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Prediction of Residual Stresses in Roller Burnished Components- A Finite Element Approach

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Abstract

Surface finish is an important factor in creating the durable metal components, and fatigue strength can be improved if compressive residual stresses are produced in the surface. Burnishing is a finishing process and compressive residual stresses are induced during the process. The present study of minimizing the surface roughness based on the experimental work, and finite element model was developed to evaluate the analytical results. Commercial purity Mild Steel and Aluminium were selected as work specimens and a high carbon high chromium roller was used as a tool for the burnishing process.

Keywords: Roller burnishing, Surface Roughness, Compressive Residual Stresses.

Introduction

Burnishing is a process in which the peaks of metallic surfaces are displaced to fill the valleys by plastic deformation. This can be achieved by pressing a hard and highly polished roller against the surface of metallic work piece. Fig 1 shows the schematic representation of roller burnishing process. Burnishing process is considered as a cold-working finishing process, differing from other cold-working, surface treatment processes such as shot peening and sand blasting etc. in that it produces a good surface finish and also induces residual compressive stresses at the metallic surface [1]. Accordingly. Burnishing distinguishes itself from the chip-forming finishing processes such as grinding, honing, lapping and super finishing which induce residual tensile stresses at the machined surface layer [2]. The changes in surface characteristics due to burnishing will cause improvements in surface hardness, wear resistance, fatigue resistance, yield and tensile strength and corrosion resistance, as claimed by many authors [3-6]. Process parameters such as the roller diameter (d), the burnishing force (p), the feed rate (f), the speed (v) and the number of tool passes (N), affect the surface roughness (Ra). The burnishing force and number of tool passes are the most predominant of the parameters that have an effect on the surface roughness of the work piece during the burnishing process [7]. The process parameters like speed, feed rate and number of tool passes also has an effect on surface roundness and reduction of diameter [8].Mathematical expressions for the optimum burnishing force and induced residual compressive stresses are derived based on dimensional analysis as well as from theory of elasticity [9].

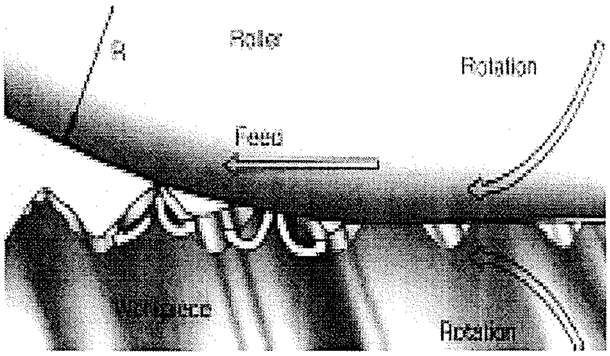

Figure 1: Principle Scheme of Burnishing

Burnishing is a means of producing a layer of compressive residual stresses of high magnitude. These stresses improve high cycle fatigue performance [10]. Residual compressive stresses approaching the material yield strength are developed using a series of passes of a freely rotating roller tool producing cold work, level of less than 3 to5% [11].

In the present work an attempt has been to study the effect of burnishing forces on surface roughness and residual stress distribution during the burnishing process using finite element analysis (FEA).

Experimental Setup

A 36mm diameter and 25mm width roller was used as the burnishing tool. The roller was held in a tool holder made up of mild steel material as shown in fig-2. The roller was made up of high carbon high chromium Steel and having hardness of 58 (Rockwell C grade) and Ra of 0.0015μm.

Experiments were conducted on two different materials mild steel and aluminium. These materials were turned for finish cut at high speed, low feed and low depth of cut on the centre lathe prior to the roller burnishing process. Grooves were made along the length of the work pieces to study the effect of changing various burnishing forces keeping the burnishing parameters constant. The burnishing force was measured with a tool dynamometer and surface roughness was measured with a taly surf instrument.

