Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 45 (2016) 287 – 290

www.elsevier.com/locate/procedia

3rd CIRP Conference on Surface Integrity (CIRP CSI)

Minimum Quantity Lubrication: Influence of the oil nature on surface integrity

Sana Werda[a,b,]*, Arnaud Duchosal[a], Guénhaël Le Quilliec[a], Antoine Morandeau[b], René Leroy[a]

[a]University François-Rabelais, 7 avenue Marcel Dassault, Tours 37200, France
[b]Sandvik Coromant, rue Henri Garih, Fondettes 37230, France

* Corresponding author. Tel.: +33247625202; fax: +33247625791. *E-mail address*: sana.werda@sandvik.com

Abstract

Minimum Quantity Lubrication (MQL) is a lubrication method in machining field. It consists in spraying very small amount of oil to the cutting edge with compressed air. This technique decreases friction between chip and the cutting face of the tool which leads to better surface finish and tool life. Well-chosen oil will give best results on surface integrity. Regarding the choice of oil, this paper aims to identify the evolution of tool temperature, tool wear, surface roughness and cutting forces in milling process. The influence of two oils (synthetic ester and fatty alcohol) is investigated and compared with dry machining.

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on Surface Integrity (CIRP CSI)

Keywords: MQL; Milling tool; Synthetic ester; Fatty alcohol; Surface roughness; Tool life.

1. Introduction

Minimum Quantity Lubrication (MQL) machining involves the application of a minimal amount of an oil-based lubricant to the machining process. This technique decreases friction between chip and the cutting face of the tool which leads to better surface finish and tool life [1]. Due to small amount of fluid, MQL lubricants need to be efficient. Understanding the correlations between fluid properties and MQL performance can help in selecting lubricants.

In literature, there are so many fluids used in MQL with vastly different physical properties (density, viscosity, nature, flash point, thermal conductivity…). Some researchers [2,3] tried to characterize different oils and they found that high viscous oil preserves small particle diameters or MMAD (mass median aerodynamic diameter) and generates lower oil consumption (~mist concentration) [2,3]. Suda et al. [4] studied primary (wear, roughness…) and secondary (biodegradability, oxidation stability…) performances for three synthetic polyol esters and a vegetable oil with a viscosity range of 19 to 48 cSt. This evaluation showed that synthetic polyol esters were optimal lubricants for MQL machining in terms of primary and secondary performances and that viscosity was unimportant in tapping tests. However, oil viscosity influence has been studied by comparing palm oil (40 cSt) to a synthetic ester (19 cSt) while drilling TA6V [5]. This study showed that high viscous oil produced lower cutting forces, lower workpiece temperature and better flank wear progression. On the other side, in tribology tests with carbide pin and aluminum 324.0 cylinder [6], alcohol based oil (27.2 cSt) showed low friction coefficient compared with vegetable oil (36.2 cSt) at low sliding velocity (<200m/min). But at high sliding velocity, both MQL oils were not effective since they gave friction coefficients close to a dry test. Similar observations were made by Rahman et al. [7], MQL was effective especially at low cutting speed (75 m/min), but it seemed to make no improvement on tool performance in higher cutting speed such as 125 m/min in end milling ASSAB 718HH steel. These differences seem to be due to the lower heat resistance of the uncoated carbide tool and the highly viscous oil which lead to a poor cooling ability [8]. TiAlN and TiN coated carbide tool with higher heat resistance exhibited a poor cooling effect with high oil viscosity (28 cSt) and a better lubricating effect for low oil viscosity (5 cSt) [8]. The high viscous oil gave 6 % longer cutting length for low cutting velocity (150 m/min) in end milling NAK80 die steel

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on Surface Integrity (CIRP CSI)
doi:10.1016/j.procir.2016.02.330

[8]. But it is 11 % shorter under a higher cutting speed condition (250 m/min). The reason may be due to the fact that low-viscosity oil contains a higher fraction of low molecular weight components, which can volatilize more easily and thereby provides better cooling effect [9]. To sum up, the above results lead to the following observations:

- High viscous oils gave better lubrication effect especially at low cutting speed. The trend goes to lower cutting forces [5] and to increase cutting length [8].
- Low viscous oils gave better coolant effect at high speed machining. The trend goes to give better surface roughness [3] and longer tool life [8].

