IOP Conf. Series: Materials Science and Engineering **382** (2018) 032052 doi:10.1088/1757-899X/382/3/032052

Electrolytic Abrasive Edge Honing of Cemented Carbide Cutting Tools

Li Zhuyu[1], Wang Hongyang[1], Su Haoyang[2], Zhang Wei[1]

[1]School of Mechanical Engineering and Automation, Dalian Polytechnic University, Dalian 116034, China

[2]Zhejiang Jingong Technology Inc., Shaoxing 312030, China

Corresponding author's e-mail address: li_zy@dlpu.edu.cn (Li Zhuyu)

Abstract. The traditional mechanical cutting edge honing has some disadvantages, such as low efficiency and edge profile irregularities. Based on the phenomenon of rapid erosion on sharp corners by electrolysis and flowing abrasive to remove the oxide films, an innovative electro-abrasive honing process on the cemented carbide cutting edge is proposed. An accurate rounded contour is formed to enhance the edge strength. There are little micro-chipping or grinding traces observed near the cutting edge after honing. The surface roughness decreases from Ra0.31 to Ra0.14 inspected by white light interferometer (WLI). However, some micron-grade craters appreciably extend further into the rake/flank faces. The Co content decreases from 5.8% to 0.6% detected inside the corrosion craters by energy dispersive spectrometer (EDS). It demonstrates that the microstructure of corrosion crater is formed in the high-grade Co areas because Co has a lower electrode potential than W. Some impurity elements K, Cl, Na and N, detected in the micro craters, are estimated as the residual of electrolytes. The results of the honed surface element data show that only W, C and no oxides appear. It is verified that to remove oxide films by the electro-abrasive process is feasible.

1. Introduction

Cemented carbide, characterized by high hardness, strength and wear resistance, has been widely used in cutting tools manufacturing. However, its impact toughness is lower than high speed steel (HSS) and the micro-chipping is often generated on the edge even after a fine grinding [1]. In recent years, cutting edge honing has been universally recognized as one of the critical finishing processes in cemented carbide tools production [2-6]. It can eliminate the microstructure chipping, cracks and strength the cutting edge by honing a chamfer with the order of several tens of micrometers [7]. Several cutting edge preparation techniques, e.g. brushing, abrasive stirring have been utilized, but the preparation is still difficult to form a regular contour by material uniform removal with these mechanical treatments [8,9]. Many performance tests [10-12] have shown that the cutting edge radius has a considerable influence on the cutting force, temperatures, tool wear, etc. If the honed size or shape is not appropriate, it will increase the cutting force and the incidence of edge collapse or severe wear in the early cutting stage.

Koehler investigated the variations of cutting edge shape and profile for twist drill that affect the distribution of the cutting force components. Uhlmann [13] used abrasive stirring method to hone the milling tools with radius of 4μm / 8μm rounded edge. In comparison to unprepared end mills, the maximum width of flank wear land could be reduced by 14 %. In order to improve the machining efficiency, some new methods, for example, the abrasive water jet blasting [9], magnetic polishing [14,15]and laser [16] were used. But, the edge radius variability could be as high as 40% along the same edge. Yussefian [17] proposed a novel edge honing process that employs electrical discharge machining (EDM) to decrease the generated edge variability. Further research employed a foil electrode as the counterface to hone the carbide inserts with the intricate geometric features [18]. It indicates that the abrasive hybrid machining process is superior and effective to generate the controlled round edges.

This paper presents a non-contact edge preparation method that electrolytic combined with abrasive machining. It is based on the well-known phenomenon that sharp edges inevitable are rapidly eroded to be round in the electrochemical condition. At the same time a passive film was formed, that is an insoluble film of oxide on the electrode to protect the metal and prevent further dissolution. A simple and low-cost solution employs the flowing abrasive with the electrolyte to remove the oxide films successively.

Since there are no cutting forces and thermal damage acting on the tool, surface integrity will be maintained without stress and burr [19]. Through the degree of ion removal, there is no cold hardening and no cutting traces. It is a stable and efficient process verified by the following experiments.

