ANALYZING THE NEAR-SURFACE DEFORMATION GRADIENTS DUE TO SHOT PEENING AND BALL-BURNISHING OF ALPHA BRASS AND STAINLESS STEEL

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ABSTRACT

The change in near-surface properties as induced by shot peening and ball-burnishing was evaluated on an α-brass CuZn30 and an austenitic stainless steel X5CrNi18-10 (AISI 304). The depth profiles of near-surface microstructures, microhardness and full width at half maximum (FWHM) of X-ray interference lines were determined. By comparing the induced changes in microstructure, microhardness and FWHM with materials being cold rolled to certain thickness reductions, the local deformation degrees in the mechanically surface treated materials could be estimated. The experimental results indicate that near surface deformation degrees in shot peened or ball-burnished surface layers are very high and can easily reach values corresponding to 80 % of thickness reduction or $\varphi = 1.6$ in terms of true strain.

KEY WORDS

Microhardness-depth profiles, FWHM-depth profiles, local deformation degrees

INTRODUCTION

Mechanical surface treatments such as shot peening (SP) and ball burnishing (BB) are widely utilized for enhancing fatigue strength and durability by combining some beneficial effects, i.e., work hardening and compressive residual stress in the near-surface zone [V. Schulze 2006]. In fact, a large number of studies have been carried out and reported significant improvements in fatigue performance by SP and BB on a variety of materials [I. Altenberger 2005; L. Wagner 1999; A.M. Hassan 1997; A.M. Hassan 1998]. However, there remain some uncertainties about interrelationship among the working parameters, local deformation, residual stress and fatigue performance. For example, in [P.S. Prevey et al. 2002] it was claimed that local deformation degrees in so-called low plasticity burnishing (LPB) resulted in deformation degrees of less than 10% while other studies [L. Wagner 1999] indicated much higher degrees of induced plastic strain.

The present study aims at investigating the microstructural changes in near-surface zones of shot peened and ball-burnished α-brass and stainless steel. These materials were chosen because marked work hardening was expected in plastic deformation due to their very low stacking fault energies [D. Hull 1975] which makes the determination of process-induced deformation degrees easy.

EXPERIMENTAL

The alloy CuZn30 was received as a casting from which blanks of 20 mm thickness were cut and unidirectionally hot rolled at 750°C to a deformation degree of $\varphi = 0.7$. Material was stress relieved at 350°C for 1 hour. The alloy AISI 304 was received in plate form with 20 mm thickness. The plate was hot rolled at 800 °C to a deformation degree of φ = 0.7 and subsequently recrystallized at 1050 °C for 0.5 hours. Hourglass-shaped specimens were prepared from both alloys with the load axis perpendicular to the rolling direction. Part of these specimens were shot peened using an injector type machine and cast steel shot S230 with an average shot size of 0.6 mm. Peening was done to various Almen intensities using 200 % coverage. Another part of specimens was ball-burnished by means of a conventional lathe using a device by which a hard metal ball of Ø3 mm (HG3) or Ø6 mm (HG6) is hydrostatically pressed onto the rotating specimen surface. Various rolling pressures ranging from 50 to 400 bars were employed. In addition, some specimens were electrolytically polished to serve as reference.

Cylindrical bars with a diameter of 10 mm were machined to study the effects of shot peening intensity and ball-burnishing pressure on surface layer properties. After using rolling pressures beyond 300 bar (HG6) in CuZn30, surface flaking was observed while no such surface damage was found in AISI 304 even after burnishing with the highest pressure of 400 bar. On cross-sections of these cylinders, micro-hardness depth-profiles were measured using Vickers hardness. For X-ray diffraction measurements, flat surfaces were prepared on some cylinders prior to shot peening and ball-burnishing. This was achieved by machining away about 3 mm from the lateral side followed by polishing. The FWHM of the {311} interference lines was evaluated by using a Siemens X-ray diffractometer D-5000 and CoK$_\alpha$-radiation.

In order to estimate the local deformation degrees in the surface layer after shot peening and ball-burnishing, the following procedure was applied as shown schematically in Figure 1. The microhardness and FWHM values measured after mechanical surface treatments were compared with corresponding values measured on blanks after being cold worked to known thickness reductions ranging from 10 to 90 %. Finally, this enabled an estimation of the deformation degree-depth profiles in the mechanically surface treated conditions.

