufacturing industry is burnishing.

The field of surface engineering is highly respected and this field has demonstrated many developments that have improved the operational life of engineering components over the years. Of late, a new field ‘engineered surfaces’ is emerging as an effective and economic route to successful manufacture.

Engineers who want to improve the life of a component eventually have to take into consideration the surface of the component. In this contest, Roller Burnishing (RB) is relatively a new method of surface enhancement, which has raised surface treatment to the next level of sophistication.

Development of Roller Burnishing (RB) has been one of the major innovations in the field of ‘engineered surfaces’. Roller Burnishing (RB) differs significantly from other surface enhancement methods such as conventional burnishing, shot peening, laser peening and oil jet peening.

In addition, the components processed by Roller Burnishing (RB) possess combination of important properties, which may not be obtained by other surface enhancement methods. These include surface finish, surface micro-hardness, fatigue life, corrosion resistance, wear resistance, dimensional tolerances, and residual stresses etc. Many of these characteristics are highly essential in automotive, aerospace, marine and other industrial applications. Thus, RB raises burnishing to the next level of sophistication. As a result, RB is gaining rapid prominence as surface enhancement technique.

A literature survey shows that work on the burnishing process has been conducted by many researchers and the process also improves the properties of the parts, e.g: wear resistance[9], hardness[10], surface quality[1,2,8,9,10,11], corrosion resistance[3,4,11,12,13] and increased maximum residual stress in compression[8,10].The majority of the research existing in literature on the effect of burnishing parameters on the burnished surface have been experimental in nature. This paper examines the use of roller burnishing process to examine corrosion resistance, residual compressive stresses and electrical conductivity for AISI 4340 steel.

2. METHODOLOGY

A set of screening experiments to be conducted using one-factor-at-a-time method on general purpose lathe machine.

The purpose of these experiments is to identify the most significant process parameters for the work material considered.

Following process parameters are chosen for this study: burnishing pressure, burnishing speed, burnishing feed, Roller material, Roller diameter, length, number of passes and depth of penetration etc.

From these experiments, detailed preliminary investigations will be conducted.

3. EXPERIMENTAL SETUP

Burnishing is a versatile process that improves the surface finish and dimensions of the turned parts, without usage of extensive tooling. A conventional lathe, on which the work pieces were turned, can be used for burnishing, thereby eliminating the time and effort for remounting the work piece. The tool used for burnishing consists of one or more ball or roller, held in a casing. This tool can be mounted on the tool post of the lathe. When the tool is made to come in contact with the rotating work piece, the friction force rotates the balls or rollers of the tool, in a planetary motion. Burnishing process is considered as a cold working process, because the surface of the work piece is subjected to severe stress due to the planetary motion between the tool & work piece and the pressure applied by the tool. When this stress exceeds the yield strength of the material, it results in the plastic flow of the material from the peaks of the surface irregularities into the valleys, thereby reducing the surface roughness. This also induces thermally stable and long lasting compressive residual stresses.

Roller Burnishing: Roller burnishing, as the name suggests, employs a tool with single or multiple rollers. For a multiple roller tools, the rollers are present around the circumference of a supporting shank. Figure 2 shows the schematic of burnishing operation with single roller burnishing tool. The shank will be connected to the machine, which can be a drilling machine or milling machine or even a lathe. When the tool is made to come in contact with the work piece, the rollers around the shank also rotate, resulting in the burnishing of the work piece.

4. EXPERIMENTAL DETAILS

4.1 Material: Iron & steel alloy AISI 4340 was used in the experiment, supplied as 16 mm diameter bar and (1m) long; the chemical compositions are shown in Table 1. Appropriate specimens were cut from this bar to an approximate length of 200 mm using a sawing machine as shown in figure 1.[2]

Table1. Chemical Composition of AISI 4340

C%	Si%	Mn%	S%	P%	Cr%	Mo%	Ni%
0.36-0.44	0.1-0.35	0.45-0.7	0.040max	0.035max	1-1.4	0.20-0.35	1.30-1.70