2. The cutting edge electrolytic abrasive honing

A schematic view of the various elements present in the electrolytic abrasive honing equipment is shown in figure 1. A carbide blank with a straight cutting edge was fixed on the moving table. The anode is the blank and the cathode is a brass spray nozzle. The blank can be moved horizontally when honing. The abrasive with the pressure electrolyte is flowing out onto the carbide tool's edge from the spray nozzle. A pump supplies the continuous pressure. The operation process is shown below:

(1) To fix the carbide tools on the table. The cutting edge must be horizontal and parallel to the end side of the nozzle. A constant equilibrium gap between the anode and the cathode needs to be aligned before honing.

(2) After the pump is turned on, the electrolyte solution with abrasive is flowing out. The workpiece is controlled by a step motor to move uniformly along *Y*-axis. The radius of the cutting edge is dependent on the processing time adjusted by the speed of the workpiece feeding.

IOP Conf. Series: Materials Science and Engineering **382** (2018) 032052 doi:10.1088/1757-899X/382/3/032052

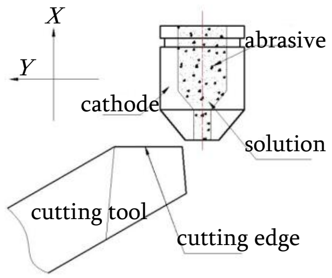


Figure 1. Schematic representation of electro-abrasive edge honing

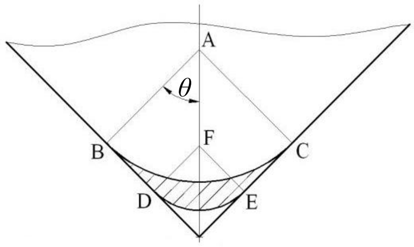


Figure 2. Concept and calculation of removal ratio

3. The removal rate calculation

The modeling removal rate to shape a round profile is set below:

In figure 2, θ is the half wedge angle between line OA and OB. The length of the unprepared edge radius DF is R_1 and after honing the edge radius OB is changed to be R_2. The shadow squares are the total removal materials:

$$S_1 = (R_2^2 - R_1^2) \cdot (\tan\theta - \theta) \quad (1)$$

The volumes of the total removal are:

$$V = S_1 \cdot L = (R_2^2 - R_1^2) \cdot (\tan\theta - \theta) \cdot L \quad (2)$$

L is the length of cutting edge.

4. Experimental setup

Solid carbide blank K10 with chamfer angle 90° has a straight cutting edge. Its diameter is 10mm. Its physic mechanics performance is shown in Table 1.

The grain size of Al_2O_3 abrasive is W20; the concentration of electrolyte solution is 15%; the electrolyte voltage is 12V; The pressure of electrolyte is 1MPa; the volume of solution is 5L/min; honing time is 15seconds; the gap between the anode and the cathode is 0.4mm; the electrolyte formula is $NaNO_2$(3.8%), Na_2HPO_4(1.4%),$Na_2B_4O_7$(0.3%),$NaNO_3$(0.3%),H_2O(94.2%)

Table.1 Physical mechanics performance of K10 carbide

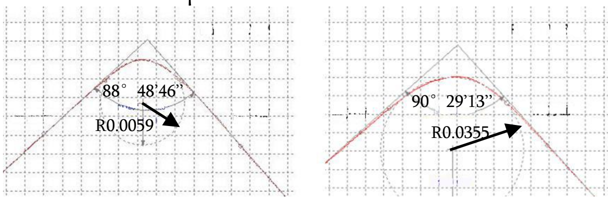
Average grain size /μm	WC /%	Co /%	Hardness /HRA	Transverse rupture strength /MPa
0.8	94	6	94	3585

5. Experiment of honing

Experiments are conducted on a modified lathe. Its X-axis is manual feed and Y-axis is a step motor servo drive. The abrasive are stirred with the electrolyte solution, so the pump must be equipped with filter. After electrolyte honing, all of the electrolyte solution flow back to the electrolytic tank. Pump must work last more than1 minute to brush all the components in the circuit.

