Erasmus Mundus Joint Master in Manufacturing 4.0 by intElligent and susTAinable technologies

meta4.0

MASTER's Degree Thesis

Analysing the influence of the workpiece geometry on the coolant flow field distribution during the milling process with internal coolant supply

Candidate: *Md Ibthisum ALAM*
Supervisors: *Prof. Dr.-Ing. Martin DIX (Technical University of Chemnitz), Dr.-Ing. Matthias REHM (Technical University of Chemnitz), Prof. Cédric COURBON (Centrale Lyon ENISE), Prof. Daniele UGUES (Politecnico di Torino)*

Abstract:
In the context of sustainable manufacturing, an efficient coolant delivery system is essential to minimize tool wear while maintaining the machined surface quality. The cooling performance, however, strongly varies depending on operating parameters and tool-workpiece interaction. The current study addressed this issue and developed a Computational Fluid Dynamics (CFD) model to evaluate coolant flow behavior in internally cooled milling. The simulations from the model were tested against surrogated experimental rigs, and the comparison showed good agreement. The analysis was based on the Design of Experiments (DOE) framework, particularly Central Composite Design (CCD), where the influence of three factors, namely workpiece geometry (flat vs. curved), rotational speed (250–750 RPM) and coolant flow rate (20 30 l/min), on four performance metrics such as average coolant velocity, coolant volume fraction, coolant coverage area, and turbulence kinetic energy (TKE) were

investigated. A preliminary assessment on the influence of coolant type was also executed, and water and water-based semi-synthetic coolant showed almost identical results, deviating within the range of 1-2%. The DOE outputs demonstrated the dominance of coolant flow rate on enhancing jet momentum and turbulence intensity, while workpiece geometry heavily defined the coolant retention and distribution, with curved geometries consistently obtaining superior results. Rotational speed had a lesser yet significant impact as higher spindle speed (750 RPM) improving velocity and turbulence, but at the same time, diminishing coolant volume fraction and coverage. Regarding interaction effects, any involvement of geometry was found to be significant, highlighting the need for geometry-specific optimization strategies. Through the study, a validated CFD-DOE framework was established for analyzing coolant delivery in milling. The insights obtained are directly transferable to tool design and process planning, hence providing scope for geometry-adaptive cooling strategies for advanced manufacturing.

Keywords: Sustainable Manufacturing, End Milling, Computational Fluid Dynamics (CFD), Design of Experiments (DOE).

September 2025