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Investigations on the Surface Hardness and Roughness of Roller Burnished Surfaces

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Abstract

Burnishing, a plastic deformation finishing process, improves the surface characteristics when applied to cylindrical workpieces. This paper reports the results of an experimental investigation to study the influence of burnishing speed, number of passes and type of lubricant used on the surface hardness and roughness. The roughness peaks are flattened and the quality of the workpiece surface hardness and roughness is improved. FE results obtained indicates the maximum stress induced in the work piece reduces at higher speeds.

Keywords:— *Burnishing, Surface Hardness, Roughness, FE analysis, Maximum Stress.*

I. Introduction

Burnishing is a chipless finishing method, employs a rolling tool, pressed against the rotating workpiece, in order to achieve plastic deformation of the surface layer of the workpiece. The principle of the burnishing process, shown in Figure 1, is based on an indenting tool (ball or roller) rolling against the workpiece surface [1]. Plastic flow of the original asperities occurs when the yield point of the workpiece material is exceeded [2]. In this way, asperities are flattened. Compressive stresses are also induced in the surface layer, giving several improvements to mechanical properties. Burnishing can improve both the surface strength and roughness. The increase of surface strength serves to improve fatigue resistance under dynamic loads [3].

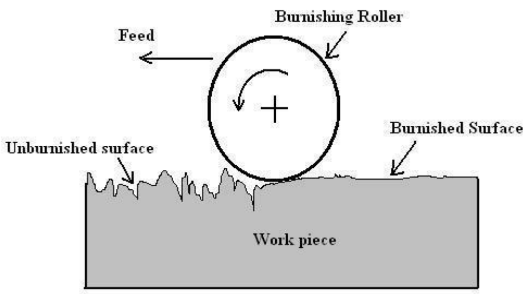

Figure 1: Principle of Burnishing

The process of burnishing is performed by applying a highly polished and hardened ball or roller with external force onto the surface of a cylindrical work piece. The process parameters speed, feed, number of tool passes, tool diameter and material, lubricant influences the surface characteristics viz., surface finish, surface hardness, compressive residual stress, microstructure, wear resistance and fatigue of the workpiece. The burnishing process increases the surface hardness of the work piece, which in turn increases corrosion resistance, improves tensile strength and maintains dimensional stability of the work piece. The process parameters have immense effect on the end results of any manufacturing process. Extensive work is reported on the effect of various parameters on the surface and material characteristics of the components. Experimental work was conducted on vertical machining center to establish the effects of various burnishing parameters on the surface finish of high carbon high chrome steel [4]. The process parameters considered were burnishing speed, ball material, lubricant, burnishing forces and feed. Tungsten carbide ball provided better and consistent surface finish. Grease was found to be a better lubricant than cutting oil. The effect of speed, feed, force, number of tool passes and ball diameter on the surface roughness and hardness of two different nonferrous metals are reported. The burnishing force and the number of tool passes are considered as predominant factors that significantly affect the surface characteristics.

Apart from the conventional parameters, the influence of the tool size, lubricants and supporting methods for the tool on the roughness of the finished surface, using cemented carbide ball, in roller burnishing could be performed at speeds of up to 400m/min. The effect of lubricant oil on burnishing process with low viscosity and ores containing sulfur and phosphorus as effect of reducing roughness of the burnished surface when the cemented carbide, silicon nitride ceramic and bearing steel ball tools are used. High degree of strain hardening is produced on the surface of the burnished component [5]. Burnishing load is also a main factor affecting the wear resistance and the work hardening of the process and the components. Improved bearing length ratio could be obtained on burnished surfaces as compared to grinded surfaces [6]. Cold working of the surface by burnishing improves the hardness of the work piece up to certain depth. The distribution of hardness beneath the surface is observed to improve after the roller burnishing process. The damage caused to the burnishing tool surface to work harden annealed steel bar shows that the burnishing force has a maximum effect on work hardening happening during this process. The effect of burnishing on the surface hardness of alloyed aluminium shows that an improvement in the micro-hardness is evident up to a depth of 0.45 mm, below the burnished surface. It is a very rare circumstance that a surface finishing processes results in the improvement in the strength of the component. Tensile stresses induced by machining and forming processes cause many adverse effects. So the elimination of these tensile stresses and induction of compressive stresses is possible by burnishing without varying the environment and component design [7]. Burnishing improves the resistance against stress corrosion cracking and depends on the magnitude of the cold working underwent by the surface. Fatigue strength of the components depends on the compressive stresses induced during the burnishing process [8]. The thermal stability of the compressive residual stress fields produced by burnishing improves the High Cycle Fatigue strength and is observed to be more when compared to shot peened surfaces. This is due to high degree of work hardening and induced compressive residual stress [9].The application of low plasticity burnishing to improve the life of the components subjected to various damage mechanisms, like corrosion, pitting, fretting and foreign object damage shows that the induction of thermally stable compressive residual stresses is the reason for the improvement in the life of the components that undergo burnishing [10]. In this paper, roller burnishing process is employed on a ferrous and nonferrous material to study the effect of roller speed, number of passes and coolant on surface hardness and roughness through experiments. FE analysis is performed to compute the maximum deformation and stress levels induced in the workpiece.

