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REVIEW ARTICLE

Edge preparation methods for cutting tools: a review

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ABSTRACT Edge preparation can remove cutting edge defects, such as burrs, chippings, and grinding marks, generated in the grinding process and improve the cutting performance and service life of tools. Various edge preparation methods have been proposed for different tool matrix materials, geometries, and application requirements. This study presents a scientific and systematic review of the development of tool edge preparation technology and provides ideas for its future development. First, typical edge characterization methods, which associate the microgeometric characteristics of the cutting edge with cutting performance, are briefly introduced. Then, edge preparation methods for cutting tools, in which materials at the cutting edge area are removed to decrease defects and obtain a suitable microgeometry of the cutting edge for machining, are discussed. New edge preparation methods are explored on the basis of existing processing technologies, and the principles, advantages, and limitations of these methods are systematically summarized and analyzed. Edge preparation methods are classified into two categories: mechanical processing methods and nontraditional processing methods. These methods are compared from the aspects of edge consistency, surface quality, efficiency, processing difficulty, machining cost, and general availability. In this manner, a more intuitive understanding of the characteristics can be gained. Finally, the future development direction of tool edge preparation technology is prospected.

KEYWORDS edge preparation method, preparation principle, cutting edge geometry, edge characterization, tool performance

1 Introduction

High-performance machining is inseparable from the excellent properties of cutting tools [1]. With the continuous advancement of machine tool design, tool control, and system monitoring, machining operations have been developing rapidly in ultraprecision cutting, high-speed cutting, near-net machining, and dry cutting of difficult-to-machine materials [2]. Stringent requirements have been proposed for cutting tools. Defects, including small chippings and burrs (Fig. 1(a)) [3], are generated in the manufacturing process of the cutting edge. These defects can easily concentrate stress at the cutting edge during the cutting process, subsequently aggravating the wear and collapse of the cutting edge, shortening the service life of the tool, and deteriorating the surface quality of the machined parts [3–5]. Cutting edge preparation during tool manufacturing or before the use of tools is necessary to ensure excellent cutting performance.

Figure 1(b) illustrates the purposes of edge preparation, which are to remove the microdefects generated by the cutting edge in the initial forming process, improve the stress state of the tool surface, and obtain a high stability edge with a certain microshape [5]. Reasonable cutting edge preparation can effectively improve the mechanical and thermal load state of the cutting edge of tools during the cutting process, which reduces the wear of the tool [6], prolongs the service life of the tool (Fig. 2), enhances the stability of the tool in the cutting process, and improves the surface quality of the processed parts [7–10]. For coated tools, cutting edge preparation as a preprocess can provide better surface preparation for coating treatment [11]. Edge preparation has become the fourth key factor

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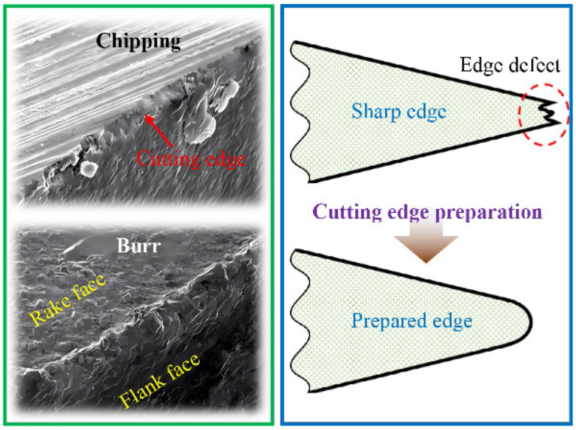


(a) (b)

Fig. 1 (a) Edge defects [3], reproduced with permission from Elsevier; (b) cutting edge preparation.

for determining tool performance in addition to substrate material, geometric parameters, and coating treatment [4].

According to Ref. [12], before the round edge appeared for the first time at the end of the 19th century, the tool edge was believed to be a completely sharp straight line. By the mid-20th century, researchers found that the round edge in the cutting process of the tool was influenced by the “size effect” and “ploughing effect”; that is, a certain degree of round edge allows for tools to be in a more reasonable stress state during the working process, which can ultimately improve cutting performance [13–14]. Researchers also found that apart from the round edge, some other edge shapes can remarkably improve the cutting force, temperature, and surface quality of machined parts [15]. With the rapid development of mechanical cutting technology, the effect of edge preparation on the wear resistance, microhardness, and service life of cutting tools has received increased attention [16].

Different edge preparation methods for obtaining the ideal cutting edge shape have been proposed and proven in the past decades. Tool edge preparation technology is named in different ways in the literature, including “edge preparation” [4], “edge passivation” [17], and “edge honing” [3]. According to the processing principle, edge preparation methods for cutting tools can be divided into mechanical processing methods that are driven by mechanical action and nontraditional processing methods that use nonmechanical energy, such as light energy, electricity, and magnetic force. This study reviews and summarizes the edge preparation methods for cutting tools and their development and the prospects for the future development of tool edge preparation technology. Figure 3 shows the overall framework of this review. Edge characterization can describe the microgeometry and morphology of the edge of cutting tools. Thus, this review provides a brief introduction to some typical characterization methods before classifying and discussing the methods of cutting edge preparation. Additionally, this research offers a preliminary comparison of the main cutting edge preparation methods from different aspects to improve the understanding of the benefits of these methods.

