M3-002 Microstructure and Microhardness of AISI 316L after Surface Mechanical Attrition Treatment

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ABSTRACT

Surface treatment is crucial for improving mechanical and physical properties of metals. This paper discusses the effect of surface mechanical attrition treatment (SMAT) on microhardness and microstructure of AISI 316L. The polished samples were treated for 0 - 20 minutes. The result shows reduced grains size and enhancement of microhardness on the sample's surface and subsurface by increasing SMAT duration. Both the grains size and the microhardness are relatively constant at a distance of up to 1 mm from the treated surface.

Keywords: microstructure, microhardness, AISI 316L, surface treatment

1. Introduction

Mechanical strength is one of the most important properties on metals. It can be enhanced by varying their chemical composition [1] and introducing refined grains into their structure [2]. Grains refinement can be obtained using four techniques: (1) consolidation of nanocrystalline powders, (2) physical, chemical, and electrochemical deposition, (3) crystallization of amorphous materials, and (4) severe plastic deformation (SPD) [3]. Compared with the others, SPD enhances mechanical strength without introducing certain substances into the material [2,4].

Surface mechanical attrition treatment (SMAT) is one of the newly developed techniques to perform SPD [2,4-6]. It reduces the size of surface grains into the smaller one by repetitive impact of milling balls. However, it differs to the conventional shot peening in several aspects. SMAT utilizes larger spherical balls (>1 mm) than that in shot peening (0.2 – 1 mm). The velocity of milling balls in SMAT is around 1-20 m/s and directed randomly to the treated surface. In contrary, the velocity of particles in shot peening is typically about 100 m/s and directed normally to the treated surface [6]. SMAT is potential to be used in industrial application because of its flexibility and simplicity to obtain refined grains [2,7].

The result of SMAT depends on the processing parameters [6] and is often indicated by enhancement of surface hardness. The previous study shows enhanced surface hardness as the increase of vibration amplitude [4] and milling ball diameter [8]. However, the effect of duration during the SMAT on surface hardness has not yet been defined.

The aim of this study is to investigate the effect of duration during which SMAT is conducted on the microstructure and microhardness of AISI 316L. The microstructure and the microhardness distribution of the sample's cross sectional area are presented to elucidate the presence of refined grains at the surface and subsurface after SMAT. AISI 316L is used in this study due to its wide application in petrochemical, nuclear, chemical, food industries, and medical devices.

2. Materials and Methods

Samples were prepared from AISI 316L with a dimension of 100 × 12 × 4 mm. The samples' chemical compositions (%wt) are 0.0316 C, 0.4360 Si, 0.0002 S, 0.0202 P, 1.2369 Mn, 10.9653 Ni, 24.3038 Cr, 1.7477 Mo, 0.8637 Cu, 0.0354 W, 0.0134 Ti, 0.0130 Sn, 0.0110 Al, 0.000 Pb, 0.0015 Ca, 0.0362 Zn, and 60.28 Fe. All samples were polished prior to the treatment.

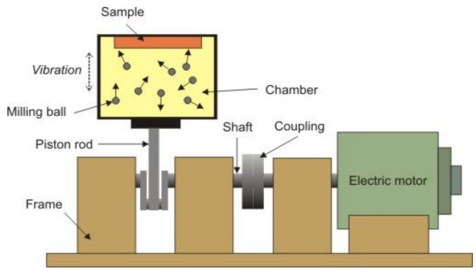

Fig. 1. The construction of SMAT machine

The principles of SMAT have been introduced by Lu and Lu (2004) [6]. Figure 1 shows the construction of SMAT machine used in this study. The experiment used 250 stainless steel balls with diameter of 3/16 in. A constant shaft rotation of 1400 rpm was used to vibrate the chamber. The duration of treatment varies from 0, 5, 10, 15, and 20 minutes.

The samples were cut laterally after the treatment to expose its cross-sectional area for the microstructure observation and the microhardness measurement. The sample's microstructure was observed using Olympus microscope while the microhardness was measured using Buehler microhardness tester.

3. Results

Figure 3 shows the subsurface microstructure of the untreated- and treated-samples.
The result of SMAT is indicated by the presence of refined grains in a few micrometers deep from the surface. The grains size in the untreated-subsurface is larger than that of the treated-ones. However, the effect of increasing duration for treatment on the grains size reduction is not shown obviously.

