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Experimental method to analyze the oil mist impingement over an insert used in MQL milling process

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ABSTRACT

This paper proposes an original method to determine the oil mist impingement over an insert based on different machining configurations (rotation velocities) and different inner canalization designs, without material removal, on milling tool. The oil mist spray is determined using different holders as an insert. Glass plate and blotting paper are used and evaluated in this work to get as much information as possible, based on micro–macro scale observations. The imprint size of the oil mist spray distribution, the particle sizes and the fluid film formation have been studied to determine the effects of the different configurations on the oil mist impingement behavior. The droplet impingements and distributions on the glass plate are analyzed under a 3-D profilometer (microscopic scale). On the blotting paper, the distributions are analyzed with pictures of the oil marks (macroscopic scale). This original method gives quite fast particle distributions that can be used in industry. The different experimental results give large information about the oil mist behavior sprayed on the glass plate. Increasing rotation velocities increases the oil mist amount in the cutting area. Increasing the canalization orientation design gives a better focused spray. The rake angle has strictly no influence on the oil mist spray distribution. But sputtering effects have been highlighted and should be avoided to keep MQL efficiency.

1. Introduction

In the last years, investigations have been carried out to reduce or eliminate the large amount of lubricants used in machining (oils or emulsions) for economical reasons. Investigations in automotive industry estimated that the cutting fluids played a significant role in the total manufacturing cost. For some materials more difficult to machine, this proportion can reach 20% to 30% [1]. This cost is several times higher than tool costs (design, manufacture, coating, etc.) which vary between 2% and 4% of the total manufacturing cost.

Furthermore, there are environmental motivations since the use of less lubricant results in lower pollution. Indeed, cutting fluids require regular maintenance to keep their best features. This is a very favourable environment for the development of bacteria and fungi that can alter and reduce the lubricant effect of the fluid. Bacteria can be very dangerous for the operator's skin and lungs [2]. Recent studies have focused on cryogenic CO_2 cooling process in drilling [3] to counter the negative impact of the bacterial growth. This technic gave very good tool life results and was a suitable choice for machining of materi-

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als that are incapable of using liquid coolant (i.e.: composites). But the cryogenic CO_2 device had a huge impact on the manufacturing cost as well as a negative ecological impact.

Due to the above mentioned reasons, minimum quantity lubricant (MQL) may be more suitable to improve machinability at reduced cost. The two-phase "air + oil" mixture has significant influence on the workpiece-carbide tool thermo-mechanical behavior, in High Speed Machining (HSM). The pressurized oil mist sprayed on the cutting edge avoids the sticking phenomena highlighted by [4]. Temperature decreasing during machining, really good finishing surface and exceptional tool life time were largely obtained with minimal fluid coolant compared with dry or flood lubrication process [5–8]. All these parameters, ensured with the minimal fluid process, led to high production rate. For these reasons, the cutting zone has to be well lubricated and judiciously cooled by spraying the coolant process on the cutting edge. The oil mist is able to reach the cutting edge thanks to the small size of the oil droplets and the tool surface roughness. But the oil mist sprayed is limited by the extremely high pressure in the tool/chip contact area, estimated at 3 GPa in some extreme cutting conditions [9]. This very high pressure precludes any fluid access to the rake face, particularly along the plastic part of the tool–chip contact length. One of the solutions consists in creating intermittent machining (as in milling) or in turning presented by [10,11]. Some grooves allow the tool face to be sprayed by the oil mist and significant effects have been noticed on the surface finish results.

Thus, the context of the study is focused on milling tool development with inner canalizations. The milling process offers natural interrupted cutting during the rotation and avoids the external nozzle position errors due to manipulation by different users. All studies to date have focused on external nozzles minimal fluid coolant process [8,12,13], judiciously oriented [6].

Recent researches focus on inner canalization on milling cutting tools to answer to large-scale industries production request. Oil mist characteristics are performed with heavy measurement devices such as the laser granulometry method, the Particle Image Velocity and the residual gravimetry method to get particle sizes, particle velocities and oil consumptions, respectively [14,15]. The geometry of the inner canalizations depends on different parameters (inlet pressures, cutting speed) and is not as easy to determine as the external spray nozzles. Several phenomena appear during the tool rotation and the small particle size of the oil mist has to be preserved [16–18]. Moreover, the lubrication is only efficient for oil included on the tool/chip interface calls "cutting area". For these mentioned reasons, the oil mist behavior is essential to know to find out the optimal configurations to ensure a micro coolant effect as good as possible while avoiding wasting oil.

The main goal of this paper is to establish a method for determining the oil mist impingement outside different inner canalizations orientations (secondary canalizations), in order to understand the oil mist behavior. This method uses, on the one hand, blotting paper to have an overall idea of the oil mist distributions in a large time-scale. Blotting paper is quite easy to use and to fix on cutting faces. Moreover, it does not need specific measurement device, as mentioned above. Due to the absorption properties of the blotting paper, the oil mist distribution is quite fast to obtain in large time scales (300 s), which represent machining time-scales. On the other hand, oil mist distributions are analyzed on glass plate with 3-D profilometer device with short time-scale (5 s). This microscopic analysis gives accurate details on oil mist distributions, such as small particle (Ø < 100 μm) impingements on the cutting area, not observable on blotting paper. Moreover, the microscopic oil mist impingements analysis can predict the overall impingements behavior, mentioned in blotting paper analysis.

To sum up, the advantages of using the original method proposed here are:

- Oil mist distribution is quite fast to get, in macroscopic scale and large time scale which is close to the time of machining,
- Oil mist distribution is accurate to get, in a microscopic scale and short experimental time test under 3-D analysis,
- Complementarity between both technics by comparing blotting paper observations and 3-D profilometer analysis tendencies.

In the second section, a detailed presentation of the method is used to get oil mist impingements information for different configurations. Different rotation velocities (machining configurations) with different secondary canalizations orientations are considered. The methodology consists in analyzing the imprint of the film fluid formation for a large rotation velocity range. The localization of the imprint gives information about the quality of the oil mist and its interaction with extreme outlet configurations. Finally, the conclusion summarizes the relevance of such an approach and results are presented.

2. Experimental setup

2.1. Materials and equipment

The study of MQL was performed on a Hermle C40 Computer Numerical Control (CNC) machine tool. The oil mist generation was provided by an external mixing device (a Lubrilean Digital Super generator developed by SKF). The Digital Super commercial software is used to run the mixing device in order to control the air and the oil mist flow rates. The considered oil is a synthetic biodegradable polyols ester with sulfur and phosphorus extreme pressure additives (PX 5130), which have a high viscosity of 80 mm^2/s at 40 °C.

Experimental procedures are realized on a model based on FSD 1230 milling tool with seven carbide inserts, from SANDVIK COROMANT.

The prototype was made up of secondary channels connected to a main central channel. The secondary channels were oriented at different angles based on the vertical axis