Application of foil electrodes for electro-erosion edge honing of complex-shaped carbide inserts

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Abstract

Electro-erosion honing is a novel process that exploits the undesirable but inevitable phenomenon of localized electrode wear in sink electrical discharge machining that rapidly rounds off sharp edges, for the edge honing of cutting tools. The process essentially entails the sinking of a sharp edge of a cutting tool into a counterface of an appropriate material to generate the round edge geometry. This paper proposes the innovative application of a foil counterface, with a view to expanding the capability of this process in the honing of tools with such geometric features as nose radii and curved edges. Such a configuration involves no particular alignment requirements, and facilitates the simultaneous processing of a batch of inserts. In consideration of their industrial significance, the process is evaluated in the honing of cemented carbide inserts. The novel process is demonstrated to address the limitation of the conventional brush honing process in being capable of generating consistent edge geometry, while delivering comparable tool life.

Key words: cemented carbide, edge preparation, edge radius variability, surface integrity, tool life.

J. Matls. Proc. Tech. 213 (2013) 434--443

1 Introduction

The critical importance of the cutting edge in machining can be appreciated by considering the fact that all components that comprise the machining sys-

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tem, however sophisticated they may be, would be rendered entirely ineffective, should the cutting edge cease to perform as intended. With a view to ensuring consistent tool performance, cutting edges are commonly prepared to correspond to an approximately round shape, of a radius of several tens of micrometers. In addition to this process enhancing edge strength towards precluding catastrophic tool failure, extending tool life and improving coatability, it exerts a considerable influence on the mechanics of chip formation, with consequent implications on the integrity of the generated surface. Accordingly, techniques for the characterization as well as the preparation of the cutting edge are assuming great importance of late, especially in the machining of high-value components.

Brush honing and micro-blasting are two common techniques that are currently used for edge honing. The former relies on the abrasive action of fine grits dispersed in a brush, and the latter the erosive effect of grits transported in a pressurized air stream. The major issue with these techniques is the significant variability in the geometry of the generated edge (Denkena et al., 2010), which is manifest not just between inserts, but also along the edges of the same insert. For instance, the edge radius variability could be as high as 40% along the same edge (Endres and Kountanya, 2002) and up to 35% off the nominal value (Schimmel et al., 2000) which is the reason that manufacturers find it expedient to specify edge hones in classes that span a rather wide range of radius values. Recent work by Bassett et al. (2012) documented the transient nature of the brush honing process arising from the condition of the filaments in the brush. In their work, brush honing of 80 inserts to a target edge radius of 30 ± 5 μm in the stable region corresponded to a standard deviation of 12%; however, only about 75% of the honed inserts were found to be within the specified limits, which underscored the need for appropriately adapting and optimizing the process.

Machining performance measures such as tool life and residual stresses in the machined surface exhibit optimal values with respect to edge radius, and hence a high variability in edge geometry is not acceptable, in the interest of securing a robust process output. Furthermore, tool performance can be enhanced by a systematic variation in the edge geometry along the edge in applications such as hard cutting (Klocke and Kratz, 2005), and hence a capability for controlled fabrication of precise edge hones is desirable. In addition to the process control aspect above, conventional edge preparation techniques are also limited when preparing tools fabricated from materials of an extreme hardness such as polycrystalline diamond. These issues have led to the conception of alternative approaches to edge preparation, a brief review of which follows.

In consideration of the acute edge geometry variability inherent to conventional brush honing, Denkena et al. (2008) proposed the application of 5-axes brush honing technology for fabricating tailored tools of a controlled geometry along the edge. Karpuscheski et al. (2009) demonstrated a magneto-abrasive method that is reportedly capable of robust edge honing. The process was shown to enhance the stability of the cutting edges of high speed steel drills, which translated into improved wear behavior that yielded a two-fold increase in drill life. Aurich et al. (2011) recently reported on the use of a low-cost marking laser for the edge honing of cemented carbide inserts. In this process, layers of tool material in the cutting edge are sequentially ablated over several passes to fabricate hones of a specified radius. This method was shown to enhance tool life by more than 50% as compared to ground tools with sharp edges.

Yussefian et al. (2010) presented the proof-of-concept of a novel process called electro-erosion edge honing that employs electrical discharge machining (EDM) for the edge preparation of electrically conducting tools. The process was demonstrated to be capable of enhancing the life of high speed steel tools by as much as 4 times as that of ground edges, and of generating edges with less than 10% variability, which is minimal compared to conventional processes.

The present paper builds on the concept above, and proposes the innovative application of foil electrodes as a means of expanding the application envelope of electro-erosion edge honing towards the preparation of tools with a complex macro-geometry, such as those with nose radii and curved edges. In light of their industrial relevance, the process is evaluated in the honing of cemented carbide inserts, with reference to the variability in edge geometry, surface quality, tool life and processing time. The essential features of the electro-erosion edge honing process are presented in the next section, so as to lead into presenting the new developments.

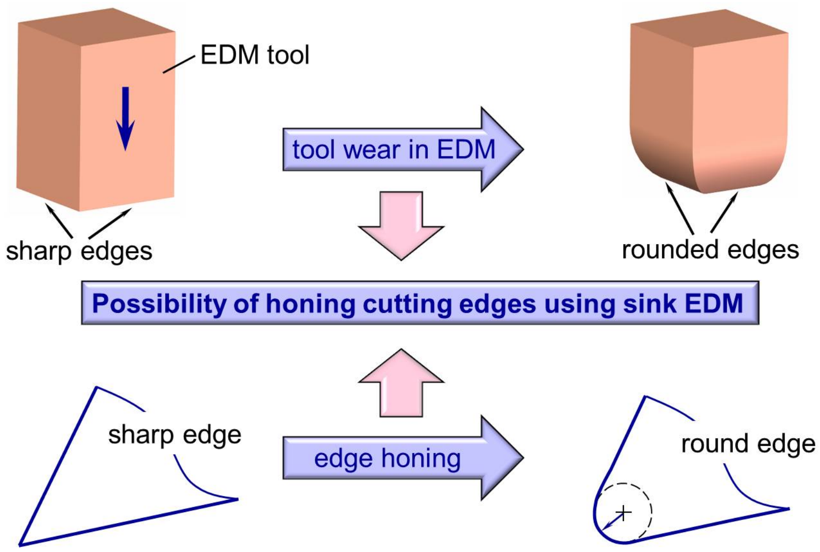

Fig. 1. Principle of electro-erosion edge honing.