2 Characterization methods of the cutting edge

Edge characterization provides the premise of describing the morphology and microgeometry of the cutting edge; it also links the edge preparation process and the cutting process. The edge morphology of tools, in contrast to the macroscale size parameters of tools, can only be fitted and characterized at the microscale. As shown in Fig. 4, the edge shape mainly includes three types: sharp edge, chamfer edge, and round edge [18]. The sharp edge is a

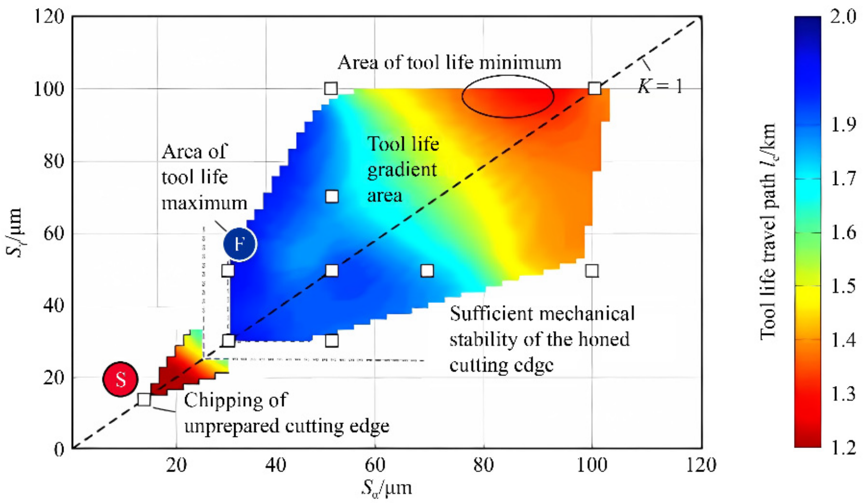


Fig. 2 Tool life map of edge shape parameters [7], reproduced with permission from Elsevier.

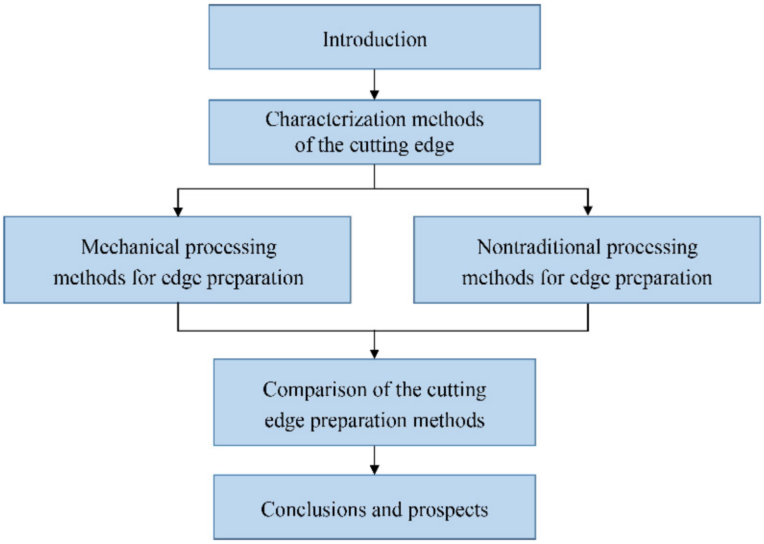


Fig. 3 Framework of this review.

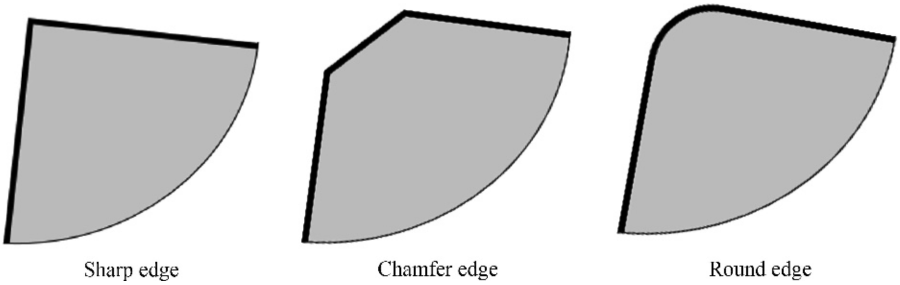


Fig. 4 Basic shapes of a cutting edge.

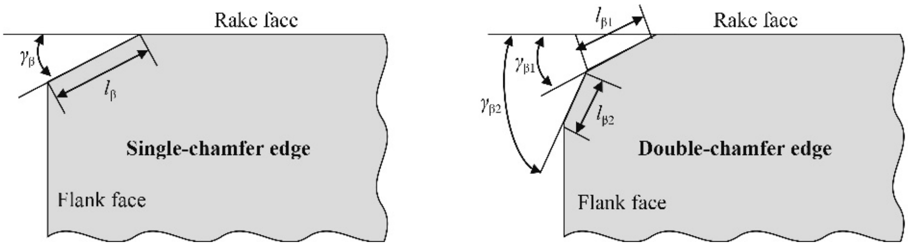


Fig. 5 Characterization methods of chamfering edges.

straight edge formed naturally by the intersection of the rake face and the flank face of the tool. The chamfer edge is equivalent to a microcutter surface, such as chamfering at the edge. The cross-sectional profile of the rounded edge is a smooth arc.

