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In Vitro Corrosion Response of FSW Processed Al-Cu-Mg/Fe-Cr-Ni Dissimilar Alloys for Marine Applications

Fayaz Ahmad Mir[1] · Noor Zaman Khan[1] · Turali Narayana[2] · Nadeem Fayaz Lone[3] · Arshad Noor Siddiquee[4] · Firdoos Afzal Bhat[1] · Haseeb A khan[5] · Salman H Alrokayan[5]

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Abstract
This study investigates the corrosion behavior of FSWed SS304/AA2024-T3 joints in chloride-rich environments, focusing on welding-induced microstructural changes affecting localized and galvanic corrosion. FSW was performed using optimized parameters: 360 rpm tool rotation, 25 mm/min welding speed, 1.75° tilt angle, and 1.5 mm tool pin offset toward the Al side. Microstructural analysis revealed an ultra-refined stir zone (SZ) with a 4.2 µm average grain size due to plastic deformation (PD) and dynamic recrystallization (DRX). 360 h corrosion immersion testing in 3.5% NaCl solution showed the FSWed joint had a corrosion rate (CR) of 0.0205 mm/year, significantly lower than AA2024-T3 (CR = 0.1044 mm/year) and similar to SS304 (CR = 0.0173 mm/year). Corrosion morphology indicated pitting, intergranular corrosion (IGC), and blistering at the Al/SS interface due to galvanic effects and intermetallic compounds (IMCs) like $FeAl_3$. While FSW improves corrosion resistance via grain refinement, galvanic interactions and interface heterogeneity highlight the need for interface optimization and surface treatments for better marine durability.

Keywords FSW · SS304/AA2024-T3 · Dissimilar metal welding · Microstructure · Corrosion

1 Introduction

A multi-material approach to achieving effective structural light-weighting has gained increasing attention over the last decade [1]. The marine industry requires lightweight, corrosion-resistant materials for improved durability and efficiency, leading to the use of hybrid structures with stainless steel (SS) and aluminum (Al) alloys [2]. These materials are vital for marine systems like ship hulls and offshore platforms, where weight reduction and durability are key. Al alloys like AA2024-T3 offers excellent strength-to-weight ratio, heat transfer, and formability, while stainless steels like SS304 ensures high strength, toughness, corrosion, and wear resistance. However, Al alloys are prone to chloride-induced corrosion due to a soft surface and unstable passive layer. Microstructure refinement improves corrosion resistance, with welding methods, post-weld treatments, plastic deformation, and grain size affecting dissimilar joint corrosion. Friction stir welding (FSW) improves material bonding and microstructure, making it ideal for corrosion-resistant hybrid joints in marine components [3–7]. FSWed dissimilar joints generally have lower corrosion rates than their base materials, though Al/SS joints remain vulnerable to galvanic corrosion [8]. Al alloys struggle to maintain a stable oxide layer, while SS faces pitting and stress corrosion cracking due to Cl^- ion destabilization. The potential difference between Al and SS accelerates galvanic corrosion, with intermetallic compounds (IMCs) like $FeAl_3$ and Fe_2Al_5 at the interface acting as local anodes, further promoting Al dissolution. This potential difference refers to the electrochemical corrosion potential gap between the two metals

✉ Fayaz Ahmad Mir
Fayaz_07phd19@nitsri.ac.in

1 Department of Mechanical Engineering, National Institute of Technology Srinagar, Srinagar, J&K 190006, India

2 Department of Mechanical Engineering, Aditya Institute of Technology and Management, Tekkali, AP 532201, India

3 Department of Mechanical, Industrial, and Mechatronics Engineering, Toronto Metropolitan University, Toronto, ON M5B 2K3, Canada

4 Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi 110025, India

5 Department of Biochemistry, College of Science, King Saud University, Riyadh 11451, Saudi Arabia