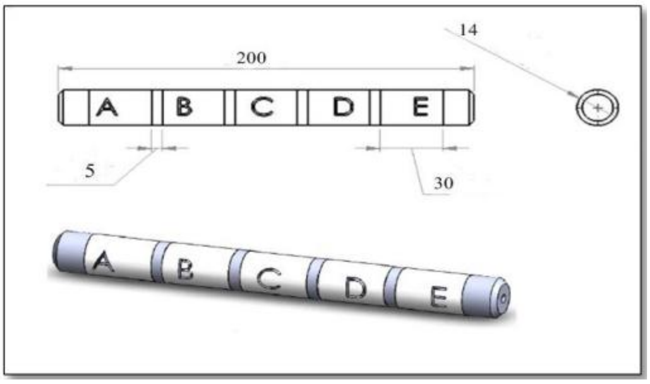

Figure 1: Specimen dimension

4.2 Experimental Setup

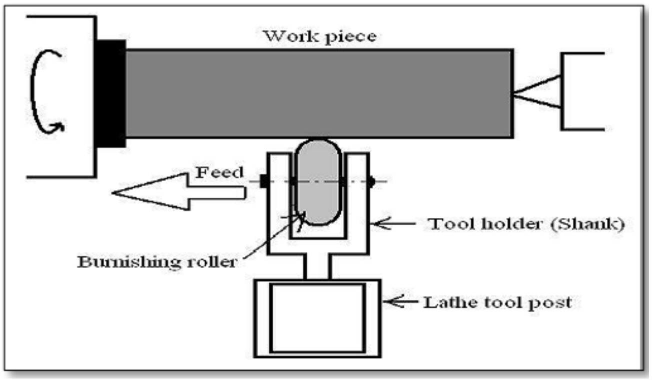

Figure 2: Experimental setup

4.3 Burnishing tool: A 60 mm diameter hardened roller was used for burnishing.

Figure 3: Roller burnishing tool

4.4 Burnishing Procedure:

1. Saw the original rod (1m long) into 5 specimens (each 200m).

2. Turning each specimen to a diameter of 14 mm on the TURNER lathe.

3. Each specimen is subjected to the turning conditions listed in Table 3.

Directly after each specimen turning; the cutting tool was replaced by the roller burnishing tool to enable the burnishing process to be carried out on the specimens using the same lathe while maintaining the same centricity of the specimen. Throughout the experimental program of this study the turning and burnishing were carried out dry.

Cleaning the roller was carried out continuously in order to prevent any hard particles from entering the contact surface between the tool and the specimen, such hard particles usually leaving deep scratches, which may damage the burnished surface of the specimen.

The operating parameters range was collected from the machine Catalogue

Preliminary experiments are carried out using one-factor-at-a-time approach. Based on these experiments, most significant burnishing process parameters were identified.

Table2. The Turning Conditions

Cutting Speed (rpm)	Feed (f) (mm/rev)	Number of passes	Burnishing Force(N)
820	0.2	4	7

5. TESTING EQUIPMENTS

The three output responses i.e Corrosion resistance, Residual stresses and electrical conductivity are measured by using a corrosion testing unit , X-Ray Diffractometer and Kelvin's Double Bridge respectively. On each work piece three readings are taken at different points on entire length of the workpiece and then average value is taken in order to reduce error. The equipments are shown in figures 4,5 and 6 below.

Figure 4: Corrosion resistance

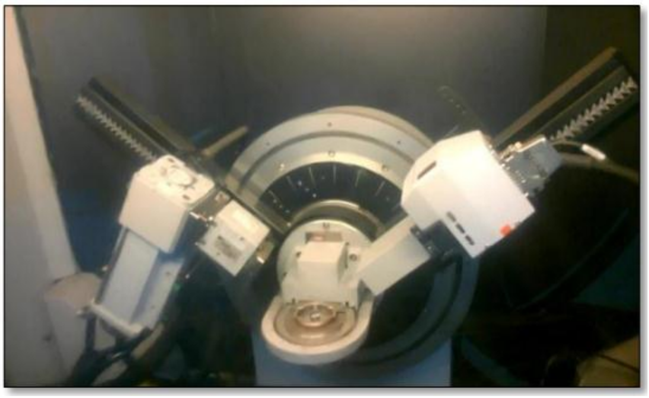

Figure 5: X-Ray Diffractometer

Figure 6: Kelvin's Double Bridge

6. RESULTS & DISCUSSION:

6.1 Corrosion Test:

Corrosion is a phenomenon, in which the material of the component reacts with the environment surrounding it. This results in the removal or addition of material to the exposed surface. In most of the cases this event is undesirable, as it reduces the life of the component and results in premature failures. Corrosion resistance of the components can be improved by subjecting them to additional processes like painting, doping etc. But these processes involve additional cost and time. Burnishing process, apart from improving the surface finish also improve the corrosion resistance. The main reason for this is enhanced hardness, refined grain size and induced compressive stresses. The induced compressive stresses also hinder the stress corrosion cracking phenomenon, which is quite common when components have to operate under cyclic loads in corrosive environment. The current work includes extensive study of improvement in corrosion resistance of roller burnished components.