2 Electro-erosion edge honing process

The electro-erosion edge honing process exploits the well-known issue of inevitable localized electrode wear in sink EDM (Crookall and Fereday, 1973) that rapidly and selectively rounds-off sharp edges (Fig. 1). The process represents an innovative approach in the extension of sink EDM into the domain of tool manufacture, noting that the limitations inherent to EDM are of little consequence in this case.

Firstly, the relatively low material removal rate of EDM is not of any detriment, as the volume of material that is to be removed to generate the edge hone is very minimal. The time required for the preparation of an edge is accordingly on the order of just several seconds, which is comparable to conventional processes. The low removal volume further allows for very conservative EDM parameters, which ensures that the integrity of the generated edge that is critical to its performance is not compromised. The excellent repeatability of controlled EDM processes is indeed an advantage in the generation of precise edge hones, which as indicated previously, is currently an issue with conventional edge preparation processes. Lastly, as EDM is a thermal process, it is not limited by the hardness of the tool material, which would enable the processing of even ultra-hard materials like polycrystalline diamond, provided the binder is metallic to render the composite to be of the requisite electrical conductivity.

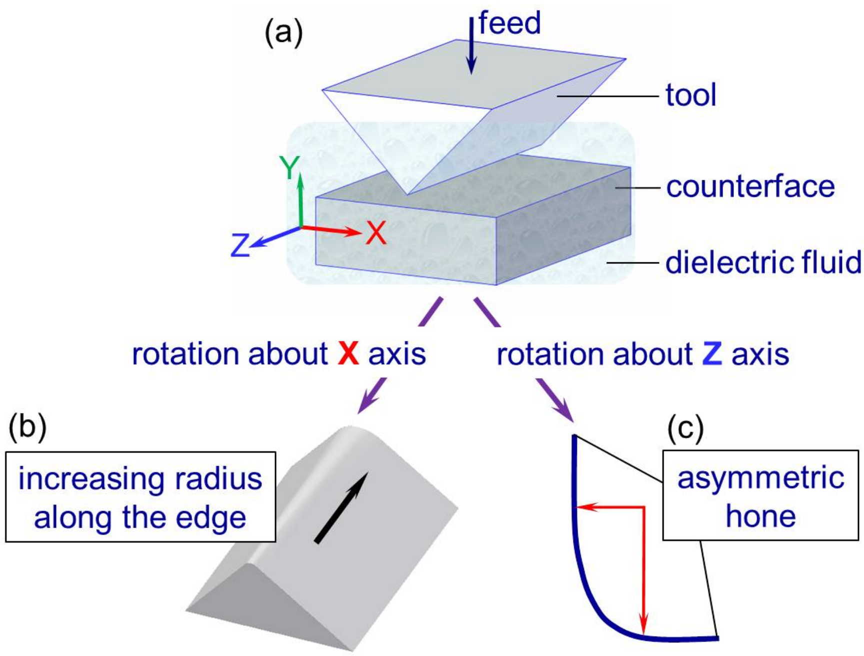

Fig. 2. Kinematic configurations of electro-erosion edge honing.

2.1 Application of a foil counterface

The implementation of electro-erosion honing in its simplest form (Yussefian et al., 2010) entails the symmetric sinking of the cutting edge into a flat and thick counterface (Fig. 2a) under servo control in the presence of a dielectric fluid, so as to induce wear at the edge to generate a rounded shape. A variant of this kinematic involves the rotation of the edge about the X-axis (Fig. 2b) that corresponds to the generation of a variable edge radius along its length. Similarly, a rotation of the edge about the Z-axis (Fig. 2c) would result in an asymmetric hone, such as a waterfall hone. In spite of these prospects, alignment of the tool about the said axes is crucial, if the objective is to generate a symmetric hone that is uniform along the edge.

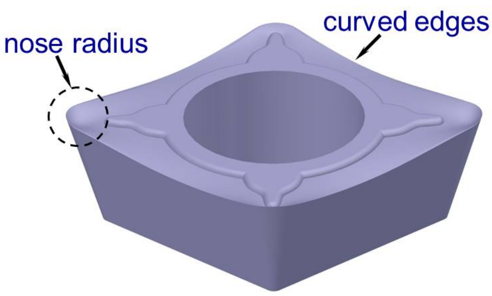

Fig. 3. Example of a tool insert with a complex geometry.

Furthermore, while the configuration shown in Fig. 2a is adequate for the preparation of inserts of a simple geometry such as SNEA-type with straight edges and a flat rake face, it is limited in the preparation of complex-shaped ones such as CCMT-type (Fig. 3), the geometry of which involves such features as a pronounced tool nose and curved cutting edges. When inserts such as of the latter type are sunk into the counterface, geometric variations along the profile of the cutting edge would manifest systematic trends in the edge radius (Fig. 4a), consistent with the differences in the processing time associated with individual segments that comprise the edge. One approach to solving this issue is to conceive a counterface of a shape that is complementary to the geometry of the edge profile; however, this is not an ideal solution, considering the additional effort associated with fabricating the counterface specific to the particular insert at hand, and having to precisely align it relative to the insert prior to the honing process.

To this end, this paper presents a simple and elegant solution that employs a foil electrode as the counterface. In this case, the tool is sunk into and through the foil counterface under servo control (Fig. 4b), such that thermal erosion of the material from the tool leading to the generation of the hone is limited by the thickness of the foil. This ensures a uniform hone radius along the edge irrespective of the geometry of the tool profile. As the edge radius is controlled by the machining time, for a set of specified pulse parameters, edge hones of

