



Surface Nanostructuring of AISI 1017 by Severe Shot Peening

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Abstract

In this study, AISI 1017 low carbon steel was subjected to severe shot peening (SSP) by using 35 mmA Almen intensity. SSP led to surface severe plastic deformation by the impingement of the shot media with very high air pressure. 40-50 μm highly deformed nanograin layer was formed right below the surface by means of sub grain creation with dislocation interaction and non-homogenous strain. Nanoindentation tests were performed to detect the hardness and reduced modulus of fine grained layer and the results reveal the hardness increased up to almost 1,5 times with compared to core. The reduced modulus is also influenced from very hard nanocrystalline layer.

Keywords

Defects; Deformation and fracture; Severe shot peening; Severe plastic deformation; SMAT; Nanostructured layer

Introduction

Nanostructured materials have been assessed as crucial for metallurgical, industrial and biological environments [1-3]. These materials have been manufactured with two methods, one is bottom-up and the other is top-down. The top-down method called "severe plastic deformation (SPD)" methods principle is to create large deformations on the coarse grain bulk materials and convert them into bulk nanostructured materials [4]. The great interest have been shown to these materials due to having very high hardness and strength [5]. Also electrical, magnetic and superplastic behaviors can be improved via nanograin formation mechanisms [6]. Besides, the application of severe plastic deformation to create bulk nanostructured materials have some limitations. Higher force requirements, non-uniform strain exposure, unexpected material failures and also limited sample sizes are given as the examples [7].

Most failures of metallic materials such as fatigue, fretting fatigue, corrosion and wear are directly related with surface characteristics [8,9]. Therefore, refining the surface grain layers by using surface severe plastic deformation (S²PD) applications could be beneficial for overcoming such type of these failures [10,11]. S²PD methods have been applied to induce nanograin layer on and just below the surface and cover the most common applications such as surface mechanical attrition treatment (SMAT) [12], surface nanocrystallization and hardening (SNH) [13], ultrasonic nanocrystal surface modification (UNSM) [14-17]. In recent years, severe shot peening (SSP) has been

applied for exposing high plastic deformation to surfaces besides increasing fatigue strength by inducing compressive residual stresses [18-21]. The studies reveal SSP influence with Almen intensity higher than the conventional ones behaves like the methods mentioned above [22-24]. Application of SSP is much more easier, only changing the initial parameters of shot peening equipment will be adequate. Also type of the application provides convenience for complex and intrinsic samples regardless of size and dimensions [4,25-27].

In this study, AISI 1017 low carbon steel was applied to the SSP with 35mmA Almen intensity. Then the surface was investigated by using optical microscopy, scanning electron microscopy (SEM) and high resolution transmission electron microscopy (HRTEM). Nanoindentation tests were performed to show the hardness change and compare the results with the microstructural observations.

Experimental

AISI 1017 low carbon steel specimens with the following chemical compositions in mass (%) C 0,15-0,20, Mn 0,30-0,60, P 0,04(max), S 0,05(max) and balance Fe. The specimens were ground with 180-1200 grit papers then mechanically polished. Annealing treatment has been applied at 810°C for 30 minutes and then cooled in the furnace to room temperature. Air blast severe shot peening was performed via 2000S Peenmatic shot peening equipment. 35 mmA Almen intensity was selected to compensate severe plastic deformation conditions. Shot peening parameters used for the treatment are shown in Table 1.

The specimens were analyzed via optical microscopy (Zeiss AXIO A1 optical microscope), SEM (Tescan MAIA3 XMU) and HRTEM (JEOL JEM 2100). The specimens were ion polished as mechanically thinning to a thickness of 80 μm by disc grinding and to about 5 μm by dimple grinding from metal side. Hardness distribution from surface to interior was determined by using Shimadzu DUH-W201S ultra micro-hardness tester. The applied load was 50 mN with a duration of 10 s.

Results and Discussion

SSP applied with 35mmA Almen intensity leads to form highly deformed, oriented layer with a thickness of approximately 40-50 μm . The peened specimens microstructure can be seen from Figure 1. The deformed layer shows SSP is an effective way to expose severe plastic deformation at least as much as SMAT and etc [28,29].

