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Experimental Investigation and Finite Element Analysis for the Study of Residual Stresses in Roller Burnished Components

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Abstract

Burnishing is a surface modification process, which involves plastic deformation of the material at the surface of the component due to the application a highly polished and hard roller, under pressure. This results in the improvement of the surface finish of the component and induces residual compressive stresses on the surface of the component. The present work deals with the optimization of the burnishing force for the best surface finish, at constant speed and feed, for Aluminium and Mild steel workpieces. A 3-dimensional finite element model is proposed for the simulation of the burnishing process, and the analysis is carried out at the optimum force determined experimentally. The induced compressive stress in the components is determined from the finite element analysis and this value is then compared with the results obtained from X-ray diffraction technique.

Keywords: Burnishing, optimization of force, Finite element analysis, surface finish, residual stresses, X-ray diffraction.

Introduction

Burnishing is a surface modification process, without actual removal of metal. In this process a tool is rubbed on the metal surface of the part with sufficient force to cause plastic flow of the metal from the peaks of the surface asperity into the valleys, which results in an improved surface finish. Burnishing was developed as means for imparting residual compressive stresses to surface layers of metal parts in order to increase their fatigue lives, apart from improving the surface finish. The changes in surface characteristics due to burnishing will cause improvements in surface hardness [1], wear resistance [2], fatigue strength [3, 4] and microstructure [5] of the surface. Surface compressive stresses to enhance the fatigue life could also be produced by shot peening and laser shock peening. But in these processes, thermal relaxation was found to result in loss of the surface-layer compressive stresses, with consequent shortening of component life. Hence, what is needed is a means of imparting thermally stable surface compressive stresses. Burnishing is a process, which can impart thermally stable surface compressive stresses.

The principle action of the burnishing takes place in the central plasticization zone, where the metal in both the peaks and valleys become plastic due to the applied pressure by the burnishing roller. Under this condition the metal of the peaks flow plastically into the valleys. Since this action is only local, the overall geometry of the workpiece is not changed, i.e. the cross section shape and length are not altered. Metal is neither lost nor gained during deformation. Thus the final diameter of the component is the mean of the peaks and valleys diameter. The reduction in the surface roughness value by the application of burnishing is schematically shown in figure 1.

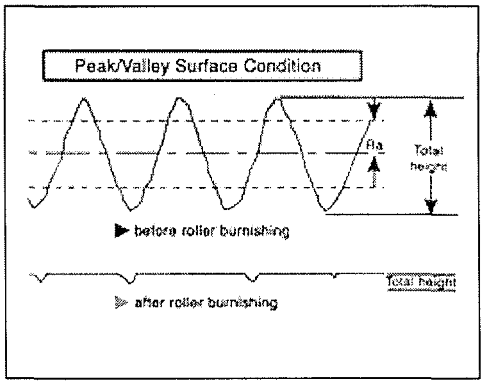


Figure 1: Reduction in surface roughness value by applying burnishing.

Experimentation

A series of burnishing processes were conducted on a center lathe for optimization of force. The workpieces on which burnishing is conducted are solid shafts of diameter 25 mm and 30 mm long. The applied force is varied by varying the depth of penetration of the tool. The process was carried out at a speed of 13.6 m/min and feed

0.054 mm/rev. The roller used for experimentation is of diameter 30 mm and 20 mm wide. The chemical composition of the roller material (high carbon high chromium steel) is given in table 1.

Table1: Chemical composition of roller material [HCHC steel]

Element	C	Cr	Mn	Si	P	S
%	1.10	1.60	0.50	0.35	0.025	0.025

The roller-burnishing tool is mounted in the tool post of a lathe tool dynamometer to measure the burnishing force. The dynamometer used here is a four-component dynamometer, which measures the cutting force, feed force, thrust force and torque. The thrust force is considered as the burnishing force. The other two forces are neglected, as they are very much less in magnitude as compared to the thrust force.

Figure 2 shows the schematic diagram of the experimental setup of the burnishing process and the photograph of the experimental setup. The surface roughness values of the burnished components are measured by a Handysurf instrument. The force at which the best surface finish is obtained is determined and is referred to as the optimum force.

