Microstructure and mechanical properties of CP-Ti subjected to UIT

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Abstract. The ultrasonic impact treatment (UIT) effect on microstructure and mechanical properties of commercial purity titanium (CP-Ti) was studied. The microstrucrure was investigated by X-ray diffraction analysis and optical profilometer New View 6200. The microhardness of CP-Ti specimens was measured by microhardness tester with the Vickers pyramid. It was found that UIT of CP-Ti specimens led to severe plastic deformation of surface layer with a thickness equals to 120 μm. This was accompanied by an increase in compressive residual stresses, a growth of the microhardness, a crystallographic texture change and a rise of density of deformation twins in surface layers of titanium specimens. It was shown that the deformation twins play a determining role in microstructure and mechanical properties changes of the surface layer of titanium specimens.

1. Introduction

It is well-known, that ultrasonic impact treatment (UIT) has been an efficient way to improve the physical and mechanical properties of constructional materials [1-8]. Many articles covered UIT is aimed to study the effect UIT modes on performance properties of steels. For example, it has been shown in [9] that UIT of S45C steel leads to an increase in fatigue life with the growth of a vibration strike number by as much as 33%. Furthermore, Yasuoka et al. [10] have revealed that UIT is appropriate for improving the fatigue strength of SUS304 shafts especially at optimum static load. Moreover, Ye et al. [11] have studied UIT processing of SUS 304. Their results have shown that this process leads to high levels of near- surface compressive residual stresses and dramatic changes in microstructure and hence local and bulk mechanical properties.However, the issue of the UIT effect on the physical and mechanical properties of titanium alloys remains poorly understood. The purpose of this work is to study the effect of ultrasonic impact treatment on microstructure and mechanical properties of commercial purity titanium. It is expected that UIT of CP-Ti allows us to change its texture, values of residual stresses and microhardness.

2. Experimental details

The specimens of commercial purity titanium (0.2 % Al, 0.4 % Zr, 0.3 % Mn, 0.01 % Cr, 0,06 % Si, 0,2 % Fe, 0,02 % Cu and 98.8 % Ti) were annealed for an hour in a vacuum chamber at a temperature of 750 °C and then mechanically polished to a mirror finish. The average grain size of specimens was approximately 100 μm (figure 1). After that, the specimens were subjected by UIT. The UIT of the titanium specimens was carried out by excitation of ultrasonic oscillations in a treating tool. The processing parameters of UIT are presented in table 1.

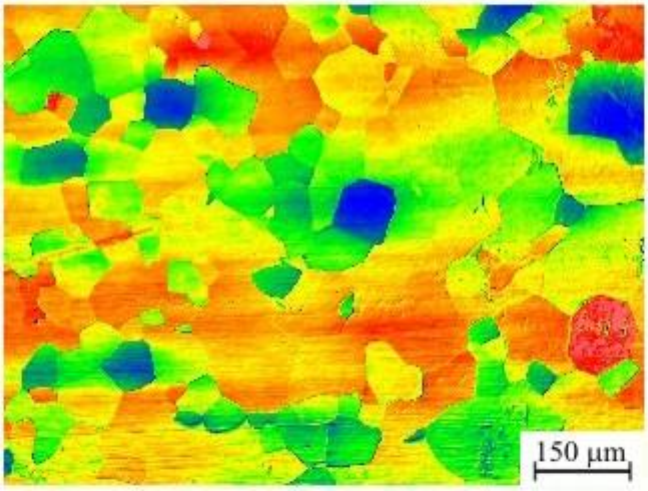

Figure 1. The surface microstructure of the titanium specimens.

Table 1. The processing parameters of UIT.

Frequency (kHz)	22
Amplitude (μm)	40
Static load (N)	200
Diameter of the deforming tool (mm)	5
Scanning speed (ms^{-1})	0,015

The microstructure of the titanium specimens was studied by optical profilometer New View 6200. X-ray diffraction analysis of specimens was performed by a DRON-7 X-ray diffractometer with Co K_{α}-radiation. The thickness of the modified surface layer was estimated from the measurement of the in-depth microhardness of the titanium specimens after UIT. The measurements were performed by microhardness tester with the Vickers pyramid. The indenter load was equal to 50 g. All the measurements were conducted at room temperature.

