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Influence of Finishing by Burnishing on Surface Characteristics

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The aim of this study was to analyze the evolution of residual stresses, microhardness, and roughness in relation to the finishing process. The x-ray diffraction (XRD) technique was used to determine the residual stresses, which were measured from the surface to the bottom of the machined workpiece. Processes that were studied included turning, grinding, and burnishing. Burnishing was done on a surface that was initially turned, or turned and then ground. A duplex stainless steel was used in this study. This material belongs to a high-strength stainless steel family with high corrosion resistance properties. We noted that the burnishing process produces the best quality of the surface when compared with turning or grinding.

Keywords burnishing, duplex stainless steel, machining, residual stresses, roughness

1. Introduction

Chip forming cutting includes all of the processes (such as turning and grinding) that can be used to obtain mechanical workpieces with all of the imposed dimensional, roughness, and geometric specifications. Finishing by turning or grinding has the largest influence on the surface quality defined through roughness, microhardness, and residual stresses.[1-3]

Burnishing is a chipless working process.[4] It is a finishing process that uses superficial plastic deformation. The aim of such a machining method is not to obtain required dimensional accuracy but to produce the surface finish, and more importantly, to produce the compressive residual stresses in the material surface. The use of burnishing as the finishing operation of pieces after turning or after grinding improves wear resistance, fatigue, tensile strength, and corrosion resistance. The burnishing process can replace grinding for finishing piston of jack working in hydraulic machines. In this study, burnishing is produced with the use of a lathe machine.

The surface quality is defined through roughness, microhardness, and residual stresses.[5,6] The surface characteristics are compared when optimal parameters are used for each process.[7-11] The x-ray diffraction (XRD) method was used to evaluate residual stresses in variation with depth from the machined surface.[12,13] We studied and compared the influence of different processes on surface quality and on the affected depth from the machined surface.

2. Experimental Techniques

2.1 Workpiece Material

Duplex stainless steel (DSS) (Table 1) was used for seawater circulation pumps in a thermal power plant.[1,2] It offers excellent corrosion resistance together with high mechanical properties, good weldability, and castability, which make it suitable for marine applications.[2] Samples were solutionized at 1100 °C/1 h, followed by water quenching, then aged at 800 °C/1 h. The Vickers hardness of this material is equal to 300 for a load of 200 g. Microstructural observations of the studied steel showed classic ($\delta + \gamma$) microstructure. After aging at 800 °C, almost δ-phase transformed into a eutectoid-like constituent (Fig. 1).[2,3]

2.2 Cutting Parameters

Surfaces are finished by turning, grinding after turning, burnishing after turning, or burnishing after grinding. In finishing by turning with a carbide tool, the cutting depth a is set to 0.5 mm for all tests, feed f is set to 0.06 mm/rev, cutting speed V_c is set to 200 m/min, and the piece diameter D is set to 60 mm.

In finishing by grinding, the cutting depth a is set to 0.1 mm for all tests, parallel feed rate V_{lf} is set to 11 double course [dc]/min, perpendicular feed rate V_{tf} is set to 4 μm/dc, cutting speed V_c is set to 35 m/s, and the course C is set to 55 mm.

The finishing by burnishing is made on a turned surface or on a ground surface. For different burnishing tests, the applied force by the tool on the machined surface F is set to 350 N and the diameter d of the ball-burnishing tool is set to 9 mm. This ball is free to rotate inside the tool, which can be held in a manner similar to a cutting tool post of the lathe machine

Table 1 DSS Composition, wt.%

C	Si	Mn	Cr	Mo	Ni	N	Cu
0.02	0.62	0.4	24.66	2.81	7.43	0.16	2.52

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(Fig. 2). A single pass of the tool ($N = 1$) was used throughout the experiments.

In burnishing, when using a carbon chromium steel ball, the feed f is set to 0.06 mm/rev for all tests and the cutting speed V_c is set to 100 m/min. For the same process, lubrication was performed using oil to limit friction and temperature elevation when the surface was machined.

2.3 XRD Technique

The residual stress components were analyzed by x-ray in the γ-phase diffraction using the $\sin^2\psi$ method.[6]

The residual stresses were calculated from the strain distribution derived from the measured inter-reticular plane spacing:

$$\varepsilon_{\phi\psi} = \frac{1}{2} S_2[(\sigma_{11}^{\phi} - \sigma_{33}^{\phi})\sin^2\psi + \sigma_{13}^{\phi}\sin 2\psi + \sigma_{33}^{\phi}] + S_1[\sigma_{11}^{\phi} + \sigma_{22}^{\phi} + \sigma_{33}^{\phi}]$$

where S_1 and $\frac{1}{2}S_2$ are the elastic radio-crystallographic constants.