Therefore, this paper proposed to analyze the contributions of the oil properties on X100CrMoV5 steel alloy in semi-finishing. The micro coolant process is ensured by tool inner channels. The effect of oil properties are analyzed on tool life, dissipated temperature, surface roughness and cutting forces separately. In conclusion, this study assessed two different MQL oils and found the most efficient one towards industrial needs.

2. Experimental set-up

The study of MQL was performed on a computer numerical control (CNC) machine tool Hermle C40. MQL generation was provided by an external device (a Lubrilean Digital Super generator developed by SKF). The considered milling tool was a CM200 from Sandvik Coromant (ø32 mm) with three teeth. The workpiece material used for the experiments was X100CrMoV5 steel alloy used in molding application. Machining tests were carried with one insert type RCKT 12 04 M0-PH 4240. Two oils from Total were tested in machining. Cutting conditions and oils characteristics are given in tables 1 and 2 respectively.

Fig. 1 shows the experimental set-up. Two blocks were used to measure different characteristics. Block 1 was used to evaluate temperature, surface roughness and tool lifetime. Block 2 (with specific attachment adapted to the effort table) was used to evaluate cutting forces (Fig. 1). All experiments were repeated three times.

Table 1. Cutting conditions.

Cutting velocity	Vc=135 m/min
Feed rate	Fz=0.38 mm/rev
Depth of cut	Ap=2 mm
Engagement	Ae=70 %

Table 2. Oil characteristics.

	PX5130	PX5131
Viscosity (40°C) (cSt)	80	28
Density (15°C) (Kg/m3)	930	835
Flash point (°C)	>300	180
Nature	Synthetic ester+ additives	Modified fatty alcohol

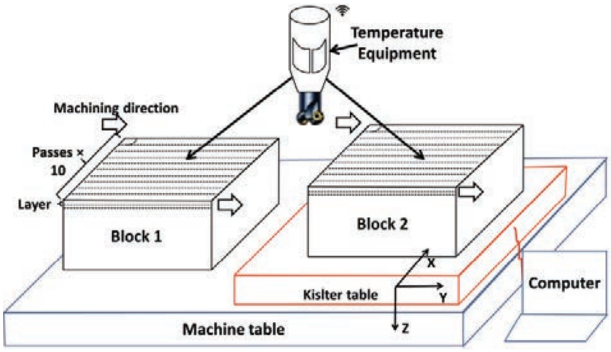

Fig 1. Experimental set-up.

3. Experimental procedure

The experimental procedure consists in doing lifetime tests on block 1 with regular force measurement passes on block 2.

Measurement protocol steps consist of:

1) Measuring cutting temperature while machining one layer of 2 mm depth of cut on block 1 (corresponding to 1.22 minutes of material contact).
2) Measuring surface roughness on machined surface with Mahr Perthometer.
3) Measuring insert flank wear with magnification device.
4) Machining 9 mm long on block 2 to measure cutting forces with Kistler table through DynoWare software.
5) Loop repeating from step 1 to 4 till the flank wear of the insert reaches 0.3 mm.

A flank wear of 0.3 mm is the common flank wear limit recommended by tool manufacturers. Tip seat cutting temperature was measured through a wireless thermocouple from ATCOM. All the temperature equipment was embedded in a Capto C5–Cylindrical shank tool holder. The transmitted signal was recorded through the software ATR6ACU Conf. The thermocouples were clamped between insert and tip seat in a slot of 0.1 mm depth. K-type used thermocouples have a diameter of 0.13 mm. Blocks 1 and 2 were from the same batch.

4. Results and discussions

4.1. Effects on cutting temperature

Fig. 2 shows the effect of MQL on tip seat temperature when milling. As can be seen from this Fig. 2-a, the insert encountered a cyclic variation of temperature while machining one layer with MQL. One layer is assumed to be 10 passes as shown on Fig. 1. This variation led to a thermal cyclic loading of the insert. Maximal values were picked and plotted in the Fig. 2-b.

Fig. 2-b shows that maximal temperature values are almost constant when machining one layer with MQL especially at the beginning of the lifetime (deviation of 4°C). At the end of the lifetime test, this deviation was about 10°C and that can be due to cumulated wear of the insert. The same observation for