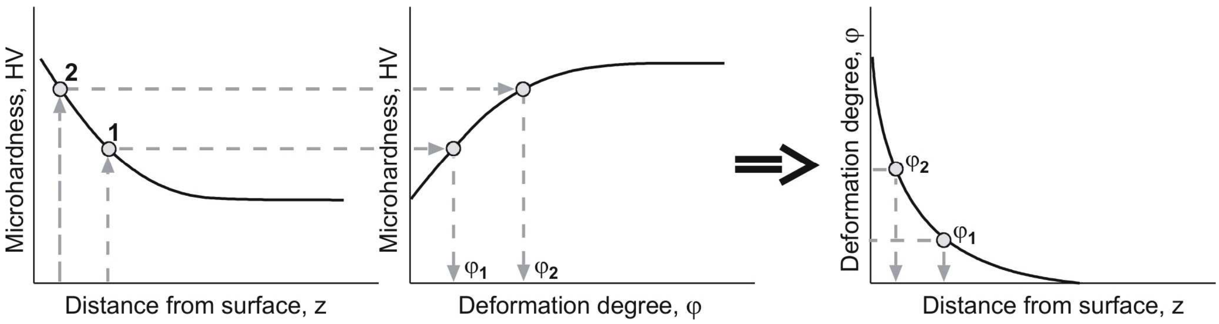
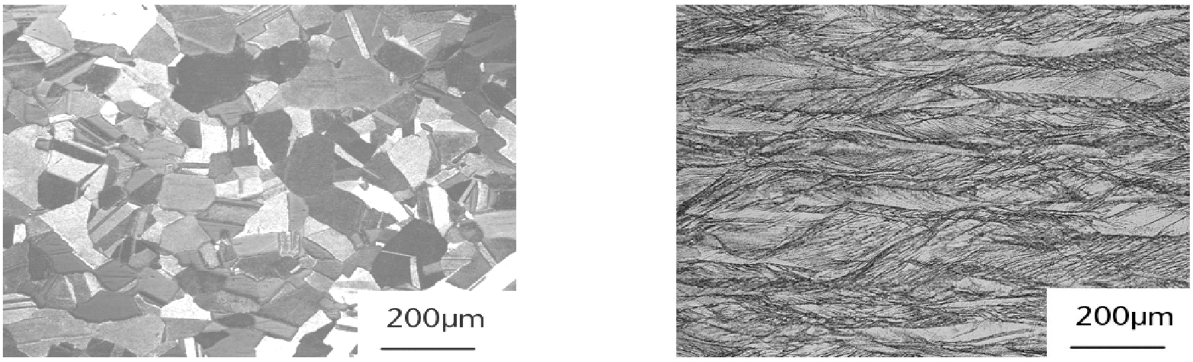


Fig. 1: Flow chart for estimating local deformation degrees in mechanically surface treated conditions

RESULTS AND DISCUSSION

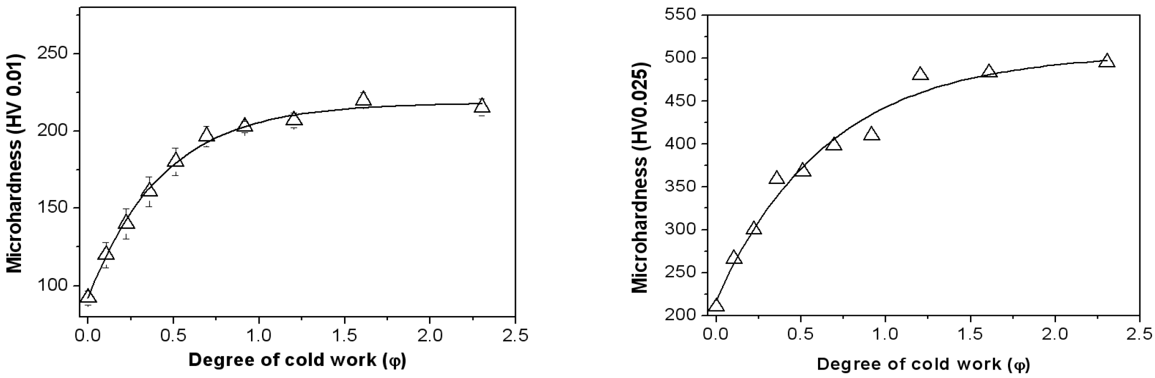
The microstructures of CuZn30 are illustrated in Figure 2 where the undeformed (φ = 0) and cold rolled (φ = 0.7) conditions are shown in Figures 2a and 2b, respectively. After cold rolling, the equiaxed grains of the undeformed microstructure of CuZn30 (Fig. 2a) appear as pancakes which contain high densities of slip bands (Fig. 2b). Results obtained on AISI 304 are very similar to those on CuZn30.