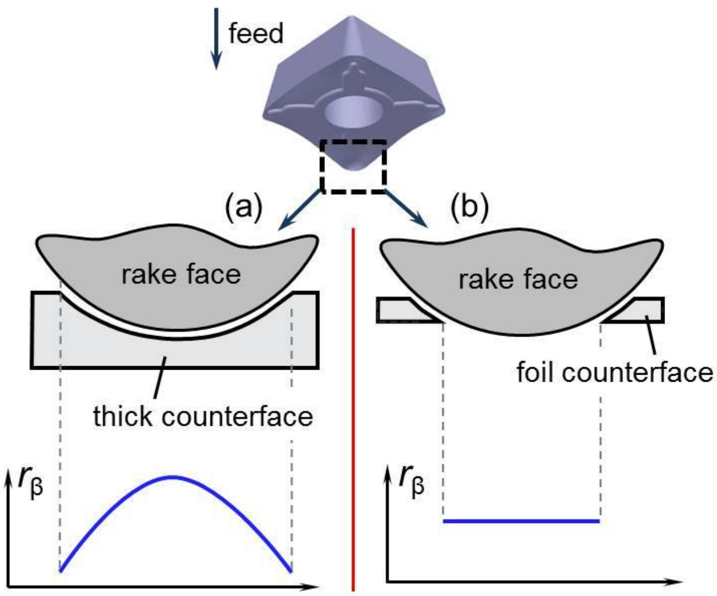

Fig. 4. A comparison of the application of thick and foil counterfaces.

different radii can be generated by simply varying the thickness of the foil. Such a configuration further obviates the need for any alignment of the tool with respect to the counterface, and enables the simultaneous preparation of a batch of inserts, both of which are of much significance in insert manufacture.

2.2 Choice of counterface material, polarity and pulse parameters

In the electro-erosion edge honing process, the wear ratio ν that refers to the relative volume of material removed from the tool to that from the counterface, controls the meso-geometry of the edge in terms of it being a hone or a chamfer (Yussefian et al., 2010). An intriguing aspect of this process is that the rounded shape is generated by the radial excursion of the electrical discharges in the machining gap, which obviates the need for any elaborate relative motion between the tool and the counterface. The threshold wear ratio ν_t that corresponds to the generation of a circular edge can be obtained by considering a section of the tool and the counterface in the XY-plane in Fig. 2, as shown in Fig. 5. For an unit thickness of the tool, the volume of material removed from the tool V_t is given by:

$$V_t = {r_\beta}^2 \left[\cot\left(\frac{\beta}{2}\right) - \left(\frac{\pi - \beta}{2}\right) \right] \tag{1}$$

where r_β is the edge radius and β is the wedge angle of the tool. Similarly, the volume of material removed from the counterface is calculated as:

$$V_c = (r_\beta + s)^2 \left[\left(\frac{\pi - \beta}{2}\right) - \sin\left(\frac{\beta}{2}\right)\cos\left(\frac{\beta}{2}\right) \right] \tag{2}$$

where s is the inter-electrode gap width. The equations above enable the

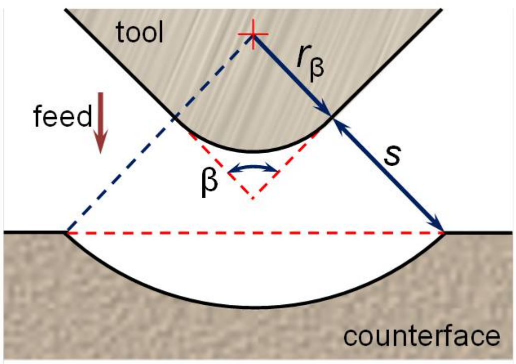

Fig. 5. Concept and calculation of threshold wear ratio.

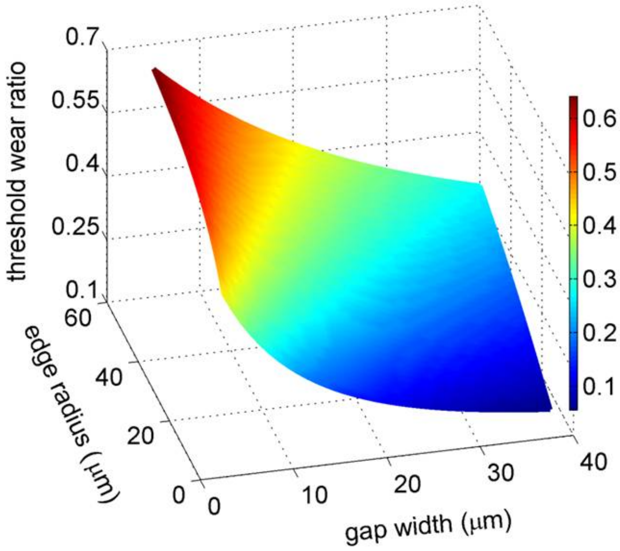

Fig. 6. Threshold wear ratio for a wedge angle of 90°.

threshold wear ratio ν_t to be calculated as (V_t/V_c). For typical values of edge radius and gap width on the order of 40 μm and 15 μm, respectively, this simple geometric model specifies the target wear ratio that corresponds to a rounded edge to be around 0.4 (Fig. 6).

Measurement of wear ratios referring to several counterface materials under both polarities indicated a negatively polarized aluminum counterface to correspond to a wear ratio of 0.4 when machining cemented carbide. The sectional as well as three-dimensional views of an edge generated experimentally under this combination does indeed correspond to a well-rounded edge, as shown in Fig. 7a. Relative to this ideal case, Figs. 7b–7d depict the effect of the counterface material and the polarity in terms of the wear ratio and the corresponding edge geometries. When using an aluminum counterface in positive polarity, the wear ratio reduces by an order of magnitude to 0.04, which refers to inadequate edge honing (Fig. 7b), on account of not enough material being removed off the tool.

Wear ratios much higher than the threshold value, on the other hand, result in the generation of a chamfer rather than a hone, as the discharges tend to traverse a linear rather than a radial path in the machining gap. This is precisely what was observed when using a copper counterface under negative polarity (Fig. 7c), for which the wear ratio was measured to be 5.0. Wear ratios smaller than the threshold refer to excessive in-feed of the tool into the counterface, which brings about an undesired incurrence of material removal

