Preliminary Investigations into Roller Burnishing Process

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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 dimensional tolerances, surface hardness, surface roughness and fatigue life on AISI 4340 steel (EN24 steel).

Keywords: Roller Burnishing, Dimensional Tolerances, Surface Hardness, Surface Roughness and Fatigue Life..

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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[], hardness[1, 4-6, 8, 10-14, 16-18, 21-23], surface quality[1-10, 12-18, 20-23] and increased maximum residual stress in compression[13].The majority of the research existing in literature on the effect of burnishing parameters on the burnished surface have been experimental in nature. Very few analytical models are available. This paper examines the use of roller burnishing process to give a good surface integrity 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 Table1. Appropriate specimens were cut from this bar to an approximate length of 200 mm using a sawing machine as shown in figure 1. [5]

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

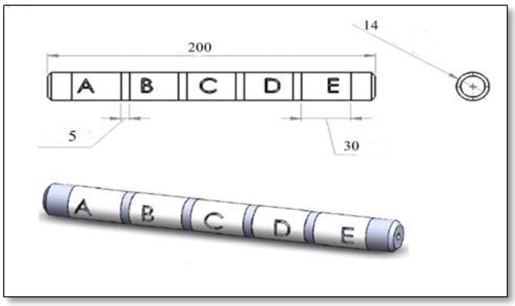

Fig.1 Specimen dimension

4.2 Experimental Setup.

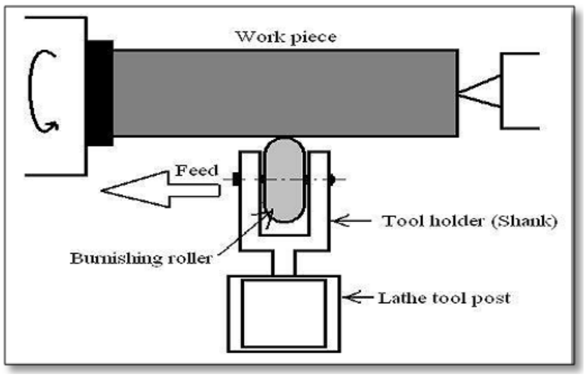

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Fig.2 Experimental setup

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

Fig.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 2.

4. 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.

5. 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.

6. 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 four output responses i.e. dimensional tolerance, hardness, surface roughness and fatigue are measured by using a digital vernier caliper, surface roughness tester, Rockwell hardness tester and fatigue testing machine 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 4,5,6 and 7 below.

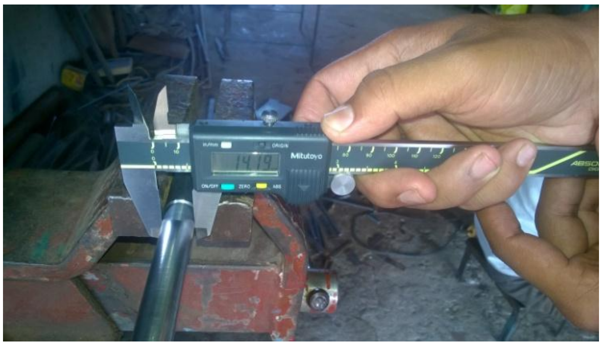

Fig.4 Digital Vernier Caliper

Fig.5 Surface Roughness Tester

Fig.6 Hardness Tester

Fig.7 Fatigue Testing Machine

6. RESULTS & DISCUSSION:

6.1 Dimensional Tolerance Test:

The specimen is turned in a lathe machine to the required dimension as shown in the fig. The turned diameter is measured by the digital vernier calliper and the dimensions are noted. The same specimen is burnished by the roller burnishing tool and again the readings are noted. The results before and after burnishing are tabulated as follows:

Table 3. Dimensional Tolerance Test results

Measured number	Dimensions in mm			
	Before Burnishing	After Burnishing	Difference	Relative difference
1	14.0	13.96	-0.04	0.28
2	14.01	13.95	-0.06	0.43
3	14.0	13.95	-0.05	0.36
Avg	14.00	13.95	-0.05	0.36

From the above readings it is clear that burnished component is having better dimensional tolerance compared with unburnished component

6.2 Hardness Test

The microhardness values are obtained as a function of radial distance from burnished surface to the centre. A microhardness machine (Model: Micromet 2100, Buehler Ltd, USA) with Vickers indenter and 500 g indenter load was employed for this purpose.