In SEM microstructure (Figure 2) reveals the deformed layer in detail. Homogenous ferrite-pearlite structure in the core structure vanishes in the deformed layer. Bagherifard and Guagliano [30] show the distinction of conventional shot peening (CSP) and SSP effect on low alloy steel and the heavily deformed layer is much thicker than CSP however the surface peened with SSP is much more deteriorated which is similar to this study. Besides creation of ultra fine grain layer, the treatments leads to surface deterioration. Higher pressure application for SSP can not prevent hazardous effects on the [31] surface. Thus, surface quality and integrity should be assessed simultaneously with microstructural improvement during SSP.

Figure 3a shows typical HRTEM observations of highly deformed surface layer. During deformation, cementite phases are broken

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Received: May 27, 2017 Accepted: June 24, 2017 Published: June 29, 2017

Table 1: The air blast severe shot peening initial parameters.

Almen intensity	Shot size	Coverage (%)	Time (s)	Pressure (psi)	Arc height (mmA)
35mmA	S230	200	20	105	0,35

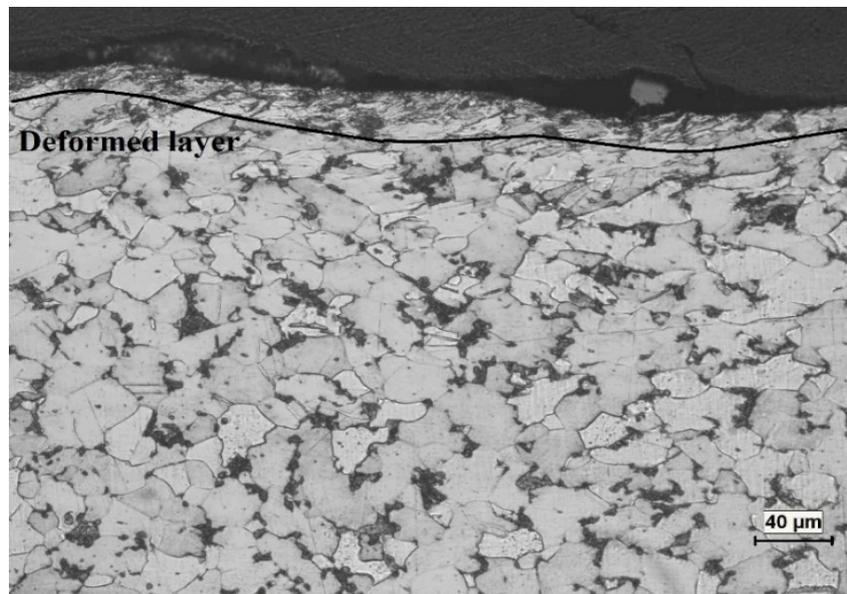


Figure 1: The cross section optical microscope observation of severe shot peened specimen.

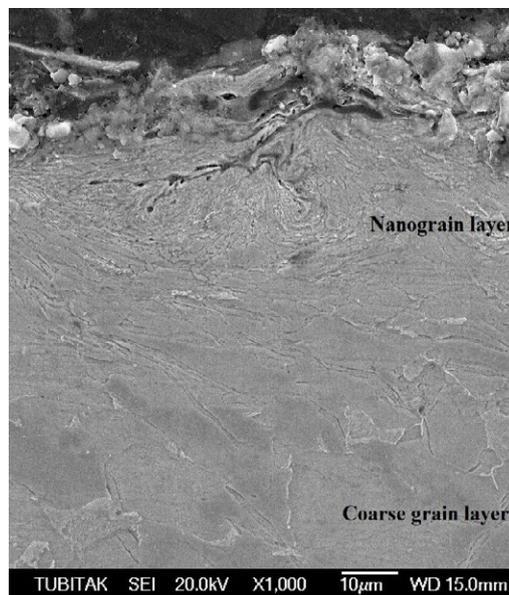


Figure 2: SEM microstructure of the ultrafined grain layer.

where subgrain formations under 100 nm are observed in Figure 3b particularly inside the subgrains. Since, Moering et al. presents white layers in HRTEM investigations prove the fragmentation of Fe_3C compounds due to supersaturation of carbon into nanocrystalline alpha-iron [31]. The grain refinement is formed as non-uniform and non-homogenous. Since the grain sizes could be assessed within a broad range (40-400 nm). Also SMAT application to ultra low carbon steel forms the grain size distribution with is between 10 nm and 100 nm [32]. However, the microstructure has high density

dislocations and interactions (Figure 3c) and stacking faults near the grain boundary (Figure 3a). Also in Figure 3b, ultrafine subgrains are distinguished via grain boundaries. In severe plastic deformation treatments the deformation intensifies near the grain boundaries [33] and subgrain is formed so this is consistent with the study HRTEM investigations. Typical BCC metals for instance low alloy steels have high stacking fault energy [6]. Exposure of severe plastic deformation leads to dislocation movement, tangles and dense walls (Figure 3c). This dislocation behavior can be accepted as the first step of subgrain

formation [1]. The actual subgrains and its boundaries are created by high dislocation interactions regardless of active or inactive type. Subgrains are formed in the original grains inside original grain boundaries (Figure 3b) [6].

