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Wear of ceramic tools in hard machining

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Materials

ABSTRACT

Purpose: The principle purpose of this investigation is to recognize the wear phenomenon of the mixed ceramic tips against 60 HRC alloy steel specimens in dry and hard turning operations. This knowledge allows optimal machining chains to be planned by the manufacturing engineers.
Design/methodology/approach: Light optical microscopy (LOM), scanning electron microscopy (SEM), BSE technique and X-ray diffraction analysis (XRM) were applied for observations of worn tool surfaces, wear products and the distinction of wear mechanisms occurring.
Findings: It was found that wear mechanisms observed in the machining tests involve abrasion, fracture, plastic flow, material transfer and tribochemical effects which appear depending on the mechanical and thermal conditions generated on the wear zones.
Research limitations/implications: Investigations were performed under varying feed rate, constant cutting speed of 100 m/min and small depth of cut of 0.2 mm to perform finishing cuts.
Practical implications: In this study both microscopic and microstructural aspects of ceramic tool wear were taken into consideration. Moreover, the development of the crater and flank wear and the associated wear mechanisms were identified.
Originality/value: In particular, two types of transfer layer formation with different morphologies occurring at the rake-chip interface are distinguished.
Keywords: Ceramics and glasses; Wear resistance; Hard machining; Tool wear; Wear mechanisms

1. Introduction

In recent years, hard machining (HM) of steel parts hardened to about 60 HRC performed by both mixed ceramic and CBN tools became very popular and effective technology replacing successively grinding operations, traditionally used in many mass-production manufacturing processes [1-4]. Hard machining can be performed in several typical machining operations, especially in turning, milling, drilling, threading and broaching operations.

Unfortunately, extreme tribological conditions developing at dry severe friction and high tool-chip and work-flank interface temperatures tend towards the acceleration of tool wear, and as a consequence to relatively fast deterioration of surface finish and dimensional and shape accuracy. Today, research activities in HM sector are primarily focused on CBN tool wear (the predominantly used tool material) [5-7]. Oppositely, new data on turning hardened AISI 5140 and 100Cr6 bearing steels using ceramic tools are reported in Refs. [8] and [9]. In general, alumina-based ceramic tools are regularly (persistently) used by metal cutting sector because of high hot hardness up to 1300-1500 ^{0}C, abrasive resistance and chemical stability. It is noted [10] that in machining steels with alumina-based ceramics, wear of the flank and rake faces was controlled by a thermally activated brittle fracture and a relatively thermal plastic flow mechanisms respectively. According to Hutchings [11], local plastic flow and brittle fracture can occur between ceramics and metals in sliding wear. Additionally, tribochemical reactions can modify the sliding interface which, in turn, can lead to the formation of transfer films.

A comprehensive survey of the typical wear mechanisms observed in two ceramic cutting tools (alumina-based and silicon nitride-based tools) including abrasive, adhesive, tribochemical and wear by fracture was done by Stachowiak et al. [12]. It was revealed in this study that alumina–based ceramics containing TiC or TiN compounds is more susceptible to additional chemical reactions in cutting ferrous alloys which tend towards higher crater wear by solution.

Additionally, it is concluded [13,14] that notch wear mostly occurred in machining hard materials using ceramic tool materials with low toughness. Generally, the wear scars produced by notch wear are rough and the depth of notch wear progresses with the increase of cutting speed while saw type chips are visibly formed.

Due to promising results regarding obtainable surface finish and acceptable tool life, the author examines the wear progress and appropriate wear mechanisms occurring in different zones on the mixed ceramic inserts used in conjunction with a low chromium alloy steel of 60 HRC hardness. This steel is frequently used by constructors for many highly and cyclically loaded machine parts.

2. Wear testing and analyzing procedures

2.1. Machining conditions

In this investigation, mixed ceramic hard turning (MC HT) tests at defined cutting time were performed on a high rigidity conventional lathe. Bars of a low chromium alloy steel equivalent to AISI 5140 (DIN 41Cr4) hardened by quenching to 60±1 HRC were used. They were 150 mm long with an external diameter of 75 mm. The cutting tool material was Sandvik CC650 mixed alumina containing 71% Al_2O_3, 28% TiC and 1% other. Conventional SNGN 120408 T01020 ISO insert configurations were used.

The cutting conditions used during machining operations are: constant cutting speed of 100 m/min, 0.2 mm depth of cut were kept similarly to previous author's reports [15,16]. In general, wear tests were performed during 15 min. On the whole, three worn areas of the ceramic tips localized on the rake face, within the tool corner and the secondary flank face were examined. In each trial, the VBC wear indicator on the tool corner was measured after every 3.5 min.

