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Influence of oxygen on the tool wear in machining

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ABSTRACT

High temperatures generated in machining are known to facilitate oxidation wear. A controlled atmosphere chamber was developed to investigate the effects of oxygen on tool wear and high speed machining tests were conducted on air and in argon. Cemented carbide, cermet and cubic boron nitride tooling was used on alloyed steel, hardened tool steel and superalloy Alloy 718. Machining in argon resulted in higher flank wear, higher cutting forces, and larger tool–chip contact length on the rake face. However, in hard machining, argon atmosphere reduced rake cratering. Transmission electron microscopy of tools worn on air showed formation of nanocrystalline Al_2O_3 film on the rake when machining aluminium containing Alloy 718, while no oxide films was detectable in the other cases.

1. Introduction

Oxidation in machining is one of the mechanisms – alongside with abrasion, adhesion, and diffusion – which govern tool deterioration [1].

Investigation of the oxygen impact on the machining process requires the use of oxygen-free environment, such as in a vacuum or inert gas chamber [1–9]. Majority of studies address the issues of machining mechanics: cutting forces [2,3], tool–chip contact length [4,5], friction [4,6], build-up edge formation [2], and surface quality [2]. It was shown that the impact of the oxygen-free environment is defined by the tool-workpiece material pair. Machining of iron [2,5] and copper [3] in vacuum demonstrate an increase of forces and contact length, while machining of aluminium [6] results in decreased or invariable force and contact parameters for carbon steel, HSS and coated tooling.

The impact on tool wear, however, was given less attention. It was shown that the reduction of O_2 content results in the decrease of notch wear for cemented carbide tools [7,10]. Similar impact of the oxygen-free environment was found on the tool rake cratering in turning cooper [9] and milling stainless steel [8].

In this study, oxidation wear mechanism in high speed machining with cemented carbide, cermet, pcBN tooling and different workpiece materials was investigated.

2. Experimental work

The developed controlled environment chamber represents a steel box with gas curtain tubing in the upper part (Fig. 1a). Another gas supply circuit represents 3 secondary nozzles attached above and on the sides of a toolholder. Gas is also introduced into the cutting zone through 3 primary nozzles of PDJNL3225P15JETL (Seco Tools) high pressure jet holder (Fig. 1a and b). The curtain and secondary nozzles are connected to one gas flow regulator, while the primary nozzles to another regulator. Frontal box opening was covered with a safety glass for visual observation of the machining process. The lower part of the chamber has an opening for chip evacuation.

ARCAL Prime gas supplied by Air Liquide with the purity of argon 99.998% and content of $O_2 \leq 5$ ppm was used in the tests. Initial machining tests with a flow rate of 35 l/min and gas pressure of 1.8 bar through each set of nozzles has shown insufficient protection of the tool rake and the flank, similarly to Ref. [7]. Increase of the flow per nozzle set to 100 l/min at 3.2 bar prevented oxidation on the tool rake, however oxide deposit on the flank remained in the direct vicinity of the wear land. Only one nozzle supplies argon directly towards the flank while five nozzles and the curtain protect the rake. Further increase to 200 l/min at 4.7 bar ensured approx. 250 μm band of oxide free region on the flank (Fig. 1d). Therefore a total of 400 l/min, or one complete exchange of atmosphere in the controlled environment chamber every 0.15 s, was maintained during the machining tests in Ar. After disengagement the gas flow was kept for another 180 s to exclude tool oxidation during cooling. Machining on air was done under identical conditions, but using filtered compressed air, in order to assert similar gas circulation and cooling. It was shown [5] that the oxygen partial pressure of ≤1 mbar or ≤0.1% was sufficient for oxidation prevention in machining ferrous alloys, and therefore current setup is referred to as oxygen-free environment throughout the paper.

Machining was done at two cutting speeds, while depth of cut and feed were selected to ensure proper chip breaking and

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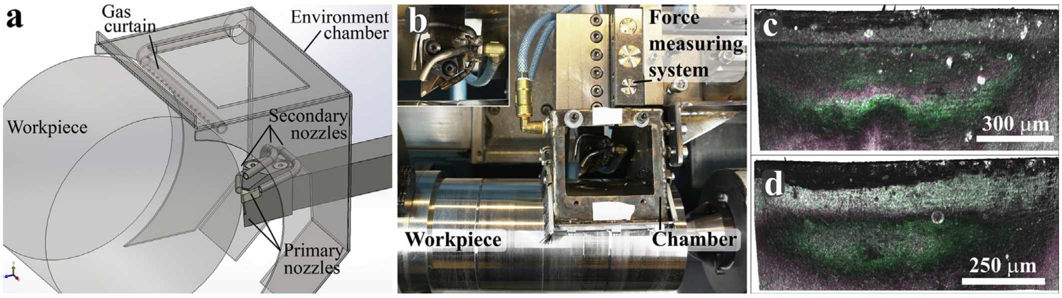

Fig. 1. (a) Schematic of the controlled environment chamber; (b) experimental setup when machining Alloy 718; oxide deposit on the flank of cemented carbide tool after 45 s machining (c) on air and (d) in argon.

Table 1
Experimental test array.