According to the nanoindentation measurements, surface have been exactly influenced from severe plastic deformation. Thus, the nanohardness values are much higher than the core. The hardness alteration is compatible with optical microscope and SEM observations. The topmost layer (approximately 40 μm) mostly influenced from severe plastic deformation could be easily realized according to the orientation of grains. The plastic deformation effect has been substantially vanished after 150 μm (Figure 4). Also the reduced elastic modulus has been investigated by means of indentation-depth curves and Oliver & Pharr mathematical approach [34]. Nanocrystalline layer with high hardness leads to increase reduced modulus through the interior of 40 μm.

Conclusions

In this study, AISI 1017 low carbon steel was exposed to SSP with an Almen intensity of 35 mmA. The effect severe plastic deformation

created by SSP were analyzed via optical microscopy, SEM, HRTEM and nanoindentation tests. Following results can be drawn according to the practical approaches.

Optical microscope and SEM observations presents the deformed and oriented layer which has so much distinctions from the core structure on and right below the surface. The thickness of the layer can be identified approximately 40 μm.

According to the HRTEM results, SSP forms nanocrystalline layer with the grain size of 40 nm to 400 nm. The distribution of the grains and also grain sizes can be assessed as non-uniform and non-homogenous. The HRTEM approach reveals the formation of nanocrystalline layer is directly related with dislocation movement, interactions and then sub-grain formation. In the figures highly dislocation densed grains and subgrains are distinguished.

Nanocrystalline layer makes the structure so hard with compared to interior. Moreover, reduced modulus on the surface is also improved. The change in elastic modulus and hardness could pave the way for particularly tensile strength.

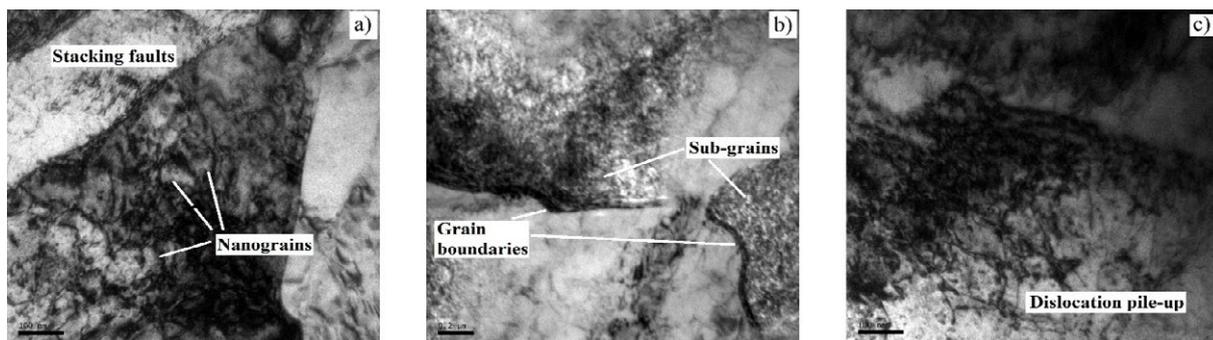


Figure 3: HRTEM structures of severe shot peened specimen.