Figure 3e and 3f show the sample's microstructure after 20 minutes in SMAT at a depth of ±0.2 and >1.0 mm from the surface, respectively. Reduced grains size at a depth of ±0.2 are shown in comparison with those located somewhere >1.0 mm from the surface.

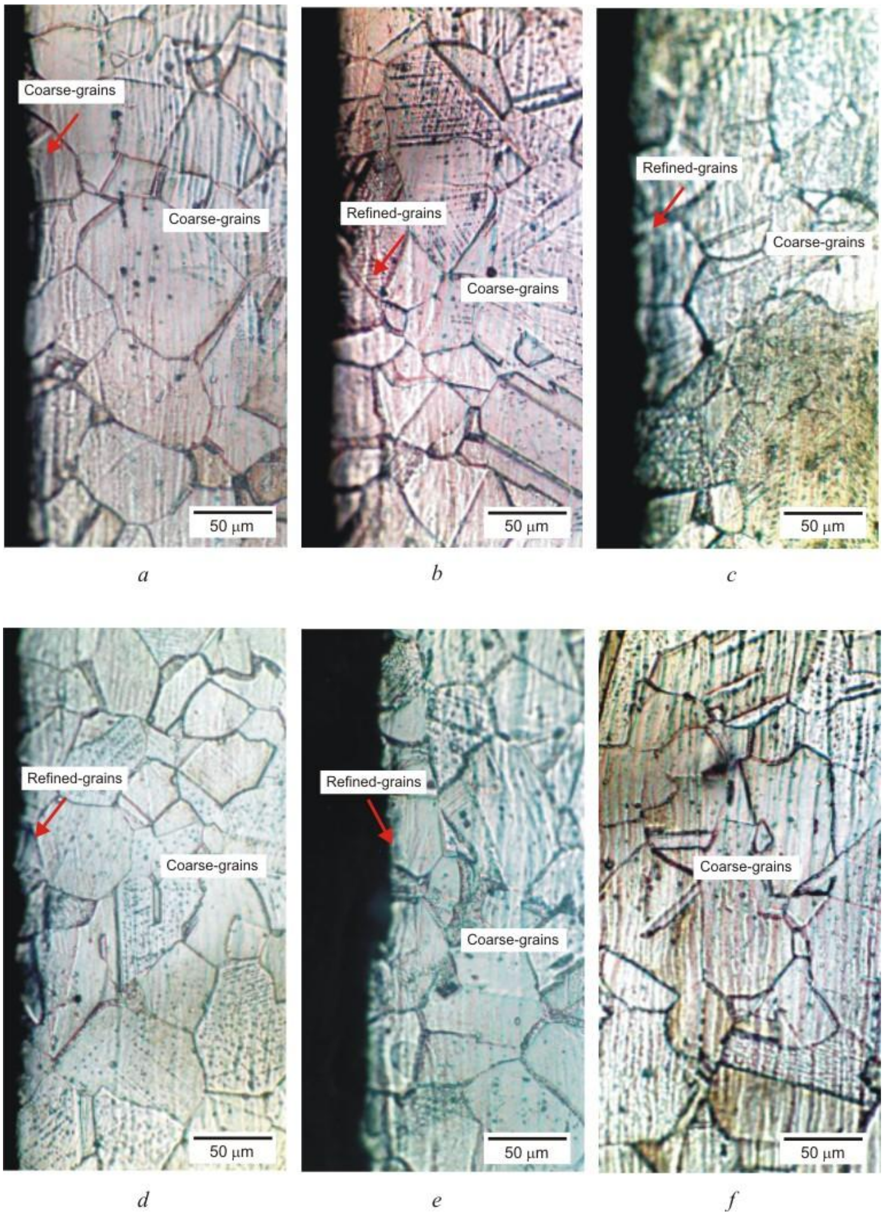

Figure 3. The microstructure of sample's subsurface at a depth of ± 0.2 mm after (a) 0, (b) 5, (c) 10, (d) 15, (e) 20 minutes of treatment and (f) at a depth of up to 1.0 mm after 20 minutes of treatment.