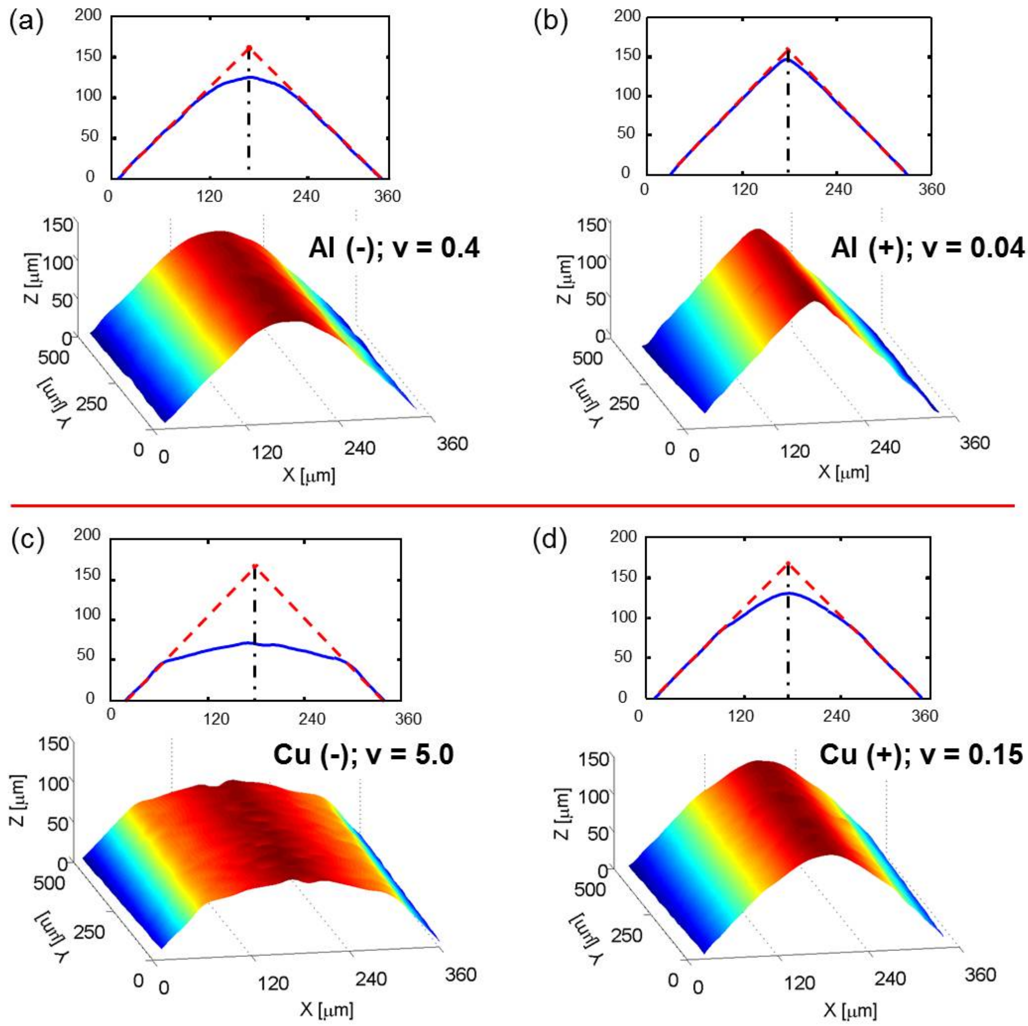

Fig. 7. Effect of counterface material and polarity on edge geometry.

on the rake and clearance faces, as opposed to localized removal just at the cutting edge. This situation was observed when using a copper counterface under positive polarity (Fig. 7d), which corresponded to a wear ratio of 0.15. A comparison of the four cases above clearly signifies the critical importance of the right combination of counterface material and polarity; a negatively polarized aluminum counterface that generates the desired honed was hence used in this work.

An appropriate selection of pulse parameters for the electro-erosion honing of cemented carbide tools needs to entail due consideration of the potential deleterious thermal effects (Jahan et al., 2011) on the performance of the generated surface, while maintaining the processing times to be comparable with those of conventional techniques. Previous work by Juhr et al. (2004) on spark erosion of cemented carbides has identified the pulse on-time to be the dominant parameter that controls surface damage, with the recommendation that it be less than 0.5 μs for minimal strength degradation. Furthermore, the transverse rupture strength of cemented carbide machined by EDM has been reported (Lin et al., 2008) to exhibit a decreasing trend with respect to pulse current. A pulse on-time t_i of 0.4 μs and a pulse current i_e of 1.2 A, which happened to be the lowest possible values on the machine tool available in our laboratory, were hence used in the present work. The corresponding processing time will be shown later to be on the same order as that of the brush honing process.

As the boiling point of cobalt and the melting point of tungsten carbide are virtually the same, during EDM of tungsten carbide composite cemented by cobalt, tungsten carbide grains tend to get physically dislodged as individual units, once the cobalt binder around it is selectively removed. The implication of this occurrence is that the gap voltage (which controls the gap width) and the pulse off-time ought to be high enough to facilitate effective evacuation of the carbide grains off the machining gap, but for which the stability of the process will be affected adversely. Experiments conducted to investigate the effect of the average gap voltage on wear ratio revealed a rather weak sensitivity relative to the effects of counterface material and polarity, further indicating that the desired wear ratio of 0.4 referred to an average gap voltage of 50 V (Fig. 8). The process was further observed to be the most stable when the gap voltage was set at 50 V. A pulse off-time t_o of 1.12 μs (that refers to a duty factor of $\sim$35%) and a gap voltage of 50 V were hence selected, in consideration of the fact that higher values would affect the processing time and the surface integrity, respectively.

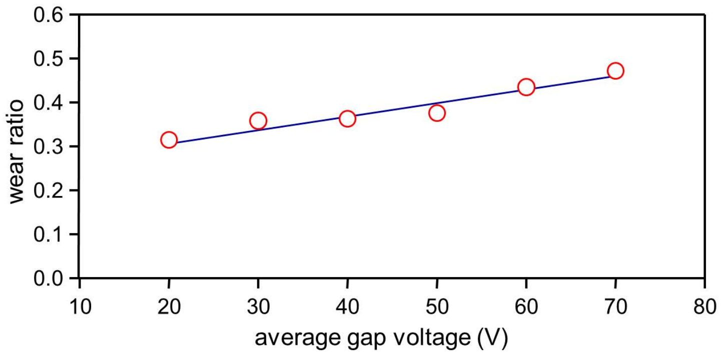

Fig. 8. Effect of gap voltage on wear ratio (t_{on} 0.4 μs, i_e 1.2 A).

In terms of process design, the counterface material and polarity are chosen with reference to the wear ratio that corresponds to the desired edge geometry, and the pulse energy is limited in the interests of maintaining an appropriate surface integrity. Determination of the gap voltage and pulse off-time involve due consideration of process stability and processing time, and the edge radius is controlled by the thickness of the foil counterface.

