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Microstructural Evolution of SS304 upon Various Shot Peening Treatments

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Shot peening is an effective way of introducing plastic deformation on the surface of the materials, which in turn enhances hardness, corrosion resistance, fatigue life, etc' Shot peening produces a gradient strain from the treated surface into the specimens inducing a depth-dependent microstructure from the top treated surface down to the unmodified matrix. Investigation of the gradient microstructure typically includes electron-microscopy analyses of the plan-view and the cross-section of the specimens. Typical thinning procedures of the plan-view and cross-sectional specimen for transmission electron microscope (TEM) observation include slicing, face to face bonding of the treated surfaces, dimpling and final-thinning by ion milling. It is well known that the pre- and final- thinning processes are time consuming with a high possibility of microstructural damage. To date, various shot-peening induced microstructures of deformation such as α'-martensitic transformation, dislocation, stacking fault, deformation twin (DT) and ε-martensite have been reported [1]. However, comprehensive study of the shot peening induced depth-dependent structures and their relationship with mechanical properties and the process parameters has yet to be carried out for reliable application in design.

In this work, plastic deformation is introduced to an austenitic (γ) stainless steel (SS304) by using the air blast shot peening (ABSP), ultrasonic shot peening (USP) and ultrasonic nanocrystalline surface modification (UNSM) techniques. The objectives are 1) development of efficient time-saving, damage-free, and position specific thinning method of plan-view and cross-sectional specimens for TEM observation, 2) characterization and comprehensive investigation of the deformation structures, 3) determination of the effect of strain on the deformation microstructure, and 4) underlying grain refinement mechanism.

The plates of SS304 were subjected to ABSP, USP or UNSM treatment. After the treatment, the surface of the specimens was characterized by using scanning electron microscope, X-ray diffractometer and TEM. To characterize the depth specific microstructure after treatment, the plan-view and cross-sectional specimens were prepared for electron backscatter diffraction and TEM study. For preparation of the plan-view and cross-sectional TEM specimens, dimpling- and milling- free processes were successfully developed.

The original matrix consists of large grains with annealing twins free of stacking faults with minimal dislocations. Various deformation structures were generated after ABSP, USP and UNSM treatments, i.e., planar dislocation arrays (PDA), DT, ε-martensite, shear band (SB) and α'-martensite with change of depth into the specimen. According to the defects formed, several regions could be classified above the unmodified original matrix deep down: (1) As it gets to the treated surface, the PDA show up in the first layer; (2) At the next layer, the DT intersection is frequently observed, with nano-sized ε-martensite within the DTs and at the intersections of DTs (Fig. 1a); (3) SBs were formed at the layer further above, which cut through the DTs (Fig. 2b); (4) When the depth decreased to near the topmost surface, α'-martensite was revealed by detailed analysis of the selected area electron diffraction pattern (SADP, Fig. 2b); and (5) In the topmost surface layer, the nanograins were observed as shown in Fig. 2.

It is natural to observe the dependence of deformation structures on the depth in the shot peened specimens, since the amount of strain increases as it gets close to the top treated surface from the matrix deep down. The key in the successful preparation of the depth specific cross-sectional and the plan-view TEM specimens in this study is electrolytic polishing with careful control of electropolishing process with timely on and off of one side of the double-jet polisher. The sequence or development of the defects depending on the amount of strain is: (1) The PDA and DT structures in the low strain region; (2) DT-SB/DT intersection and ε-martensite structures in the medium strain region; and then (3) the α'-martensite in the high strain region. The grain refinement mechanism is related to: (1) sub-division of coarse grains by DTs and SBs as well as their interaction, and (2) formation of nano-sized α'-martensite. No significant differences were observed on the deformation microstructures and grain refinement mechanisms of SS304 upon the ABSP, USP or UNSM treatments [2].

References

[1] K.H. Lo, C.H. Shek and J.K.L. Lai, Materials Science and Engineering **R65** (2009), p. 39.
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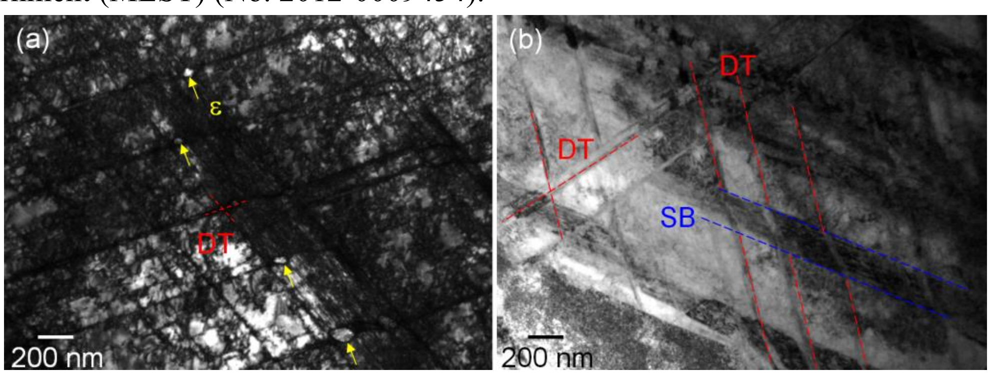

Figure 1. Typical cross-sectional TEM images of the USP treated specimen at the depth of (a) ~110 μm and (b) ~50 μm.

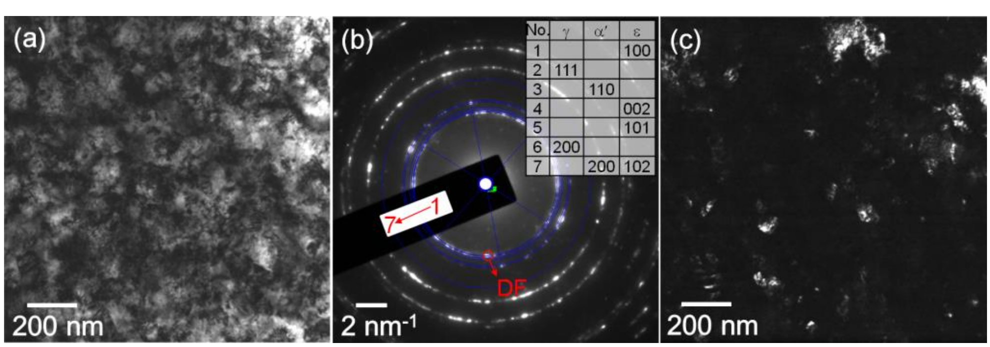

Figure 2. Typical plan-view TEM (a) bright field, (b) corresponding SADP, and (c) dark field images of the USP treated specimen at the topmost surface, showing the developed nanostructure in the topmost surface. The indexing of the ring-like SADP (b) confirmed the formation of the α'-martensite, and the presence of nano-sized γ and ε-martensite.

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