# Novel Friction Stir Processing Approaches for Efficient and Homogeneous Fabrication of Surface Metal Matrix Composites


## Abstract

*The demand for lightweight, high-performance materials in automotive, aerospace, and defense sectors has driven the development of Aluminum-based metal matrix composites (MMCs) due to their ability to enhance surface hardness, wear resistance, and functional performance while preserving the lightweight nature of aluminum alloys. Friction stir processing (FSP) has emerged as a promising solid-state technique for surface MMC fabrication, offering several advantages over conventional liquid-state and powder-based methods, including lower processing temperatures, elimination of melting-related defects such as porosity and intermetallic formation, and improved interfacial bonding between the matrix and reinforcement. Despite these advantages, fabrication of surface MMCs using FSP typically relies on pre-placed reinforcement techniques such as groove or blind-hole filling, which involve multiple pre-processing steps, increase fabrication time and cost, and often lead to non-uniform particle distribution. To achieve acceptable reinforcement homogeneity, multi-pass FSP is commonly employed, further increasing processing time, energy consumption, and limiting industrial applicability. To overcome these limitations, this thesis presents novel friction stir processing approaches aimed at efficient and homogeneous fabrication of surface metal matrix composites. A comprehensive literature review is first presented to identify key challenges in existing FSP-based composite fabrication routes. A counter-rotating twin-tool friction stir processing (CRTTFSP) technique is then systematically utilized for Al/SiC surface composite fabrication. The simultaneous operation of two closely spaced counter-rotating tools significantly enhances heat generation and material flow, enabling defect-free composite fabrication with uniform reinforcement distribution in a single pass. CRTTFSP achieved up to 90.57% reduction in processing time compared to conventional dual-pass FSP, while increasing microhardness by approximately 36% compared to the base aluminum. To further improve process efficiency, an in-situ reinforcement deposition friction stir processing (IRDFSP) system was designed and developed to eliminate pre-processing steps such as groove machining, particle filling, and groove sealing. The IRDFSP system integrates a mechanized powder feeder with a trailing FSP tool, enabling continuous reinforcement deposition and effective stirring during processing. Despite generating approximately 7%*

*lower peak temperature than CRTTFSP, IRDFSP achieved comparable particle homogeneity due to the combined stirring action of the auger probe and trailing tool. The IRDFSP process reduced total fabrication time by approximately 62-73% compared to conventional and multi-pass FSP routes. The fabricated Al/SiC composites exhibited a ~26% reduction in specific wear rate, demonstrating superior surface durability. Therefore, these techniques offer significant potential for industrial implementation by enabling efficient, scalable, and reliable surface composite fabrication.*

**Keywords:** *Friction stir processing; Metal matrix composites; Al/SiC; Wear analysis; Particle distribution; Microhardness*