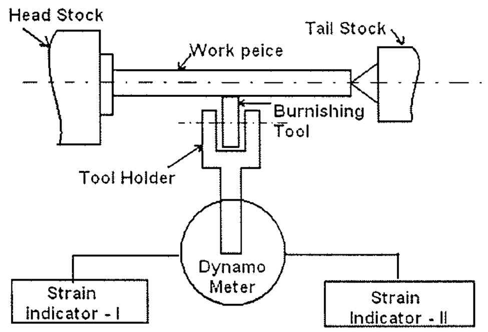

Figure 2: Schematic Diagram of Experimental Set-Up For Burnishing

Analytical Modelling

Compressive residual stress is calculated from numerical approach. In this numerical approach roughness is considered as a triangular asperity. The height of the triangle was considered as the roughness of the workpiece before burnishing. The normal force is acting on the apex of the asperity. The representation of the triangular model for numerical approach is shown in Fig 3. The depth of deformed layer depends on the normal load (F_n), the yield strength of the material (σ_y) and the asperity angle (α) [9].

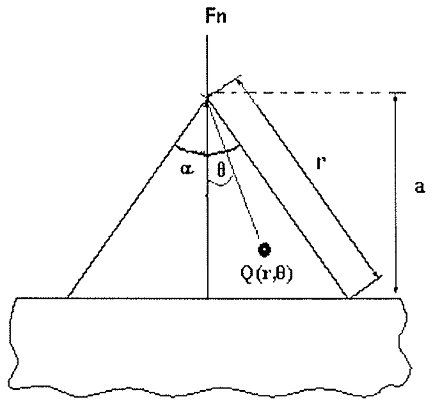

Figure 3: Coordinates of a point Q(r, θ) within a triangular asperity

The radial stress at point Q(r,θ) due to normal load P_n, is given by

$$\sigma_{r,0} = \frac{F_n \cos\theta}{(\alpha + \frac{1}{2}\sin\alpha)\, r} \tag{1}$$

Where 'r' is flank length
'a' is asperity height

Assuming that every point in the asperity as attained the plastic state before the valleys are filled with the peaks, the stress at Q(r,θ) may be equal to the yield strength (σ_y)of the material

$$\sigma_y = \frac{F_n \cos(\alpha/2)}{(\alpha + \frac{1}{2}\sin\alpha)\, r} \quad (2)$$

Substituting, $r = (a / \cos(\alpha/2))$, we get

$$\sigma_y = \frac{F_n \cos^2(\alpha/2)}{(\alpha + \frac{1}{2}\sin\alpha)\, a} \quad (3)$$

Finite Element Approach

The analysis process has been simulated using commercially available FEA package ANSYS-10. In FEA the burnishing process was modeled as 2D and the surface roughness was considered as a triangular asperity with included angle of 90^0. The height of the triangular asperity was considered as the surface roughness before burnishing i.e. 4.58μm for Mild Steel and 5.98μm for Aluminium. FEA model was shown in Fig 4.

The material properties of both the specimens, used in the FEA were shown in the table-1 [12]. PLANE-42, 2-D structural solid element was selected for the analysis.

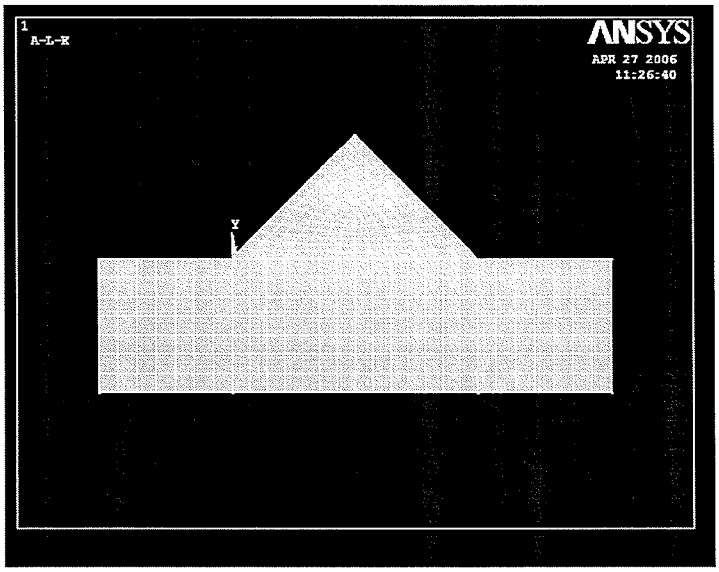

Figure 4: Finite Element Model

	Young's modulus (MPa)	Yield strength (MPa)		Poison's ratio	Density Kg/m^3
		min	max		
Mild Steel	2.0x10^5	205	1725	0.27	6920
Aluminium	0.7x10^5	35	550	0.34	2700

