
Tribological Insights into Supercritical CO₂ and MQL in Titanium Alloy Machining for Sustainable Manufacturing

Nan Xu^{*1}, Jack Secker², Muhammad Raihan¹, Nikil Kapur¹, Harvey Thompson¹,
Christopher Taylor², and Ardian Morina¹

¹University of Leeds – United Kingdom

²University of Sheffield [Sheffield] – United Kingdom

Abstract

The use of emulsion coolants at high flow rates is widespread in machining processes such as milling, turning, and drilling. While effective, this practice poses substantial environmental, economic, and health challenges. Recent innovations, such as minimal quantity lubrication (MQL) and cryogenic machining with supercritical CO₂ (scCO₂), offer sustainable alternatives by reducing coolant consumption by up to four orders of magnitude while enhancing tool life and lowering manufacturing costs. However, a lack of understanding regarding lubricant selection, lubrication mechanisms, and heat transfer in mixed scCO₂+MQL systems hinders their broader industrial implementation.

This study employs a bespoke high-speed, high-load pin-on-disk tribometer to simulate cutting conditions and monitor tribological behaviours at the tungsten carbide pin/Ti64 disc interface, including friction forces, heat generation, and pin wear. Real-time temperature data at the pin/disk interface is captured using a thermocouple, enabling detailed investigation under conditions that closely replicate machining environments. The experimental matrix includes parameters such as sliding speed, temperature, coolant properties, flow rates, and MQL types and concentrations.

Additionally, the study investigates surface films formed during testing using advanced characterization techniques. 3D optical profilometer and Focused Ion Beam Transmission Electron Microscopy are used to evaluate physical properties, such as thickness, distribution, and nanostructure, while Scanning Electron Microscopy and Energy Dispersive X-Ray analysis provide insights into chemical composition.

This research advances understanding of how scCO₂ and MQL influence tribological performance under simulated cutting conditions. By exploring mechanisms governing tool wear and surface interactions, it establishes a mechanistic model that correlates tribological behaviour with scCO₂ and MQL parameters. These findings provide critical knowledge to optimize sustainable machining systems, contributing to environmentally conscious manufacturing advancements.

*Speaker