5.1 Contrast of edge morphology before and after honing

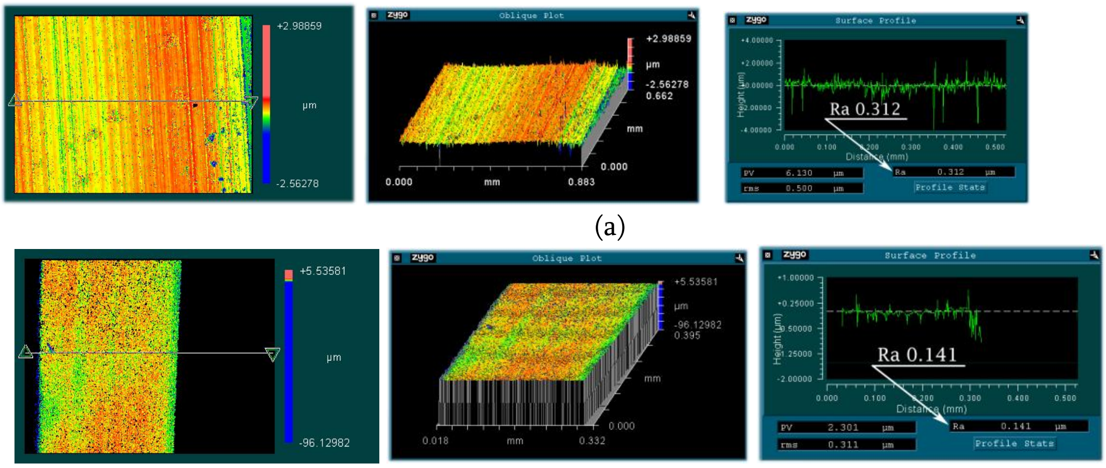
The micro morphology of the cutting tools surface after honed is analyzed by MMD-100B profilometer, for an edge with a nominal radius of 30μm. While the processing time is adjusted from 5 to 15 seconds, the removal material is going up steadily. After 15 seconds, the removal ratio is descendent. The radius of the honed round edge is 35.5μm (figure 3b), in comparison to unprepared of 5.9μm (figure 3a). When honing on the threshold time of 15 seconds, the maximum deviation of measured radius values is 5.5μm.



(a) (b)

Figure 3. Profile of the cutting edge

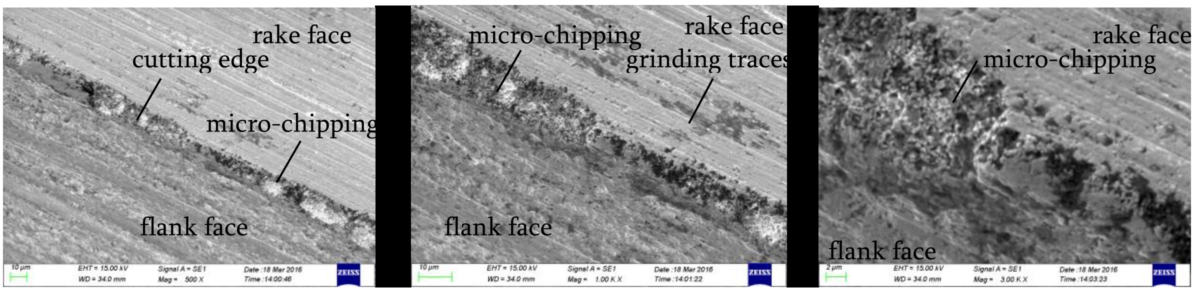
The surface roughness of the cutting edge was measured by New view-7100 profilometer, made by ZYGO company with white light interferometer (WLI). Its surface roughness is measured to decease from Ra 0.31 unprepared (figure 4a) to Ra0.14 after honed (figure 4b).



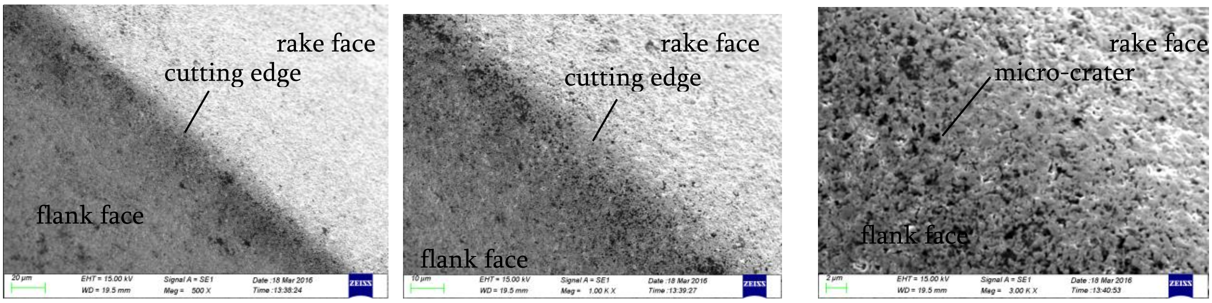
(a)

