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NANOCRYSTALLINE STRUCTURE FORMATION IN ALUMINIUM ALLOY BY CONTROLLED BALL IMPACT TECHNIQUE

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Abstract : A new surface modification technique called as Controlled ball impact process has been developed to impart compressive residual stress and creation of nanostructured surface layer on the metallic materials in order to improve the surface mechanical properties. Hardened steel ball was impinged at a high strain rate on the aluminium samples in a controlled manner. The mean grain size determined by transmission electron microscope is about 8 nm in the top surface layer of the specimen peened at a sample traveling velocity of 0.76 mm s^{-1}. The nanocrystalline surface of aluminium alloy was characterized using a dynamic ultra micro-hardness tester. The peening coverage, number of overlapping impacts, surface hardness and surface roughness depend upon the sample traveling velocity for a given ball diameter and impact velocity.

Keywords: *Surface nanocrystallization, Al alloy, Controlled ball impact, Grain refinement*

Introduction

Nanocrystalline materials possess high strength and hardness compared to the coarse grained polycrystalline counterparts [1,2]. Nanostructured surface layer on the surface of metallic materials were produced by several surface deformation process. The ultrafine grain structures are produced by inducing intense strains and high strain rates into the surface layer of the aluminium alloy by ultrasonic peening [3]. Controlled ball impact peening (CBI) is one of the potentional ways to create nanocrystalline structure by imparting high strain rates on the surface layer of metallic materials developed in-house. Nanocrystalline surface layer was produced on the surface of AISI 304 stainless steel by imparting high strain rate using controlled ball impact process [4]. The objective of the present work is to describe the nanostructure surface layer formation in an aluminium alloy AA6063-T6 by means of a controlled ball impact test facility with different sample traveling velocity. The microstructure features of the treated surface layer were characterized using X-ray diffraction (XRD) analysis and transmission electron microscopy (TEM) with the aim of understanding the microstructural evolution and mechanisms of grain refinement associated with the formation of nanostructured layer.

Experimental Details and Test Material

In this work aluminum alloy, AA6063-T6 is used. Samples of dimension 25 mm x 10 mm surface area obtained from a 6 mm thick plate were polished and then treated by the controlled ball impact process. Controlled ball impact peening was carried out using a 2 mm diameter hardened steel ball at a strain rate of 2320 s^{-1} and the samples were precisely moved using programmable logic controlled linear actuator. Controlled impacts were performed at different sample traveling velocities, 0.76, 1.02 and 1.27 mm s^{-1}. The changes in the mechanical properties of the treated surface were studied using a dynamic ultra micro-hardness tester. Microhardness of the nanocrystalline surface layer was measured on the metallographically prepared cross-sectioned surface using a berkovich indenter along the specimen thickness. The surface roughness was measured using a profilometer and X-ray diffraction of the treated surface layer was performed to quantify the average grain size and micro-strain accumulated [5].

Results and Discussion

Figure 1 represents typical load-depth curves obtained from microindentation experiments of the treated and untreated cross sectioned sample obtained at a distance of 30 microns from the treated surface layer. The two parameters measured from the obtained load depth curve are hardness and elastic modulus. Hardness depends upon the indentation depth and η value represents the elastic behavior of the material. Under the fixed maximum load, lower the indentation depth harder is the material. The ratio (η) of the recoverable deformation energy (W_e) to the total deformation energy (W_{tot}) is a measure of elastic behavior of the material [6]. The area enclosed by the unloading curve and the maximum depth represents the recoverable deformation energy and the area enclosed by the loading curve and the maximum depth represents the total deformation energy. The left hand side shift of the force depth curve compared to the untreated sample indicates the presence of a compressive residual stress developed by the controlled ball impact peening. The hardness and η value are higher at the surface and gradually decrease with an increase in distance from the surface and eventually became stable after 450 μm. The increase in surface hardness and η value by the treatment are due to formation of nanostructure and high density dislocations. Table 1 illustrates the indentation work (η) and the maximum indentation depth (h_{max}).

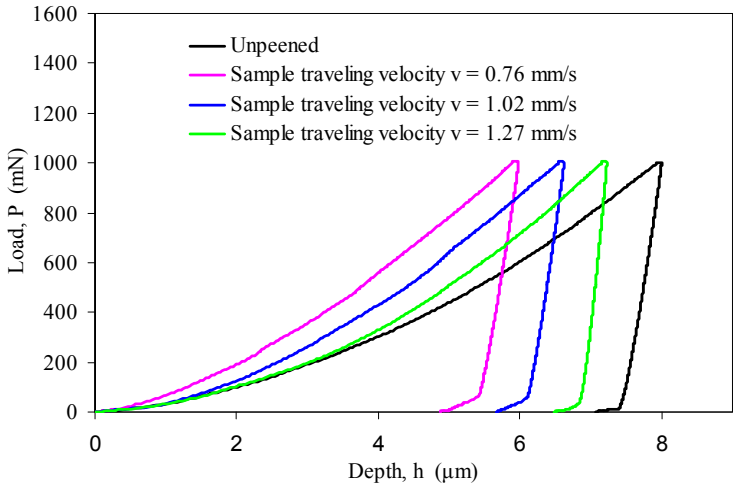

Figure 1 Load depth curves from microindentation experiments.

