

# Performance analysis of Al stainless steel joints fabricated by friction stir welding: Microstructure, mechanical, and tribology

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## Abstract

Hybrid structures, incorporating both aluminum and steel, hold potential for applications in automobile, aerospace, and marine industries. This research delves into the effects of friction stir welding on dissimilar joints (AA2024-T3 and SS304), with a focus on microstructural, mechanical, and tribological aspects. The study identifies optimal welding conditions at (tool rotational speed 710 r/min, traverse speed 20 mm/min, tool pin offset 1.5 mm towards aluminum, and tilt angle of 1.75 deg) that yield a well-defined joint interface, contrasting with flaws observed at a 40 mm/min traverse speed due to insufficient heat input. Under optimal conditions at 20 mm/min, a well-clean serrated interface, defect-free microstructural evolution, improved surface characteristics; enhanced mechanical performance resulting in higher ultimate tensile strength of 319 MPa with joint efficiency of 72.5 and better tribological performance were achieved with lower wear rate of  $1.1607 \times 10^{-5}$  g/Nm compared to those at 40 mm/min, highlighting the crucial role of optimized friction stir welding parameters in achieving high-quality dissimilar joints with desirable properties.

## Keywords

Friction stir welding, microstructure, mechanical properties, tribology, SS304, AA2024-T3

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## Introduction

Weight reduction is crucial in aerospace and automotive industries due to emissions and fuel efficiency regulations.<sup>1</sup> Hybrid structures, combining materials like aluminum (Al) and stainless steel (SS), offer a solution.<sup>2</sup> The combination of lightweight Al with SS finds applications in various industries, supporting weight reduction, pollution control, and increased efficiency.<sup>2–5</sup> However, joining such dissimilar materials poses challenges in conventional fusion welding.<sup>6</sup> Friction stir welding (FSW), developed by TWI presents advantages over fusion welding. Researchers explored the welding of dissimilar materials, specifically AISI 1010 steel and 101 copper, and found that the addition of nanofillers had a substantial impact on the mechanical performance of the welds.<sup>7</sup> Ahmed et al.<sup>8</sup> studied effect of dwelling time and plunge depth on friction stir spot welded (FSSWed) dissimilar joints between Al and steel and reported a significant influence of them on mechanical properties. In another study researchers studied underwater FSW heat-resistant SS to study the effect of the different cooling mediums and tool rotation rates on the thermal cycles, plastic deformation, tool wear, and microstructure

evolution.<sup>9</sup> Researchers studied friction welding of dissimilar materials and reported a significant effect on microstructural and mechanical properties of the welded joints.<sup>10–12</sup> Various researchers explored the effect of FSW parameters on the wear behavior of FSWed 6160-T6 and 7075-T651 Al alloys, noting that tool rotation significantly affects wear rates, with better wear resistance achieved at 1250 r/min compared to 1550 r/min.<sup>13</sup> Liu et al.<sup>14</sup> reported, in FSW of AA6061 and TRIP 800/830 steel, higher tool rotation boosts weld temperature, lowers tool movement forces, and shapes the intermetallic compound layer, impacting material integrity. Kar et al.<sup>15</sup> found that in FSW of dissimilar materials, the tool's combined shoulder and pin action led to dynamic recrystallization, refining aluminum in the

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