a) φ = 0 b) φ = 0.7

Fig. 2: Microstructures of CuZn30

Figure 3 illustrates the variation in microhardness with deformation degree of both cold rolled conditions of CuZn30 (Fig. 3a) and AISI 304 (Fig. 3b).



a) CuZn30 b) AISI 304

Fig. 3: Microhardness vs. deformation degree in cold rolling

As expected, the hardness increase with the degree of cold work is very pronounced in both alloys due their very low stacking fault energies [L. Wagner 1999; D. Hull 1975]. Both alloys exhibit hardness saturation at deformation degrees of about 1.2.

The change in interference line profiles in CuZn30 from an undeformed (φ = 0) to a heavily deformed (φ = 1.2) condition is shown in Figure 4 indicating also the determination of FWHM. The variation of FWHM as a function of degree of cold work is illustrated in Figure 5. The FWHM-depth profile is very similar to the microhardness-depth profile (compare Figs. 5 and 3a).

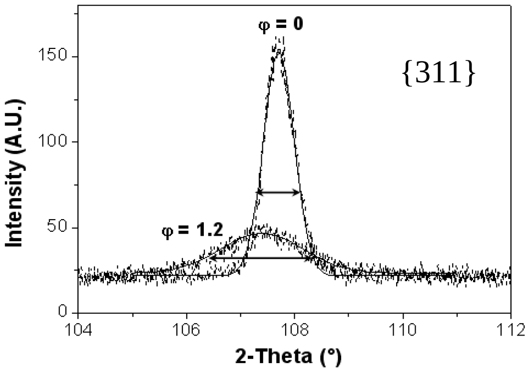


Fig. 4: Interference line profiles in CuZn30

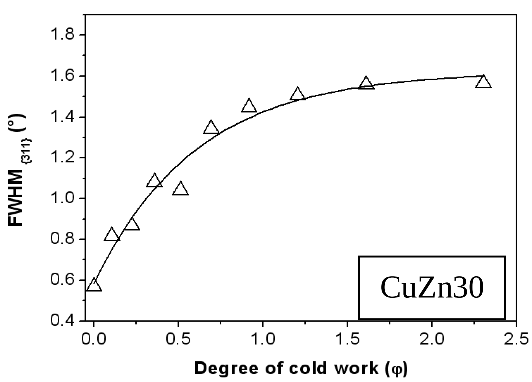
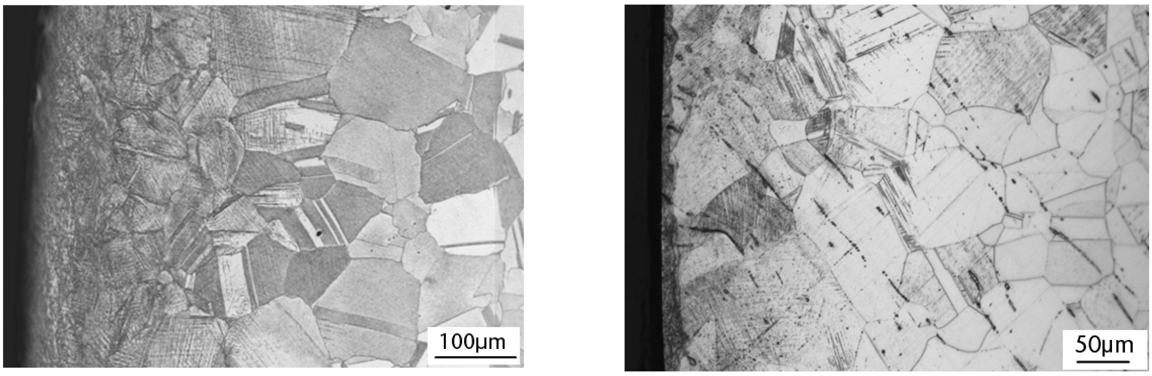