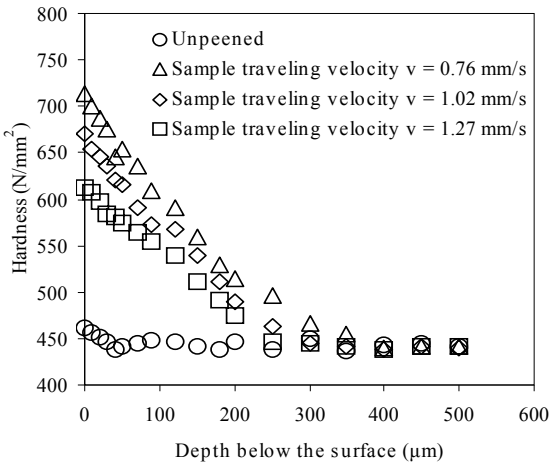

Figure 2 Microhardness profile of as-received and ball impact peened samples

Table 1 Surface properties determined by microindentation and XRD analysis.

Specimen	Maximum depth (μm)	η (%)	Grain size, (nm)	Microstrain (%)
Unpeened	8.2 ± 0.3	6.03 ± 0.3		
Sample traveling velocity v = 0.76 mm/s	6.2 ± 0.2	13.5 ± 0.1	72±2	0.207±.01
Sample traveling velocity v = 1.02 mm/s	6.62 ± 0.1	12.5 ± 0.2	96±1	0.187±.01
Sample traveling velocity v = 1.27 mm/s	7.1 ± 0.1	11.7 ± 0.2	128±3	152±.015

Figure 2 represents the Martens hardness variation along the depth of the as-received and treated surfaces at different sample traveling velocity. Hardness measurement conducted through the metallographically prepared cross-sectioned specimen indicates the depth of the hardened layer is ~ 300 μm and depends upon the sample traveling velocity. Peening at a low sample traveling velocity causes multiple impacts and severe plastic deformation of the surface resulting in increased depth of hardened layer. In the peened samples the magnitude of hardness was high at the surface and decreased with increased distance from the surface. The strengthening of the treated sample is primarily attributed to the substantial grain refinement into the nanometer level. Higher hardness of the treated surface is due to increased grain boundaries and strain hardening. The grain boundary can block the dislocation movement rendering the material to be harder.

It is observed that after the controlled ball impact peening there was an evident line broadening, reduction in peak intensity of the Braggs diffraction peaks and a shift in the centroid position of these diffraction peaks relative to the coarse grained sample. These changes result due to the grain refinement, development of micro-strain and micro-distortion of the crystalline lattice. The variation of the average grain size and microstrain of the treated samples with different sample traveling velocities are shown in Table 1. The average grain size and micro-strain accumulated on the surface layer determined using Scherrer and Wilson method revealed the formation of ultrafine grain crystalline size of 72 nm with a microstrain of 0.21% for the specimen peened at a sample traveling velocity of 0.76 mm s^{-1}. The evident broadening of Braggs diffraction peaks are due to grain refinement and an increase in the atomic level microstrain. It can be noticed the

magnitude of microstrain are higher at lower sample traveling velocity due to decreased grain size.

Transmission electron microscopy dark field image and an insert corresponding to selected area diffraction pattern (SAED) of the top surface layer of CBI treated sample with a sample traveling velocity of 0.76 mm s^{-1} illustrates the equiaxed microstructure into a nanometer regime with random crystallographic orientation. The selected area electron diffraction pattern indicates the grains are randomly oriented with highly misoriented boundaries. The mean grain size of the nanocrystalline surface layer is approximately 8 nm for the specimen peened at a sample traveling velocity, 0.76 mm s^{-1}. High strain rate and multi-directional loading imparted in the contact zone generates the localized multiple shear bands, which were responsible for the nanostructured surface layer formation.

Conclusion

The controlled ball impact peening introduces the compressive residual stress with a marginal increase in the surface roughness with increasing sample traveling velocity. Microstructural investigations have revealed that the controlled ball impact peening process can introduce ultrafine grain structures in the surface layer of the materials. The grain size is about 8 nm in the top surface layer for a sample traveling velocity of 0.76 mm s^{-1}. The closer the distance from the top surface of the nanocrystalline layer finer is the grain size due to the increment of strain over the entire deformed layer.

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