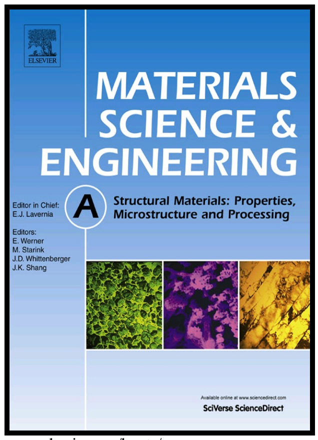

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Evolution of microstructure and tensile properties during solution treatment of nickel-based UNS N10276 alloy

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Abstract: Influence of solution treatment (ST) on microstructure evolution and mechanical behavior of nickel-based UNS N10276 alloy were investigated by a variety of techniques such as optical metallography, scanning electron microscopy, transmission electron microscopy and tensile testing. The average grain size remained almost unaffected by hold time at 1050 °C, resulting from the pinning effect of secondary phase on the grain boundary. A sharp increase in grain size and grain growth rate was observed with increasing solutionizing temperature up to 1150 °C irrespective of hold time, which was mainly related to the complete dissolution of precipitated particles as well as to the enhanced diffusion of solute atoms. The rate of grain growth reduced with extending solutionizing time and decreasing temperature. Flow curve parameters based on Ludwigson equation for the alloy after heat treatment were determined. The dissolution of secondary phase particles, combined with the grain growth, increased the work hardening exponent (n) and dramatically improved the tensile ductilities (TD), but reduced the tensile strengths (TS) to large extent. Both TD and n monotonically increased with increasing solutionizing temperature and prolonging hold time as the alloy was solutionized beyond 1100 °C, while the TS and strain hardening rate (SHR) showed a reverse varying trend to that of TD and n. As the heat treatment was performed at 1050 °C, tensile properties were not monotonically changing with hold time, which is associated with the increase in amount of precipitates and with the Ostwald ripening of precipitated particles. On the basis of Hall–Petch relation and experimental data, the mathematical relationships between tensile properties and grain size of the alloy solutionized at temperatures higher than 1150 °C, were obtained by linear regression analysis. The Hall–Petch strengthening coefficient for yield strength of the UNS N10276 alloy was estimated to be 18.35 MPa·mm$^{1/2}$.

Key words: Solution treatment, Grain growth, Tensile properties, Work hardening, UNS N10276 alloy

1. Introduction

Nickel-based UNS N10276 alloy is a wrought Ni–Cr–Mo–W alloy, showing an outstanding combination of corrosion resistance and mechanical properties [1]. Due to such superior characteristics of this alloy, it has been used for the manufacture of rotor and stator shielding (RSS) in the nuclear reactor coolant pump of AP1000 advanced passive plant [2, 3]. Moreover, it also finds wide applications in chemical processing, pollution control and aerospace industries. In order to improve its corrosion resistance and high temperature strength, this alloy contains high levels of the refractory metal elements, Mo, Cr and W, which may render it prone to the precipitation of topologically close-packed (TCP) intermetallic phases and carbides during air cooling after hot working or welding of the large-scale workpiece. Investigation in previous published reports have identified three distinct second phases in alloy UNS N10276, and they are TCP μ phase, M_6C carbides and P phase, respectively, all of which are very rich in Mo, W and Ni [4]. The amount of μ phase is much larger than that of M_6C and P phase. The μ phase is known to be hard and brittle, which has detrimental effects on low temperature tensile and impact toughness as well as high temperature creep properties [5]. Furthermore, the precipitation of these secondary phases depleted the alloying elements from the γ matrix, and inevitably deteriorates the corrosion resistance to large extent. Therefore, this alloy is supplied in the solutionized plus water quenched condition, with view to dissolving any undesirable precipitated particles, and to freezing the high temperature, precipitation-free, face-centered cubic structure.

UNS N10276 alloy sheet with thickness of 0.4 to 0.76 mm, which was prepared through hot rolling and cold rolling, is used for fabricating RSS. To ensure that the alloy has an excellent ability to be cold rolled, the hot rolled plate should be solutionized at an appropriate temperature to release stress and dissolve the secondary phases. Also, cold rolled sheet should be solutionized at elevated temperature to eliminate the deformed structure. In general, stress relief temperatures commonly used for steels, stainless steels, and some other nickel-based alloys are not effective for UNS N10276 alloy. Although the heat treatment performed at an intermediate temperature is sufficient

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