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Nanostructure and surface roughness in the processed surface layer of Ti-6Al-4V via shot peening

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ABSTRACT

Shot peening process of Ti-6Al-4V was performed at the air pressures ranging from 0.15 MPa to 0.35 MPa and processing durations ranging from 15 min to 60 min so as to obtain the effects of the shot peening on the structure characteristic and surface roughness of Ti-6Al-4V. The experimental results showed that the nanocrystalline layer in Ti-6Al-4V could be fabricated via shot peening at the air pressure above 0.25 MPa and the processing duration above 30 min. The thickness of deformation layer and the degree of grain refinement increased with an increase in the air pressure and processing duration, but the corresponding surface became rougher. In order to obtain a good combination between the grain refinement and the surface roughness, shot peening of Ti-6Al-4V should be performed at a smaller air pressure and a longer processing duration.

1. Introduction

Surface nanocrystallization (SNC) [1] which can transform the coarse-grained surface layer of bulk metallic materials into nanocrystalline layer by means of severe plastic deformation (SPD) provides a very potential approach for improving surface and overall properties of metallic materials, such as hardness [2], wear resistance [3], tensile strength [4], fatigue strength [5] and so on. Shot peening (SP) [6] extensively used in practice can be applied to acquire a nanocrystalline surface layer in bulk metallic materials. The investigations on SNC via SP have attracted an intense research interest during the last decades. Han et al. [7] produced a nanocrystalline layer with a grain size of 35 nm on the surface of bulk TA17 alloy and they pointed out that the microhardness on the topmost surface was about twice that of the coarse-grained matrix. Yang et al. [8] obtained the nanograins in the surface layer of AISI H13 steel with the grain size mainly ranging from 5 nm to 15 nm and found the stress-induced phase transformation in the nanocrystalline layer during SP process. Bagherifard et al. [9] reported that the nanocrystalline surface layer in AISI 316L steel via SP promoted a higher resistance towards crack initiation. Zhong et al. [10] showed that SNC on the processed surface layer of pure Fe via SP enhanced the activation energy and promoted the diffusion coefficient of Al atom during deposition. Hassani-Gangaraj et al. [11] developed a model linking finite element simulation of SP to the dislocation density to predict the grain/subgrain size in the nanocrystalline layer of AISI 4340 steel.

Generally, SP induces both important effects including the variation of the roughness and grain refinement on the surface of metallic materials, that is, the surface roughness will perforce change after SP except for grain refinement [12]. Surface roughness as a crucial surface feature plays an important role in the subsequent application. Stress concentration may be induced due to the large surface roughness, resulting in the crack initiation under fatigue loading [13]. Therefore, a big thickness of nanocrystalline layer in bulk metallic materials with a small surface roughness will be the ideal state during SP. However, they are considered as two competitive ones [14]. Consequently, it is of great importance to study the effect of the SP processing parameters on the grain refinement and surface roughness so as to obtain the correct combination. The correlation studies have been conducted for various metallic materials, such as cast iron [15], AISI 304 steel [16] and so on. Titanium alloys have been widely used in aerospace, transportation, chemical and biomedical fields due to low specific gravity, high strength, good stability at elevated temperatures, outstanding fatigue and corrosion resistance [17]. With the rapid development of industry, it is of great significance to obtain a nanocrystalline layer on the surface of titanium alloys so as to vanquish the severe service-environments. Therefore, it is a key to determine a good combination between the grain refinement and surface roughness so as to improve the surface characteristics of titanium alloys via shot peening. However, the investigations on the effects of the SP processing parameters on the structure characteristics and surface roughness have been barely given for titanium alloys.

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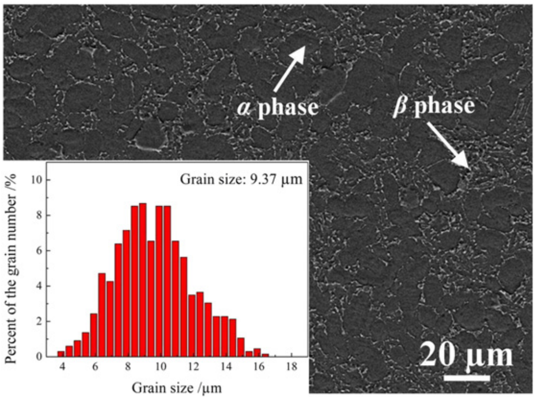

Fig. 1. The as-annealed microstructure of Ti-6Al-4V.

In this work, SP is applied to achieve SNC of Ti-6Al-4V and the processed surface layer of Ti-6Al-4V is characterized by scanning electron microscopy (SEM), X-ray diffraction (XRD), transmission electron microscopy (TEM) and laser scanning confocal microscope, respectively. Effects of the SP processing parameters, including air pressure and processing duration, on the structure characteristics and surface roughness of Ti-6Al-4V are investigated.

