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Microstructure-driven enhancements in tribological and corrosion properties of friction stir welded Al 2024-T3/304 stainless steel joints

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ABSTRACT

This study examines the microstructure-driven enhancements in tribological and corrosion properties of friction stir welded (FSW) 304 stainless steel (SS) and 2024-T3 aluminium (Al) alloy joints. Effective welding parameters produced a wavy interface with embedded steel fragments and thin intermetallic compounds (IMCs). The FSWed specimen exhibited superior corrosion resistance (E_{corr}: -7.21×10^2 mV, corrosion rate: 1.66×10^{-2} mmpy) compared to base material (BM) 2024-T3 Al alloy (E_{corr}: -8.08×10^2 mV, corrosion rate: 2.11×10^{-2} mmpy). Tribological assessments revealed the superior wear resistance of FSWed specimens, evidenced by its lowest wear rate (2.073×10^{-4} mm^3/N.m), surface roughness (0.20 µm), and average change in wear depth ΔH (3.07 µm), compared to BM 2024-T3, which exhibited higher values of 4.532×10^{-4} mm^3/N.m, 1.09 µm, and 6.91 µm, respectively.

1. Introduction

A significant challenge in the mobility industry is enhancing energy efficiency to reduce emissions and remain competitive [1]. Regulatory agencies worldwide, including the International Civil Aviation Organization, impose emission limits. One effective strategy is reducing mass, with a 100 kg weight reduction in the automotive sector decreasing CO_2 emissions by 9 g/km [2]. In aerospace, reducing mass increases load capacity. Using low-density aluminum and strong, corrosion-resistant stainless steel creates lighter, more efficient hybrid structures [3,4]. However, traditional joining methods often lead to defects like porosity and residual stresses [5]. Friction stir welding (FSW), developed in 1991 at TWI in the UK, is highly effective for joining dissimilar materials and is used in various industries including marine, military, automotive, and aerospace [6]. FSW is a solid-state welding process where a rotating tool moves along the surfaces of two clamped plates [7]. Friction generates heat at the shoulder and pin surfaces, softening the material for welding. Severe plastic deformation and metal flow occur as the tool moves along, forming a joint. The advancing side (AS) aligns with the welding direction, while the retreating side (RS) does not. The defense systems division of Boeing achieved significant cost savings and reduced construction time using FSW for rocket fuel tanks in the Delta II and IV programs, reducing costs by 20 % compared to traditional rivet fixation. In 2012, Honda Motors began using FSW for mass production of the 2013 Accord at its Ohio plant [8,9]. Researchers investigated FSW of dissimilar Al alloys, specifically between 7075-T651/6061-T6. They found that the rotation speed of the tool significantly influences the wear performance of the welded joints and reported that a tool rotation speed of 1250 rpm provided better wear resistance compared to 1550 rpm [10]. In another study carried out by Zuo et al. [11], the researchers explored the FSW process applied to Al alloys. They specifically examined how FSW affected the wear performance of the welded joints compared to the base alloy. Their findings indicated an improvement in wear resistance for the FSWed joints relative to the untreated base alloy. Moreover, they highlighted that among the various FSW process parameters studied, the rotation speed of the tool had the most pronounced influence on the surface topography of the welded joints. This suggests that optimizing the tool rotation speed during FSW can not only enhance wear resistance but also significantly impact the physical characteristics and quality of the welded surfaces. This dual benefit underscores the importance of precise parameter control in achieving desired surface

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