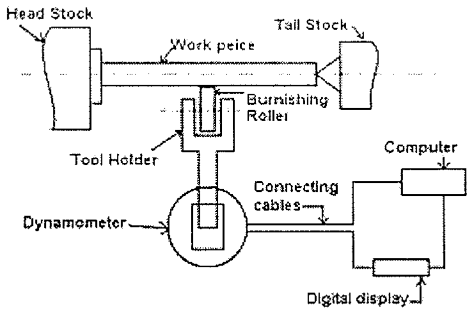
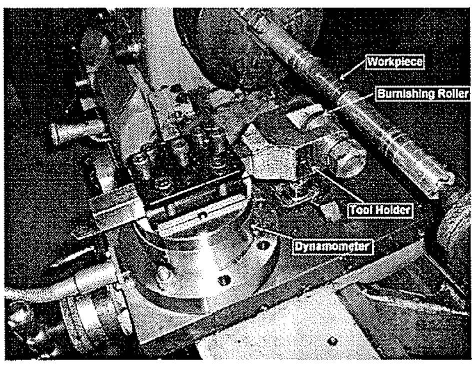


Figure 2(a): Schematic diagram of Experimental setup for burnishing process.



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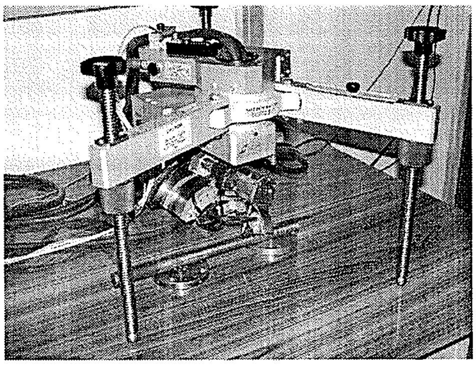

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Figure 2(b): Photograph of the experimental setup. **Figure 2(c):** photograph of setup for induced stress measurement by x-ray diffraction technique.

The residual stresses in the burnished components are measured by X-ray diffraction technique. This is shown in Figure 2(c). Cr K-alpha radiation is used to measure strains along HK1-311 plane with diffraction angle 139° for Aluminium and HK1-211 plane with diffraction angle 156° for Mild Steel. Each residual stress measurement is evaluated from atleast 5 measurements of lattice spacing spreads over a range of orientations to the surface of the specimen, the accuracy of stress measurements being approximately ±20 MPa.

Finite Element Analysis

The finite element analysis of burnishing process is carried out on a commercial FEA package- ANSYS 10.0. A 3-dimensional contact model is generated for the analysis. This is shown in figure 3. The dimensions of the model are taken exactly equal to the workpiece and tool dimensions. The model developed here is a static one, which does not take into account the feed and speed of the operation. The finite elements (from ANSYS library) used for this analysis are CONTA174 and TARGE170. These elements are 3-D surface-to-surface contact elements. The contact surface (tool) is specified by CONTA174 element and the target surface (workpiece) is specified by TARGE170 element. Three-dimensional contact analysis is preferred to analyze burnishing because the surface-to-surface contact between the tool and work-piece in the plastic zone can be modeled precisely.

The materials selected for the analysis are aluminium and mild steel for work pieces and high carbon high chromium steel for the tool. The material properties are specified as shown in table 2.

Table 2: Material properties of workpieces.

	Young's Modulus [MPa]	Poisson's ratio	Density [Kg/m^3]	Yield Strength	
				Min.	Max
Mild Steel	2.0×10^5	0.27	6920	205	1725
Aluminium	0.7×10^5	0.34	2700	35	550

The 3D geometric model is generated using the preprocessor of the same software. The tool is meshed using CONTA174 element and the workpiece is meshed using TARGE170 element. The symmetric boundary conditions are applied to the symmetric faces. The load is then applied on the tool, which inturn is transferred to the workpiece. The problem can now be solved, by applying the solution control options. The results of the analysis can be obtained from the post processor.

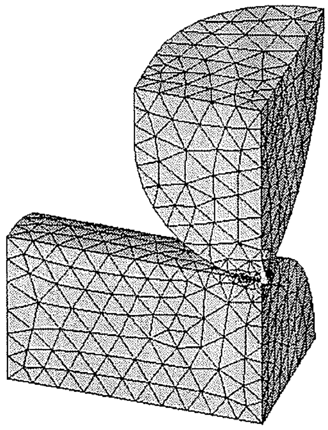

Figure 3: Finite Element Model for contact analysis.

Results and Discussions

The results of experimental investigation of burnishing process for the optimization of burnishing force, X-ray diffraction and FEA are presented.

Optimization of force

The applied force in burnishing can be increased by increasing the depth of penetration. The process is carried out at various forces and the roughness values are measured. The optimum force is determined for the best surface finish obtained.