Fig. 5: FWHM vs. degree of cold work

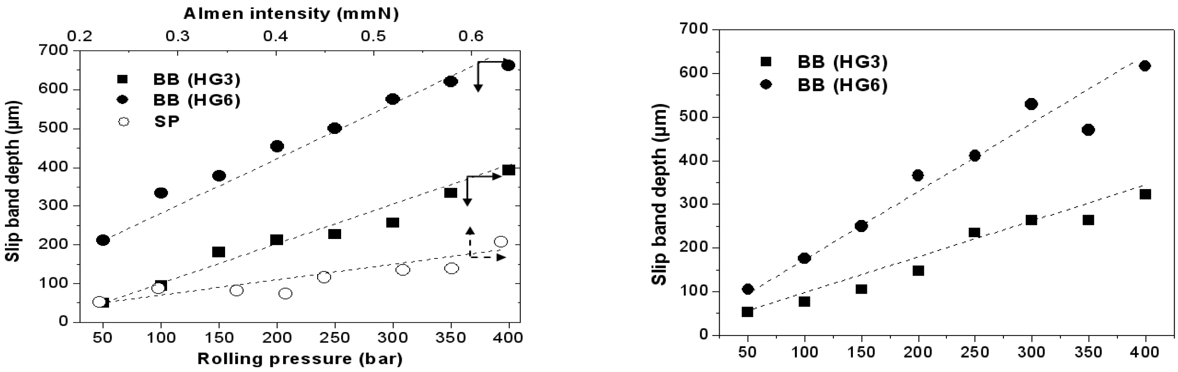
Examples of the near-surface microstructures after ball-burnishing are seen in Figure 6. Slip bands are clearly visible in both CuZn30 (Fig. 6a) and AISI 304 (Fig. 6b).



a) CuZn30 b) AISI 304

Fig. 6: Near-surface cross sections after ball-burnishing (HG3, p = 300bar)

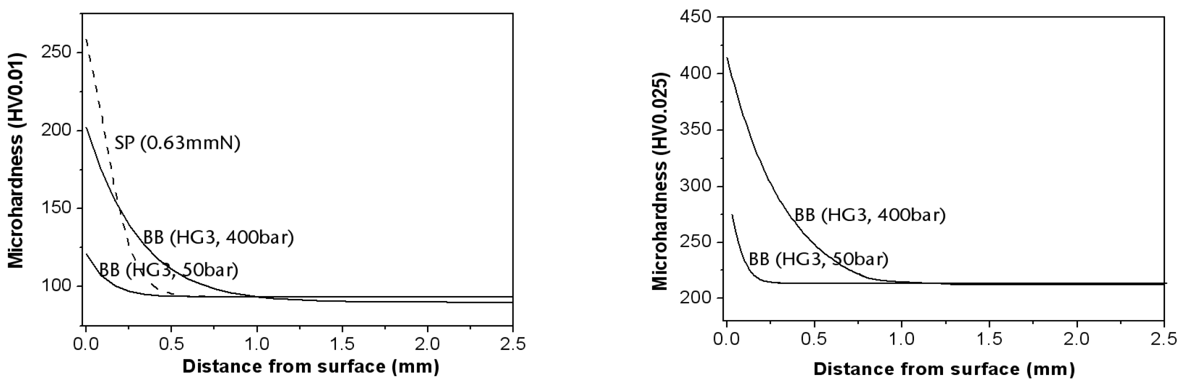
The maximum depths of induced slip band formation were determined for various surface treated conditions and plotted vs. Almen intensity and rolling pressure in Figure 7. These depths linearly increase with Almen intensity and rolling pressure as shown on CuZn30 (Fig. 7a). Larger ball sizes in burnishing led to greater depths of slip band formation in both CuZn30 (Fig. 7a) and AISI 304 (Fig. 7b).