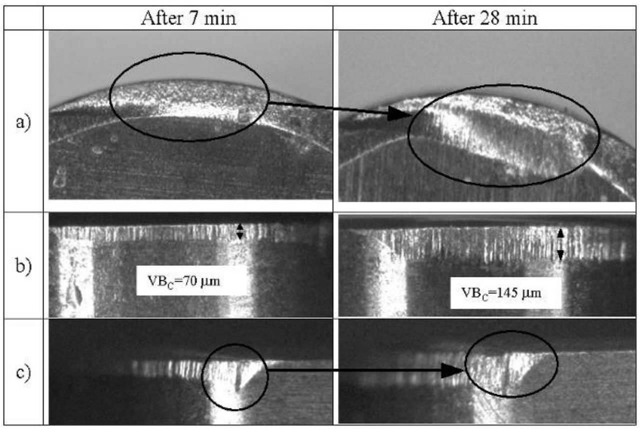


Fig. 1. Wear effects observed for conventional insert on rake face (a) corner (b) secondary flank face (c) for f=0.1 mm/rev. Magnification-20x

2.2. Microscopic and microstructual analyses

First of all, an Olympus PME3 optical microscope equipped with a high-resolution digital camera was employed to examine worn surfaces of the ceramic inserts and for localisation of the predominant wear regions. The selected wear scars formed on the contact surfaces of the inserts were visualised and digitalised and were stored in a PC computer. Investigations of the material structure and chemical composition in selected micro-areas of the worn surfaces were performed on a scanning electron microscope (Philips XL 20) equipped with an energy dispersive analyser of X-ray (EDAX). In this series of analyses the acceleration voltage of 20 kV and a variety of magnification ranging from 17x to 4000x was selected. A part of observations was performed using the so-called "z" contrast creating by means of the BSE (Back Scattering Electron) technique.

3. Results and discussions

3.1. Macroscopic characterization of tool wear

Fig. 1 integrally illustrates the images of the rake faces (a), corners (b) and secondary flank (c) surfaces after first 7 min of cutting time and their final states after 28 min of HT tests for conventional ceramic tips. As shown in Fig. 1 visible wear effects on the all of the three parts of the tool occur after first 7 min of cutting duration and they progress successively up to the end of natural wear tests. Extensive wear of rake face occurring non-uniformly on the chamfer is more concentrated in the vicinity of the secondary cutting edge. Moreover, worn zone is extended below the cutting edge causing the creation of a characteristic deep triangular groove adjacent to the corner (Fig. 1c), named as notch wear. A number of smaller grooves in the area of tool corner is observed.

In addition, the high temperature of visibly above 1000^0C generated during hard machining can facilitate the material plastification and hence cause a remarkable increase of material side flow. Local damages of ceramics and probably plastically-deformed work material smeared on the tool due to extremely high mechanical and thermal loads were observed. One of the experimental evidence of the wear mode reported is that highly-heated red chips were produced.

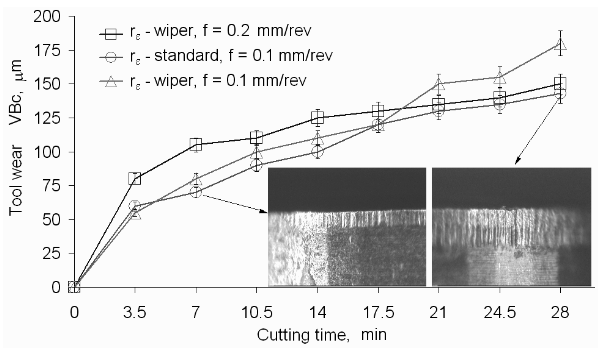


Fig. 2. Corner wear indicator VB_C *versus* cutting time for conventional and wiper ceramic inserts

The records of VBC tool wear indicator obtained during natural wear tests for both tool geometries used are shown in Fig. 2. It is shown in Fig. 2 that comparable values of tool corner wear and similar tool wear curves were recorded for both tips and the same feed rate of 0.1 mm/rev up to 17.5 mm of the test time, i.e. roughly for commonly used tool life of 15 min. On the other hand, after this time wiper tools working with double feed rate of 0.21 mm/rev indicated similar wear behaviour to single-rounded inserts. It is worth noticing that in all cases the shapes of recorded wear curves fit well the well-known Lorentz's wear curve [17] with characteristic first running-in period and than slower wear rate at the second part of test.