The XRD spectra of the aged samples[3] showed an enlargement of the austenite (311) peak, which suggested the formation of another austenite phase. This indicates that the σ-phase is forming in the DSS at the expense of the ferrite phase by eutectoid decomposition: $\delta \rightarrow \sigma + \gamma'$. Hence, for residual stresses determination, the Bragg angle corresponds to the (311) peak relative to the face-centered cubic (fcc) crystallographic structure, which is the case for austenitic stainless steel.

The surface was initially electrolytically polished, step by step, to determine the evolution of the residual stress with depth from the machined surface.

3. Results and Discussion

3.1 Roughness R_a

Roughness was analyzed using the R_a factor. Table 3 shows its evolution when the process changes.

The turned surface has a roughness equal to 0.68 μm. When the surface is then ground, its roughness R_a is equal to 0.59 μm.

For the burnished sample, which is initially turned or ground, R_a values are 0.17 and 0.16 μm, respectively (Table 3). The decrease of R_a when samples are burnished can be explained by the fact that the applied force will smooth out the irregularities of the surface by forcing the metal to spread and flow plastically from the peaks of the asperities to fill the valleys. These results are confirmed by analysis of the surface profile (Fig. 3).

3.2 Microhardness

The Vickers hardness number was measured with a load equal to 200 g. Microhardness is greatest near the surface layer and decreases rapidly as the depth increases (Fig. 4). This is because the region confined to the surface is subjected to maximum work hardening. The depth of this work-hardened layer will vary for each process depending on the type of mechanical and thermal interaction.

For burnished samples, the maximum microhardness value is higher and penetrates deeper (75 μm) into the surface layer than that for grinding (35 μm). This is due to an increase in

Table 2 X-ray Parameters

Test Material	Spot Area, mm^2	½S_2, $(N/mm^2)^{-1}$	S_1, $(N/mm^2)^{-1}$	Wavelength	Radiation	Filter	Bragg Angle 2θ°
Feγ	1.0	$7.091\ 10^{-6}$	$-1.649\ 10^{-6}$	Mn	Kα	Cr	150.5 (*hkl*) (311)

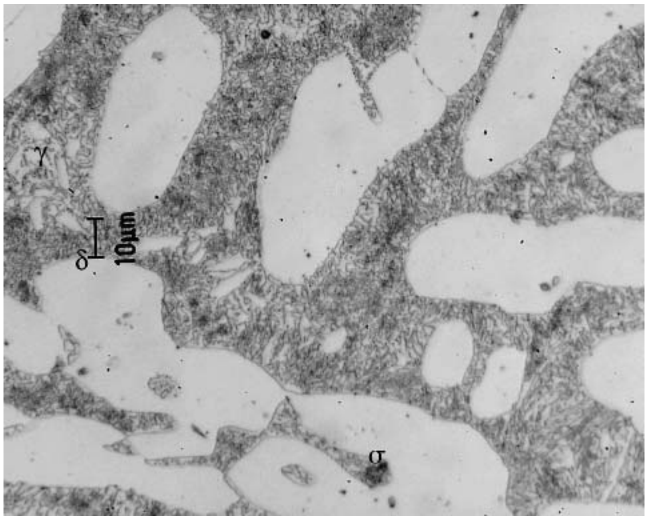


Fig. 1 Microstructure of samples aged at 800 °C/1 h; optical micrograph

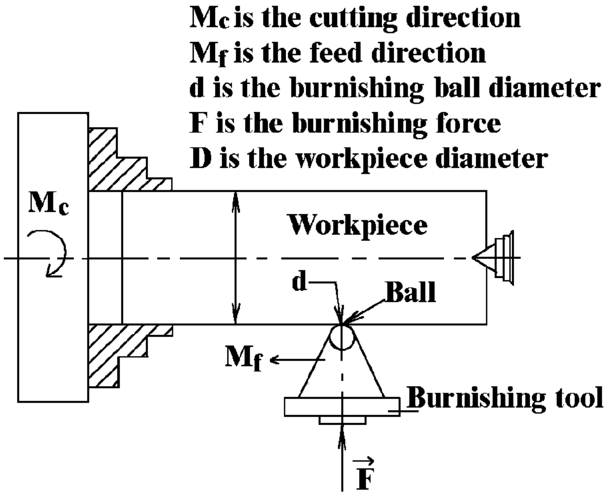


Fig. 2 Geometric and kinematic parameters of burnishing

work hardening when burnishing. In addition, it is important to note that grinding permits a depth equal to 50 μm to be cut (Fig. 4). Hence, a part of the depth of the work-hardened layer obtained in turning is removed by grinding.

