Journal of Manufacturing Processes 24 (2016) 107–115

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

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

Technical Paper

The influence of the cooling conditions on the cutting tool wear and the chip formation mechanism

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ARTICLE INFO

Article history:
Received 31 March 2016
Received in revised form 22 August 2016
Accepted 22 August 2016
Available online 5 September 2016

Keywords:
Cutting tool wear
MQCL
EP/AW additive
Chip shape
Friction coefficient on the rake face

ABSTRACT

The paper presents the influence of the cutting zone cooling method on the wear of a cutting tool made of sintered carbide P25 during the process of turning AISI 1045 steel. The following cooling variants have been considered: dry machining, MQCL method and MQCL + EP/AW. The tests have been performed with different cutting speeds. This work also emphasizes the influence of the cutting tool wear on the chip shape and the indices of the chip formation zone: the chip thickening coefficient and the friction coefficient on the rake face. It has been found that during MQCL + EP/AW cooling, the tool wear decreases by 20% at the lowest cutting speed to 51% at the highest cutting speeds as compared to dry machining. Application of the EP/AW additive also results in a reduction of the friction coefficient on the rake face. In consequence it advantageously influences the chip shape. In a scanning analysis of the tool point, it has been found that a thin layer of a tribofilm is formed on the wedge surfaces, which results in an improvement of the machining process conditions.

1. Introduction

The disadvantageous effects resulting from high temperature and friction in machining can be controlled by the process of effective heat removal from the cutting zone and reduction of friction from the tool–chip interface. This can be obtained by the application of adequate cooling/lubrication fluids (CLFs). Therefore, the CLFs used in machining processes must have good properties for reducing the temperature in the tool–chip interface under machining. In addition to the removal of large quantities of heat, the CLFs should reduce the normal and shear stresses and their distribution along the interfaces [1,2]. In practice, when this method is applied, only a part of the CLFs is used for cooling and lubricating the cutting zone. The cost of CLFs is estimated to be about 17–20% of the total manufacturing cost of a component [1,3]. The growing awareness for protection of environment and human health has resulted in investigations of the application of dry machining or cooling with use of CLFs in very small quantities and of effective utilization of those methods in industry.

Dry machining is one of the earliest methods of processing proposed by scientists with a view to developing Green and environmental protection machining [4]. Nowadays, the technique is applied in many machining processes [4–6]. However, excessive heat generated in the cutting zone results in high energy concentration at the workpiece surface [5], which can deteriorate the quality of the machined surface [6]. Therefore, in machining processes where dry machining cannot be applied due to the process or workpiece materials, methods based on very small CLFs quantities, are an alternative. Those methods are MQL (minimum quantity lubrication) [2,7–10] and MQCL (minimum quantity cooling lubrication) [11–13]. Studies by several authors have been focused on the relations between dry cutting and cutting with MQL and MQCL [14–17]. So far, it has been proved that the MQL and MQCL methods, as compared to dry machining and conventional machining, reduce the machined surface roughness [11,17], the cutting tool wear [17–19], temperature in the cutting zone, friction [2], extend the tool life [10,15] and have advantageously influenced the chip shape [16,19].

Setti et al. [2] have proved that addition of Al_2O_3 and CuO nanoparticles to the base oil in the MQL method reduces friction in the cutting zone during the process of grinding. The results have shown that the kind of nanoparticles and their concentration in the base fluid as well as the rate of the active medium flow play a

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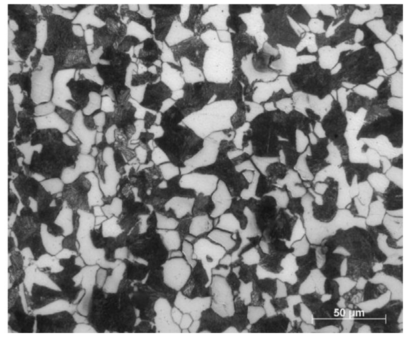
http://dx.doi.org/10.1016/j.jmapro.2016.08.006
1526-6125/

Table 1
Chemical composition, structure and mechanical properties of AISI 1045 steel.

Magnification ×500



Chemical composition								Mechanical properties			
C %	Si_{max} %	S_{max} %	P_{max} %	Mn %	Cr_{max} %	Cu_{max} %	Ni_{max} %	Re MPa	Rm MPa	A5 %	HB
0.42–0.5	0.4	0.045	0.045	0.5–0.8	0.4	0.3	0.4	305	580	16	250

significant role in the reduction of the phenomenon of friction. The application of nanofluid results in reduction of tangential forces and temperature in the cutting zone. It has been determined that effective lubrication with nanofluid results in formation of chip which reduces the tool wear of the flat area on wheel surfaces.