Table 1: Chemical Composition of Aluminum Alloy

Element	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
% Wt	90	0.15	1.5	0.5	2.5	0.2	0.3	0.15	5.4

Table 2: Physical Properties of Aluminum Alloy

Property	Density g/cc	BHN	UTS MPa	Yield Strength MPa	Thermal conductivity W/mK	Fracture Toughness MPa	Youngs Modulus GPa	% Elonation
Value	2.81	150	572	503	130	20	70	11

Table 3: Chemical Composition of Mild Steel

Element	Fe	C	Mn	P	S
% Wt	99.1	0.15	0.7	0.02	0.03

Table 4: Physical Properties of Mild Steel

Property	Density g/cc	BHN	UTS MPa	Yield Strength MPa	Poisson Ratio	Bulk Modulus GPa	Youngs Modulus GPa	% Elongation
Value	7.87	126	440	370	0.3	140	210	15

Table 5: Chemical Composition of High Speed Steel (Tool Material)

Element	C	Mn	P	S	Si	Cr	Ni	Ni	Fe
% Wt	0.08	2	0.045	0.03	0.75	0.18	0.12	0.1	Remaining

Table 6: Physical Properties of High Speed Steel

Property	Density g/cc	BHN	UTS MPa	Yield Strength MPa	Thermal conductivity W/mK	Bulk Modulus GPa	Young’s Modulus GPa	% Elongation
Value	7.85	188	510	390	14	150	220	15

2. Materials and Methods

Two work piece materials are selected for this analysis viz., Mild steel (AISI 1020) Ferrous Material and Aluminum (AA1200) Non Ferrous Material. The roller burnishing tool is made up of High speed steel. The chemical composition, physical properties of the workpiece and tool material are shown in table 1 – 6 respectively.

III. Finite Element Analysis

Structural analysis of the tool and work piece is performed in ANSYS. The total deformation, fatigue life of tool, maximum principal stress and maximum shear stress for 207 rpm is shown in Figure 2–5 respectively. The results obtained for 207, 284 and 444 rpm are tabulated in Table 7 and 8 for mild steel and aluminum respectively. The experimental layout varying work piece rotational speed, number of passes and the nature of lubricant is shown in Table 9. Based on the lathe machine speed limits, workpiece rotational speed, 207, 284 and 444 rpm are selected. Single, double and triple passes are considered. Air, water and kerosene are used as lubricants. The burnishing tool, operation performed during experimentation, the burnished components of all experiments are shown in Figure 6 – 8 in sequence. The surface hardness of the mild steel and aluminum areas measured in Brinell hardness tester and the obtained results are shown in Table. 10 and the corresponding graphs are shown in Figure 9. The surface roughness of the mild steel and aluminum samples are is measured in Talysurf roughness tester and the obtained results are shown in Table. 11 and the corresponding graphs are shown in Figure 10.