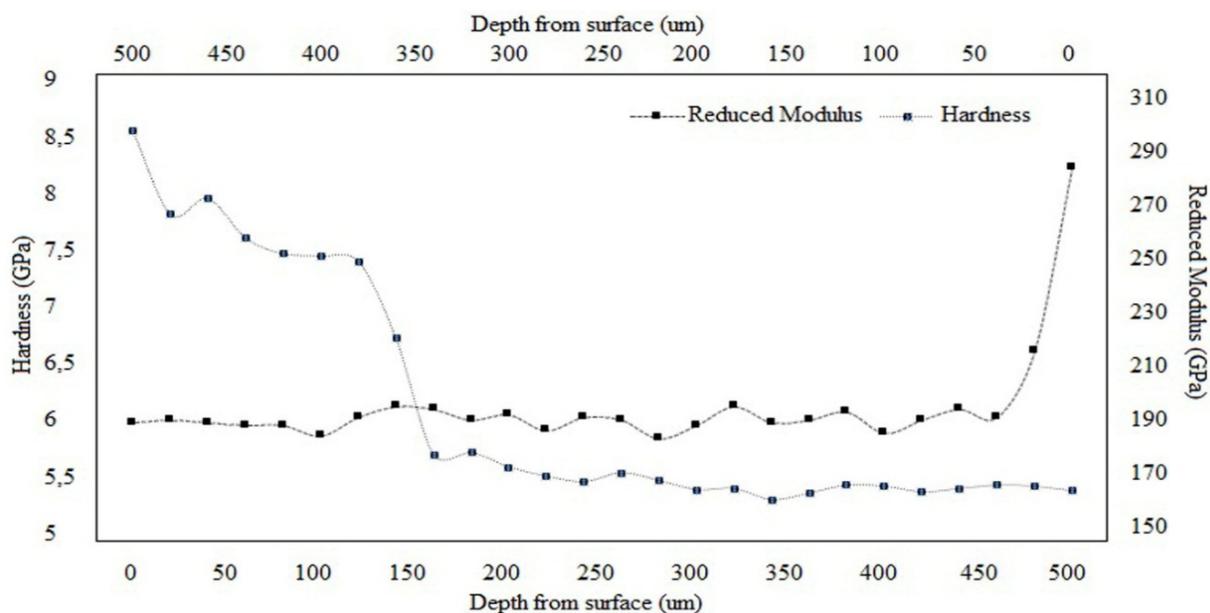


Figure 4: Reduced modulus and hardness alteration of the severe shot peened specimen.

