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PAPER

Friction stir welding of AA2024-T3 and SS304 alloys: microstructural analysis, microhardness evaluation, and tensile performance

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Abstract

This study examines the feasibility of friction stir welding (FSW) for dissimilar butt joints formed between 3 mm thick 2024-T3 aluminum alloy and AISI 304 stainless steel. It explores the impact of operational parameters, particularly traverse speeds of 20 and 40 mm min^{-1}, a fixed tool rotation speed of 450 rpm, a tool pin offset of 1.5 mm, and a tool shoulder diameter of 18 mm, on microstructure, microhardness, and tensile strength. A traverse speed of 40 mm min^{-1} resulted in a lower peak temperature of 257.75 °C, while optimal conditions at a speed of 20 mm min^{-1} led to peak temperatures of 356.5 °C. This higher temperature facilitated material deformation, improved flow, enhanced mixing, and contributed to grain refinement, with an average grain size of 4.2 μm. Vickers microhardness tests revealed a maximum hardness of 339 Hv at a traverse speed of 40 mm min^{-1} and 413 Hv at 20 mm min^{-1}. The ultimate tensile strength (UTS) reached 338 MPa, resulting in a joint efficiency (JE %) of 76.81% for the weld performed at optimal conditions.

1. Introduction

Multi-material vehicle structures are increasingly seen as a top choice for reducing automotive weight, particularly given rising concerns over energy conservation and environmental protection [1–3]. Aluminum (Al) alloy paired with stainless steel (SS) is a common and desirable combination [4]. Aluminum and its alloys are known for the properties like low density, sufficient strength, and ease of manufacturing [5]. Whereas, SS is known for high strength, corrosion resistance, and toughness [2–5]. Utilizing hybrid structures made from these materials in industries such as automotive, aerospace, and shipbuilding significantly reduces costs and enhances efficiency by lowering the overall weight of vehicles and crafts [6–10]. Reducing weight in vehicles and crafts leads directly to lower fuel consumption and decreased exhaust emissions. This results in significant improvements in fuel efficiency, operational range, and pollution control [11–14]. The use of lighter materials in the automotive, aerospace, and shipbuilding sectors not only improves the performance and efficiency of vehicles and vessels but also significantly reduces fuel consumption and exhaust emissions. These improvements are crucial for meeting stricter environmental regulations and achieving sustainability goals, playing a pivotal role in the global effort to minimize environmental impact [15–18]. Joining dissimilar materials using fusion welding involves several challenges, including the formation of extensive intermetallic compounds (IMCs), residual stresses and distortion due to differences in thermal and mechanical properties [19]. The residual stresses and distortion can be mitigated with preheating and controlled cooling [20]. The formation of brittle IMCs at the weld interface can be reduced by optimizing heat input [21]. Managing different melting points requires precise parameter adjustments and techniques such as solid-state welding. Discrepancies in mechanical properties can lead to uneven load distribution, which can be addressed with graded joints and optimized designs. Weldability issues and heat-affected zone