Table 1: Material properties of work specimen

Results and Discussion

Surface Roughness

The effect of burnishing force on the surface roughness for Steel and Aluminium is shown in Fig 5 and Fig 6 respectively. It can be seen from the curves of these graphs the surface roughness decreases with the increase in force to a minimum value after which it starts to increase. Although the burnishing force are greater in the later process, this force increases the penetration depth of the roller inside the surface will be increased, leading to a smoothing of the surface, if the force increases beyond the optimal value deteriorating the surface finish, because flaking of the surface due to high work hardening induced into the surface by the increase in the amount of plastic deformation.

Comparison of the practical and FEA values are presented in the table 2 and table-3 for both the materials. The deformed shapes of these materials in Finite Element Model are shown in Fig 7 and Fig 8.

Table 2: Roughness Values For Various Forces – Mild Steel Specimen

Force (N)	Surface Roughness (μm)		Deviation	Error (%)
	Experimental	FEA		
294.30	2.97	3.168	0.198	6.66
343.35	2.72	2.933	0.213	7.83
392.40	2.53	2.698	0.168	6.64
441.45	2.27	2.463	0.193	8.50
490.50	2.04	2.227	0.230	9.16
539.55	2.18			

Table 3: Roughness Values for Various Forces – Aluminium Specimen

Force (N)	Surface Roughness (μ m)		Devia-tion	Error (%)
	Experi mental	FEA		
196.20	3.53	3.789	0.259	7.33
245.25	3.05	3.238	0.188	6.16
294.30	2.39	2.59	0.200	8.36
343.35	1.98	2.141	0.161	8.13
392.40	1.44	1.584	0.144	10.0
441.45	1.57	--	--	--