(b)

Figure 4. Morphology of electro-abrasive honed and unprepared cutting edge



(a) (b) (c)



(d) (e) (f)

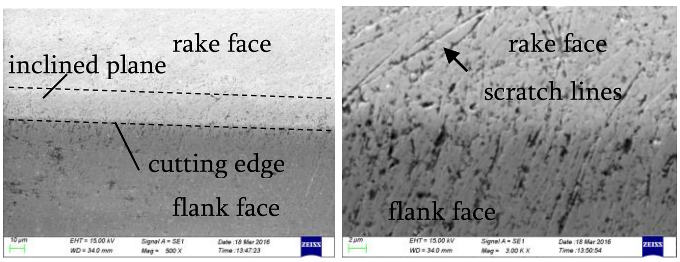
Figure 5. SEM micrograph of electro-abrasive honed and unprepared cutting edge

Figure 5a and d are scanning electron micrographs (500X) of unprepared (ground) and electro-abrasive honed cutting edges, respectively. A topography that is characteristic of EDM surfaces can be seen along the cutting edge in figure 5e (1000X) and figure 5f (3000X). Micro-chippings along the unprepared cutting edge are intermittently present to reveal the edge uneven. Grinding traces by abrasive scratching can be seen on the rake and flank faces before preparation. After honing, the cutting edge surface is smoother in comparison to the corresponding unprepared one. The surface integrity improvement demonstrates that the surface can be polished by the electro-abrasive honing method.

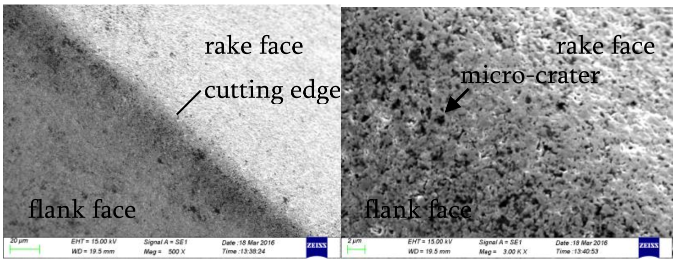
5.2 Comparison of edge morphology between electro-abrasive and brush honing

The electro-abrasive honing is compared with the traditional brush honing. A carbide blank sample is honed by brush with the setting parameters: total brushing time 43seconds (including 25 seconds clockwise rotation and 18 seconds anticlockwise rotation), brush cover depth 4mm.

Figure 6a and c are scanning electron micrographs (500X) of brushed and electro-abrasive honed cutting edges. The micro-chipping can not be seen on the brushed edge but its shape of brushed edge is approximate to a plane chatter of 15μm width. This width is larger than the micro-chipping width about 2μm. It indicates that the size of initial cracks will be fabricated to entail the shape of honed edge by brush processing. However, the electro-abrasive honed edge size is independent of its unprepared original conditions, due to the sharp corners rapidly degeneration by electro-erosion.

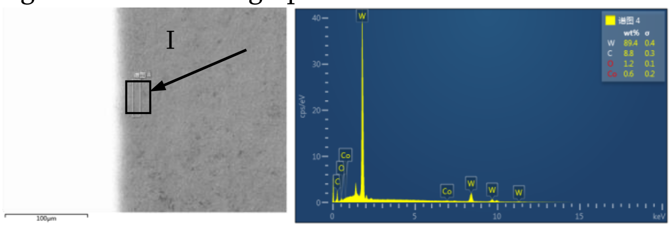


(a) (b)