3 Experimental

The objectives of the experimental work were two-fold: (i) to evaluate the capability of the electro-erosion honing process using a foil counterface in generating consistent edge geometry along nose radii and curved edges, and (ii) to quantify the tool life of cemented carbide inserts honed using this process, with a view to comparing them against those of brush-honed inserts of a similar edge radius. To this end, experiments involved uncoated pressed and sintered carbide inserts of CCMT geometry (see Fig. 3) and uncoated ground inserts of SNEA geometry, respectively.

Experiments were conducted on a ram type EDM machine tool, in an oil-based dielectric under conditions of no external flushing, at a constant servo gain. Aluminum foil counterfaces of thickness ranging from 25–100 μm were used to generate edges with edge radius values in the range of about 30–50 μm. A photograph and a schematic of the experimental set-up are shown in Fig. 9a and 9b, respectively. The foil counterface was held taut using magnets to counteract their inherent compliance. An imprint from the edge honing operation can be seen on the counterface in Fig. 9a. The baseline machining parameters corresponded to values presented in the previous section as per

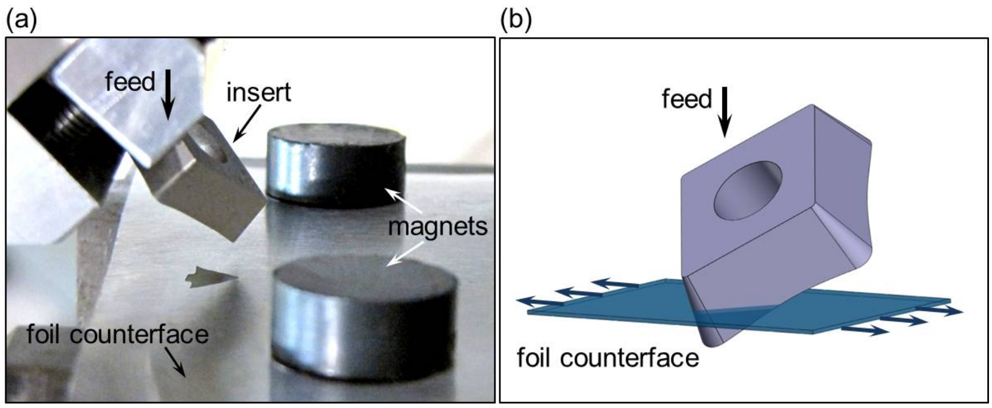

Fig. 9. Experimental configuration for electro-erosion honing.

the rationale indicated therein. To place the effect of the pulse parameters in perspective, experiments referring to a higher pulse on-time and gap voltage were also conducted. Some prepared edges were sectioned and polished to examine the geometry and integrity of the edge, and some were subject to accelerated tool life tests using a scheme outlined by Armarego and Brown (1969).

4 Results and Discussion

4.1 Edge geometry

Fig. 10a shows a micrograph of an electro-erosion honed edge of a pressed and sintered CCMT insert shown in Fig. 3. The excellent edge quality along the curved profile as seen in the inset in Fig. 10b is physical evidence to the efficacy of a foil electrode in being able to uniformly hone curved edges. Fig. 10c presents a comparison of the quality of the cutting edge between the honed and the unprepared sections of the edge. The segment of the edge left intentionally unprepared can be seen to sustain edge chipping as well as residual flash from the insert compaction process prior to sintering, at the location where the honing is terminated. Examination of the honed segment indicates electro-erosion honing to have effectively purged such detrimental features from the edge, which is a mechanism by which the honing process enhances both tool performance and reliability.

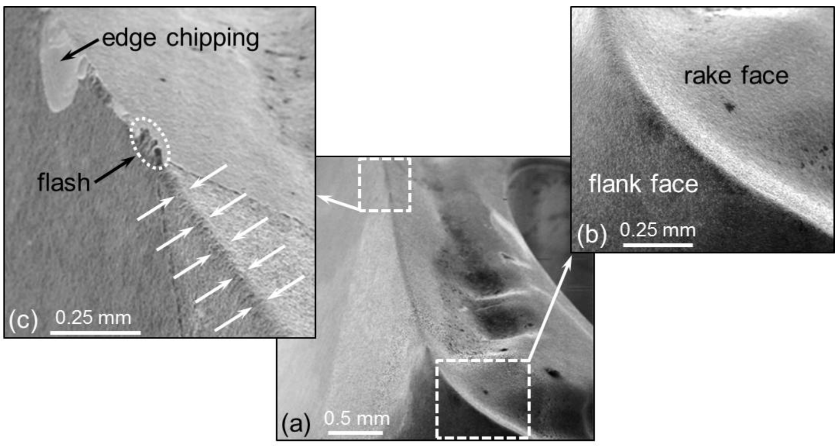

Fig. 10. (a) Electro-erosion honed edge of CCMT insert, (b) honing quality along a curved edge, and (c) edge chipping and flash on the unprepared edge (white arrows indicate the honed segment).

Various geometric parameters have of late been proposed for the characterization of cutting edges (Wyen et al., 2012); in the present work, edge geometry was however quantified in terms of the edge radius considering that the honed edges were symmetric. Cutting edge measurements were conducted by processing the image data acquired using an optical microscope equipped with an automated stage to acquire a series of uniformly spaced images in the vertical direction. For the 30–50 μm range of edge radius values encountered in the present work, the field of view of the microscope was kept constant to be 450×600 μm^2 which corresponded to a XY (horizontal plane) resolution of 0.47 μm. The Z (vertical) resolution of the automatic stage was set to 1 μm. A B-spline surface was approximated through the point cloud data obtained using the microscope to reconstruct the cutting edge. This surface was then sectioned at 20 equally-spaced positions along the edge length of 450 μm to characterize the cutting edge using the cutting edge radius parameter r_β computed using circular regression. The uncertainty of this optical measurement method was investigated in consideration of variables such as the field of view, Z step height and lighting intensity. For a symmetrical cutting edge with an edge radius of 50 μm, this exercise indicated the measurement uncertainty to be 1.5 μm.