The microhardness distribution across the samples' cross-sectional area is presented in figure 4. The highest H_v is obtained at the treated surface (H_v = 120 – 150 kg/mm^2) for all duration of treatment. The H_v of the treated samples decreases and approaches the values of the untreated-sample (H_v = 80 – 100 kg/mm^2) at the depth of up to ±1 mm. Enhancement on H_v at the sample's subsurface is clearly shown by the increase of SMAT duration. However, it decreases as the increase of duration from 5 to 10 minutes. The thickness of hardened layer at the SMAT samples increases following the enhancement of microhardness.

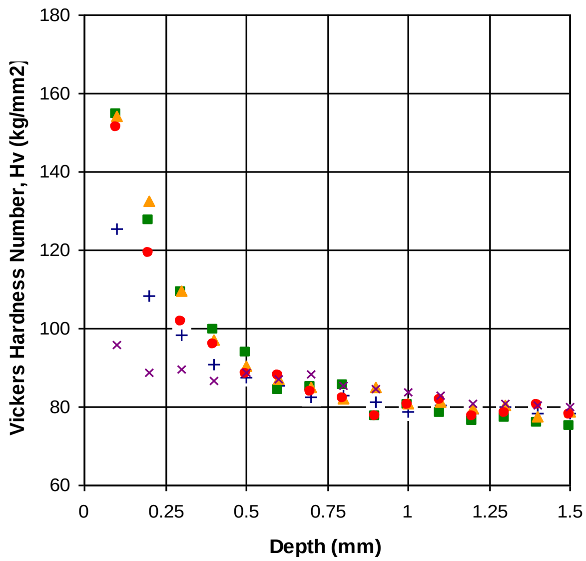

Fig. 4. Microhardness distribution across the samples' cross-sectional area after SMAT process for 0/control (×), 5 (+), 10 (■), 15 (▲), and 20 (●) minutes.

4. Discussions

Surface mechanical attrition treatment (SMAT) transforms the original coarse-grains of a bulk material into refined-grains through random and repetitive impact of milling balls [6]. Such an impact delivers load to induce grains evolution in the material surface and subsurface. The grain refining mechanisms in stainless steel during SMAT are in the following route: (1) formation of mechanical twinning, (2) grain subdivision by twin-twin intersection and (3) formation of randomly oriented nanocrystallites [4,7,9]. Grains with nanometer scale are formed in the last stage of the route. The formation of surface nanocrystallites with a constant impact load proceeds with the duration of treatment. The presence of refined grains increases the sample's hardness. Accordingly, the completion in the grains refinement process during the SMAT determines the hardness. This is consistent with Hall-Petch theory that reveals an inverse relationship between the hardness and grains size [4].

In this study, the grains size reduction at the subsurface due to SMAT with different treating duration is presented. The grains size reduction in the SMAT is shown in comparison with the untreated-samples. A more reduction in grains size resulting from increasing duration is not shown obviously. This is probably due to a very small size of nanocrystallites which are formed after the treatment and making them unobservable under the used microscope in this study. However, the effect of duration in treatment is clearly indicated by the increase of microhardness.

The microhardness at the sample's subsurface decreases gradually and approaches the values of untreated sample at a distance of up to 1 mm. Increasing SMAT duration enhances microhardness on the sample's subsurface. This implies that more surface nanocrystallites are formed by extending duration of treatment. A slight decrease on microhardness is shown at the duration from 10 to 20 minutes. This is probably induced by the presence of grains redistribution and recovery during the treatment. Increasing duration of treatment increases the temperature during the ball-surface collision. Such an increased temperature to a certain value transforms the refined grains into the coarse ones. Hence, the sample's hardness decreases in accordance with Hall-Petch theory [10]. A similar phenomenon has been studied by annealing the SMAT samples into a temperature of 923 K for 1 hour [6]. The hardness drops after annealing and this indicates that the hardening mechanism of SMAT is attributed by the presence of refined grains, instead of introduction of certain substances from the SMAT media.

5. Conclusion

Enhancement on microhardness of AISI 316L via surface grains refinement can be devoted using surface mechanical attrition treatment (SMAT). The duration of treatment contributes on the grains refinement and the microhardness enhancement. In this study, increasing duration of SMAT does not obviously reduce the surface grains size, but clearly enhances the microhardness

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