a) CuZn30 b) AISI 304

Fig. 7: Maximum depths of slip band activity vs. Almen intensity and rolling pressure

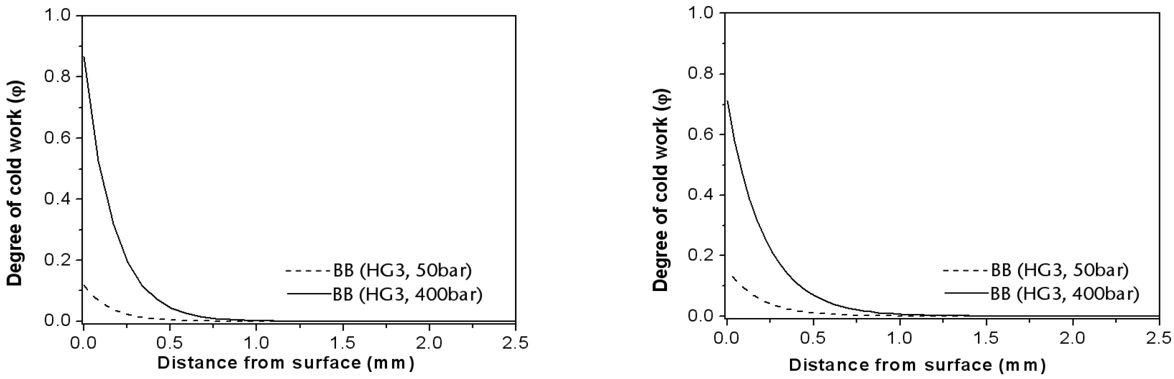
The microhardness-depth profiles in CuZn30 (Fig. 8a) and AISI 304 (Fig. 8b) indicate increasing hardness values and greater penetration depths with increasing rolling pressure in ball-burnishing. Compared to ball-burnishing, higher near-surface hardness values were observed after shot peening as indicated in Figure 8a.



a) CuZn30 b) AISI 304

Fig. 8: Microhardness-depth profiles

For estimating the local deformation degrees induced by shot peening or ball-burnishing, the measured values of microhardness in the surface zones (Fig. 8) are compared to those determined on materials cold rolled to various thickness reductions (Fig. 4). Results are illustrated in Fig. 9.



a) CuZn30 b) AISI 304

Fig. 9: Degree of cold work in ball-burnishing vs. distance from the surface

The maximum hardness values obtained on AISI 304 in the surface zone of ball-burnished specimens is plotted on the master curve obtained from cold rolled materials in Figure 10. Depending on the process parameters in ball-burnishing, a large variation in local deformation degrees is observed. Maximum values of φ = 1.8 are found using HG6 at p= 400 bar.

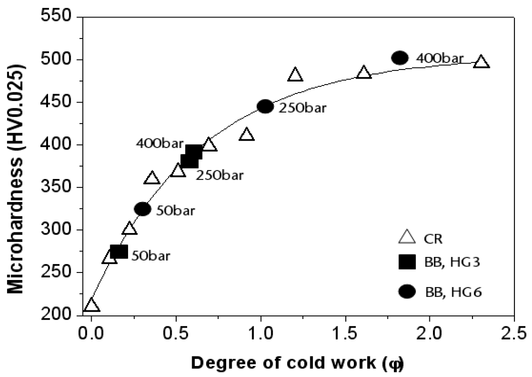


Fig. 10: Microhardness vs. degree of cold work

SUMMARY

The deformation degrees in near-surface zones of mechanically surface treated samples are estimated by comparing the microstructure, microhardness and FWHM with those of materials being cold rolled to various thickness reductions. The depths of induced plastic deformation as illustrated by the occurrence of slip band formation, work hardening and FWHM profiles increase with Almen intensity and both ball size and rolling pressure in shot peening and ball-burnishing, respectively. Maximum achievable hardness values in shot peening are typically higher and work hardening penetration depths lower than in ball-burnishing.

As demonstrated, degrees of local plastic deformation in the near-surface zones after shot peening and ball-burnishing can reach values way above φ = 1.0.

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