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Environmentally assisted cracking resistance of Al−Cu−Li alloy AA2195 using slow strain rate test in 3.5% NaCl solution

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Abstract: The general corrosion and environmental cracking resistances of Al−Cu−Li alloy AA2195 were investigated in 3.5% NaCl environment and compared with those of another high strength alloy AA2219. The general corrosion resistance of these alloys was examined using immersion corrosion and potentiodynamic polarization tests, while the stress corrosion cracking (SCC) resistance was evaluated by slow strain rate test (SSRT) method. The tested samples were further characterized by SEM−EDS and optical profilometry to study the change in corrosion morphology, elemental content and depth of corrosion attack. The reduction in ductility was used as a parameter to evaluate the SCC susceptibility of the alloys. The results indicated that the corrosion resistance of AA2195 alloy was better than that of AA2219 alloy as it exhibited lower corrosion rate, along with lower pit depth and density. However, the SCC index ($\varepsilon_{NaCl}/\varepsilon_{air}$) measured was greater than 0.90, indicating good environmental cracking resistance of both the alloys. Detailed fractography of the failed samples under SEM−EDS, in general, revealed a typical ductile cracking morphology for both the alloys.
Key words: Al−Cu−Li alloy; stress corrosion cracking; fractography; potentiodynamic polarization

1 Introduction

The Al−Cu−Li alloy AA2195 is used in the aerospace industry due to its light mass, high strength, good toughness and weldability. When compared with the conventional AA2219 alloy, this alloy offers an improved strength of 30%−40% and a reduction in density of 10% [1,2]. In view of the above advantages, this alloy has been considered as a replacement of AA2219 alloy for the fabrication of cryogenic propellant tanks. High strength of the alloy is achieved mainly by the precipitation of $T1$ phases (Al_2CuLi) after thermo-mechanical working followed by aging. Although the stress corrosion cracking (SCC) resistance of AA2219 alloy in T87 temper condition has been reasonably studied and found that the alloy exhibits good SCC resistance, similar studies on AA2195 have not yet studied and reported in detail. Limited results on the environmental cracking resistance of AA2195 alloy remain contradictory and vary depending on the aging temperature and the level of thermomechanical working. HU and MELETIS [3] compared the corrosion and SCC resistance of AA2195 and AA2219 alloys using slow strain rate test (SSRT) and constant load (CL) test methods. Their study indicated that the alloy suffered SCC under SSRT conditions where the crack initiation was mostly from pitting. According to them, the mechanism of SCC was due to hydrogen absorption from the localized corrosion pits. They also reported that the SCC resistance of AA2195 was better than that of AA2219 alloy under the tested conditions. However, their results did not show the details of thermo-mechanical working and the aging temperature of the alloy tested for SCC. Similar high SCC susceptibility for weldalite 049 was reported by MOSHIER et al [4]. They compared two alloys with different Cu contents (5.30% and 4.80%, mass fraction) in which the alloy with higher Cu content failed by SCC. The lower Cu-containing alloy did not show SCC as it underwent severe pitting. The reason for the absence of SCC for the lower Cu-containing alloy was not explained in their work. Both the alloys were stretched to 3% followed by aging at 160 °C. In a recently reported work, WANG et al [5] examined the SCC resistance of AA2195 alloy by subjecting the alloy to different aging temperatures

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(135−200 °C). Based on the SEM fracture morphology, they concluded that the alloy suffered lower SCC susceptibility at low aging temperatures than at high aging temperatures. They did not introduce any cold working prior to artificial aging.

The objective of the present investigation is to evaluate the environmentally assisted cracking behaviour of AA2195 alloy after subjecting the alloy to 7% cold working prior to artificial aging. The corrosion and SCC resistances of the alloy were comparatively studied with those of AA2219 alloy under the same temper condition in 3.5% NaCl solution.