With a view to validating the optical measurement technique, Fig. 11a illustrates a comparison of symmetric edge profiles obtained using the optical microscope, white light interferometer (WLI) and form tracer, for an edge with a nominal edge radius r_β of 60 μm. The maximum deviation between the

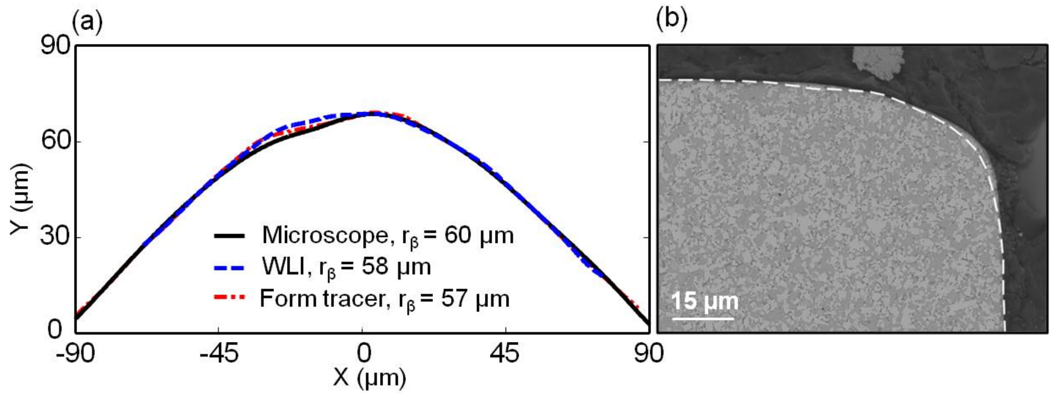

Fig. 11. (a) Comparison of cutting edge profiles obtained by optical microscope, white light interferometer (WLI) and form tracer; (b) overlay of profile (broken white line) obtained using the microscope on a micrograph showing the section of the edge.

edge radius values measured using these devices was found to be 5%. Fig. 11b compares the profiles of a sharper asymmetric edge obtained using the optical microscope with that from subsequent physical sectioning and polishing of the edge at the same location. In this instance, the maximum deviation between the two profiles was measured to be 2 μm.

Fig. 12a displays the distribution of the edge radius measured using the said optical technique among 5 inserts that were chosen randomly, in the form of a Box plot. By convention, the boxes refer to the 25/75 percentile and the whiskers to the range. Each box contains 60 measurements along the cutting edge, corresponding to 20 edge measurements each taken 20 μm apart along the leading and trailing segments of the edge, as well as the tool nose region.

While the variability in the as-pressed and sintered inserts was 20%, electro-erosion honing reduced this to 13%, which is significantly smaller than the 35–40% measured on commercially retailed inserts (Endres and Kountanya, 2002; Schimmel et al., 2000). Such a process response attests to and is a consequence of the excellent repeatability of controlled EDM processes. Fig. 12b depicts the distribution of the edge radius along a single edge, at and on either side of the tool nose, which provides a quantitative measure of the consistency in edge geometry. The mean edge radius of the pressed and sintered CCMT insert was 12 μm with a 19% variation along the edge. Electro-erosion honing of the insert to a target nominal edge radius of 30 μm reduced the variability along the edge to 13%.

Fig. 13a depicts the geometry, topography and cross-section of an electro-erosion honed insert. To place this in perspective, corresponding views of a brush honed insert (Fig. 13b) and a ground insert (Fig. 13c) are also provided. The prepared edges refer to a nominal edge radius of 40 μm. The cross-sectional view of the electro-erosion honed insert confirms the efficacy of the proposed process in generating a symmetric, rounded edge. The surface roughness of the electro-erosion honed edge was measured to be 0.2 μm Ra, which is similar in scale to the brush honed inserts (0.14 μm Ra). Aspects of a comparison of the performance of brush honed and electro-erosion honed inserts is discussed next.

In general, electrical discharge machined surfaces entail issues relating to recast material, micro-cracks and tensile residual stresses, as a consequence of the mechanism of material removal being primarily thermal in nature. In cemented carbides, this translates into a degradation in the flexural strength (Casas et al., 2006) and the tribological response (Bonny et al., 2009). In this light, the key to productive EDM of cemented carbides is the careful selection of machining parameter combinations and/or the adoption of strategies such as the application of successively finer machining regimes, in order to minimize the adverse effects without incurring an undue penalty on the machining rate. For instance, with the application of appropriate machining parameters, cemented carbide punches machined using wire-EDM have been shown (Lauwers et al., 2005) to be comparable to those that were finished by grinding, in terms of wear behavior and tool life.

In the context above, the baseline EDM parameters in this work related to a pulse on-time t_i of 0.4 μs, a discharge current i_e of 1.2 A, and a gap voltage U of 50 V, as detailed in section 2.2. With a view to placing these parameters in perspective, experiments were also conducted using a more aggressive set of parameters, which referred to an on-time t_i of 13 μs and a gap voltage U of

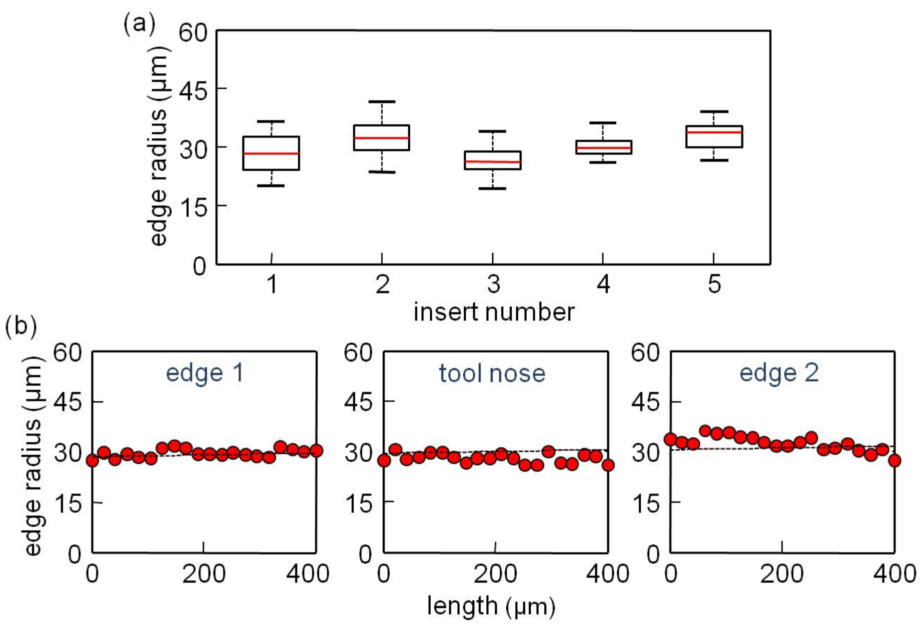

Fig. 12. Variability in edge radius: (a) between inserts. (b) along the edge of a single insert.