References

1. Valiev RZ, Islamgaliev RK, Alexandrov IV (2000) Bulk nanostructured materials from severe plastic deformation. Prog Mater Sci 45: 103-109.
2. Raja KS, Namjoshi SA, Misra M (2005) Improved corrosion resistance of Ni–22Cr–13Mo–4W alloy by surface nanocrystallization. Mater Lett 59: 570-574.
3. Liao XZ, Srinivasan SG, Zhao YH, Baskes MI, Zhu YT (2004) Formation mechanism of wide stacking faults in nanocrystalline Al. Appl Phys Lett 84: 3564-3566.
4. Unal O, Varol R (2014) Almen intensity effect on microstructure and mechanical properties of low carbon steel subjected to severe shot peening. Appl Surf Sci 290: 40-47.
5. Unal O, Karaoglanli CA, Varol R, Kobayashi A (2014) Microstructure evolution and mechanical behavior of severe shot peened commercially pure titanium. Vacuum 110: 202-206.
6. Zehetbauer MJ, Zhu YT (2009) Bulk nanostructured materials. Wiley-WCH, Weinheim, Germany.
7. Estrin Y, Vinogradov A (2013) Extreme grain refinement by severe plastic deformation: A wealth of challenging science. Acta Mater 61: 782-817.
8. Unal O, Zulcic I, Varol R, Karademir I, Ates S (2016) Novel type shot peening applications on railway axle steel. Journal of Mineral Metal and Material Engineering 2: 1-5.
9. Unal O, Varol R, Erdogan A, Gok MS (2013) Wear behaviour of low carbon steel after severe shot peening. Mater Res Innov 17: 519-523.
10. Lin Y, Lu J, Wang L, Xu T, Xue Q (2006) Surface nanocrystallization by surface mechanical attrition treatment and its effect on structure and properties of plasma nitrided AISI 321 stainless steel. Acta Mater 54: 5599-5605.
11. Karademir I, Unal O, Ates S, Gokce H, Gok MS (2017) Effect of severe plastic deformation on wear properties of aluminum matrix composites. Acta Phys Pol A 131: 487-489.
12. Liu S, Gao SY, Zhou YF, Xing XL, Hou XR, et al. (2014) A research on the microstructure evolution of austenite stainless steel by surface mechanical attrition treatment. Mat Sci Eng A-Struct 617: 127-138.
13. Dai K, Shaw L (2007) Comparison between shot peening and surface nanocrystallization and hardening processes. Mat Sci Eng B-Solid A 463: 46-53.
14. Wu B, Wang P, Pyoun YS, Zhang J, Murakami RI (2013) Study on the fatigue properties of plasma nitriding S45C with a pre-ultrasonic nanocrystal surface modification process. Surf Coat Technol 216: 191-198.
15. Amanov A, Cho IS, Kim DE, Pyun YS (2012) Fretting wear and friction reduction of CP titanium and Ti-6Al-4V alloy by ultrasonic nanocrystalline surface modification. Surf Coat Technol 207: 135-142.
16. Amanov A, Sasaki S, Young S (2013) Frictional behavior of duplex nano-corrugated and nanostructured Cu alloy produced by unsm. Procedia Engineering 68: 491-496.
17. Amanov A, Pyun YS, Sasaki S (2014) Effects of ultrasonic nanocrystalline surface modification (UNSM) technique on the tribological behavior of sintered Cu-based alloy. Tribol Int 72: 187-197.
18. Xie L, Jiang C, Ji V (2011) Thermal relaxation of residual stresses in shot peened surface layer of (TiB+TiC)/Ti-6Al-4V composite at elevated temperatures. Mater Sci Eng A 528: 6478-6483.
19. Xie L, Zhang J, Xiong C, Wu L, Jiang C, et al. (2012) Investigation on experiments and numerical modelling of the residual stress distribution in deformed surface layer of Ti-6Al-4V after shot peening. Mater Design 41: 314-318.
20. Xie L, Jiang C, Lu W (2013) The influence of shot peening on the surface properties of (TiB + TiC)/Ti-6Al-4V. Appl Surf Sci 280: 981-988.
21. Zhan K, Jiang CH, Ji V (2013) Uniformity of residual stress distribution on the surface of S30432 austenitic stainless steel by different shot peening processes. Mater Lett 99: 61-64.
22. Unal O, Varol R (2015) Surface severe plastic deformation of AISI 304 via conventional shot peening, severe shot peening and re-peening. Appl Surf Sci 351: 289-295.
23. Bagherifard S, Guagliano M (2011) Influence of mesh parameters on FE simulation of severe shot peening (SSP) aimed at generating nanocrystallized surface layer. Procedia Engineering 10: 2923-2930.
24. Hassani-Gangaraj SM, Moridi A, Guagliano M, Ghidini A (2014) Nitriding duration reduction without sacrificing mechanical characteristics and fatigue behavior: The beneficial effect of surface nano-crystallization by prior severe shot peening. Mater Design 55: 492-498.
25. Unal O (2016) Optimization of shot peening parameters by response surface methodology. Surf Coat Technol 305: 99-109.
26. Maleki E (2016) Modeling of severe shot peening effects to obtain nanocrystalline surface on cast iron using artificial neural network. Materials Today: Proceedings 3: 2197-2206.
27. Maleki E, Farrahi GH, Sherafatnia K (2016) Application of artificial neural network to predict the effects of severe shot peening on properties of low carbon steel. Machining, Joining and Modifications of Advanced Materials, Springer Nature, Berlin, Germany.
28. Liu G, Wang SC, Lou XF, Lu J, Lu K (2001) Low carbon steel with nanostructured surface layer induced by high-energy shot peening. Scripta Mater 44: 1791-1795.
29. Wang ZB, Tao NR, Li S, Wang W, Liu G, et al. (2003) Effect of surface nanocrystallization on friction and wear properties in low carbon steel. Mater Sci Eng A 352: 144-149.
30. Bagherifard S, Guagliano M (2012) Fatigue behavior of a low-alloy steel with nanostructured surface obtained by severe shot peening. Eng Fract Mech 81: 56-68.
31. Moering J, Ma X, Chen G, Miao P, Li G, et al. (2015) The role of shear strain on texture and microstructural gradients in low carbon steel processed by surface mechanical attrition treatment. Scripta Mater 108: 100-103.
32. Balke P, De Hosson JTM (2001) Orientation imaging microscopic observations of in situ deformed ultra low carbon steel. Scripta Mater 44: 461-466.
33. Khodabakhshi F, Kazeminezhad M (2011) The effect of constrained groove pressing on grain size, dislocation density and electrical resistivity of low carbon steel. Mater Design 32: 3280-3286.
34. Oliver WC (2004) Measurement of hardness and elastic modulus by instrumented indentation: Advances in understanding and refinements to methodology. J Mater Res 19:20.

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