Abstract

The demand for efficient thermal management solutions in electronics, electric vehicles, and data centers has driven interest in advanced manufacturing methods for cold plate fabrication. Friction Stir Channeling (FSC), a solid-state process, offers a cost-effective, single-step solution for fabricating internal cooling channels in metals without the need for post-processing. However, challenges such as defect formation, higher internal surface roughness, inconsistent channel geometry, and limited process understanding have restricted its industrial adoption.

This work provides a comprehensive investigation into the FSC process through five targeted modules. A novel marker-insert technique was employed to visualize material flow, revealing the distinct roles of pin and shoulder in channel formation and defect mitigation. The influence of key process parameters, rotational speed, traverse speed, and tool clearance, was systematically studied to define an optimal process window for high-quality channels. Best results were achieved within 1000-2000 rpm and 50-200 mm/min, with 1.2 mm clearance, balancing channel uniformity, hydraulic performance, and surface quality. Tool design parameters, including thread pitch, pin dimensions, and shoulder geometry, were also examined. Scroll shoulders and moderate thread pitches (1.25-1.5 mm) showed improved material redistribution and reduced surface defects. Additionally, the FSC technique was extended to 3D geometries through Friction Stir Spiral Tunneling (FSST), demonstrating potential for waste heat recovery in tubular structures with minimal material degradation. Defects were classified by mechanism and severity, and a feature-based detection method using Empirical Mode Decomposition (EMD) and frequency analysis was proposed. This enables real-time monitoring of subsurface defects like irregular channel geometry. The study offers practical guidelines for optimizing FSC and FSST, enhancing their readiness for industrial use. It establishes FSC as a scalable, sustainable alternative for next-generation thermal management systems.

Keywords : Friction Stir Channeling, Thermal Management, Cold Plate Manufacturing