2.1 Characterization methods of chamfer edges

The chamfer edge is formed by grinding a microchamfer at the tool edge. Chamfers can be classified according to their number, i.e., a single-chamfer edge and a double-chamfer edge (Fig. 5) [12]. In general, the chamfer edge is characterized by the length of the chamfer edge l_β and the angle between the chamfer edge and the rake face γ_β. When the formed chamfer is a tool face, the chamfer with a negative rake angle is the chamfer edge (Fig. 6(a)). The chamfering edge that forms a negative clearance angle is a negative chamfer edge (Fig. 6(b)); its main function is to increase the contact area between the tool and the workpiece, thus eliminating vibration during processing. The chamfering edge with a clearance angle of 0° is a flat edge (Fig. 6(c)), which mainly plays the role of support guidance and extrusion finishing [18,19].

2.2 Characterization methods of round edges

1) Common characterization methods

The characterization of a round edge is more complex

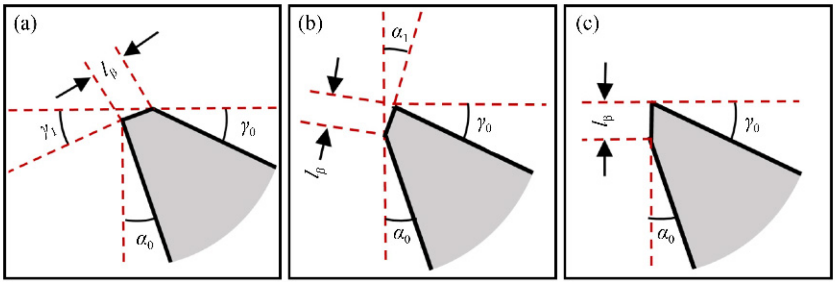


Fig. 6 Single-chamfer edge types: (a) chamfer edge, (b) negative chamfer edge, and (c) flat edge.

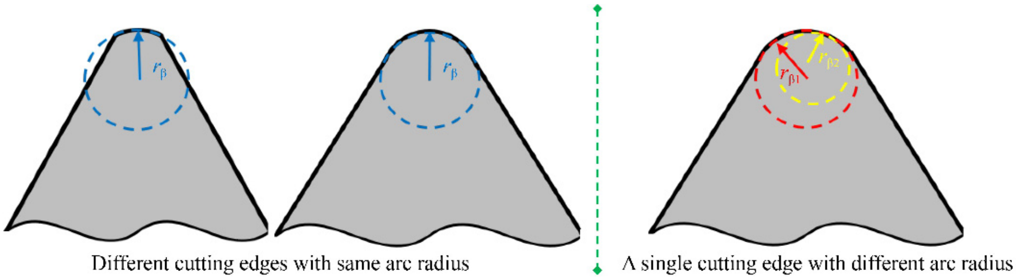


Fig. 7 Characterization error caused by the single-edge radius characterization method.

than that of a chamfering edge. The ideal round edge is a standard arc. For round edges, only three measurement points are considered in the transition region of the rake face and the flank face to fit an arc with a radius of γ_β. This scheme is the simplest single-edge radius characterization method. However, the actual edge shape is usually an irregular arc entailing a large difference in the edge radius measured at different positions. More measurements and fittings are needed to ensure the accuracy of the measurement results. As shown in Fig. 7 [20], this oversimplified characterization method cannot distinguish edges with the same radii, although different morphologies can be deduced. However, more parameters are needed to describe comprehensively the tool edge morphology [12,20].

Denkena et al. [21] established the form-factor characterization method, also known as *K*-factor characterization, to overcome the shortcomings of the single-edge radius characterization method. Figure 8 shows the ratio of S_γ to S_α. This ratio is defined as the form factor *K*, which represents the inclination direction of the edge arc. S_α and S_γ represent the distance between the theoretical tip and transition point “2” of the rake face and transition point “1” of the flank face, respectively. Δr, which is the distance between the line connecting the highest point of the edge arc and the theoretical tip (i.e., it characterizes the degree of edge flattening), and angle φ, which is the area between the line connecting the ideal tip to the highest point of the edge, form a symmetrical line of the edge. An edge with a *K* of 1 is an ideal round edge or “symmetric edge”; an edge with a *K* of < 1 is called a “waterfall edge”; and an edge with a *K* of > 1 is called a “trumpet edge” or “reverse waterfall edge” [18,22].

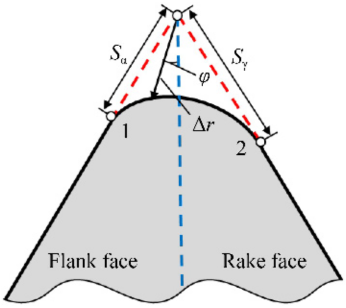


Fig. 8 Form-factor characterization method of the cutting edge.

