Microlubrication Effects During End Milling AISI 1018 Steel

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ABSTRACT

Flood cooling is primarily used to cool and lubricate the cutting tool and workpiece interface during a machining process. But the adverse health effects caused by the use of flood coolants are drawing manufacturers’ attention to develop methods for controlling occupational exposure to cutting fluids. Microlubrication serves as an alternative to flood cooling by reducing the volume of cutting fluid used in the machining process. In this study the effects of microlubrication during end milling of AISI 1018 steel was investigated using vegetable based cutting fluid aerosol. A solid carbide cutting tool was used with varying cutting speeds and feed rates having a constant depth of cut. A full factorial experiment was conducted and regression models were generated along with parameter optimization for the aerosol mass concentration and the aerosol particle size. The study shows that with a proper selection of the cutting parameters it is possible to reduce the aerosol mass concentration in end milling under microlubrication. But more scientific assessments are needed to lower the mass concentration of the aerosol particles, below the recommended value of 5 mg/m³ by Occupational Safety and Health Administration (OSHA). Limited studies have been reported to investigate the effectiveness and quality of mist produced under microlubrication. No study has been reported to date on end milling 1018 steel under microlubrication.

Keywords: Aerosol Mass Concentration, Aerosol Particle Size, Design of Experiments, Microlubrication, Milling, Steel, Minimum Quantity Lubrication

INTRODUCTION

Metal cutting processes have been in practice since centuries. But the first appearance of metal cutting fluid in the literature was observed in the mid-19th century (Northcott, 1868). A more comprehensive earlier work on cutting fluids was reported by F. W. Taylor (Taylor, 1906). Since then, metal cutting fluids or metal working fluids (MWFs) are used to cool and lubricate the tool/workpiece interface during metal cutting. The MWFs increase the tool life and achieve faster production rates (Wang & Clarens, 2013; Clarens et al., 2008). The MWFs

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also perform important functions such as chip transportation and dissipating generated heat at tool/workpiece interface which results in the reduction of tool wear (Jayal & Balaji, 2009). We cannot completely stop the use of MWFs because of their beneficial contributions. But the exposure of MWFs is also the cause of growing occupational health hazards. MWFs in the form of airborne particles often remain suspended in the working environment for an extended period of time and can be inhaled by the workers causing health concerns (Sutherland et al., 2000). U.S. National Institute for Occupational Safety and Health (NIOSH) recommends that the exposure limits (RELs) to MWF aerosols cannot exceed 0.5 mg/m$^3$ total particulate mass as a time weighted average (TWA) concentration for up to 10-hrs per day during a 40-hrs work week (NIOSH, 1998) and cannot exceed 10 mg/m$^3$ as a 15-minute TWA short-term exposure limit (STEL) (Park, 2012). The Occupational Safety and Health Administration (OSHA) have currently two permissible exposure limits (PELs) applied to MWFs. They are 5 mg/m$^3$ for an 8-hour TWA for mineral oil mist and 15 mg/m$^3$ for an 8-hour TWA for Particulates not otherwise classified (PNOC) (Sheehan, 1999). While, The American Conference of Governmental Hygienists (ACGIH) threshold limit value (TLV) and Health Safety Executive, UK, occupational exposure limits (OELs) for mineral oils mist is 5 mg/m$^3$ for an 8-hour TWA, and 10 mg/m$^3$ for a 15-minute STEL (Park, 2012). The Swiss recommendations for PELs is 0.2 mg/m$^3$ for heavy oil with boiling point greater than 350°C of aerosol and/or 20 mg/m$^3$ of oil aerosol plus vapor for medium or light oil. The German Institute of Occupational Health (BGIA) standard is 10 mg/m$^3$ of oil aerosol plus vapor. While in France, The National Institute for Research and Safety (INRS) proposes a recommended value of 1 mg/m$^3$ of aerosol (Huynh et al., 2009). But, the oil mist level in the U.S. automotive parts manufacturing facilities has been estimated to be 20-90 mg/m$^3$ with the use of flood coolant (Bennett & Bennett, 1985). The exposure to such amounts of MWFs may contribute to adverse health effects and safety issues, including toxicity, dermatitis, respiratory disorders and cancer (Boubekri & Shaikh, 2012). Studies among the U.S. automobile workers have also reported increased rates of laryngeal and certain digestive tract cancers in relation to MWF exposures (Greaves et al., 1997). Also, the costs related to the use of MWFs range from 7-17% of the total costs of the manufactured work piece (Weinert et al., 2004) as compared to the tool cost which is only about 2-4% (Zhang et al., 2012). Due to these problems, Microlubrication has been sought as an alternative to minimize the use of cutting fluids.

Microlubrication consists of atomizing a very small quantity of lubricant ranging between 10 to 50 ml/hr directed toward the cutting tool/workpiece interface in the form of aerosol. Microlubrication is also known as ‘Minimum quantity lubrication’ (MQL) and ‘Near-Dry Machining’. In microlubrication technique, the lubrication is obtained via the lubricant, and the cooling is achieved by the pressurized air that reaches the cutting tool/workpiece interface. Investigations have shown that microlubrication is effective at reducing cutting tool/workpiece interface temperature, tool wear, thermal distortion and material adhesion to the tool (Irfan et al., 2013). In some studies using microlubrication the performance was equivalent to or better than flood cooling (Zhiqiang et al., 2013; Kurgin et al., 2011). The aerosol during microlubrication can be produced by two mechanisms: atomization and vaporization/condensation. In atomization, aerosol is produced by the disintegration of lubricant jet by the kinetic energy of lubricant itself, by exposure to high velocity air or as a result of mechanical energy applied externally through a rotating or vibrating device (Adler et al., 2006). Vaporization is produced as a result of heat generated at the tool/workpiece interface. This heat is transferred to the lubricant and raises its temperature above the saturation temperature resulting in boiling and vapor production at the workpiece/lubricant interface. This vapor condenses spontaneously generating aerosol/mist (Sutherland et al., 2000).
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