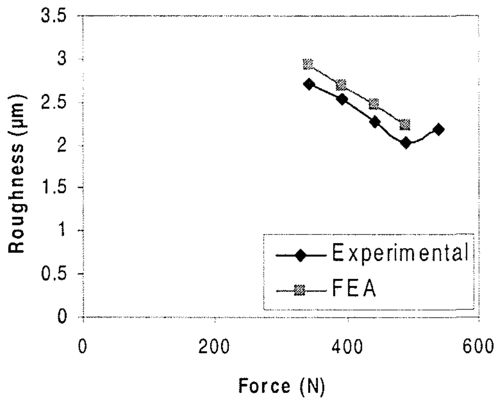

Figure 5: Force Vs Roughness For Mild Steel

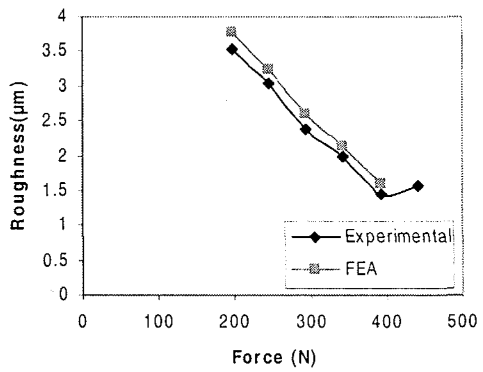

Figure 6: Force Vs Roughness For Aluminium

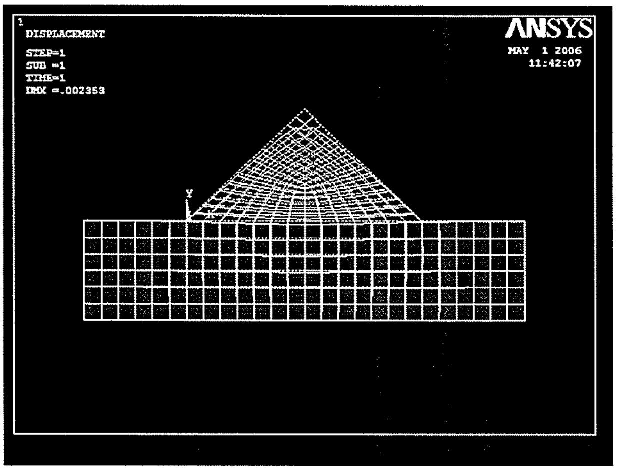

Figure 7: Deformation At Optimum Burnishing Force On Mild Steel

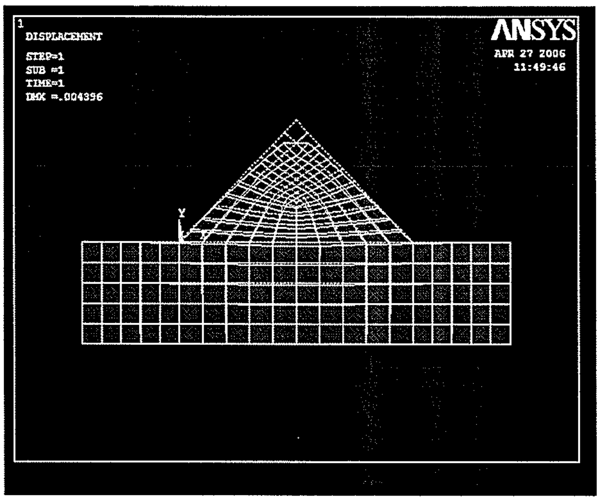

Figure 8: Deformation At Optimum Burnishing Force On Aluminium

Residual Stresses

Induction of compressive residual stresses is the main advantage in the burnishing process. The stresses were calculated analytically by using the equation3. The induced stresses are observed from the FEA and analytical values are presented in the Table 4 and Table 5 for Mild Steel and Aluminium respectively. The stresses were increased with increase in burnishing force as shown in Fig 9. The stress distributions are presented in the Fig 12 and Fig 13 for Mild Steel and Aluminium.

The compressive residual stresses obtained through Analytical and FEA were compared and plotted in the Fig 10 and Fig 11 for Mild Steel and Aluminium. It can be observed from the graphs that, as the force increases residual stresses are also increasing.

Table 4: Residual Stresses for Mild Steel

Force (N)	Residual Compressive Stresses (MPa)	
	Analytical	FEA
294.30	275.60	296.14
343.35	321.60	345.49
392.40	367.55	394.85
441.45	413.90	444.21
490.50	459.44	493.56

Table 5: Residual Stresses for Aluminium

Force (N)	Residual Compressive Stresses (MPa)	
	Analytical	FEA
196.20	89.58	95.11
245.25	111.97	118.89
294.30	134.37	142.67
343.35	156.77	166.45
392.40	179.16	190.22

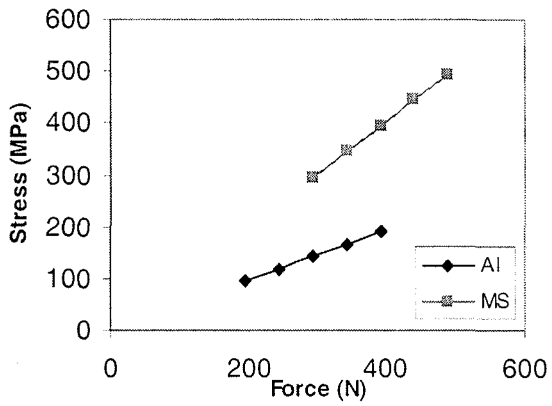

Figure 9: Force Vs Stress From FEA.