The *K*-factor characterization of the cutting edge is determined on the basis of the intersection point of the extension line of the rake and flank face. The characterization results deviate considerably from the true value due to the different selection approaches to transition points. However, given the simple characterization parameters and ease of describing the edge morphology, the *K*-factor characterization method and single-edge radius characterization method have been widely used.

2) Others

In addition to the single-edge radius and form-factor characterization methods, other methods have been proposed to characterize round edges.

As cited in Ref. [20], Tikal et al. proposed a geometric method to divide the fitting edge radius of the edge, and the arc radius r_0 of the edge is fitted by the four radii obtained via geometric division. However, this method cannot meet the requirements of characterizing the morphology of different cutting edges, as shown in Fig. 9. Subsequently, cutting edge width B_f, cutting edge inclination angle φ_0, and the two transition radii r_1 and r_2 are introduced in the round edge characterization. This method is rarely used because of its complicated fitting process.

To avoid the difficulty of separating the edge from the tool surface during fitting, Rodríguez [4] used a six-degree polynomial to fit the edge arc. Figure 10(a) shows the two intersection points of the edge and the uncut chip taken as the transition points. The uncut chip thickness h is determined according to the effective rake angle γ_e. Then, the edge is divided into two parts at the highest point n of the edge to describe the symmetry of the edge, i.e., $S = p/q$. However, the cutting edge vertex n and the effective rake angle γ_e are constantly changing in the cutting process, hence the difficulty of linking the machining conditions during machining. This scenario is problematic for cutting edge characterization.

The characterization method proposed by Denkena et al. [23] also links edge fitting and characterization with the actual processing situation. Figure 10(b) shows the contact points of the chip and the edge on the rake and flank, denoted by P_γ and P_α, respectively. The contact length between the edge and chip is in the range of P_γ to P_α. The undeformed chip thickness during tool machining is denoted by h_0, and the intersection point of the undeformed chip and cutting edge is taken as the separation point s. The chip above point s flows to the rake face, while the chip below point s enters the plough area A_α. Then, the actual contour of the cutting edge can be obtained according to the macrorake angle γ and flank angle α of the tool. In this characterization method, the edge can be designed according to the actual processing requirements, but it is not conducive to the general characterization of the edge.

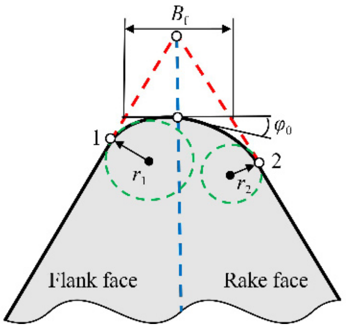


Fig. 9 Geometric characterization method of the cutting edge.

Some methods obtain the edge shape by iterative fitting and characterization. Wyen et al. [20,24] proposed a method for solving the unique edge radius by Gaussian least square fitting. The characterization process is shown in Fig. 11(a). A vertical line of the angle bisector is drawn on the intersection of the tool tip angle bisector and the actual edge. The ratio of the distance between the intersection of the vertical line on both sides and the tool face extension line and the actual edge is given by $S = D_\gamma / D_\alpha$, which represents the inclination of the edge.

A method to fit the cutting edge by using the B-spline curve with free nodes was introduced by Yussefian and Koshy [25]. The transition point between the cutting edge and the tool surface is accurately identified by intelligently placing nodes. In this manner, the residual error of the B-spline data fitted to the tool contour can be minimized. The characterization parameters are shown in Fig. 11(b). S_f and S_r are the extension areas of the cutting edge relative to the flank face and the rake face, respectively. S_a represents the degree of asymmetry of the contour, and θ is the angle between the symmetry axis of the cutting edge curve and the bisector of the ideal tool tip angle. r_a is the radius of curvature of the highest point of the cutting edge, and f_a represents the degree of cutting edge preparation.

Different methods can characterize the cutting edge according to specific requirements and combine the obtained data with those from fitting and characterization techniques. Song et al. [26] combined the single-edge radius and K-factor characterization methods based on the fractal interpolation edge surface reconstruction method. They also proposed a two-scale multi-index characterization method, including boundary point recognition and

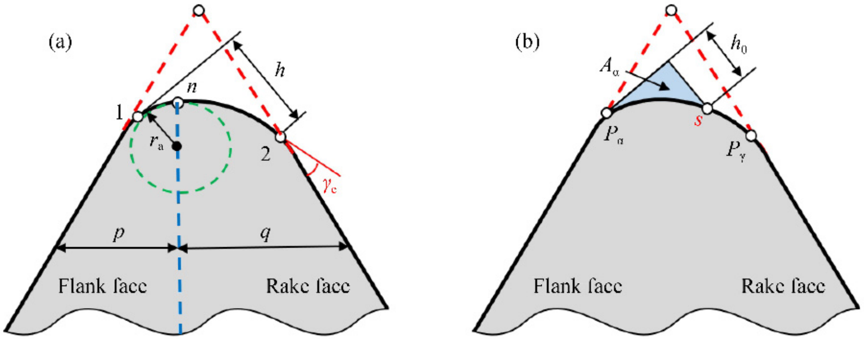


Fig. 10 Edge characterization methods associated with the cutting process: (a) proposed by Rodríguez [4] and (b) proposed by Denkena et al. [23].

