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Evaluation of Environmental Effects and Process Impact of Cutting Fluids

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Abstract: A better understanding of the function of cutting fluids is machining processes is being sought. This effort includes the development and validation of predictive models for mist formation in machining. The effects of cutting fluids on process-related heat transfer and lubrication are also under investigation. Finally, because the behavior of cutting fluids depends on such critical thermophysical properties as specific heat, viscosity, density and thermal conductivity, these properties are being described as a function of concentration, temperature, and fluid type (synthetic, semi-synthetic, and soluble oils) commonly used in machining. Progress in each of these areas is briefly described.

Introduction: The primary function of a cutting fluid is temperature control through cooling and lubrication. A secondary function of a cutting fluid is to flush away chips and metal fines from the tool/workpiece interface. However, the negative effects associated with cutting fluid usage include the formation of cutting fluid mist that may cause respiratory disease among factory workers, and fluid disposal/treatment concerns. There is a lack of adequate models to describe both the process performance and the environmental/health impact of cutting fluids. The focus of this research is to develop and validate such models for process and environmental performance so that conditions may be selected that balance conflicting objectives.

Process Performance: A fundamental understanding of cutting fluid process performance depends on the availability of the physical and thermal properties of cutting fluids. A number of experiments were performed that measured fluid viscosity, density, surface tension, specific heat, and thermal conductivity as a function of cutting fluid type, concentration, and temperature. Models for heat transfer, lubricity, evaporation, and atomization depend on these properties. A recently completed analytical and experimental investigation has examined the role that cutting fluids play in removing heat from the workpiece during a cylinder boring operation. Dry boring experiments were conducted to estimate the amount of heat transferred into the workpiece in a boring operation using an inverse heat transfer method. For these experiments, the convection coefficient was identified from the technical literature [1]. Wet boring experiments were then conducted to estimate the convection coefficient associated with the cutting fluid application once again using the inverse heat transfer method. The inverse heat transfer method relies on a one-dimensional heat transfer model that includes heat convection on the inner and outer bore walls to predict the temperature distribution in the cylinder bore. With values for the heat source strength and convection coefficient available for both wet and dry boring experiments, the temperature distribution was used to calculate the thermal expansion of the bore using the finite element method (FEM). Surface error due to the cutting forces was also predicted using FEM and added to the thermally induced surface error to give the total surface error. The actual surface errors of bores machined under dry and wet cutting conditions was measured and compared with the predicted surface errors. Very good agreement between the measured and predicted values was observed.
**Mist Formation:** Cutting fluid mist represents a significant environmental safety and health hazard. The primary objective of this research is to develop a better understanding of the fundamental mechanisms of cutting fluid mist formation (evaporation, atomization, splashing and droplet processes). Efforts to describe the atomization mechanism have been described by Yue et al. [2]. A hardware testbed has recently been established to validate the atomization model associated with a rotating workpiece. The cutting fluid mist droplet size distribution has been obtained by use of a Laser Aerosol Spectrometer for a variety of conditions. The variables examined in this experimental study include rotating speed, workpiece diameter, nozzle diameter, fluid jet velocity, as well as cutting fluid oil concentration. The effects of these variables show reasonably good agreement with theoretical results. In addition to the atomization mechanism, attention is also being focused on mist formation via an evaporation/condensation mechanism. It might be expected that the cutting fluid evaporation rate depends on the atmospheric vapor concentration and mist size distribution. Analytical computations have been made to predict the evaporation rate of the cutting fluid under ambient conditions for typical cutting fluid systems. The total evaporation rate and the oil composition with time were predicted based on the molecular weight and vapor pressure using a multi-component evaporation model. The calculation shows that the evaporative emission rate is not significant. Experimental measurements of the mass flux of cutting fluids yields the same conclusion. During machining, a considerable amount of heat generated may result in boiling and evaporation, which may be a significant issue for cutting fluid mist formation. At present, the burnout phenomenon is being examined, with the rate of mechanical energy supplied to the wake configuration equal to the energy being absorbed [3]. Using this rate-of-energy stability criterion method, the evaporation rate of an impinging cutting fluid jet in the case of CHF (Critical Heat Flux) may be predicted.

**Summary and Continuing Work:** A database of cutting fluid properties is being created to provide the necessary data for the Cutting Fluid Evaluation Software Testbed (CFEST) [4]. The analytical models incorporated into CFEST include heat generation, heat transfer, mist formation and chip carry-off, and are linked to the Universities of California and Illinois health and environmental impact modules. Continuing research work will emphasize development of new and refinement of existing models for mist-related mechanisms, as well their experimental verification.

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**References:**