3. Results and discussion

According to investigations, deformation twins of a high density are generated in the surface and subsurface regions of CP-Ti specimens subjected to UIT (figure 2). It should be noted, that the twin length is limited by grain size. The deformation twins can intersect with each other. As shown on the figure 2, b UIT of specimens leads to the severe plastic deformation of the material surface. The thickness of the deformation layer is about 120 μm.

Figure 3 shows that the initial microhardness of the titanium specimens is 1300 MPa. However, further UIT leads to an increase in surface microhardness up to 2000 MPa. The thickness of plastic deformation surface layer is about 120 μm that correlates well with the data obtained by microstructural investigations (figure 2).

Figure 4 presents the results of X-ray diffraction analysis. According to obtained data, UIT of CP-Ti specimens causes a substantial decrease in intensity of diffraction peaks and appearance of additional peaks at high angles. This indicates that a crystallographic texture of specimen surface layer is changed. Moreover, a broadening of diffraction peaks is also observed after UIT of CP-Ti specimens (figure 4). It means that a lattice distortions value of specimens is increased. In addition, X-ray diffraction analysis showed that UIT results in a formation of compressive residual stresses (210 MPa) in the surface layer of the titanium specimens.

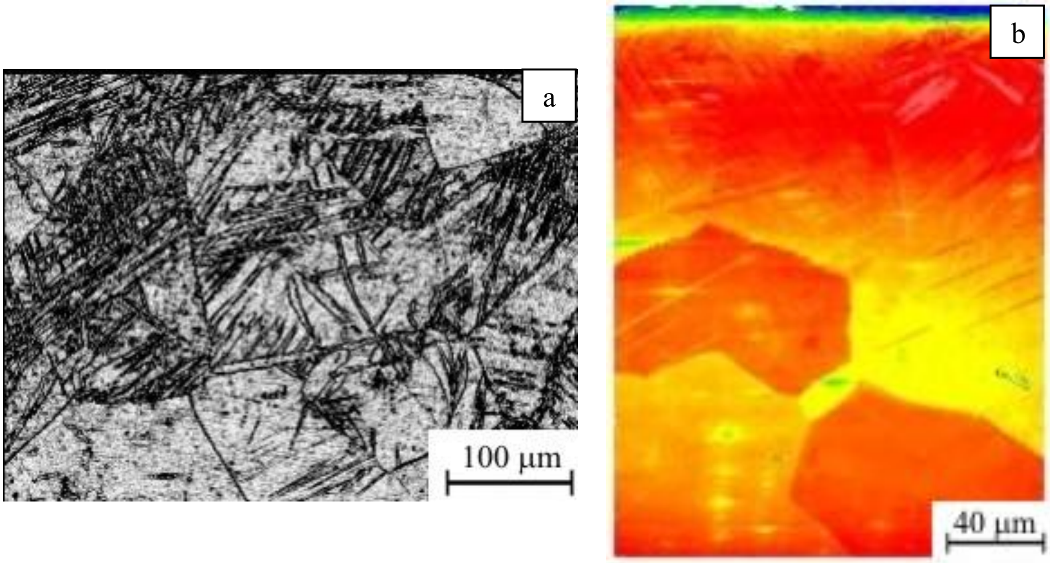

Figure 2. The surface (a) and the cross-sectional (b) microstructure of the titanium specimens subjected to UIT.

The deformation twins that are observed in the surface and subsurface regions of CP-Ti specimens subjected to UIT lead to the reorientation of grains [12,13]. Hence, there is a change of a crystallographic texture in titanium specimens (figure 4). Moreover, the intersection of deformation twins promotes a grain refinement. As a result, the microhardness in the surface layer of titanium specimens is increased.