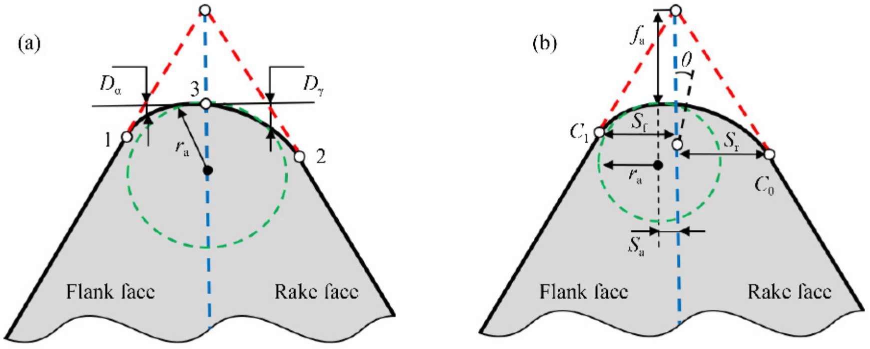


Fig. 11 Iterative fitting characterization methods: (a) proposed by Wyen et al. [20,24] and (b) proposed by Yussefian and Koshy [25].

fractal dimension, to characterize the microscale characteristics of the edge. The three indicators of the characterization method (edge radius, *K*-factor, and edge surface fractal dimension) represent the fitting accuracy. Meanwhile, flank wear cannot clearly depict the wear mechanism occurring along the cutting edge of drills in the carbon fiber-reinforced polymer (CFRP) drilling process. Thus, Raj and Karunamoorthy [27] characterized the microgeometry changes by using four parameters: cutting edge flattening, peak flattening, flank rounding depth, and flank rounding width. These parameters can be easily measured by optical measurement systems.

3 Mechanical processing methods for edge preparation

Mechanical processing methods (MPMs) for cutting edge preparation are driven by mechanical action. As shown in Fig. 12 [12,28], the common mechanical cutting edge preparation methods are grinding (G) [29–36], brushing (B) [37–45], drag finishing (DF) [43–55], abrasive jet machining (AJM) [17,43–45,56–67], abrasive flow machining (AFM) [11,43,68–70], vibration machining (VM) [71,72], and shear thickening polishing (STP) [28,73–77], each conveying the basic principles of edge preparation.

3.1 Grinding

In the grinding preparation of a tool edge (Fig. 13) [29], the microdefects of the edge are removed, and the ideal edge shape is obtained using the grinding wheel to regrind the formed tool edge [29–36]. This method is the most primitive edge preparation method; it uses oilstone to regrind manually the cutting edge of the tool, with the process guided by experience. Grinding has the disadvantages of low efficiency, poor effect, and poor controllability. In tool production, the tool edge is prepared using a grinding wheel controlled by machine tools.

Compared with the conventional grinding process for the chamfer edge, a much more complex grinding process is required for the round edge. Denkena et al. [31] proposed a method to form a rounded edge by grinding multiple overlapping chamfers on the edge. Figure 14 [31] shows the operation of this method. On the *X*-axis, the edge comes into contact with the grinding wheel. Then,

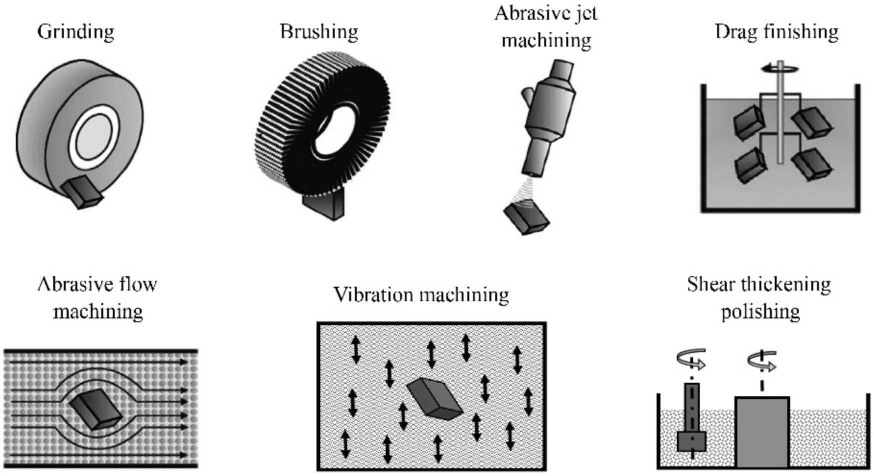


Fig. 12 Mechanical processing methods for edge preparation [12,28]. Reproduced with permissions from Refs. [12,28] from Elsevier.

the *B*-axis rotates to align the cutting edge with the grinding wheel. The *C*-axis rotation causes the grinding wheel to chamfer the edge several times to form a rounded edge. After regrinding the edges of the cemented carbide inserts, the cutting edge radius reaches a maximum of 15 μm under continuous contouring. However, the prepared cutting edge still has obvious chamfering characteristics. The grinding wheels used for processing need to be built from more flexible materials to achieve a complete round cutting edge preparation. Ventura et al. [32] used this method to prepare the cutting edge of polycrystalline cubic boron nitride (PCBN) inserts and proved in cutting experiments that the method can effectively increase the tool life and compressive residual stresses.