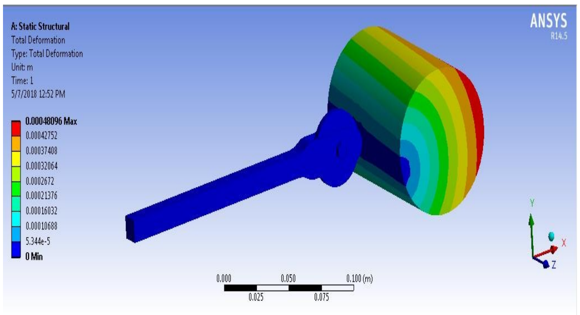

Figure 2, Total deformation

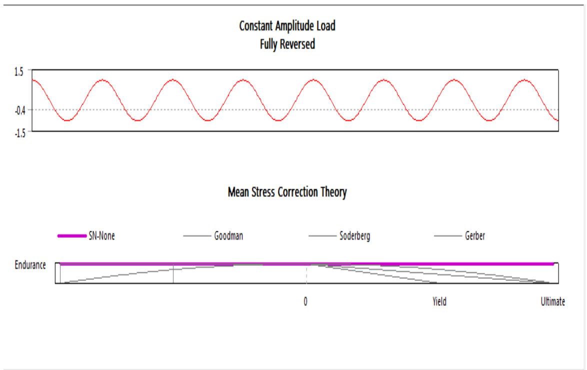

Figure 3. Fatigue tool

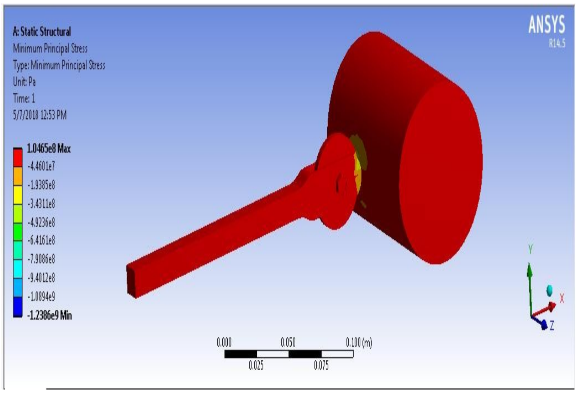

Figure 4. Minimum Principal stress

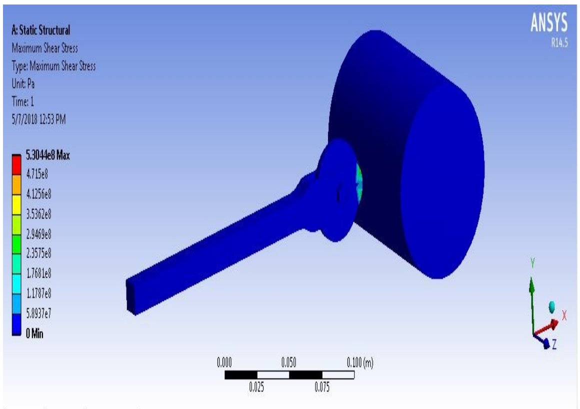

Figure 5. Maximum Shear Stress

Table 7: FE Results of Mild Steel

Particulars	Speed (rpm)		
	207	285	414
Total deformation x 10 -3(mm)	0.218	0.299	0.386
Equivalent stress x 109 (Pa)	7.558	1.041	1.511
Maximum principal stress x 108 (Pa)	5.234	7.206	1.046
Minimum principal stress x 108 (Pa)	1.535	1.313	1.907
Maximum shear stress x 108 (Pa)	4.362	6.006	0.724

Table 8: FE Results of Aluminum

Particulars	Speed (rpm)		
	207	285	414
Total deformation x 10-3 (mm)	0.427	0.662	0.856
Equivalent stress x 109 (Pa)	1.016	1.243	2.032
Maximum principal stress x 108 (Pa)	6.221	8.567	1.244
Minimum principal stress x 108 (Pa)	1.046	1.441	2.093
Maximum shear stress x 108 (Pa)	5.304	5.304	1.061

Table 9: Experiment Layout

Experiment No.	Speed(rpm)	No. of passes	Coolant
1	207	1	Air
2	207	2	Water
3	285	3	Air
4	285	2	Water
5	414	2	Air
6	414	1	water
7	414	3	Oil
8	207	2	Oil
9	285	1	Oil

Figure 6: Roller Burnishing Tool

Figure 7: Roller Burnishing Operation

Figure 8: Burnished Components

Table 10: Surface Hardness (BHN)

Mate-rial	Mild Steel (Ferrous)		Aluminum (Non Ferrous)	
Exp No.	Before Burnishing	After Burnish-ing	Before Bur-nishing	After Bur-nishing
1	60	61	50	54
2	58	65	50	56
3	54	60	54	61
4	48	54	51	58
5	41	52	51	53
6	54	58	52	60
7	48	52	50	58
8	54	56	50	56
9	52	54	51	60

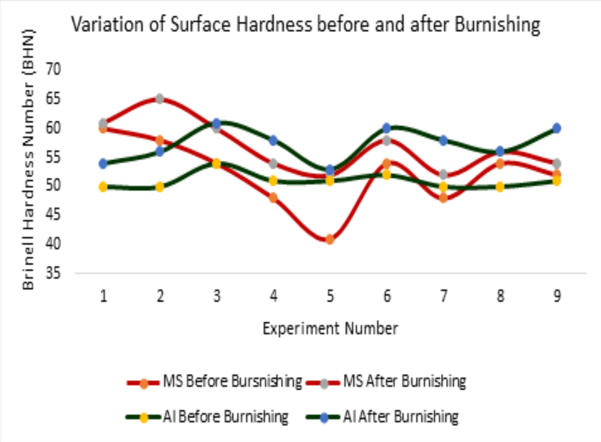

Figure 9. Variation of Surface hardness

Table No. 11 Surface Roughness (Ra, µm)

