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Ratcheting Behaviour of a Sensitized Non-Conventional Austenitic Stainless Steel

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Abstract

Austenitic stainless steels are candidate materials for many engineering applications owing to their excellent strength, ductility, toughness even at low temperatures and non-magnetic nature. In heat-transfer pipelines of heavy water reactors of nuclear power plants, underground pipelines etc. the steel is potentially used, where components frequently encounter cyclic loading. However, during prolonged service at high temperature and with aggressive environments the steel suffers from grain boundary corrosion known as sensitization. Further, sensitization in conjugation with asymmetric cyclic loading makes the situation more complex. In such cases usually, premature failure takes place. This investigation is intended to study the effect of sensitization on the asymmetric cyclic loading or ratcheting behaviour of a non-conventional austenitic stainless steel (X12CrMnNiN17-7-5). Relationships between sensitization treatments for different durations with microstructural and tensile property variation were established. Further, ratcheting experiments were carried out at different combinations of mean stress and stress amplitudes. The results indicated that accumulation of ratcheting strain increased with stress amplitude. However, it was inversely proportional to the degree of sensitization (DoS). The increase in brittleness of the material with sensitization led to decreased accumulation of ratcheting strain. The analyses of the obtained results may help the design and safety aspects of structural components made up of similar steels.

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Keywords: Austenitic stainless steel; Sensitization; Ratcheting; Stress amplitude; Mean stress

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1. Introduction

Austenitic stainless steels (ASS) have wide applications as it is non-magnetic, possess good ductility and excellent toughness even at low temperature with no ductile to brittle transition [1]. The steel is used as heat transfer pipelines where components are exposed to high temperature and corrosive environment along with cyclic loading. In such cases, the steel gets sensitized due to prolonged exposure to a temperature range of 550°C-750°C. This leads to precipitation of nitrides and/or carbides at the grain boundaries, particularly chromium carbide (generally $Cr_{23}C_6$) in the alloy while chromium depletion occurs from the neighboring zones. Further, upon sensitization, the steel becomes susceptible to inter-granular stress corrosion cracking (IGSCC) or inter-granular corrosion (IGC) [2]. Peckner et al. showed that chromium content primarily influences the corrosion resistance of steel, thereby leading to chromium depletion and further inter-granular corrosion [3]. It was found that stainless steel becomes more susceptible to sensitization as the carbon content increases solubility limit. Ghosh et al. reported that with increase in degree of sensitization, ductility and fracture toughness of AISI 304LN stainless steel deteriorates [4]. However, there is less effect of sensitization on tensile strength of the steel. Jinlong et al. studied the influence of sensitization and pre-deformation on the corrosion resistance of oxide coating on 304LN stainless steel and found that degree of sensitization (DoS) initially decreased but later increased with increase in engineering strain [5]. Akita et al. showed that water quenching and re-solution treatment could be used to suppress the sensitization effect on corrosion fatigue behaviour of 304 stainless steel by dissolving the precipitated CrN [6].

During the service life, many engineering structures including pipelines are often subjected to cyclic loading along with high temperature. Thus, there are chances of sensitization along with fatigue damage to these structures. Recently, fatigue behaviour of materials under asymmetric cyclic loading are being studied by numerous researchers. The phenomenon is known as ratcheting and accumulation of ratcheting strain could cause disaster as ratcheting strain increases progressively cycle-by-cycle [7, 8]. Xia et al. reported that both the tensile mean stress and ratcheting strain have damaging effects on the life of the component [9]. Kang et al. performed a number of uniaxial ratcheting tests on 304 ASS to study the cyclic strain characteristics, ratcheting and failure behaviour [10]. Hassan et al. have reported that plastic strain gets accumulated in the presence of both positive as well as negative values of mean stress [11]. Kreethi et al. demonstrated that ratcheting strain increases with number of cycles for various combinations of stress amplitude and mean stress for 42CrMo4 steel [12]. Yuan et al. reported that under asymmetrical cyclic loading in wrought 316LN stainless steel, the material is hardened due to mean stress and fatigue life is reduced due to accumulation of ratcheting strain [13]. All these reports indicate that prior information regarding ratcheting behaviour of a material is essential to provide utmost safety of critical engineering components before designing. It is already reported that ratcheting is greatly influenced by maximum stress, mean stress, stress amplitude, stress ratio and temperature. However, as per the best knowledge of the authors, no published report exists on the ratcheting behaviour of sensitized stainless steel. Therefore, the main objective of this research is to study the ratcheting behaviour of a non-conventional ASS. The steel is represented as X12CrMnNiN17-7-5 steel and was developed to conserve nickel [14]. The sensitization treatment of the steel was done for three different durations. The microstructural details, hardness and fractographic studies have been done to infer the changes in the tensile and mechanical properties due to thermal sensitization treatment. Ratcheting studies were done at different stress amplitudes and at a constant mean stress. Finally, post-ratcheting tensile tests were done on the ratcheted specimens to understand effect of ratcheting deformation on the tensile properties of the steel.

Nomenclature

DoS	degree of sensitization
σ_m	mean stress
σ_a	stress amplitude
SA	solution annealed at 1050°C for 1 hour
S-05	sensitized at 750°C for 5 hours
S-10	sensitized at 750°C for 10 hours
S-15	sensitized at 750°C for 15 hours