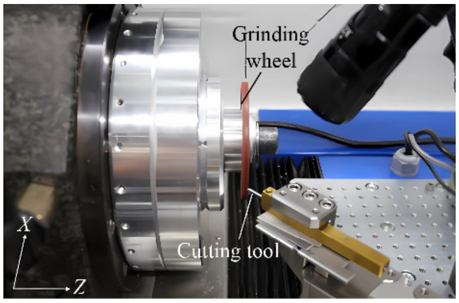


Fig. 13 Cutting edge preparation by grinding [29]. Reproduced under the terms of the CC BY license.

Effgen and Kirsch [33] and Aurich et al. [34] presented a novel approach for rounded cutting edge preparation by using elastic bonded superabrasive grinding wheels. Figure 15 [34] illustrates the action of this grinding wheel. As the grinding wheel material is viscoelastic, edge materials are removed when the cutting edge comes into contact with the grinding wheel and reaches enough mechanical preload. Furthermore, the prepared cutting edge has a smooth and continuous arc. Elastic bonded superabrasive grinding wheels can also round the chamfered edge. When machining asymmetric chamfering cutting edges, the adhesive material easily accumulates on both sides of the edge surface to form an asymmetric rounded edge. Under the same conditions, the maximum cutting edge radius can be obtained by grinding a symmetrical chamfered edge.

Aiming to investigate the influence of grinding depth (the depth of the edge embedded in the grinding wheel during grinding) and grinding wheel hardness on grinding wheel wear and edge preparation, Hartig et al. [35] used two kinds of elastically bonded superabrasive grinding wheels with bonding material hardnesses of 70 and 80

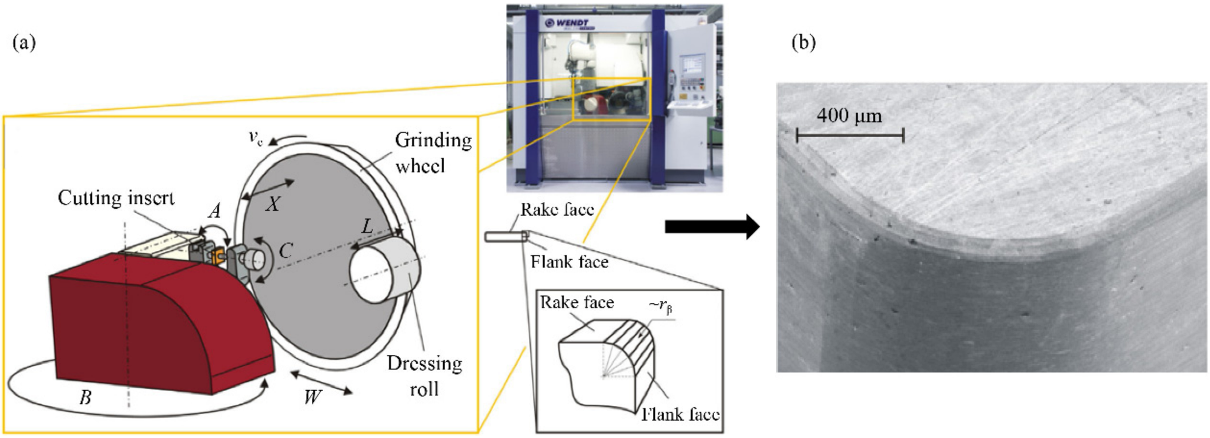


Fig. 14 Customized cutting edge preparation by grinding [31]: (a) machining principle and (b) micromorphology of the prepared edge. Reproduced with permission from Elsevier.

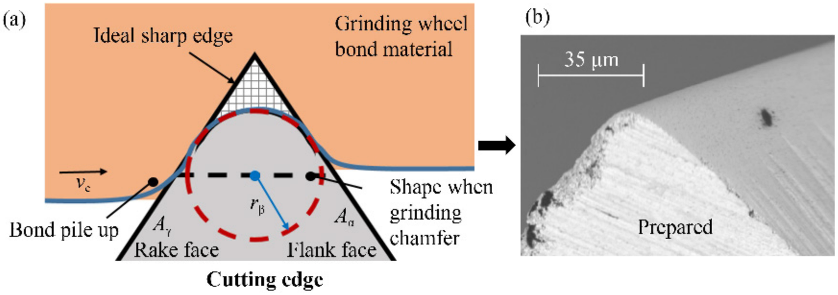


Fig. 15 Cutting edge preparation by elastic bonded superabrasive grinding wheels [34]: (a) material removal mechanism and (b) micromorphology of the prepared edge. Reproduced with permission from Elsevier.

SHA to prepare the edge of cemented carbide indexable inserts. Compared with the harder grinding wheel (80 SHA), the softer grinding wheel (70 SHA) has higher radial wear at smaller grinding depths (20 and 40 μm), but the prepared edge shape has better repeatability under this processing condition. Then, grinding wheels under different degrees of aging treatment were used in the cutting edge preparation experiments [36]. The purpose was to uncover the interaction of oil-based metalworking fluids and grinding wheels to ensure wheel performance and the effect of cutting edge preparation. They found that the aging treatment increases the diameter, thickness, and weight of the grinding wheel, reduces the hardness, and deteriorates the circular accuracy. These conditions further result in a decrease in the removal ability of the grinding wheel to the edge material. Hence, the grinding wheel used for cutting edge preparation should be preserved under dry conditions.