Weight Loss Measurement:

The specimens of different weights were immersed in different beakers containing 100 ml of 1 M hydrochloric acid solutions(with 2 ml ethanol) in the absence and presence of different concentrations such as 50, 100, 150 and 200 ppm of 2-chloro 3-formyl quinoline for about 4 h immersion time at room temperature. Mild steel strips were weighed after and before immersion time to record the weight difference. This procedure is done separately for unburnished and burnished specimens. Further, by the help of weight differences, corrosion rate is calculated.[12,13]

Weight loss of specimen before burnishing = 0.46gm

Weight loss of specimen after burnishing = 0.3gm

Corrosion rate for unburnished specimen:

v1 = (WEIGHT LOSS OF SPECIMEN)/(SURFACE AREA×TIME)×100

v1 = 0.46/(600×48)×100 = 0.16(g/cm2 h)

Corrosion rate for burnished specimen:

v2 = (WEIGHT LOSS OF SPECIMEN)/(SURFACE AREA×TIME)

v2 = 0.30/(600×48) ×100 = 0.104(g/cm2 h)

Therefore the present work shows that Corrosion Rate (CR) of unburnished AISI 4340 steel is more in comparison with that of burnished steel.

6.2 Test for residual stresses:

Compressive stress has a beneficial effect on the fatigue life and stress corrosion cracking of the material because it delays crack initiation and propagation. Tensile stresses on the contrary reduce the mechanical performance of the components. So it is always desirable to have compressive stresses induced in the components. Under the immense force of the burnishing tool, the material of the component under goes compression, there by inducing residual compressive stresses. These compressive stresses are very long lasting and do not dissipate under normal working conditions. But when the component is subjected to heat treatment or used at elevated temperatures, these compressive stresses get relaxed. So the temperate of operation of the burnished components has to be monitored and controlled to extend the life of the compressive stresses. Conventional metal forming processes like turning, milling etc induce tensile stresses in the component. So the components have inferior mechanical properties. When these components are burnished, the tensile stresses are relaxed and compressive stresses are induced in the components.

The residual stresses were measured using X-ray residual stress analyzer. In this the lattice distortion creates difference in inter-planar spacing of atoms of the material, which can be measured through X-ray diffracting technique. In this measurement the difference in the inter-planar spacing and subsequent lattice distortion are compared with the standard values of an undistorted metal and the strain is calculated. The strain in turn gives the residual stress values.

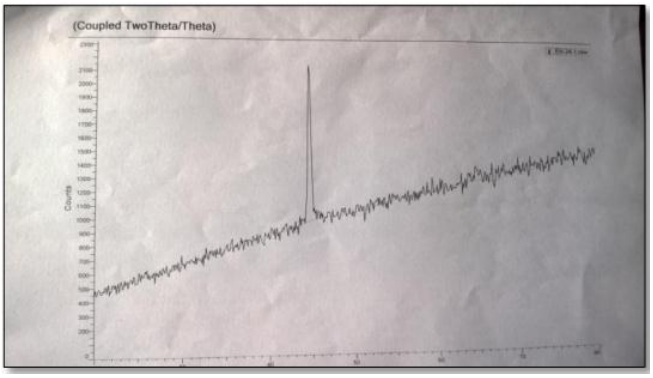

Figure 7: Residual stress

Table 3. Residual Test results

Burnishing Condition	Compressive residual stress (MPa)
BB	-208.1
AB	-248.72

[BB – before burnishing, AB – after burnishing]

The residual stresses that are determined by XRD are shown in fig. 7 for AISI 4340 steel. The data in Table 3 shown that the residual stresses gradually build up with burnishing and exhibit a peak in residual stresses. The alloy steel EN24 show significant decrease in the magnitude of compressive residual stresses. In alloy steel AISI4 340, higher extent of burnishing resulted in different extents of microstructural modification as reflected by the magnitude of compressive residual stresses.

6.3 Electrical Conductivity Test :

The electrical conductivity is the measure of how well material conduct electricity. Most of the good electrical conductors are metals, in which closely linked atomic structures allow the free movement of electrons. This particular factor of electrical conductivity is not constant and varies from material to material. However there are some general factors as well, that commonly affect the conductivity in a significant manner. Some of these factors are temperature, impurities, porosity etc. When the other factors are maintained constant, the reduction in porosity can improve the electrical conductivity of materials.

In the current study, the electrical conductivity of burnished and unburnished/turned components of AISI 4340 steel is determined to study the effect of roller burnishing.