The formation of compressive residual stresses is associated with severe plastic deformation of the surface layer of titanium specimens under the strikes of the deforming tool vibrating at high frequency.

It is well known, that grain boundaries are an effective barrier for dislocation motion and its propagation deep into the material. As a consequence, the thickness of the hardened layer is determined primarily by the grain size of specimens and limited to one or two grains (figure 2, b).

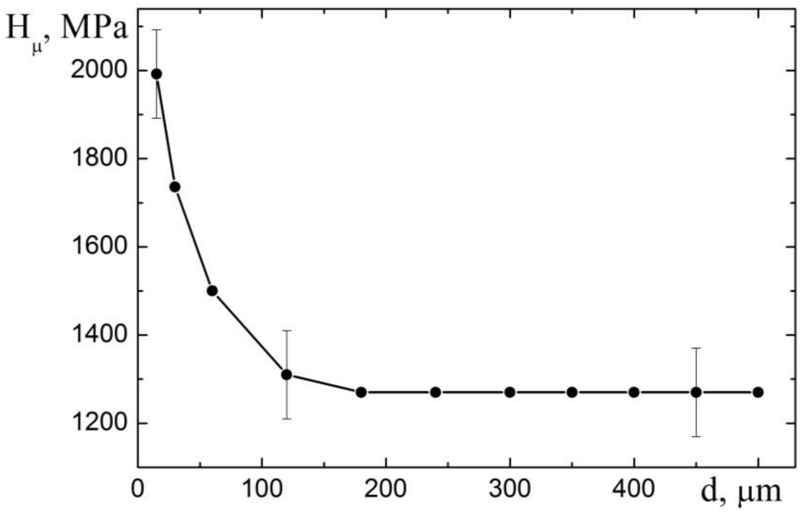

Figure 3. In-depth microhardness H_μ of the titanium specimens subjected to UIT.

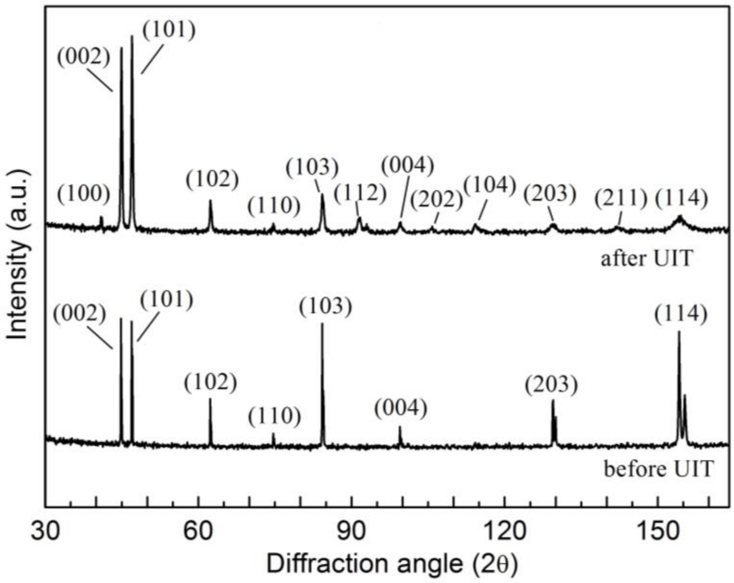

Figure 4. XRD patterns of the titanium specimens before and after UIT.

4. Conclusion

Thus, it was shown that ultrasonic impact treatment of commercial purity titanium specimens led to severe plastic deformation of their surface layer that was accompanied by an increase in compressive residual stresses, a crystallographic texture change and hardening of surface and subsurface regions. The thickness of the hardened layer was about 120 μm and limited by the grain size of titanium specimens. The main reason of the microhardness growth and a change of the crystallographic texture was a formation large numbers of the deformation twins in the surface layer of titanium specimens during ultrasonic impact treatment.

Acknowledgements

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