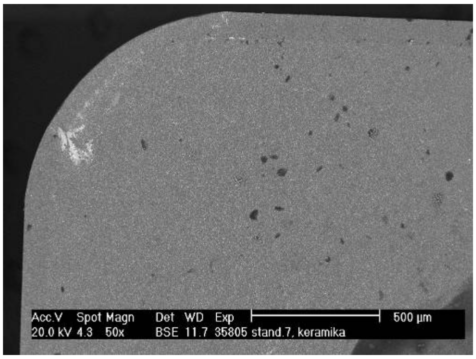
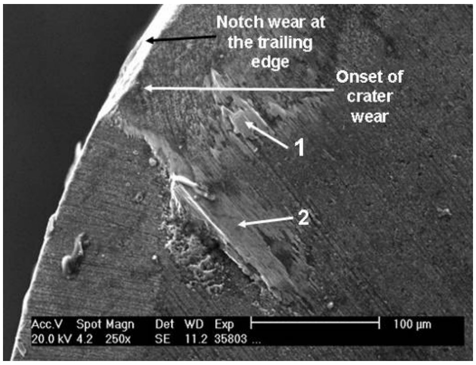


Fig. 3. Rake face with fragmentary transferred workpiece material occurring after 7 min wear test

a)



b)

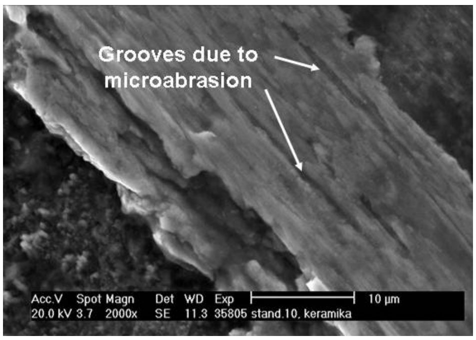


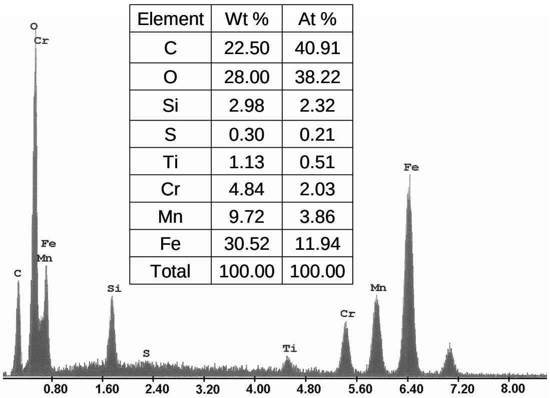
Fig. 4. Morphology of developed transfer layer on the rake face. SME (a) and BSE (b) micrographs

3.2. Wear symptoms on the rake face

The rake face along with the chamfer after running-in process taking about 7 min (first part of wear curve) is shown in Fig. 3 as exposition # 35805.

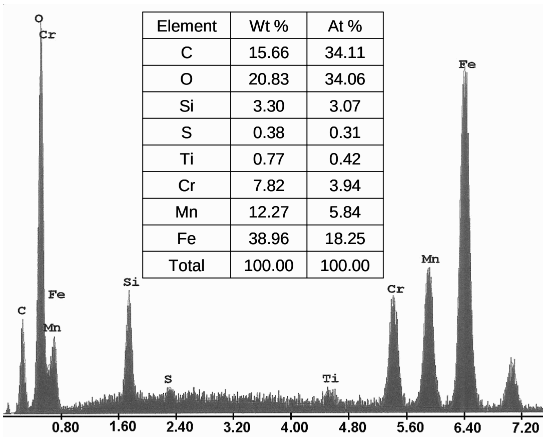
Bright dispersed areas adjacent to the cutting edge were recognized as agglomerated particles of the transferred workpiece material, whereas local dark dots can be defined as organic contaminations emerged in the final step of machining. SME image shown in Fig. 4a clearly depicts the smearing mechanism of transfer film formation, whereas BSE equivalent shows that the smeared material has a greater density than the mixed ceramics. It should also be noticed that the transferred steel material yields severe plastic deformation along the chip flow direction (Fig. 4b).

a)



Element	Wt %	At %
C	22.50	40.91
O	28.00	38.22
Si	2.98	2.32
S	0.30	0.21
Ti	1.13	0.51
Cr	4.84	2.03
Mn	9.72	3.86
Fe	30.52	11.94
Total	100.00	100.00

b)



Element	Wt %	At %
C	15.66	34.11
O	20.83	34.06
Si	3.30	3.07
S	0.38	0.31
Ti	0.77	0.42
Cr	7.82	3.94
Mn	12.27	5.84
Fe	38.96	18.25
Total	100.00	100.00

Fig. 5. MRX spectra for the transferred material in points 1 (a) and 2 (b) from Fig. 4a