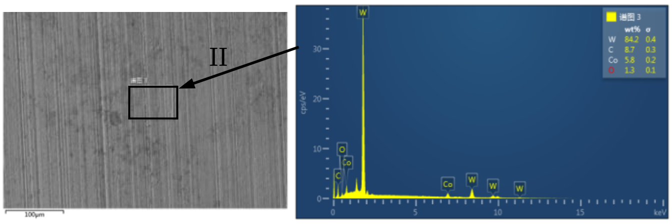


(c) (d)

Figure 6. SEM micrograph of brush honed and electro-abrasive honed cutting edge



(a)



(b)

Figure 7. EDS analysis of electro-abrasive honed and unprepared cutting edge

5.3 Analysis of micro-crater on the electro-abrasive honed surface

The topography generated between the electro-abrasive and brush processing displays that many micro-craters scatter near the cutting edge. On brushed surface (figure 6b), these micro-craters are accompanied with many chaotic scratch lines. It is the abrasive action by fine grits in the brush. Nevertheless, on the electro-abrasive honed surface (figure 6d), micro-craters with the radius of less than 1μm are smaller than that of by brush. The reason is that the electrode potential of Co is lower than that of W and C. In the high-grade Co regions, Co is prior to be ionized to form the micro-craters on the surface.

In order to identify this notion, the honed surface is inspected by energy dispersive spectrometer (EDS). As shown in figure 7a, sample of region I picked on the cutting edge represent the electro-abrasive honed surface; in the same blank, sample of region II picked far from the cutting edge are unprepared surface. The results show that the Co content in region II is 5.8%. After electro-abrasive honing, the Co content in region I is reduced to be only 0.6%. It shows that region I is the corrosion area.

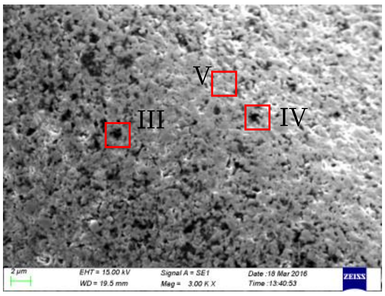


Figure 8. Sampling points of EDS analysis

As shown in Fig.7, O exits simultaneously in the region I and II, nearly with the same element content. In this light, the hypothesis of oxide can be precluded. To analysis all the elements of electrolyte solutions, one of the possibility that O mess in is the condensate water vapor formed on the surface when cleaning by the ethanol.

In order to elucidate the mechanism of the micro-craters formation, the analysis of elements and its content change are monitored on 3000X SEM. As shown in Fig.8, region III and region IV are picked randomly into the micro-craters after electro-abrasive honing, and region V picked on the surface near the cutting edge. The elements analysis results are shown in Table 2 by EDS. The “X” in Table 2 represents the element does not exist and the underline numbers represent the unidentified elements in the system.

Table.2 Chemical composition detected on cutting edge surface and in micro crater %

Item	N	Na	K	Cl	O	Co	C	W
III	3.8	0.6	1.1	1.4	1.0	0.9	19.1	72.1
IV	X	X	1.1	1.0	2.5	X	18.9	76.5
V	X	X	X	X	X	X	19.5	80.5

In the region V, there are only two elements, W and C, detected on the electro-abrasive honed surface. It is the single phase of WC. There are many kinds of elements found in region III and IV. In addition to the W, C and Co, inherent carbide elements, there are still O, K, Cl, Na, N detected on the electro-abrasive honed surface. These results, however, do not rule out whether O is oxide or nitrate. It is evident that K, Cl, Na and N are all impurity elements. It may be the electrolyte residues in the micro-craters. Na and N are both originated from sodium nitrate and sodium nitrite. All theses electrolyte was configured to be analytical pure (AR), most of them contain a certain amount of chloride and potassium ions.

By EDS analysis of micro-craters to unprepared tool surfaces, many elements are detected in the craters. It indicates that a cleaning process should be added after the electro-abrasive honing. As the surface of the tool are detected with only W, C and no other elements, it is verified to be feasible that abrasive in the electrolyte remove the oxide film during the process.

The micro-craters on the electro-abrasive honed surface are much smaller than the defects that are generated by brushing process. The impact of its eroded depth on the performance attracts considerable attention. Some research [20-21] showed that the corrosion microstructure has a great influence on the function and performance of the cutting tools. The electro-erosion mechanism can be roughly classified into two categories. Firstly, if the preferentially corrosion phase has a united microstructure, the phase will accelerate corrosion to form a continuous network. It will lead a catastrophic failure for the engineering components. On the contrary, if the phase is finely divided, the local corrosion areas fall off to form the cavities on the surfaces [20].

