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

MASTER's Degree Thesis

Development of a hybrid cryogenic cooling concept for a turning tool with internal cooling via liquid nitrogen

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Abstract:
This thesis presents the design, simulation-based evaluation, and parametric analysis of a turning tool with an integrated internal liquid nitrogen (LN2) cooling chamber for cryogenic machining applications. The primary objective is to provide a foundational design concept and demonstrate structural stability for the tool, which features an integrated cooling chamber, to guide the future development of an internally cooled cutting tool. Simulation variants were designed by design of experiment using CCD full factorial RSM. A structured DOE incorporates three continuous factors (heat transfer coefficient, tip temperature, and atmospheric temperature), and two categorical factors (insulation method and chamber size). 80 simulation matrices were developed and analysed under steady state thermal analysis, and the resulting temperature loads are applied as a boundary condition in structural analysis, which also considered machining forces representative of hard turning. Results showed superior thermal performance under chamber coating insulation by

localizing cooling around the cutting insert. The maximum Von Mises stress in this configuration is reduced by over 63% compared to dry conditions and 59.5% compared to the configuration with an insulation pad between the tool head and shank. The parametric analysis using RSM confirmed that HTC, tip temperature, insulation method, and chamber size influence the tool performance, with insulation method as the most influential factor for the tool design. These findings demonstrate that thermal loadings and structural stability are effective under the integrated LN2 cooling with a targeted insulation, providing a starting point for further optimization, experimental validation, and industrial implementation.

Keywords: Cryogenic cooling, Thermal analysis, Response Surface Method, Tool head design, Integrated cooling chamber.

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