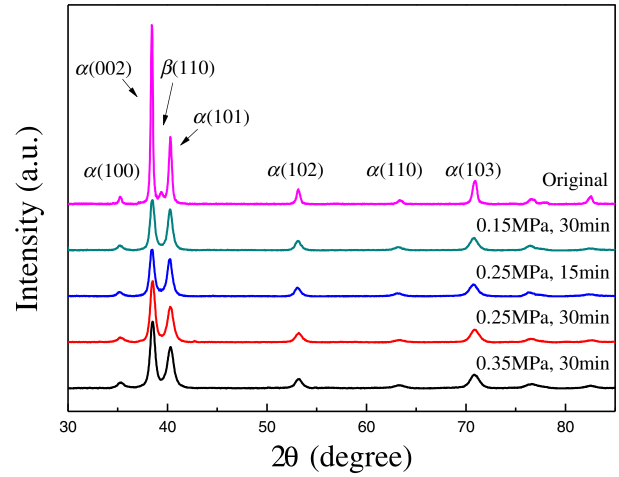

Fig. 3. XRD patterns of the surface layer in Ti-6Al-4V before and after SP.

2. Experimental Procedure

The material used in present investigation is Ti-6Al-4V bar with a diameter of 40 mm and its chemical composition (wt.%) is composed of 6.41Al, 4.19V, 0.02Fe, 0.006C, 0.001N, 0.16O, 0.002H and Bal. Ti. The

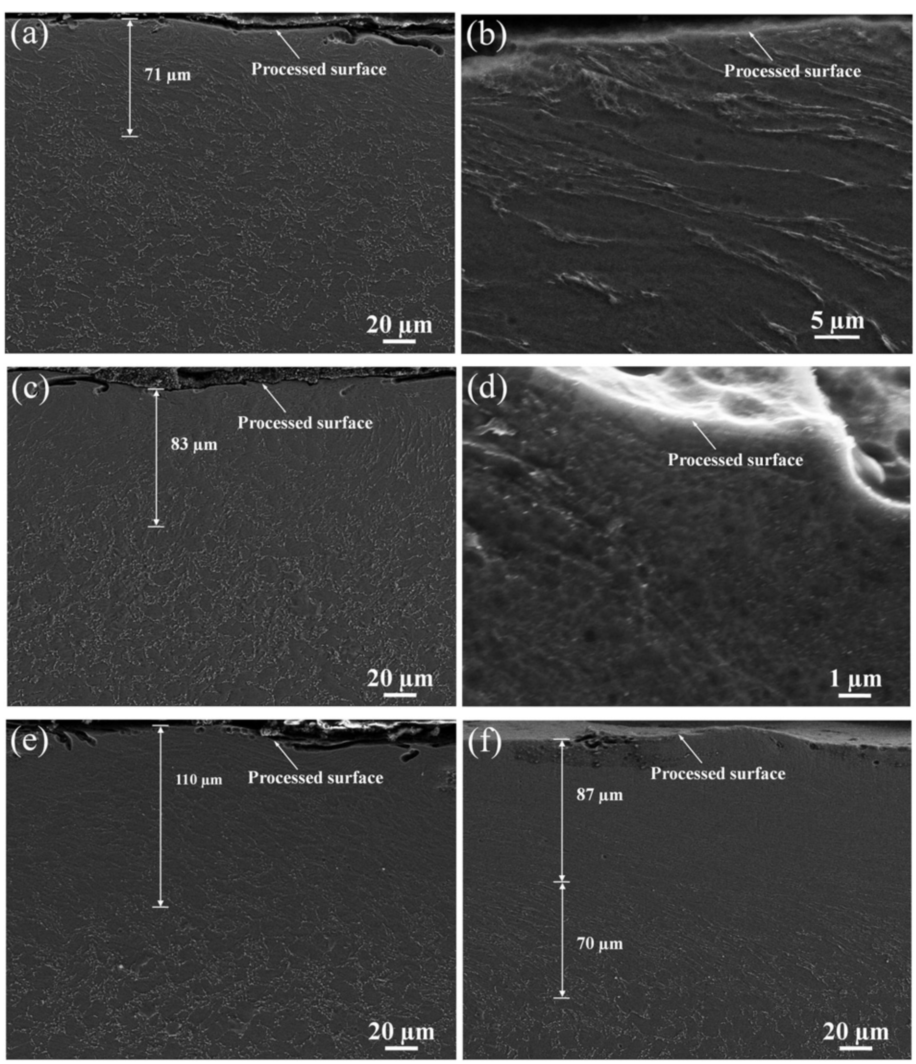

Fig. 2. Cross-sectional SEM micrographs of Ti-6Al-4V at different processing parameters: (a)(b) 0.15 MPa, 30 min; (c)(d) 0.25 MPa, 15 min; (e) 0.25 MPa, 30 min; (f) 0.35 MPa, 30 min.