Nanocrystalline Layer

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It was demonstrated that the mechanical shot peening (MSP) technique was a viable way to obtain a nanocrystalline layer on a large size pure titanium plate due to the MSP provided for severe plastic deformation (SPD) of surface high velocity balls impacting. The MSP effects of various durations in producing the surface nanocrystalline layer was characterized by optical microscope (OM), X-ray diffraction (XRD), transmission electron microscope (TEM), and Vickers micro-hardness tester. The results showed that the thickness of the SPD layer gradually increased with the MSP processing time increase, but saturated at 230 μm after 30 min. The average grain size was refined to about 18.48 nm in the nanocrystalline layer. There was equiaxed grain morphology with random crystallographic orientation in the topmost surface. By comparing with the nanocrystalline layer, acquired by surface mechanical attrition treatment (SMAT), the microstructure and properties of the nanocrystalline layer acquired by MSP was evidently superior to that of the SMAT, but the production time was cut to about a quarter of the time used for the SMAT method.

Keywords: pure titanium plate ; mechanical shot peening ; MSP ; nanocrystalline layer ; surface morphology

1. Introduction

Titanium and its alloys have attracted abundant interests because of their exceptional performance, such as high specific strength, low density, exceptional corrosion resistance, and biocompatibility, compared with conventional materials [1,2,3,4]. However, some performances and working reliability of titanium and its alloys still need to be enhanced due to the continuous development of technology [5,6]. It is generally known that material failures such as wear, corrosion, and fretting fatigue are extremely susceptible to the microstructure and properties of the material surface [7]. Hence, it would be considerably effective to utilize some surface modification to improve the material properties on the surface of the part. Since the concept of surface nanocrystallization (SNC) was firstly proposed by Lu et al. in 1999 [8], a variety of SNC methods, such as ultrasonic shot peening (USSP) [9], high energy shot peening (HESP) [10], equal-channel angular pressing (ECAP) [11], high pressure torsion (HPT) [12], surface mechanical grinding treatments (SMGT) [13], SMAT [14], etc. were sequentially developed by material scientists. Of the above-mentioned methods, surface mechanical attrition treatment (SMAT) is the most widely applied to produce nanocrystalline layer on various materials surface. The SNC process of SMAT utilizes several balls (Φ2.0–8.0 mm) that repeatedly and concentratedly impact on the surface of a workpiece [15,16,17]. The impacts uninterruptedly input compressive stresses and work hardenings to the surface region of the workpiece, which can refine the crystal particle to the orders of nanometer. The mechanical properties of materials, such as fatigue strength, hardness, and yield stress, can be dramatically enhanced through the SMAT process in terms of the Hall–Petch relationship [18].

2. Specifics

Although the SMAT enables materials to possess a nanocrystalline layer with a certain thickness, it can merely deal with small workpieces with a regular geometric shape and seems powerless in dealing with plates with a large size [19]. Furthermore, using SMAT to produce a nanocrystalline layer with a certain thickness will cost a long processing time, which is not appropriate in industrial production. As an extension of the SMAT technique, mechanical shot peening (MSP) technique is a new SNC approach that was developed in industrial production. In contrast to the SMAT technique of impacting balls moving together with the specimen, the impacting balls of the MSP technique are driven by a piston in the state of high frequency vibration to impact the static specimen. By means of multiple piston unit joints, a nanocrystalline layer on a large size plate can be obtained by the MSP technique. The SNC principle of the MSP has many similarities with that of the SMAT, which has been discussed in former literatures [20,21]. By altering MSP parameters, which mainly includes the amount or size of shot balls, processing time, and vibration frequency, various microstructures from nanometer-sized grains to sub-micrometer-sized and micrometer-sized crystallites with the deformed layer can be acquired. Therefore, the global mechanical performance can be markedly optimized by the formation of a surface nanocrystalline layer, and the interior materials still have exceptional ductility and elasticity.