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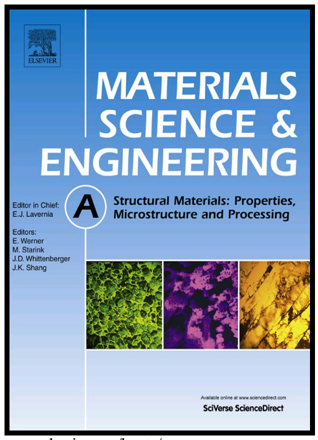

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Effect of Heat Treatment on the Temperature Dependence of the Fracture Behavior of X-750 alloy

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Abstract

X-750 is a nickel-chromium based super alloy of usefulness in a wide variety of applications such as gas turbines, rocket engines, nuclear reactors, pressure vessels, tooling, and aircraft structures. Its good mechanical properties are due to the strengthening from precipitation of γ' particles upon prior ageing heat treatment. In this work, the effect of such heat treatment on the fracture mechanisms of X-750 was studied at various temperatures by comparing it with a non-aged, solution annealed X-750. Tensile tests were conducted from room temperatures up to 900ºC; fracture surfaces were analyzed by means of SEM observations. In addition, the microstructure of both aged and solution annealed materials were studied using SEM and TEM, both on as received and on tested specimens. In terms of mechanical properties, as expected, the yield strength and the ultimate tensile strength of the aged material is better than for the solution-annealed one, and only slightly decreased with increasing temperature when tested between room temperatures and 650ºC. In this range of temperature, the fracture surface of aged material evolves from purely intergranular to purely transgranular due to the thermal activation of dislocation mobility that relieves the stress at the grain boundaries, while the rupture of the solution annealed material is due to the coalescence of voids induced by decohesion at the MC carbides/matrix interface. At higher temperatures, precipitation of γ' particles upon testing of the solution-annealed material leads to a temperature-dependent increase in both yield strength and ultimate tensile strength, which nevertheless remain below the aged material ones with the exception of the higher temperatures. At the same time, an overall decrease of the aged material mechanical properties is observed, due to the higher mobility of dislocations. Minimum ductility was observed at 750ºC for both solution annealed and aged specimen, due to the oxidation of grain boundaries leading to an environmentally-induced fracture mechanism. At higher temperatures, dynamic recrystallization occurs and thus prevents such a rupture mechanism, but finally leads to rupture by grain boundary slipping at 900ºC.

Keywords: Nickel super-alloy, X-750, Fracture Mechanisms, Tensile Tests, Heat Treatment

Introduction

X-750 is a nickel-chromium based super alloy of usefulness in a wide variety of applications. Its excellent relaxation resistance is useful for high-temperature springs and bolts; it is utilized in gas turbines, rocket engines, nuclear reactors, pressure vessels, tooling, and aircraft structures [1]. It serves an important role in the nuclear industry as a spacer material in Candu reactors, and a as core material in both Boiling Water Reactors (BWRS) and Pressurized Water Reactors(PWRs) [2–4]. Made precipitation-hardenable by additions of aluminum, niobium, and titanium; it is strengthened primarily by gamma prime precipitates during heat treatment and secondary metallic carbides [5–8]. It has good resistance to corrosion and oxidation along with high tensile and creep-rupture properties at temperatures up to 700°C [1]. Fracture characteristics of X-750 have been studied for particular cases, with varying heat treatments and strain rates. Though certain trends in deformation behavior are noted, the narrow focus leaves areas open to further investigation. Comparison of as-received (solution annealed) alloy and heat treated samples are essential. A valuable aspect of high temperature testing is ascertaining any environmental influence on fracture mechanisms, which may preclude mechanical failure; as seen in another nickel based super-alloy, Inconel 718 [9]. The transition from transgranular to intergranular cracking has also been observed in fatigue-crack propagation for X-750, for a triple heat-treated specimen [10].