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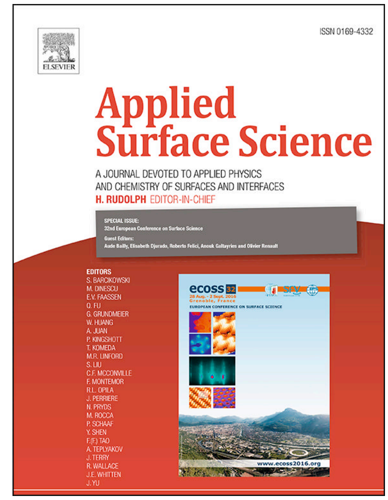

Full Length Article

The Effects of Ultrasonic Nanocrystal Surface Modification Temperature on the Mechanical Properties and Fretting Wear Resistance of Inconel 690 Alloy

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Abstract

In this study, a combination of local heat treatment (LHT) with (w/) and without (w/o) ultrasonic nanocrystal surface modification (UNSM) technique was applied to Inconel 690 alloy at room and high temperatures (RT and HT). The main purpose of this study is to investigate the influence of LHT w/ and w/o UNSM processing on the mechanical and fretting wear mitigation of Inconel 690 alloy. The surface roughness of the specimens was increased with increasing the LHT temperature w/ and w/o UNSM from RT to HT at 700 ^{0}C, while the surface hardness of the RT and HT at 300 ^{0}C specimens was increased and softening occurred at HT at 700 ^{0}C. The mechanical properties of the specimens were investigated using a tensile stress test. It was found that the stress-strain curve of the UNSM-treated at RT exhibited better mechanical characteristics in comparison with the as-received one. Moreover, the specimens treated at HT at 300 and 700 ^{0}C exhibited better results in terms of strain, but there was no significant difference in stress. The UNSM treated specimens at HT of 300 ^{0}C had better results in comparison with other specimens. In addition, the fretting wear resistance of those specimens was assessed using a ball-on-disk fretting wear tester at temperatures of 25 and 80 ^{0}C. The fretting wear resistance of Inconel 690 alloy was also increased by the combination of LHT+UNSM processing, which may be attributed to the increase in mechanical properties, increase in surface roughness, induced compressive residual stress and the presence of a nanostructured surface layer. Hence, Inconel 690 alloy with the increased mechanical properties and fretting wear resistance by the combination of LHT+UNSM processing could be beneficial for nuclear applications.

Keywords: Inconel 690; nanostructure; tensile test; hardness; fretting; UNSM

1. Introduction

Inconel 690 alloy (UNS N6690), which is used in primary water reactor (PWR) nuclear power plant steam generator, exhibits good mechanical properties and excellent corrosion resistance. The heat exchanger tube, which is usually made of Ni-based alloys such as Inconel 600, Inconel 690 and Inconel 800, is a key component of the steam generator in a nuclear reactor [1]. The service life of the steam generator, which depends upon heat exchanger tube, is the most significant issue in nuclear power plant since a great number of steam generators removed from the service to be repaired or replaced due to flow-induced vibration initiating fretting that occurs during heat exchange, where thermal energy is transferred into a steam generator, when a water passes through the tubes, while an air passed along the outside of tubes. Fretting issue of steam generator refers to small amplitude oscillatory motion occurring between tubes and their supports (or anti-vibration bars). Heat exchanger tubes in a steam generator experience a fretting between tubes their supports because of flow-induced vibration and loosening, which is attributed to the combined effects of high flow rate and small gap between tubes and supports [2, 3].

Fretting causes an internal material damage and catastrophic failure, which increase under cyclic stress in the heat exchanger system, significantly deteriorate the strength of tubes and their supports that leads to a reduction of service life of steam generator. The degradation of surface and subsurface caused by fretting is a quite complex process involving friction, wear, plastic deformation, oxidation, cracking and fatigue [4]. Although the loss of material due to fretting may not be significant, but it often leads to premature crack nucleation and subsequent growth of crack and propagation induced by plastic deformation in the subsurface, which further deteriorates the functionality of heat exchanger tube of steam generator in a nuclear reactor. Once flow-induced vibration defect occurs in the tube, a coolant with radioactive substance will leak into water steam circuit causing pollution in the environment [5, 6]. Hence, it is a challenge to increase the vibration-induced resistance to fretting wear, which drastically