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Investigation of water cavitation peening-induced microstructures in the near-surface layer of pure titanium

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ABSTRACT

The influence of water cavitation peening (WCP) treatment on the microstructure of pure titanium was investigated. The microstructural evolution in the near-surface of pure titanium as a function of WCP time was characterized by X-ray diffraction (XRD), optical microscopy (OM), scanning electron microscopy (SEM), and transmission electron microscopy (TEM). After WCP treatment, changes in the microstructure, as well as residual stress and surface morphologies as functions of WCP time, were recorded using a novel experimental design involving an in situ observation function. The obtained results indicate that twinning plays an important role in the plastic deformation and residual stresses of hexagonal close-packed (HCP) structured metal materials, and therein, that the deformation twinning and twinning interaction were induced by WCP in the strengthening layer. A stable compressive residual stress layer was found in the near-surface of the investigated pure titanium.

1. Introduction

Cavitation impact has historically attracted attention due to its costly damage to hydraulic mechanical parts, such as hydrofoil surfaces, turbopump impellers, pumps, and valves. As such, many researchers (Hammitt and De, 1979; Tomita and Shima, 1986; Chen et al., 1992; Sun et al., 2005; Tang et al., 2006) have traditionally focused their investigations into the damage mechanism of cavitation.

More recently, cavitation impact has been successfully developed as a means to improve the fatigue performance of mechanical components by introducing residual stress into the superficial layer of metallic components, in a manner similar to the more conventional process of shot peening. Qin et al. designed a new ventilation nozzle, through which suitable air can be aerated into the extra high-velocity flow in the nozzle throat, thereby forming a tremendous pressure gradient between the upstream and downstream flows. This specific method is referred to as water cavitation peening (WCP) (Qin et al., 2006a,b; Han et al., 2007a,b). Sahaya Grinspan and Gnanamoorthy successfully employed another cavitation process by injecting a high-speed oil jet into an oil-filled tank. This method, referred to as oil jet peening (OJP), effectively reduces the erosion of mechanical components (Sahaya Grinspan and Gnanamoorthy, 2006a,b,c).

Several recent investigations have revealed that WCP improves fatigue performance by introducing compressive residual stresses in the surface of metallic components (Ramulu et al., 2002; Kunaporn et al., 2005; Sahaya Grinspan and Gnanamoorthy, 2007a,b; Han et al., 2007a,b) The method has also been demonstrated to induce high uniform compressive residual stresses in gear tooth surfaces, since complicated and narrow surfaces can be more easily peened (Ju et al., 2006). Compared with conventional shot peening, WCP can obtain the smoother surfaces. The distributions of impact pressure are isotropic, therefore, process capability of WCP is uniform at different incidence angle (Qin et al., 2006a,b); however, it is unknown if WCP can induce changes in the microstructures within the strengthened layers of metallic components, as shot peening does (Martin et al., 1998; Altenberger et al., 1999; Wu et al., 2002; Harada et al., 2007; Wang et al., 2007).

Residual stresses in materials are often the result of metallurgical processes, such as casting, forging, welding, and quenching. Residual stresses from metallurgical processes usually depend on changes in thermal sources and volume accompanying the phase transformation. Generally, two types of residual stresses should be considered, that is, macro-residual stresses and micro-residual stresses (Noyan and Cohen, 1987; Totten et al., 2002). Macro-residual stresses depend on the plastic deformation of solid materials due to rapid non-uniform cooling, while micro-residual stresses are caused by strain and deformation due to phase transformation and changes in microstructure. We also know that distortions due to thermal and elastic–plastic deformation and strain, as well changes in phase transformation and texture in manufactured materials, are important regardless of the type residual

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