International Journal of Machine Tools & Manufacture 50 (2010) 521–531

Contents lists available at ScienceDirect

International Journal of Machine Tools & Manufacture

journal homepage: www.elsevier.com/locate/ijmactool

Influence of oil mist parameters on minimum quantity lubrication – MQL grinding process

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ARTICLE INFO

Article history:
Received 20 January 2010
Received in revised form
8 March 2010
Accepted 9 March 2010
Available online 15 March 2010

Keywords:
Minimum quantity lubrication
MQL nozzle position
Oil mist flow rate
Grinding forces
Surface roughness

ABSTRACT

Promising alternatives to conventional dry and fluid coolant applications are minimum quantity lubricant (MQL) or near dry grinding. Despite several researches, there have been a few investigations about the influence of MQL parameters on the process results, such as oil flow rate, air pressure, MQL nozzle position and distance from the wheel–workpiece contact zone. The current study aims to show through experiment and modeling, the effects of the above parameters on grinding performance such as grinding forces and surface roughness. The results show that the setting location of the nozzle is an important factor regarding the effective application of MQL oil mist. It has been shown that optimal grinding results can be obtained when the MQL nozzle is positioned angularly toward the wheel (at approximately 10–20° to the workpiece surface). In addition, it is found that the efficient transportation of oil droplets to the contact zone requires higher mass flow rate of the oil mist towards the grains flat area and longer deposition distance of an oil droplet. Applying the new setup, considerable reduction in the grinding forces and surface roughness has been achieved.

1. Introduction

Despite many advantages of the cutting fluids in the machining processes, there is serious concern about ecological and economical problems. Hence, multitude researches have been guided in the last few decades to reduce or even eliminate the use of cutting fluids [1–6]. During grinding, many abrasive grits are in contact with the workpiece at each second, but just a small portion of these grits have the cutting role in the real process and the others do not perform real cutting, but instead generate heat by rubbing and ploughing the workpiece surface in the contact zone. High heat generation and temperature in the contact zone are associated with a high negative rake angle and a great contact length in grinding process [4,5]. Grinding operation, without using sufficient coolant–lubricant, leads to thermal damages and dimensional inaccuracy on the workpiece surface. Hence methods of dry grinding have not yet been fully successful in industrial applications [5–7]. Since there is no cutting fluid to transfer the heat from the contact zone, problems frequently occur in terms of thermal damages on the workpiece surface, increasing the grinding energy and grinding forces, wear of the grinding wheel, low material removal rate (regarding relatively low depths of cut), as well as poor surface integrity compared to fluid grinding [4,5].

An attractive alternative for the dry grinding process is the minimum quantity lubrication (MQL) grinding. This process uses a minimum quantity of lubrication and is referred to as near dry grinding. In MQL grinding, an air–oil mixture called an aerosol is fed onto the machining zone [8–12]. Tawakoli et al. [12] investigated the effects of the workpiece material hardness and grinding parameters on the MQL grinding process. Based on the results of their investigations, significant improvement can be achieved by MQL grinding of hardened steel in comparison to dry grinding process. Silva et al. [9,10] investigated the effects of grinding parameters on ABNT 4340 steel using the MQL technique. They found that the surface roughness, radial wear, grinding forces and residual stress are improved by using the MQL technique due to the better lubrication of the grinding zone and hence a reduced friction between the grains and the workpiece material at the contact zone [9,10]. Brunner [13] showed that the MQL grinding of 16MnCr5 (SAE-5115) with 4 ml/min ester oil, as compared with 11 ml/min mineral oil, reduces process normal and tangential forces to one-third, but increases surface roughness up to 50%. Investigations by Brinksmeier et al. [14] confirmed these results and showed additionally that the type of coolant–lubricant can also considerably influence the MQL process. Hafenbraedl and Malkin [15] found that the MQL technique provides efficient lubrication, reducing the grinding power and the specific energy to a level of performance comparable or

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doi:10.1016/j.ijmachtools.2010.03.005

superior to that obtained from conventional soluble oil (at a 5% concentration and 5.3 l/min flow), while at the same time it significantly reduces grinding wheel wear. However, MQL presented slightly higher roughness values (R_a) [9,10].

Literature review shows the lack of study on the effects of MQL parameters such as oil flow rate, air pressure, MQL nozzle position and nozzle distance from the wheel–workpiece contact zone. In this paper, experiments are conducted under different MQL grinding conditions to determine the performance of the MQL parameters, regarding grinding forces and surface roughness.