It was revealed, based on the MRX spectrum (Fig. 5a) for the selected point 1 in Fig. 4a within the adhered plasticized material, that despite high content of oxygen and carbon also such elements as Fe, Mn, Cr, Si and S and Ti, typical for steels, existOn the other hand, in that thicker layer occurring in point 2 in Fig. 4a substantially lesser concentration of Cr, Mn and Fe, and also less amount of C and O was observed, as presented in adequate spectrum in Fig. 5b. Moreover, thinner deposited layer can be exposed to higher heating and as a consequence oxides can be formed (higher content of oxygen of 38 at. %). In particular, the lack of aluminum in spectra shown in Figs. 5a and b suggests that the smeared layer are formed rather from oxides of Fe, Cr and Si and manganese sulfide (MnS). In consequence, two different mechanism of transfer layer formation were revealed, namely:

1. microabrasion and oxidation of steel components resulting in small dispersed patches, and
2. smearing of soft manganese sulfides causing the formation of concentrated lumps.

4. Conclusions

1. In finish MC HT wear of tool flank faces are mainly concentrated on the tool corner and the active secondary cutting (trailing) edge.
2. In general, wear mechanisms in Al_2O_3- TiC ceramics sliding against the hardened low alloyed steel involve abrasion, fracture, plastic flow, adhesive tacking and material transfer and also tribochemical effects depending on the mechanical and thermal conditions generated in the machining tests.
3. The transferred steel layers on the rake face of conventional ceramic insert are formed by smearing from oxides of Fe, Cr and Si and manganese sulfide (MnS). In particular, smearing of soft manganese sulfides causes the formation of concentrated lumps.

References

[1] H.K. Tönshoff, C. Arendt, Amor R. Ben, Cutting of hardened steel, CIRP Annals 49/2 (2000) 547-566.

[2] G. Byrne, D. Dornfeld, B. Denkena, Advancing cutting technology, CIRP Annals 52/2 (2003) 483-507.

[3] W. König, A. Berktold, K.F. Koch, Turning versus grinding-a comparison of surface integrity aspects and attainable accuracies, CIRP Annals 42/1 (1993) 39-43.

[4] F. Klocke, E. Brinksmeier, K. Weinert, Capability profile of hard cutting and grinding processes, CIRP Annals 54/2 (2005) 557-580.

[5] K.Y. Chou, J.Ch. Evans, M.M. Barash, Experimental investigation on CBN turning of hardened AISI 52100 steel, Journal of Materials Processing Technology 124 (2002) 274-283.

[6] Y.K. Chou, Ch.J. Evans, Tool wear mechanism in continuous cutting of hardened tool steels, Wear 212 (1997) 59-65.

[7] Y.K. Chou, Hard turning of M50 steel with different microstructures in continuous and intermittent cutting, Wear 255 (2003) 1388-1394.

[8] W. Grzesik, T. Wanat, Hard turning of quenched alloy steel parts using conventional and wiper ceramic inserts. International Journal of Machine Tools and Manufacture 46 (2006) 1988-1995.

[9] G.C. Benga, A.M. Abrão, Turning of hardened 100Cr6 bearing steel with ceramic and PCBN cutting tools, Journal of Materials Processing Technology 143-144 (2003) 237-241.

[10] H. Xiao, Wear behaviour and wear mechanism of ceramic tools in machining hardened alloy steel, Wear 139 (1990) 439-451.

[11] I.M. Hutchings, Tribology. Friction and wear of engineering materials, Edward Arnold, London, 1992.

[12] G.W. Stachowiak, G.B. Stachowiak, Wear behaviour of ceramic cutting tools, Key Engineering Materials 96 (1994) 137-164.

[13] A.S. Kumar, A.R. Durai, T. Sornakumar, Wear behaviour of alumina based ceramic cutting tools on machining steels, Tribology International 39 (2006) 191-197.

[14] D. Pakuła, L.A. Dobrzański, Investigation of the structure and properties of PVD and CVD coatings deposited on the Si_3N_4 nitride ceramics, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 79-82.

[15] W. Grzesik, T. Wanat, Comparative assessment of surface roughness produced by hard machining with mixed ceramic tools including 2D and 3D analysis, Journal of Materials Processing Technology 169 (2005) 364-371.

[16] W. Grzesik, T. Wanat, Hard turning of quenched alloy steel parts using conventional and wiper ceramic inserts, International Journal of Machine Tools and Manufacture 46 (2006) 1988-1995.

[17] G. Bothroyd, W.A. Knight, Fundamentals of machining and machine tools, Marcel Dekker, New York, 1989.