Cemented carbide is a metal matrix composite where the primary tungsten carbide particles are the aggregate and metallic cobalt servers as the matrix. After the isolated Co areas are eroded, it can not continue erosion into the deeper layer. With a short duration of processing time, the oxide films are removed by flowing abrasive solutions. The WC phase is exposed on the surface again. The micro-craters are superficial and the WC phase is not stripped. It will minimize the adverse effects with an appropriate selection of the processing time and electrolysis gap.

Further work will focus on the performance tests of tool life and the integrity of the machined surface honing by this electro-abrasive honed cutting tools.

6. Conclusions

A novel process of using electrolysis hybrid abrasive method for edge honing has been established. It is identified to generate the rounded edge honing in cemented carbide tools. The honed surface roughness is reduced from Ra0.31 to Ra0.14 compared with that of unprepared edge. However, some micro-craters scatter near the edge. The content of Co element in the micro-craters decreases greatly. It indicates that most of Co is ionized. The reason of the formation of micro-craters is that Co is prior to be ionized in the cobalt rich area. More performance experiments, concerned to the tool life and the integrity of the machined surface, are needed to assess the validity of the proposed method.

Acknowledgements

The authors would like to acknowledge the financial support by the General Project of Liaoning Province Education Department (L2015046).

References

[1] Dearnley P A and Trent E M 1982 *Met. Sci. J.* **9** 60-75
[2] Fulemova J and Janda Z 2014 *Procedia Eng.* **69** 565-73
[3] Özel T 2003 *J. Mater. Process. Tech.* **141** 284-93
[4] Coelho R T, Silva L R, Jr A B, Bezerra A A 2004 *J. Mater. Process. Tech.* **148** 147-53
[5] Ridgway K, Hughes J I, Sharman A R C 2004 *Proc. Inst. Mech. Eng., Part B.* **218** 1113-23
[6] Yussefian N Z and Koshy P 2013 *Precis. Eng.* **37** 746-52
[7] Denkena B, Köhler J, Ventura C E H 2013 *Precis. Eng.* **37** 590-98
[8] Priarone P C, Rizzuti S, Settineri L, Vergnano G 2012 *J. Mater. Process. Tech.* **212** 2619-28
[9] Rodríguez C 2009 *Cutting edge preparation of precision cutting tools by applying micro-abrasive jet machining and brushing* (Kassel: Kassel University Press) p 46
[10] Çelebi C, Özlü E, Budak E 2013 *Procedia Cirp.* **8** 194-9
[11] Beaucamp A, Namba Y, Messelink W, Walker D, Charlton P, Freeman R 2014 *Procedia Cirp.* **13** 377-81
[12] Biermann D and Terwey I 2009 *CIRP-J.M.S.T.* 176-80
[13] Uhlmann E, Oberschmidt D, Kuche Y, Löwenstein A 2014 *Procedia Cirp.* **14** 349-54
[14] Cheung F Y, Zhou Z F, Geddam A, Li K Y 2008 *J. Mater. Process. Tech.* **208** 196-204
[15] Karpuschewski B, Byelyayev O, Maiboroda V S 2009 *CIRP Ann-Manuf. Techn.* **58** 295-8
[16] Aurich J C, Zimmermann M, Leitz L 2011 *Product. Eng.* **5** 17-24
[17] Yussefian N Z and Koshy P 2013 *J. Mater. Process. Tech.* **213**:434-43

[18] Yussefian N Z, Koshy P, Buchholz S, Klocke F 2010 *CIRP Ann-Manuf. Techn.* **59** 215-8
[19] Masuzawa T and Kimura M 1991 *CIRP Ann-Manuf. Techn.* **40** 199-202
[20] Kangdao, Takahiro, Tsunoda, Ikuo, Shohji, Kotaro 2016 *Acta Metall Sin-Engl.* **29** 1-10
[21] Shi K, Tsunoda T, Kusumoto K, Shohji I, Matsu K, Taguchi Y 2016 *J. Smart Process.* **4** 247-53