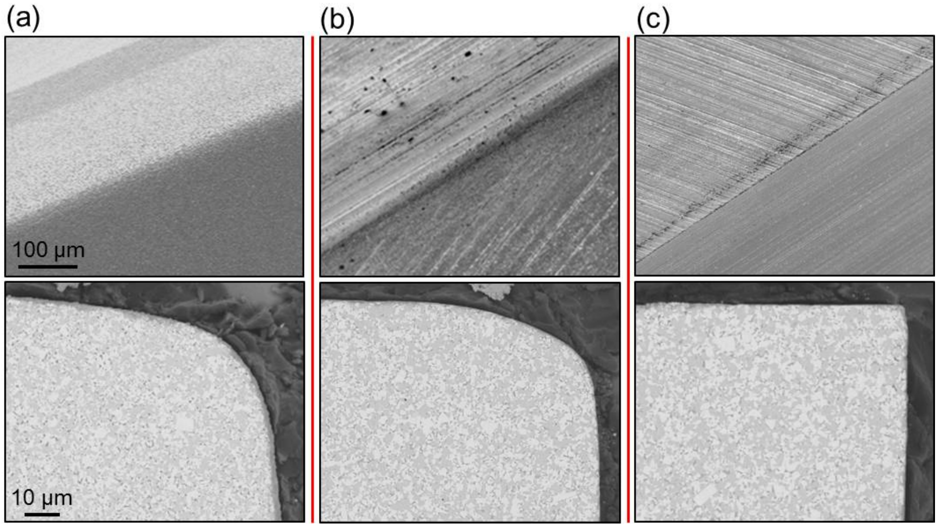

Fig. 13. A comparison of edges: (a) electro-erosion honed, (b) brush honed, and (c) ground.

110 V, other conditions remaining the same. The latter set of parameters were derived from a complementary study involving a Taguchi design of experiments approach to minimize the deviation of the generated profile from that of an ideal circle. An evaluation of the corresponding surface integrity and tool life characteristics are presented in the following.

A comparison of the topography of the surface generated using the baseline set of parameters (Fig. 14a) with that of the more severe set (Fig. 14b) denotes

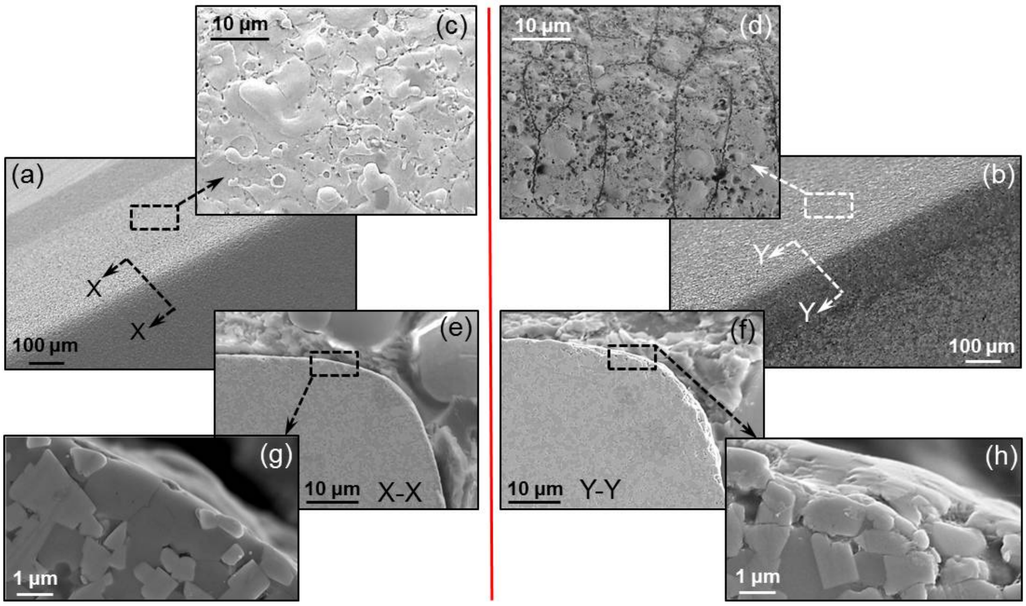

Fig. 14. Effect of pulse parameters on the integrity of cemented carbide surfaces.

the latter to correspond to a darker hue, conceivably due to the migration of carbon from the decomposition of the hydrocarbon dielectric during the honing process. These surfaces were of roughness 0.20 μm *Ra* and 0.23 μm *Ra*, respectively. Closer examination of the surfaces (Figs. 14c and 14d) indicates the baseline parameters to correspond to a significantly reduced incidence of surface micro-cracking, in terms of both the number of cracks and their length. Similarly, the cross-sectional view (section X-X) referring to the baseline set (Fig. 14e) shows the surface to be relatively free of selective binder depletion and recast material, as compared to the latter (section Y-Y, Fig. 14f). A detailed investigation of the cross-section of the surface referring to the baseline set of parameters (Fig. 14g) provided further evidence towards the absence of recast material and cobalt depletion, while revealing sparsely dispersed micro-cracks, the depths of which were on the order of just 1 μm; this is in stark contrast to the cross-section corresponding to the higher pulse energy (Fig. 14h).

An interesting consequence of the application of EDM for edge honing is that the corresponding characteristic surface topography that entails a positive skewness may be deemed to be beneficial in the anchoring of a tool coating. It is also intriguing to note that a coating can concomitantly enhance the strength (Casas et al., 2004) and the tribological performance (Casas et al., 2008) of EDM-ed surfaces.

Considering that one of the primary motivations for edge honing is to obtain robust and enhanced tool performance in the first place, it is of interest to examine how the differences in surface integrity above translate into variations in tool life. It is further essential to benchmark the performance of electro-erosion edge honed tools against that of brush honed tools. A comparison of such tool life characteristics obtained using variable speed accelerated tests (Armarego and Brown, 1969) performed in a facing operation is presented in Fig. 15a. These tests referred to a feed of 0.1 mm and a depth of cut of 1.0 mm, for a tool life criterion of 300 μm flank wear, on AISI 4140 steel workpieces of 40 HRC hardness. The tools used were uncoated SNEA grade C5 carbide from the same batch, and of a nominal edge radius of 40 μm. Typical edge profiles are shown in Fig. 15b.