Figure 4 shows the variation of surface roughness with the applied force for Mild steel and Aluminium.

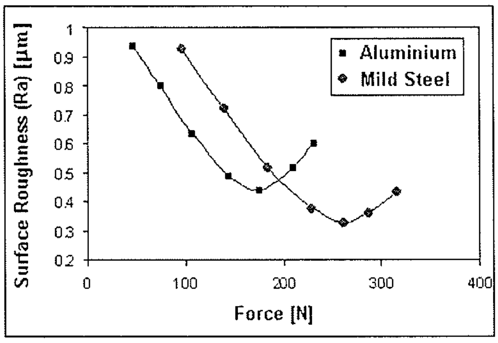

Figure 4: Variation in surface finish with force for Aluminium and Mild steel (at a speed of 13.6 m/min and feed 0.054 mm/rev).

From the above figure it can be observed that initially with an increase in the burnishing force, the surface roughness value decreases. But after reaching a particular value, the surface roughness value increases with further increase in the force. The reason for this behavior is that at lower values of the burnishing force the material from the peaks of the surface was not fully deformed to fill up the valleys thus resulting in rough surface. At higher burnishing forces due to seizure failure the surface finish was getting deteriorated. Also at higher forces the material was in plastic state and getting work hardened. Due to this work hardening effect, the material was loosing the ductility and becoming brittle. The force at which the surface roughness value tends to increase with a further increase in the force is referred to as optimum burnishing force.

The initial roughness value measured before burnishing is 1.27 μm for Aluminium and 2.064 μm for Mild steel. The recommended optimum forces determined experimentally and the corresponding surface roughness (Ra) values are tabulated in table 3.

Table 3: Optimum forces determined experimentally

Material	**Optimum force (N)**	**Surface roughness (μm)**
Aluminium	175	0.44
Mild steel	261	0.33

From the above results it can be observed that reduction in the roughness of Aluminium was 65% and that of Mild steel was 84%.

The induced compressive stresses in the burnished components are measured by X-ray diffraction technique. The results are presented in table 4.

Table 4: Residual stresses measured from X-ray diffraction method.

Material	**Residual stress [MPa]**
Aluminium	166.7
Mild Steel	567.8

FEA Results

The induced compressive stresses in the high surface finish burnished components can be determined from FEA

The optimum value of burnishing force determined experimentally is used in the Finite Element Analysis. The results of this analysis include the depth of penetration and the induced compressive stress.

The applied burnishing force is related to the depth of penetration, which inturn is related to the surface finish obtained and the residual stresses induced in the component. Thus depth of penetration plays an important role in the burnishing process. Thus an attempt is made to determine the depth of penetration from FEA.

Table 5 presents the depth of penetration, and the induced stresses for Aluminium and Mild steel.

Table 5: Finite Element Analysis results at optimum force.

Material	**Applied Force (N)**	**Depth of Penetration (μm)**	**Induced stress [MPa]**
Mild Steel	261	2.064	159.176
Aluminium	175	0.819	560.393

Figure 6 shows the stress distribution for Aluminium and figure 7 shows the stress distribution in Mild steel.

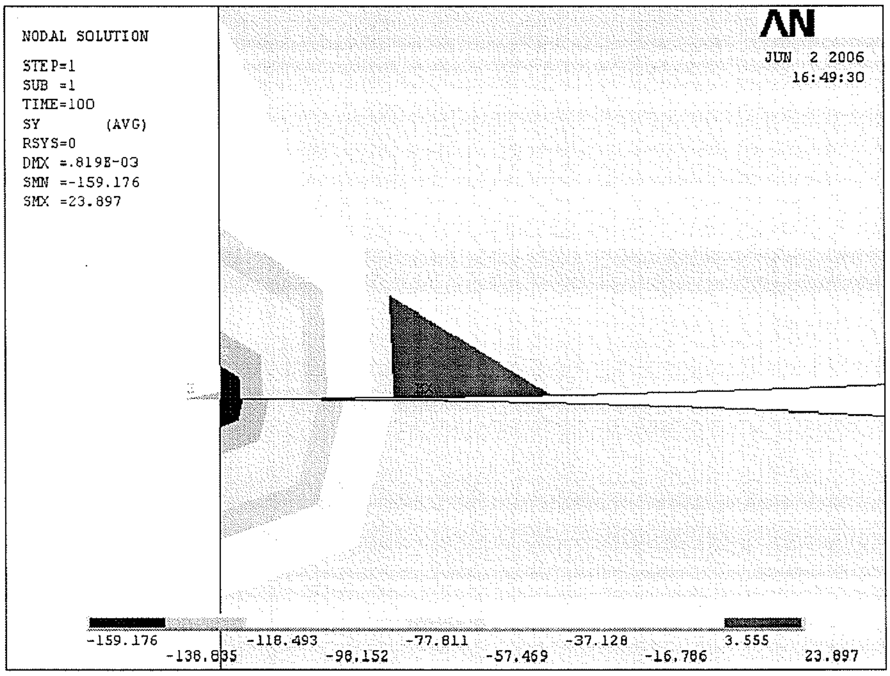

Figure 6: Stress distribution in Aluminium.