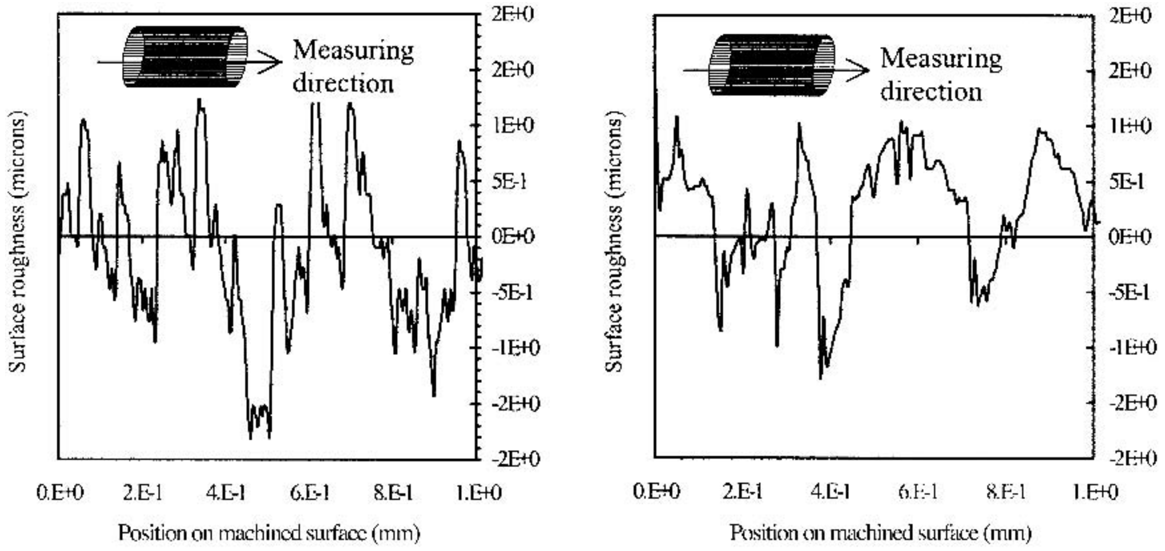
Table 3 Roughness Evolution for Different Processes

Treatment	Turning	Grinding After Turning	Burnishing After Turning	Burnishing After Grinding
R_a, μm	0.687	0.593	0.175	0.160

3.3 Residual Stresses

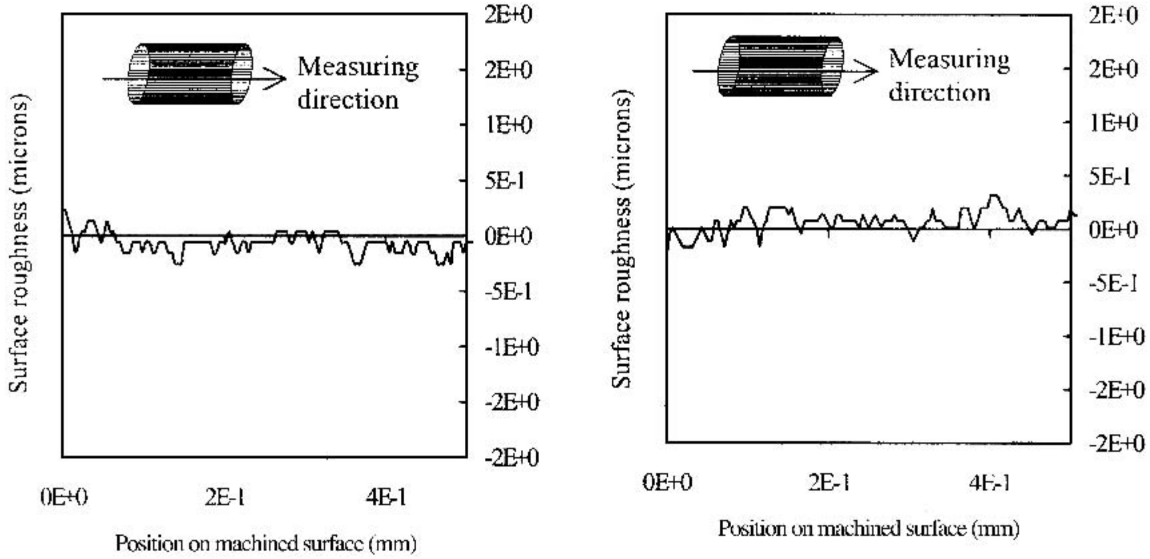
Figure 5 shows the evolution of feed direction residual stress with the depth from the machined surface. When the sample is first turned and then ground, the tensile residual stress reaches a lower level (from 900-320 N/mm^2), and penetrates deeper into the surface layer (from 250-400 μm).