2 Experimental

2.1 Materials

AA2195 alloy having nominal composition around Al−4.2Cu−1.1Li−0.35Mg−0.35Ag−0.15Zr−0.15Fe−0.10Si (mass fraction, %) was used in the form of rolled plates with thickness of approximately 4 mm. The plates were realized through series of thermomechanical treatments (forging followed by rolling) from as-cast and homogenized billets cast in vacuum induction melting furnace under inert atmosphere. The detail of the casting technique was discussed elsewhere in details [6−8]. These plates were then heat-treated to T87 temper (solution-treated at 500 °C for 0.5 h + quenching in water + 7% cold working followed by artificial aging at 146 °C for 30 h). Similarly, AA2219 alloy having nominal composition Al−5.95Cu−0.27Mn−0.1Zr−0.09V−0.06Ti−0.12Fe−0.05Si−0.02Zn (mass fraction, %) was used in the form of rolled plates in T87 temper (solution treated at 535 °C for 0.5 h + quenching in water + 7% cold working followed by artificial aging at 163 °C for 24 h). The tensile specimens were fabricated by cutting the specimen coupons in longitudinal as well as in transverse directions. Sub-scale flat rectangular specimens with effective gauge dimensions of 24 mm × 6 mm × 4 mm were used for stress corrosion cracking (SCC) tests after detailed radiographic examination and tested as per ASTM G 129.

2.2 Microstructures

For microstructural observations, the samples were sectioned and polished down to 5 μm alumina finish followed by etching in freshly prepared Keller's reagent (5 mL HNO_3, 3 mL HCl, 2 mL HF, and 190 mL distilled water) and examined under an Olympus GS 71 optical microscope (Olympus America, Center Valley, PA) and a Carl Zeiss EVO−50 scanning electron microscope (SEM; Carl Zeiss, Oberkochen, Germany). The fractured samples were examined under a SEM to observe the change in the fracture morphology as a result of the exposure to the NaCl environment.

2.3 Potentiodynamic polarization

The electrochemical corrosion of the alloys (AA2195 and AA2219) was evaluated through potentiodynamic polarization tests using a computer-controlled Zhaner IM6ex electrochemical workstation. Samples were taken from the rolling plane of both the alloys to make specimens with an area of 0.5 cm^2. The corrosion behaviour of the samples was examined in 3.5% NaCl solution (mass fraction) prepared using reagent-grade NaCl salt and deionised water. The tests were carried out using a standard three-electrode setup with platinum as the counter electrode, saturated calomel electrode (SCE) as the reference electrode, and the test specimens as the working electrode. A scan rate of 0.5 mV/s was used. All the scans were started from a potential of 300 mV below the corrosion potential (φ_{corr}). Prior to the experiment, the samples were ground with SiC papers up to 1000-grit followed by cleaning in acetone and water.

2.4 Immersion corrosion test

Immersion corrosion was performed by subjecting AA2219-T87 and AA2195-T87 alloy specimens (35 mm × 35 mm × 4 mm) in 3.5% NaCl solution for 20 d. Before immersion, all the specimens were polished up to 1000-grit SiC paper followed by ultrasonic cleaning in acetone and water. After immersion test, the specimen surfaces were cleaned by dipping in chromic−phosphoric acid as per ASTM G1 to remove the corrosion products. The surface morphology of the specimens was analyzed using stereo microscopy and optical profilometry (NANOVEA, USA). With the assistance of Mountain software package, the parameters such as average pit depth and pit density were compared between the two alloys.

2.5 Slow strain rate test (SSRT)

Stress corrosion susceptibility of alloy AA2195 was evaluated by the SSRT method as per ASTM G129 standard at a strain rate of $5 \times 10^{-7}\,s^{-1}$ and the same was compared with that of AA2219 alloy. The tests were performed in 3.5% NaCl and air as the corrosive and reference environments, respectively. SSRT was performed using a CORTEST CERT tensile testing machine (CORTEST Inc., Willoughby, OH, USA). An acrylic container was served as a cell to hold the specimen in the environment. The gauge portion of the samples was polished using 600-grit SiC paper on all the sides to obtain a smooth surface. The average elongation of the specimen was measured by a pair of linear variable displacement transducers positioned on both sides of the specimen. Galvanic corrosion of the