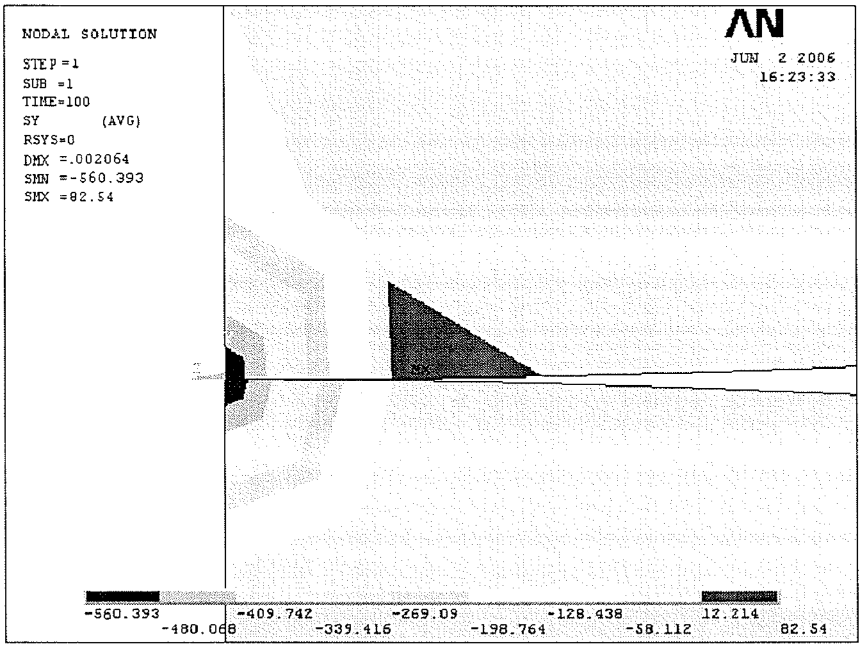

Figure 7: Stress distribution in Mild steel.

Comparison of Residual Stress Values:

The residual compressive stresses determined from FEA are compared with the X-ray diffraction results. Table 6 presents the comparison of the stress values.

Table 6: Comparison of residual stress values determined from FEA and X-ray diffraction.

Material	Residual stresses [MPa]		% of deviation
	X-ray diffraction	FEA	
Aluminium	166.7	159.176	4.5
Mild steel	567.8	560.393	1.3

From the above comparisons it can be noticed that the percentage of deviation of the FEA results from the experimental values is less than 5% for both roughness and Residual stress values.

The values obtained from FEA are quite closer to the experimentally determined values because the modeling of FEA includes surface-to-surface contact between the tool and workpiece, which represents the real phenomenon occurring in actual burnishing process.

Conclusions

The major conclusions of this work are presented.

- The optimum burnishing forces were determined experimentally and are given by 175 N for Aluminium and 261 N for Mild steel. The surface roughness value after burnishing at optimum force was found to be 0.44 μm for Aluminium and 0.33 μm for Mild steel.
- The residual stress induced in the burnished components was determined by x-ray diffraction technique and the value was found to be 166.7 MPa for Aluminium and 567.8 MPa for Mild steel.
- A 3D finite element model was proposed to simulate the burnishing process. The residual compressive stress value obtained from FEA was found to be 159.176 MPa for Aluminium and Mild steel for 560.393 MPa.
- The induced residual compressive stress values obtained from FEA were compared with the X-ray diffraction results and the deviation is found to be less than 5%.
- Thus it can be concluded that the 3–dimensional contact model is best suited for the modeling and analysis of burnishing process, as it precisely manifests the surface-to-surface contact phenomenon occurring in the burnishing process.
- It can be observed that the final surface finish and the compressive stresses induced in mild steel are superior to those in aluminium. So it can be concluded that better improvement in properties can be obtained when burnishing is applied on mild steel than on aluminium.

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