Feed direction residual stresses introduced by burnishing of turned samples have been displaced in the negative direction (−420 N/mm^2) relative to the stress level of about 900 N/mm^2 produced when the workpiece was turned. Surface layer depth is more important for burnishing (600 μm) than for turning (250 μm).



a-Turning

b- Grinding



c- Turning and burnishing

d- Turning, grinding and burnishing

Fig. 3 Feed direction roughness

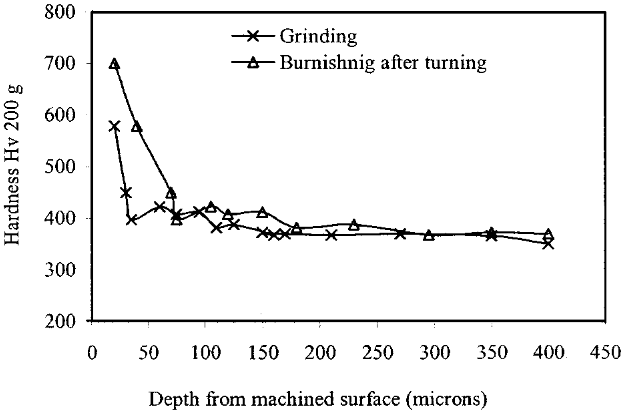


Fig. 4 Vickers microhardness evolution with depth from machined surface

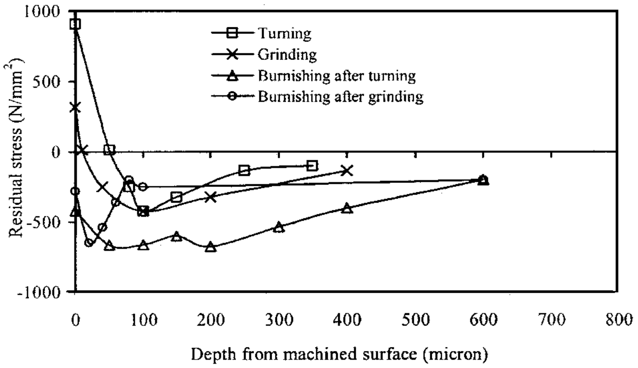


Fig. 5 Parallel residual stress evolution for cylindrical pieces

When surfaces are burnished after grinding, residual stress has been displaced in a negative direction and remains less important (–280 N/mm^2) than when surfaces are burnished after turning (–420 N/mm^2), but penetrates slightly in the depth of the sample (100 μm). In addition, note that the feed perpendicular direction residual stresses in the surface layer are identical for turned or for ground samples (200 N/mm^2) (Fig. 6).

In burnishing, feed perpendicular direction residual stresses are compressive and more important than are parallel residual stresses. The depth of the affected layer by these stresses is less important for the samples initially turned (200 μm) than for the pieces initially ground (400 μm).

4. Conclusions

The authors' intention was to show that by selecting a specific process, very good results could be obtained. For any chip-forming process and for any mechanical treatment process, the main objective is to obtain the best quality of the machined surface, which depends on roughness, microhardness, residual stresses, and material microstructure. Different results have shown that burnishing gives good surface quality, which improves wear resistance, fatigue, tensile strength, and corrosion resistance. This process has many advantages such as flexibility, low price, and a simple machining range. Surface characteristics are the best when the process is performed after grinding.

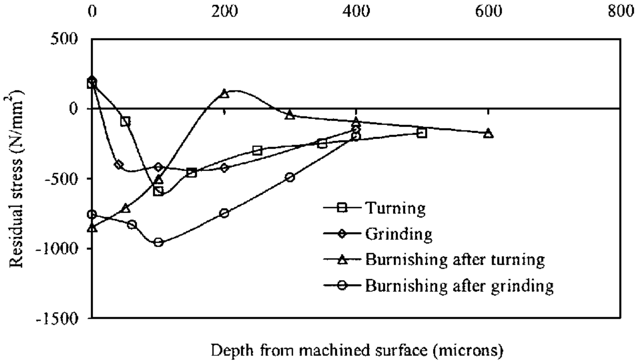


Fig. 6 Perpendicular residual stress evolution

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