The advantage of the grinding process is that the complete edge microgeometry can be processed by installing the tool once [12]. However, surface burning easily occurs during processing, which deteriorates the surface quality of the cutting edge. The grinding process is limited to the edge preparation of small batch tools with a simple edge shape.

3.2 Brushing

The brushing process allows for the removal of the edge material by scraping the surface with an abrasive brush [37–45]. The brush tool has bristles and thin filaments extruded with polymer fibers, such as nylon or metal filaments, containing abrasive materials [12].

Bassett et al. [3] explored the change in edge morphology during the material removal process by observing three different wear stages of the brush fiber. As illustrated in Fig. 16 [3], after a short period of rapid wear, the brush fiber enters the slow wear period; the shape of the edge prepared at this stage has good consistency. Once the brush fails after reaching its fatigue cycle, the abrasive brush needs to be replaced. Two types of brushes (horizontal roller brushes and vertical disc brushes) can be used to prepare rounded or chamfered edges [38,39].

Denkena et al. [40,41] introduced a five-axis brushing process to produce tailored cutting edge microgeometries. Figure 17(b) shows the machining principle of this method, including the movement mode of the brushing tool and the adjustment mode of the cutting edge position angle in the machining process. This scheme can help to identify various symmetrical ($K = 1$) and asymmetrical ($K > 1$ or $K < 1$) cutting edge preparation techniques by flexibly controlling the brush moving path and the cutting edge position angle. Nevertheless, the high control requirements of the processing equipment limit its ability to prepare tool edges in batches.

Bergs et al. [42] used high-temperature resistant brushing tools with filament-integrated diamond grits to replace the grinding wheels of a five-axis computer numerical control grinder for cutting edge preparation experiments (Fig. 18). Uniform cutting edge radii were processed on the complex cutting edges of rotary tools, including cemented carbide drills. Various symmetrical and asymmetrical cutting edges can be processed by controlling the process parameters, such as the cutting speed, feed rate, and lateral feed depth. This method is also suitable for the cutting edge preparation of small-size tools, but it cannot remove the initial grinding marks on the rake and flank faces of tools.

The brushing process has high processing efficiency and is suitable for the batch preparation of different cutting edges; hence, it is commonly used in tool factories. However, brushing easily leads to defects, such as chipping and scratching on the tool surface, resulting in poor surface quality of the prepared tool. Overall,

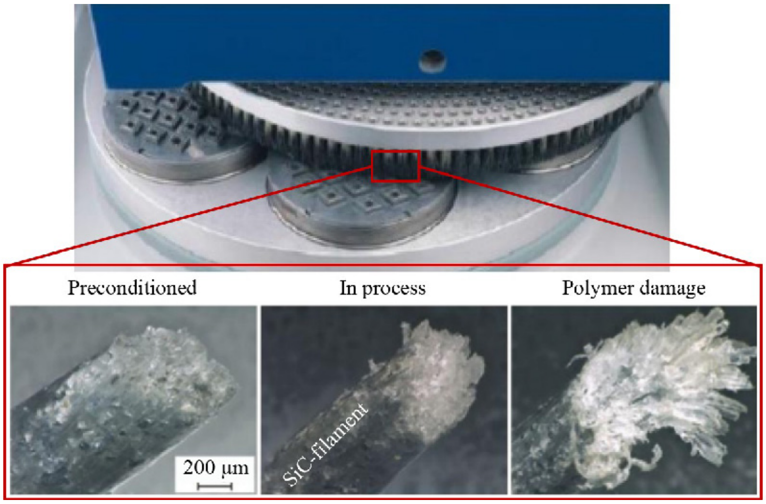


Fig. 16 Brush equipment and wear process of brush fiber during cutting edge preparation [3], reproduced with permission from Elsevier.

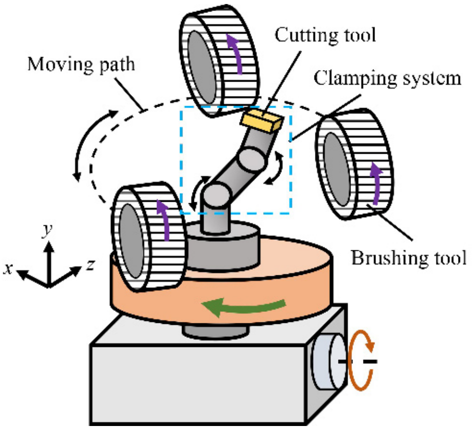


Fig. 17 Five-axis brushing process.

brushing can hardly meet the requirements of edge preparation of some precision tools.

3.3 Drag finishing

Drag finishing, also known as vertical rotary machining or immersed tumbling [44], is a machining method that allows tools to rotate in two-stage planetary motion in mixed abrasives during cutting edge preparation (Fig. 19) [43–55]. During this process, the abrasive removes the edge material by continuously scratching and impacting the edge to obtain a cutting edge with a certain shape.

