

## Microstructural Study of the Gradient Structured Austenitic Stainless Steel Treated by Shot Peening

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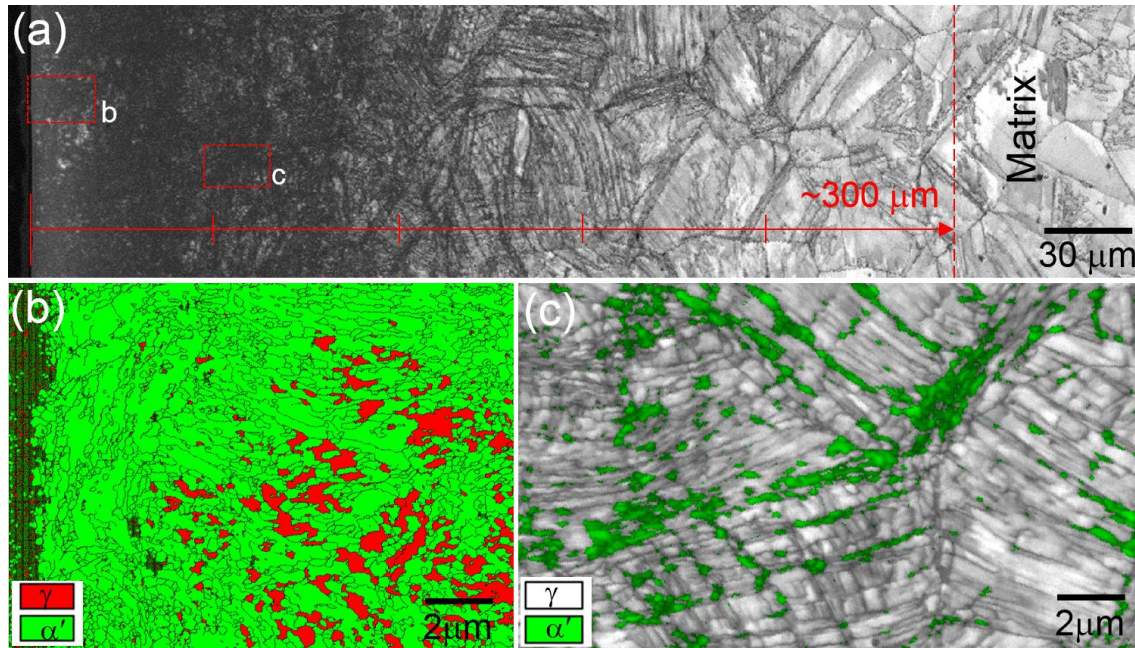
Shot peening techniques are the widely used ways to introduce plastic deformation on the surface of the materials, and resulting in the enhancement of mechanical properties such as hardness, corrosion resistance and fatigue [1]. The depth-dependent and gradient microstructure is formed from the top treated surface to the deep matrix on the shot peened specimens. Microstructural studies of the depth-dependent microstructure include plan-view and cross-sectional observation. Traditional sampling procedures of the plan-view and cross-sectional specimen for TEM observation include cutting, bonding with dummy, pre-thinning by dimpling and final-thinning by ion milling. It's known that the pre- and final- thinning processes are time consuming, and may introduce some damages to the specimen. Various deformations i.e., dislocation, stacking faults, deformation twin (DT) and martensitic (transformation) have commonly been reported in literatures.

In a previous study, the grain refinement mechanisms of an austenitic ( $\gamma$ ) stainless steel (SS304) upon shot peening were characterized as the strain induced formation of various grain boundaries, i.e., DT,  $\epsilon$ (hcp)- and  $\alpha'$ (bcc)- martensite, which divided/sub-divided the original coarse grain into the nanoscale [2].