Mate-rial	Mild Steel (Ferrous)		Aluminum (Non Ferrous)	
Exp No.	Before Burnishing	After Burnishing	Before Burnish-ing	After Bur-nishing
1	3.99	2.86	2.610	0.509
2	3.66	3.35	2.45	1.017
3	3.508	1.72	2.991	0.832
4	4.77	1.83	2.525	2.40
5	3.801	2.25	2.177	1.635
6	2.70	2.70	2.89	2.50
7	2.44	2.01	1.72	0.89
8	3.14	3.04	1.618	0.967
9	3.80	2.204	1.635	0.081

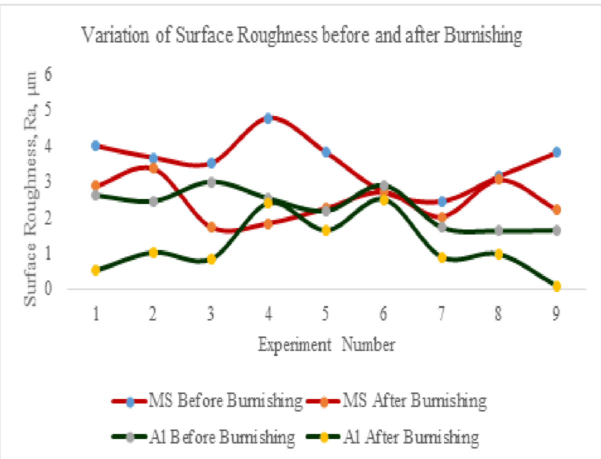

Figure 10 Variation of Surface Roughness

IV. Results and Discussion

The deterioration of the surface micro hardness and roughness in the burnishing process at high burnishing speeds is caused by the chatter that results from the burnishing tool feed given on the work piece surface. However at high burnishing speeds the micro hardness of the burnished surface increases in the number of passes. It is believed that the increase in the number of passes increases the surface hardness as a result of the increasing impact between the burnishing tool and the work piece surface. The effect of burnishing feed on both surface micro hardness and surface roughness is generally similar. The effect of feed is very clear on the high feed rate, the high surface roughness and low surface micro hardness. It is better, then, to select low feeds because the deforming action of the burnishing tool is greater and metal flow is regular at low feed. However the effect of feed on the surface micro hardness depends upon the spindle speed. When carrying out the burnishing process at very low spindle speed, an increase in feed leads to an increase in surface micro hardness. The deforming action of the roller burnishing tool is too high so that the flaking occurs at a combination of very low spindle speed with very low feed. The results show that the number of passes is one of the most significant factors affecting the surface hardness and surface roughness. This is obvious because the repeating of the burnishing process on the same workpiece leads to an increase in the structural homogeneity which results in an increase in the surface responses. However, in some cases, increasing the number of passes more than a certain number deteriorates the results because of the over hardening and consequent flaking of the surface layers. It is believed that the complex distribution of the residual stress in the surface region of the burnished workpiece is produced by mechanical, thermal and metallurgical effects that occur simultaneously. The residual stress can be tensile or compressive depending on the volume changes. The problem is further complicated because these factors often act synergistically. The maximum compressive residual stress increases with an increase in burnishing speed up to about 444 rpm. This is anticipated because the mechanical, thermal and metallurgical effects would be greater at high speed

V. Conclusions

1. In Roller Burnishing process on MS, the surface roughness decreases to a minimum value3.508µm to 1.72µm with the conditions of speed 285rpm, No. of passes 3, and coolant is air. The hardness increases to a maximum value 58BHN to 65BHN with the conditions of speed 207rpm, No. of passes 2 and coolant is water.

2. In Roller burnishing process on AL, the surface roughness decreases to a minimum value1.635µm to 0.081µm with the conditions of speed 414rpm, No. of passes 3, and coolant is kerosene. The hardness increases to a maximum value 54BHN to 61BHN with the conditions of speed 285rpm, No of passes 3 and coolant is air.

3. The maximum stress limit in the work piece decreases and the minimum stress limit increases with increase in tool rotational speed

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