To measure the surface conductance (electrical), it is essential to measure the resistance of the surface of burnished and unburnished/turned specimens, on which test has to be conducted. As metals are good conductors of electricity, their conductivity/resistivity varies in nature. Ex: The specimen under test, e.g: AISI 4340 steel, is having specific resistivity ʃ = 2.8 x 105 Ω - cm.

$$R = \int l/a,$$

where ʃ = Specific Resistivity of the specimen,

I = Length of specimen and a = cross section area

Unit of resistance = Ω (Ohm)

Conductance G = 1/R and

Unit of conductance = Ʊ (Mho).

In this test, Kelvin’s double bridge is used which is a low range resistance measuring instrument with the range 0.00001 Ω to 110 Ω.

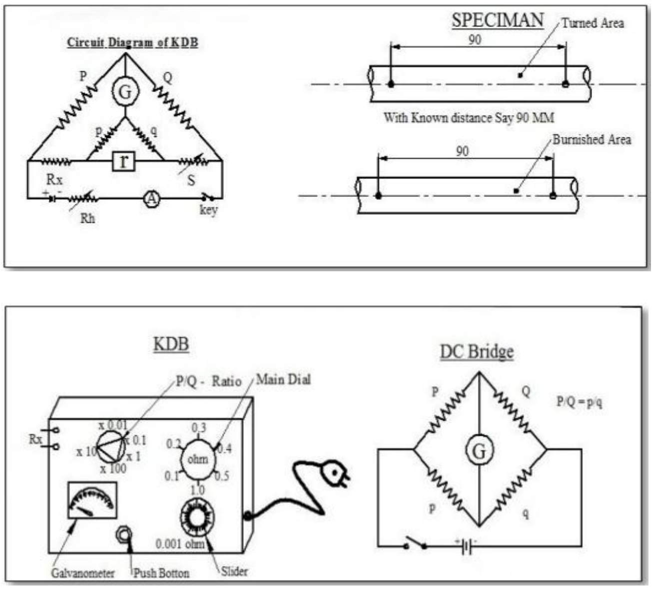

Figure8. Electrical Circuits

Bridge gets balanced when galvanometer shows null indication (zero) as galvanometer is a centre zero scale sensitive instrument.

Probes are made using template or camlin scale of 15 cm, drilling hole for 9 cm distance of active burnished and turned length.

Rx = P/Q x S, where Rx is unknown resistance

Practically Rx = P/Q ratio x (slider reading x slider multiplier + main dial reading)

Procedure:

1. Rx-unknown resistance terminals of the KDB are connected to the probes designed by using the template as shown in the above diagram.

2. KDB is turned on, as it operates on Battery / mains supply.

3. P/Q ratio is chosen from the ratio knob.

4. Main dial of the slider and slider knob are adjusted to see the galvanometer null deflection, while at each step, push button is pushed. Push button is provided to protect galvanometer against imbalanced current. Readings of P/Q ratio arm, main dial of the slider and slider (precision) and multiplier constant are noted down.

5. Calculations are done using formula, Rx = (P/Q) x S

6. 2 to 3 readings are taken on each specimen for different P/Q ratio

7. The mean resistances of the turned and burnished surface are compared. If the resistance of one of the specimens is high, it will be having low conductivity and vice versa.

8. Finally the results are concluded as shown in table 4,

Table 4

Sl. No.	P/Q Ratio	S = (Slider reading x 0.001) + main slider (for turned specimen)	Rx = (P/Q) x S (Ohms)
1.	100	(1.250 x 0.001)+0	0.1250
2.	100	(1.225 x 0.001)+0	0.1225
		Mean Rx	0.1237

Sl. No.	P/Q Ratio	S = (Slider reading x 0.001) + main slider (for burnished specimen)	Rx = (P/Q) x S (Ohms)
1.	100	(1.700 x0.001)+0	0.1700
2.	100	(1.075 x0.001)+0	0.1075
		Mean Rx	0.13875

Specimen	Resistance R_{mean} (Ohms)	Conductance G = 1/R (Mho)
Turned steel	0.1237	8.084
Burnished steel	0.13875	7.207

From the above results, it can be concluded that electrical conductivity of burnished is marginally less as compared to turned/unburnished component.

7. CONCLUSION

The roller burnishing process is very complicated and it is influenced by many factors. Thus investigating the parameters and their influences is a significant task. In brief, the conclusions of this work are as follows:

1. Corrosion Rate (CR) of unburnished AISI 4340 steel is more in comparison with that of burnished steel. This shows that the burnished component has more corrosion resistance.

2. The alloy steel AISI 4340 show significant decrease in the magnitude of compressive residual stresses. In alloy steel AISI 4340, higher extent of burnishing resulted in different extents of microstructural modification as reflected by the magnitude of compressive residual stresses.

3. The electrical conductivity of burnished component is marginally less as compared to turned/unburnished component.

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