The tool life plots indicate the electro-erosion edge honed tools using the conservative baseline pulse parameters to correspond to a tool life that is vir-

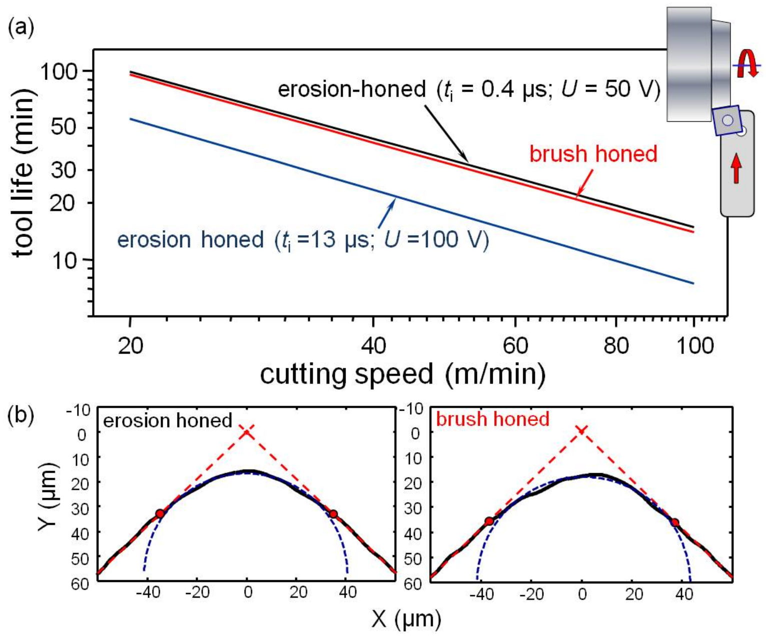

Fig. 15. (a) Taylor's tool life plots for electro-erosion honed and brush-honed inserts; (b) edge profiles of typical inserts used in tool life tests.

tually identical to that of brush honed tools. It is further evident that the surface generated using the relatively aggressive pulse parameters that refers to a seven-fold increase in pulse energy corresponds to a three-fold reduction in tool life, which is to be expected considering that such features as micro-cracks and selective cobalt erosion (see Fig. 14) depletes the surface strength and undermines the tribological response. This trend is in line with the results obtained by Bonny et al. (2009) who report the successive execution of gradually finer EDM regimes to result in the enhanced wear performance of WC-Co, as evaluated in pin-on-flat tribological tests.

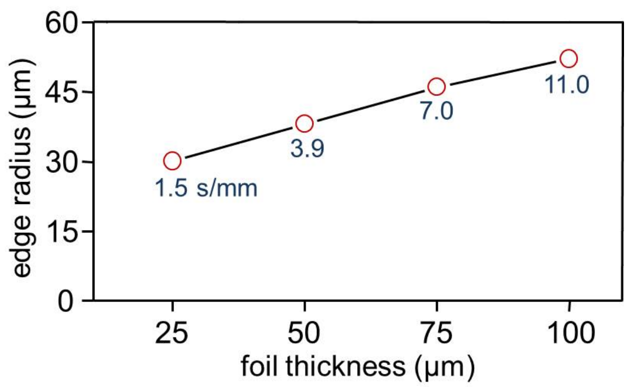

Fig. 16. Edge radius and processing time as a function of foil thickness.

Notwithstanding the capability of electro-erosion edge honing process in generating consistent edge geometry as demonstrated in this paper, an important factor that is crucial in the industrial acceptance of such a novel technology is the processing time. Fig. 16 presents edge radius and the processing time for honing an unit length of a cemented carbide edge of a wedge angle of 90° as a function of counterface thickness. The processing times indicated are comparable to that of brush honing, which at the present time is largely the standard process in industry. It may be noted that the electro-erosion honing process using foil electrodes is amenable to the simultaneous honing of a large number of inserts, with no strict requirement for any intricate alignment. It is also possible to configure the process so as to selectively hone certain edge segments of an insert with a view to reducing the cycle time.

It may be inferred from the information presented in this paper that the fabrication of a cutting edge of an appropriate geometry (e.g. honed) and surface integrity in a reasonable cycle time constrains the electro-erosion honing process to a rather restricted envelope of operating parameters. It would however be of interest to investigate possibilities for further minimizing processing time and maximizing tool life, through such avenues as a progressive decrease in the pulse energy during the course of honing an edge. The use of a dielectric fluid mixed with nano-powders (Jahan et al., 2010) that aid in dispersing the pulse energy towards improving surface quality without affecting the removal rate may also be considered. Additional strategies to process optimization may involve such approaches as pulse shaping (Juhr et al., 2004), physical vapor deposited coatings (Casas et al., 2004), and the application of secondary processes such as thermal annealing (Casas et al., 2006) and finish micro-blasting (Qu et al., 2005).

5 Conclusions

The primary focus of the work reported in this paper was on expanding the capability of the innovative electro-erosion edge honing process in the preparation of uncoated cemented carbide inserts with such geometric features as nose radii and curved edges. Specifically, the work introduced the application of a foil counterface, which facilitates the simultaneous processing of a batch of complex-shaped inserts, with no particular alignment requirements, which has significant positive implications in insert manufacture.

The use of aluminum as the counterface material in negative polarity was identified to generate rounded edge hones in cemented carbide tools, consistent with the insights gained from a simple model developed for the threshold wear ratio. Characterization of the meso-geometry of cutting edges generated in this process has shown it to correspond to less than 15% variability in edge radius, which is significantly less, as compared to values that are as high as 40% reported for brush honed inserts. This renders the process to be quite attractive in the manufacture of tools used in the precision machining of high-value components.

In the current state of development, electro-erosion honing is shown to be comparable to brush honing in terms of tool life and processing time. This novel process warrants further research as it offers significant scope for further reduction in cycle time while concurrently enhancing tool performance. Considering that electro-erosion honing is a thermal process that is not limited by tool hardness, the process further offers prospects in the edge preparation of ultra-hard polycrystalline diamond tools that currently pose problems when using conventional processes.

Acknowledgments

This work was funded by the AUTO21 Network Centers of Excellence and the C4 Consortium of Ontario. Authors gratefully acknowledge the technical and in-kind contributions of Dr. R. M'Saoubi of Seco Tools.

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