Tool material	Tool grade	Workpiece	v_c, m/min	f, mm/rev	a_p, mm	Gas
Cemented carbide	P10	34CrNiMo6	250, 280	0.35	1.00	Air, Ar
Cermet	210	34CrNiMo6	180, 200	0.30	1.00	Air, Ar
PCBN	CBN170	Alloy 718	300, 350	0.10	0.25	Air, Ar
PCBN	CBN010	Caldie	150, 200	0.05	0.25	Air, Ar

evacuation (Table 1). Wear of four tool material grades, including cemented carbide, cermet and pcBN, was investigated in machining alloyed steel, hardened cold work tool steel, and aged Alloy 718.

Optical microscopy and 3D reconstruction was performed on a Alicona InfiniteFocus. Scanning electron microscopy (SEM) was performed on a Tescan Mira3 equipped with field emission gun and Oxford EDX detector. Focus ion beam (FIB) lamella preparation was performed on a FEI Nova NanoLab 600 dual beam FIB/SEM. Standard *in-situ* lift-out procedure was employed where the lamellae were thinned to electron transparency (approx. 100 nm) using 10 kV Ga+ ions. Transmission electron microscopy (TEM) was performed on a JEOL 3000F equipped with field emission gun and Oxford EDX detector.

Uncoated P10 grade of cemented carbide was selected because it has been shown to have highest resistance to oxidation wear among the steel cutting grades [10]. Uncoated cermet with Ni–Co binder was also selected for its high resistance to oxidation [11]. CBN170 (Seco Tools) is a SiC whisker reinforced grade with 65 vol.% content of cBN and multi-modal grain size distribution specifically designed for machining superalloys. CBN010 (Seco Tools) is a signature grade with 50 vol.% content of cBN and TiC binder for finishing hard machining. All inserts were of ISO DNGA150608 type geometry. Cemented carbide and cermet have commercial chip-breakers. CBN010 has a chamfer with $b_\gamma = 0.1$ mm land and $\gamma_f = 20°$ angle. CBN170 has a flat rake.

3. Results and discussion

Fig. 2 shows the evolution of the cutting forces against flank wear (VB) for all machining cases. It can be seen that the influence of oxygen-free environment depends on the tool-workpiece material pair, as also reported in Ref. [3]. Strongest impact was found in machining with cemented carbide where argon environment resulted in an increase of F_c force by ≈15% and by ≈25% for feed F_f and passive F_p forces. In machining with cermet only the cutting force component F_c was increased by ≈10% (Fig. 2b). In machining Alloy 718 force data are inconclusive, because an additional mechanism of notching and premature edge failure (Fig. 7) dominates forces more than the environment.

Williams and Tabor [5] attributes the increase of forces in the oxygen-free environment to disappearance of slip zone and expansion of stick zone over the entire tool–chip contact, also observed in this study (Fig. 8c). This is also accompanied by larger contact length [2,3,5]. Application of commercial chip-breakers in our study creates restriction to a contact zone, thus limiting force increase only to stick zone effect.

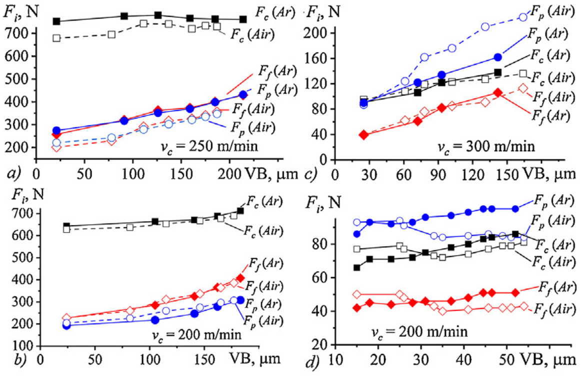

Fig. 2. Development of cutting forces with tool wear for (a) cemented carbide, (b) cermet, (c) CBN170, and (d) CBN010.

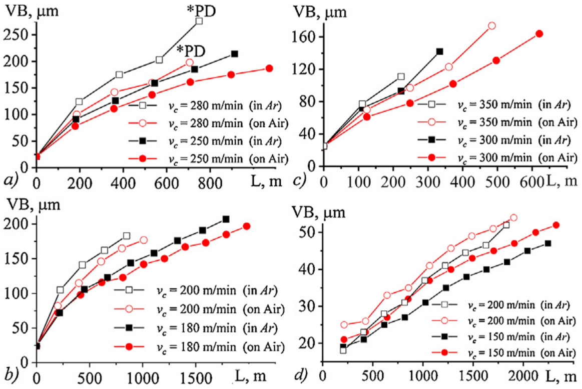

Fig. 3. Development of tool wear when machining on air and in argon by (a) cemented carbide, (b) cermet, (c) CBN170, and (d) CBN010. *PD stands for plastic deformation.

Fig. 3 shows the development of the flank wear land VB with the tool travel distance when machining on air and in argon. It can be seen that flank wear is more intensive in all cases when machining in argon, as compared to the air case. The same effect was consistently observed for both levels of cutting speed, implying that contribution of oxidation might be similar, as all tests are in the high-speed machining range.

Although the impact on rake face cratering was found to be pronounced when machining in oxygen-free environments [8,9], the impact on the flank wear has not been previously reported. In our cases of machining 34CrNiMo6 steel, cratering was suppressed by non-metallic inclusions in material microstructure, thus enabling to assess effects on flank wear.

The observed expansion of stick zone when machining in argon (Fig. 8c) is expected to aggravate secondary deformation in the flow zone [12]. This will lead to more intensive and localized heat source at the tool–chip interface [1]. Therefore an increased process temperature can be expected in these cases, thus explaining the observed intensification of flank wear when machining in oxygen-free environment. However, in the case of hard machining with CBN010, the contribution of oxidation wear

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