Table 4. Hardness results

Measured number	Hardness results,BHN			
	Before Burnishing	After Burnishing	Difference	Relative diff in %
1	271	281	10	3.55
2	268	286	18	6.29
3	273	283	10	3.53
AVG	270	283	13	4.59

From the trials it is found that there is significant change in surface hardness due to the variation in spindle speed, feed, number of passes and burnishing force. It is observed that at optimum burnishing process parameters, the rate of surface hardness is increased. Of course, the surface hardness is increased to an average of 4.59% under optimum burnishing process parameters. The best surface hardness of 286 is obtained at rotation speed 820 rpm, feed 0.2 mm/rev, burnishing force 7 N and number of passes 4, in tested conditions.

6.3 Surface Roughness Test

Surface roughness values of the work pieces are noted before and after burnishing by using stylus probe instrument. From these data, the surface finish values are also determined before and after burnishing for different burnishing speeds. It is to be noted here that either of surface roughness or surface finish can be used as representative of surface characteristic feature (the lower is surface roughness and higher is surface finish).

Table 5. Roughness results

Measured number □m	Roughness results, , µm			
	Before Burnishing	After Burnishing	Difference	Relative difference
Ra_1	2.500	1.117	-1.383	55.32
Ra_2	2.240	0.777	-1.463	65.31
Ra_3	2.261	0.750	-1.511	66.82
Average	2.333	0.881	-1.452	62.23

From the trials it is found that there is significant change in surface roughness due to the variation in spindle speed, feed, number of passes and burnishing force. It is observed that at optimum burnishing process parameters, the rate of surface roughness is reduced and a finishing surface obtained. Of course, the surface roughness is reduced to an average of 37.77% under optimum burnishing process parameters. The best surface finish of 0.750 µm is obtained at rotation speed 820 rpm, feed 0.2 mm/rev, burnishing force 7 N and number of passes 4, in tested conditions

6.4 Fatigue Life Test:

The fatigue life of the component subjected to cyclic loads is mostly governed by the stresses induced in the components. Conventional machining and finishing processes like turning, milling, grinding, induce tensile stresses in the components. These stresses deteriorate the fatigue performance. So the components which are subjected to cyclic loads are generally processed by secondary operation which relaxes these tensile stresses and induces compressive stresses. Burnishing is one such operation, which induces compressive stresses of considerable magnitude, which do not get relaxed under working conditions, except high temperatures.

In the present test, the standard fatigue specimen is checked for expected number of revolutions at specific stress. The methodology is as follows:

1. The standard specimen (Material: AISI 4340 steel) is prepared.

2. The load is selected depending upon the bending moment to be imposed.

4. The test is started by starting the motor and it will stop automatically as soon as the specimen fails.

5. The same procedure is repeated for the specimen after it is burnished.

Operating Principle:

The specimen loading arrangement results in a constant bending moment $\frac{PL}{4}$ over the test length of specimen.

P = load applied over the specimen in kg

L= Gauge length of specimen= 9.5cm

Bending moment $= M_b = \frac{PL}{4}$

Bending stress $= t_b = \frac{Mb}{Z} = \frac{Mbx32}{\pi d3}$

$[Z = \frac{\pi d3}{32}$ for circular section$]$
d=0.9cm
Assume t_b=3500kg/cm^3

Assume t_b=3500kg/cm^3

$$t_b = \frac{PLx32}{4\pi d3}$$

$$3500 = \frac{Px9.5x32}{4x\pi x0.9x0.9x0.9}$$

P=105.47kg

$P \approx 100$kg.

$$M_b \text{ (for one end)} = \frac{PL}{2} = \frac{100x9.5}{2}$$
M_b = 475kg-cm

For Bending moment M_b = 475kg-cm, unburnished specimen fatigue failure occurs at 8903 cycles. For the same bending moment Burnished specimen fatigue failure occurs at 13867 cycles.

7. RESULTS:

Table 5.Fatigue test results

Component	Number of cycles for fatigue failure
Before burnishing	8903 cycles
After burnishing	13867 cycles

It is concluded from the above results that the roller burnished component led to higher enhancement in fatigue life compared to unburnished/turned component. Roller Burnishing induced residual compressive stresses play an important role to improve the fatigue performance because it significantly retards the fatigue micro-cracks

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propagation. As a result the fatigue crack nucleation site changes from the surface to subsurface region.

8. 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. The burnished component is having better dimensional tolerance compared with unburnished component.

2. The surface hardness is increased to an average of 4.59% under optimum burnishing process parameters. The best surface hardness of 286 is obtained at rotation speed 820 rpm, feed 0.2 mm/rev, burnishing force 7 N and number of passes 4, in tested conditions.

3. The surface roughness is reduced to an average of 37.77% under optimum burnishing process parameters. The best surface finish of 0.750 µm is obtained at rotation speed 820 rpm, feed 0.2 mm/rev, burnishing force 7 N and number of passes 4, in tested conditions.

4. The roller burnished component led to higher enhancement in fatigue life compared to unburnished/turned component.

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