Investigations of Liu et al. [9] confirm the ability of forming a protective layer on the cutting tool under the conditions of MQL cooling, which extends the tool life when machining titanium alloy, Ti6Al4V, as compared to dry machining. The MQL method results in reduction of adhesion, diffusion and chemical wear.

Kaynak et al. [10,19] have determined that during turning of NiTi alloy with low cutting speeds (v_c < 25 m/min), the lowest values of the tool wear, VN_{max}, can be obtained under the conditions of the MQL method as compared to dry machining and the cryogenic method. They have also tested the chip temperature and shape. They have proved that the application of the MQL method reduces the chip temperature by 50–60% as compared to dry machining in the whole range of variable cutting speeds.

The purpose of the paper is to determine the influence of the MQCL method on the tool wear, the friction coefficient on the rake face and on the chip shape. It has also been shown how strongly the tool wear is influenced by the addition of phosphate ester-based EP/AW additive to the active medium. That is why the investigation seeks an insight into the relationship between the mechanism of wear and the chip formation in machining of AISI 1045 steel. The present study deals with a vast area of knowledge about the application of the MQCL method in industrial scale processes where the problem of chip control and the cutting tool wear plays a very important role.

2. Material of the workpiece and methods

2.1. Cutting tool and machining parameters

In the tests, cutting tool with the symbol, SNUN120408 according to ISO made of P25 sintered carbide, was used. The tool holder was a CSDBM 2020-M12. The cutting experiments were conducted with a universal lathe. Used cutting tool geometry: tool rake angle $\gamma = -8^\circ$, tool cutting edge angle $\kappa_r = 70^\circ$, tool minor cutting edge angle $\kappa_r' = 20^\circ$, corner radius r_ε = 0.8 mm. The turning process was carried out with constant cutting depth of 0.5 mm and feed of 0.15 mm/rev and with three variable cutting speeds of v_{c1} = 250 m/min, v_{c2} = 350 m/min, v_{c3} = 450 m/min.

2.2. Material under machining

The material used in the experiment was AISI 1045 carbon steel. It is a ferritic–pearlitic steel whose structure and mechanical properties can be seen in Table 1. The material was provided in the form of bars with a diameter of 160 mm from an iron mill where it had been manufactured by hot rolling.

2.3. Cooling/lubricating conditions

During the tests, the following methods of cooling were applied: dry machining, MQCL and MQCL + additive extreme pressure/anti wear (EP/AW). Emulsion mist formation was effected with the use of the device, Micronizer LENOX 1LN Micro Unit. The micronizer is provided with a knob for emulsion and air flow adjustment. During calibration of the device, the range of emulsion mass flow was determined E = 1.4–100 g/h, while the volumetric air flow P = 1.2–5.8 l/min. In the tests, the following parameters were adopted: E = 26.4 g/h, P = 5.8 l/min and the nozzle distance from the cutting zone 0.3 m [20]. The emulsion mist was supplied to the cutting zone by two nozzles located at an angle of 30° in relation to the central nozzle. The diameter of the nozzles for the selected parameters of the emulsion mist formation was 1.2 mm.

In the MQCL method, the active medium was a concentrate of EMULGOL (chemical composition: C – 72.41%, H – 16.72%, O – 2.45%, Mg – 0.032%, S – 1.53%, K – 1.17%, Ca – 2.12%, P – 0.76%, Cu – 2.41%, Fe – 0.37%, Zn – 0.027%) emulsion based on highly refined mineral oil (7%) and water (93%). In the MQCL + EP/AW method, phosphorate ester, named CRODAFOS EHA-LQ-(MH) (chemical composition: P – 99.4%, Ca – 0.47%, Fe – 0.086%), was used as a modifier. The additive percentage in the active medium was 5%. In both cases, the active medium was made with the use of electromagnetic stirrer type ES21H.

2.4. Process measurement and analysis

Assessment of the cutting tool wear (maximum width of flank wear land VB_{max}) was made according to ISO 3685:1993 every 4 min. Preliminary research performed for each of the cooling methods demonstrated irregular wear in zone B. Therefore, maximum width of the flank wear land in the central portion of the active cutting edge has been adopted as wear criterion. Cutting tool wear tests have been carried out three times for each of the cooling methods, and the averages values of wear were calculated.