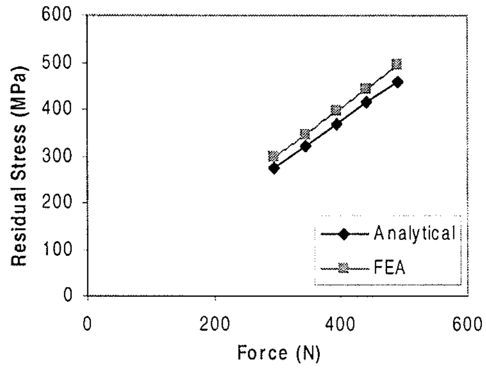

Figure 10: Force Vs Compressive Stress-Mild Steel

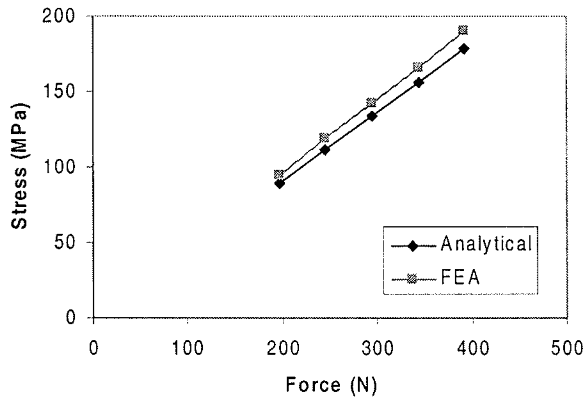

Figure 11: Force Vs Compressive Stresses-Aluminium

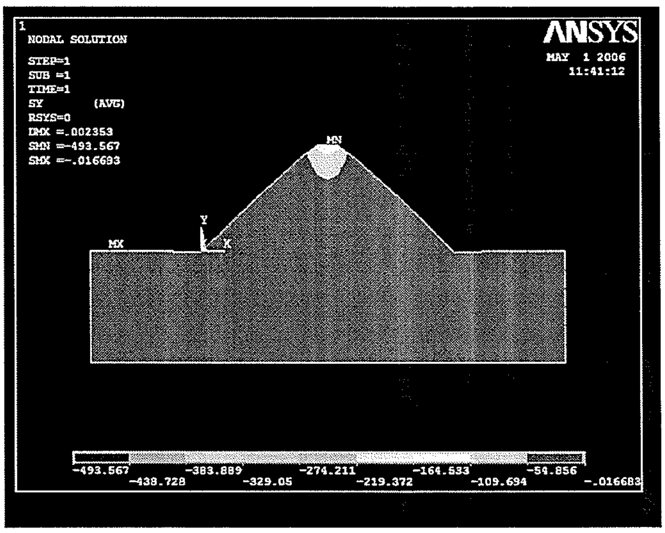

Figure 12: Residual Stress Distribution In Mild Steel

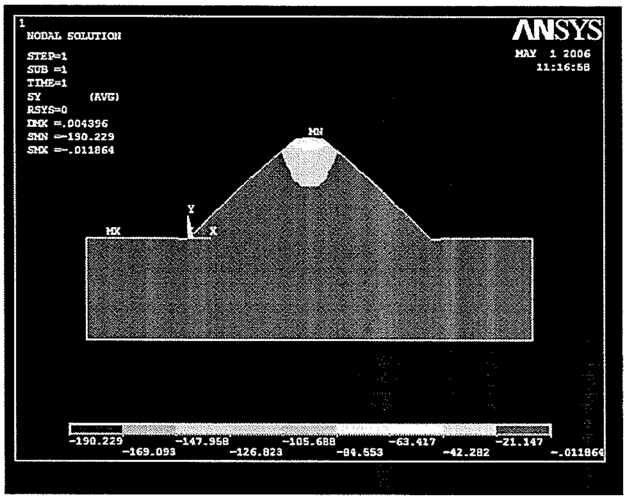

Figure 13: Residual Stress Distribution In Aluminium

Conclusions

The most important conclusions that can be drawn from the present work are

1] High surface finish can be obtained by applying the burnishing process. Experimentally observed surface roughness values are 1.97μm for Mild Steel and 1.44μm for Aluminium. Percentage reduction in surface roughness was found to be 57% for Mild Steel and 76% for Aluminium.

2] The FEA was carried out and the results are comparable with experimental results. The variations are presented in the table and the error is less than 10%.

3] It can be observed from the tables 2&3 that, as the elastic modulus increases the force require for minimize the surface roughness increases

4] Compressive residual stresses were developed within the specimen and are increased with the burnishing force as shown in Fig 8.

5] Compressive residual stresses obtained from analytical and FEA were compared and deviation of these values is found to be less than 9%.

6] The value of these stresses at optimum burnishing force observed from FEA is 493.56 MPa for Mild Steel and 190.22 MPa for Aluminium.

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