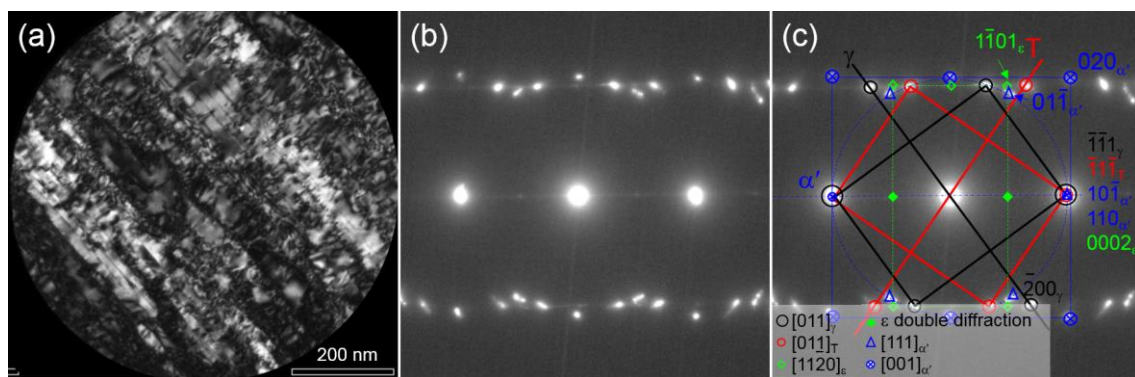
In this work, the SS304 samples were shot peened by the ultrasonic nanocrystallization surface modification (UNSM). The UNSM is designed to transfer the high energy of the ultrasonic vibration (20 kHz) with an extra static load (60N) via a single hard ball (WC, 3mm in diameter) to the surface of the specimen impacting 20,000 times per second, introducing very high plastic deformation on the sample. After treatment, the gradient microstructures were studied using the EBSD and TEM with focuses on the mechanism of the strain induced martensitic transformation. The plan-view and cross-sectional samples for TEM observation were prepared successfully by a modified/delicate manipulation of the specimen setting of the double jet-polisher.

The EBSD results indicate that the original  $\gamma$  ( $\sim 30 \mu\text{m}$  in size) grains were refined to nanoscale ( $\sim 200 \text{nm}$ ) in the very top layer/region of treated specimen. The deformation depth induced by the UNSM is  $\sim 300 \mu\text{m}$  from the top surface (Fig. 1a). In the top layer up to  $5 \mu\text{m}$  of depth, full transformation to  $\alpha'$ -martensite is observed (Fig.1b), whose size is  $\sim 200 \text{nm}$ . With the increase of the depth from the top treated surface to  $\sim 120 \mu\text{m}$ , the volume fraction of the  $\alpha'$ -martensite decreased to its initial condition of no martensite. The  $\alpha'$ -martensite is frequently observed in the intersection of the newly formed grain boundaries (Fig. 1c, DT). TEM results (Fig. 2) suggested that the strain induced martensitic transformation in SS304 treated by UNSM has the mechanisms of the direct  $\gamma \rightarrow \alpha'$  transformation, and via the intermediate  $\epsilon$  ( $\gamma \rightarrow \epsilon \rightarrow \alpha'$ ) transformation. The N-W orientation relationship appears to play a key role on both of the transformation. Further details of the transformation mechanisms are under close analysis. The findings may have implications for improved microstructural control in deformed austenitic metals and alloys.

- [1] M.A. Meyer, A. Mishra, D. J. Benson, Progress in Materials science **51**, p.424 (2006).  
 [2] Y. He, K. Li, I.S. Cho, C.S. Lee, I.G. Park, J.-I. Song, C.-W. Yang, J.-H. Lee, K. Shin, Applied Microscopy 45, p.155 (2015).  
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**Figure 1.** EBSD images of the UNSM treated specimen: (a) Image quality map (IQM) indicating the deformation depth after UNSM is up to 300 μm, (b) Phase map image of the top layer, region indicated by “b” in (a), the grains colored red and lime are the phase of γ and α', respectively. The full α'-martensite is formed in the top layer (up to 5 μm in depth). (c) IQM with indication of phase as marked “c” in (a), grains colored white and lime are the phase of γ and α', respectively.



**Figure 2.** TEM results of the UNSM treated specimen at the depth of ~ 250 μm from the top treated surface: (a) typical TEM BF, and (b) SADP, (c) SADP with its indices. Strain induced nanosized deformation twin, ε- and α'-martensite were formed. The crystal orientation relationships of the matrix and martensite are characterized as the 1) K-S:  $[011]_{\gamma} // [1\bar{1}20]_{\epsilon} // [111]_{\alpha'}$ ;  $(\bar{1}11)_{\gamma} // (0002)_{\epsilon} // (101)_{\alpha'}$  and 2) N-W:  $[011]_{\gamma} // [001]_{\alpha'}$ ;  $(111)_{\gamma} (110)_{\alpha'}$ .