2. Experimental procedure

The settings of machining parameters in the present study are summarized in Table 1. The wheels have been dressed before each experiment at the same conditions for all the test trials as shown in Table 1. Surface grinding tests were done through the 8 mm width for hardened 100Cr6 using ELB micro-cut AC8 CNC universal surface grinding machine. The equipment utilized to control the minimum quantity of lubricant (MQL) was Accu-Lube system in which an oil supply pump system is used. In this system, the compressed air and lubricant flow can be adjusted separately and mixed in the special nozzle (with nominal diameter 3 mm) to make micro droplets of cutting oil flying to the cutting zone by the compressed air. The surface roughness and grinding forces measurements were performed after the 10th pass. The workpiece roughness was measured by Hommel Tester T-1000 (mobile roughness measurement device) with a cut-off length of 0.8 mm (according to DIN EN ISO 3274:1998). At the end of each test, R_z across the grinding direction was measured at five different points of the ground surface. The grinding force components were recorded using a piezo-electric transducer based dynamometer (type Kistler 9255B) positioned under the workpiece clamping device.

Table 1
Experimental conditions.

Grinding mode	Plunge surface grinding, up and down cut
Grinding wheel	Al_2O_3 (89A60I6V217, 89A36I8V217), manufactured by TYROLIT Co.
Grinding machine	ELB micro-cut AC8 CNC
Wheel speed (V_c)	V_c=30, 45 m/s
Work speed (V_{ft})	V_{ft}=1000, 2000 mm/min
Depth of cut (a_e)	a_e=20 μm
Environments	Dry, wet, MQL
Conventional wet grinding fluid	Syntilo XPS Castrol in a 5% concentration
MQL oil flow rate (Q)	Q=20, 50, 100 ml/h
Air pressure (P)	P=2, 3, 4, 7 bar
MQL oil	HAKUFORM 20–34 MQL oil with viscosity=18 m^2/s, and ρ=850 kg/m^3
MQL spray distance to contact zone (d)	d=40, 60, 80, 120 mm
Workpiece material	Hardened (100Cr6) with 50±2 HRC (60 mm × 8 mm × 13.8 mm)
Dresser	Two point diamond dresser
Total depth of dressing (a_d)	a_d=40 μm
Dressing speed (V_d) and overlap (U_d)	V_d=350 mm/min, U_d=2

3. Results and discussion on MQL grinding performance

3.1. Effects of oil mist nozzle position

To determine the influence of the nozzle position on the contact zone lubrication, four different MQL nozzle positions were compared (Fig. 1): nozzle toward the workpiece, toward the contact zone, angular toward the wheel and toward the wheel directly. The grinding tangential force (F_t), force ratio (F_t/F_n) and surface roughness (R_z) for the ground workpieces are presented in Fig. 2 for up and down grinding conditions. The grinding force ratio or friction coefficient indicates the combination of abrasive cutting and friction between the wear flats and the workpiece. The forces are the averages of forces of ten passes. It can be seen from Fig. 2 that tangential forces and surface roughness in down grinding conditions are lower than those in up grinding ones.

As the lubrication effect increases, there is a corresponding increase in elastic–plastic deformation under the cutting edge of the abrasive grain, resulting in a decrease in workpiece roughness and friction forces [16]. Regarding Fig. 2, the minimum tangential forces and surface roughness values are obtained when the MQL

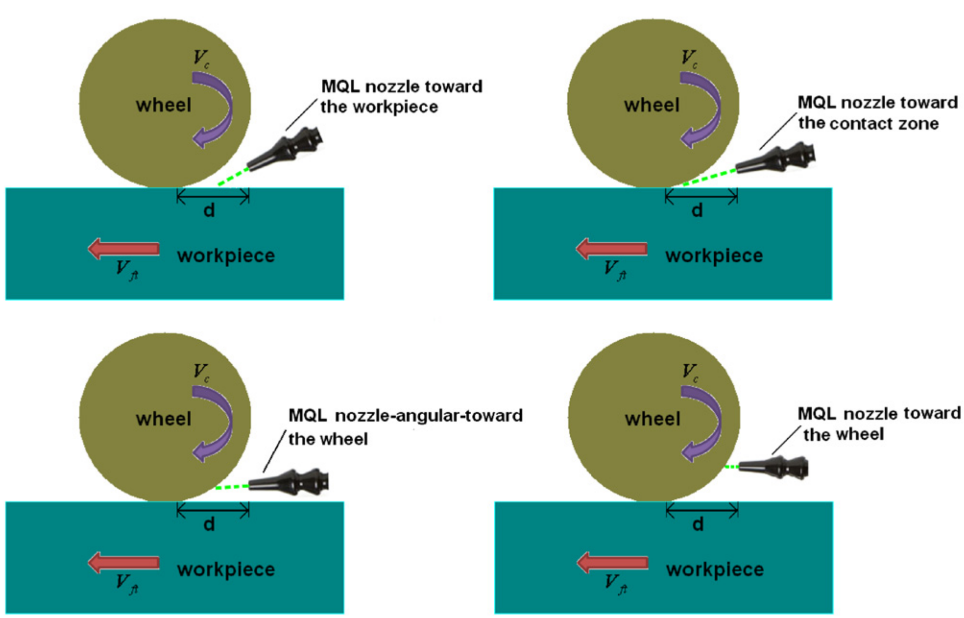

Fig. 1. Different MQL spray nozzle positions near the wheel–workpiece contact zone.