To study the influence law of process parameters on the cutting edge radius, Peter et al. [50] implemented a drag finishing experiment of cemented carbide milling cutters. The result proves that the cutting edge radius was mainly affected by the spindle speed. With the increase in spindle speed, the difference between the cutting edge radius measured on the rake face and the helical face (flank face) reached 15–16 μm. Thus, the symmetry of the cutting edge gradually weakens with increasing spindle speed. Similar results were reported by Zhao et al. [51], who utilized EDEM, a discrete element software, to simulate the drag finishing process of an end-mill. Given the erosion of the abrasive particles, the tangential cumulative energy and the normal cumulative energy of the edge increase with increasing spindle speed. Moreover, the normal cumulative energy and the wear amount of the rake face are always greater than those of the flank face. These phenomena can explain the formation of the asymmetric edge.

Lv et al. [52] compared the edge preparation effect of four abrasive media from the aspects of material removal rate, edge shape, and surface morphology. The edge radius of the solid carbide end-mills increased from 3 to 15 μm in 20 min of processing under the optimal abrasive medium. The influence of drag finishing process parameters, such as drag depth, drag time, abrasive mixing ratio, and abrasive size, on the edge radius of a broaching tool was studied by Pérez-Salinas et al. [53]. The cutting edge radius showed a nonlinear incremental relationship with processing time, abrasive particle size, and drag depth.

Zou et al. [54] proposed an ultrasonic vibration drag finishing method to prepare the edges of flat end-mills. The ultrasonic vibration device (Fig. 20) increased the cumulative energy of the edge during the machining process after using a certain high-frequency ultrasonic vibration. This scheme improved the machining efficiency and edge consistency after edge preparation to a certain extent.

A gas–solid two-phase flow abrasive cutting edge preparation method based on drag finishing was introduced by Yuan et al. [55]. Figure 21 illustrates the processing principle. Regarding tool performance, in the two-stage planetary motion of the abrasive particles, the airflow enters from the bottom of the abrasive barrel to drive the abrasive particles to move cyclically. This configuration can increase the impact frequency of the abrasive particles on the edge, and the edge material is removed rapidly under the continuous impact of the solid abrasive particles. This process enhances the edge preparation efficiency to a certain extent, but it cannot

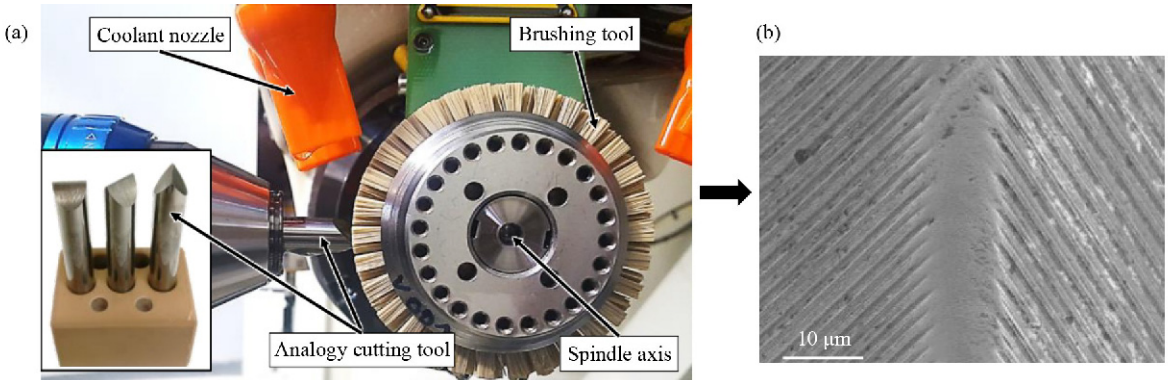


Fig. 18 Cutting edge preparation using brushing tools with filament-integrated diamond grits [42]: (a) machining equipment and (b) micromorphology of the prepared edge. Reproduced under the terms of the CC BY NC ND license.

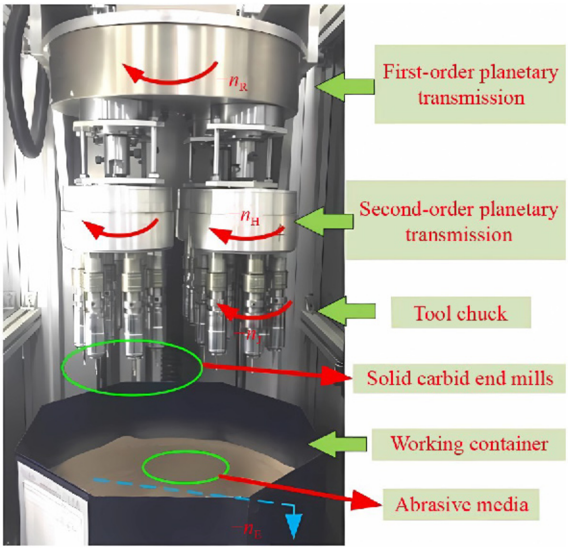


Fig. 19 Drag finishing equipment for cutting edge preparation [52], reproduced under the terms of CC BY license.

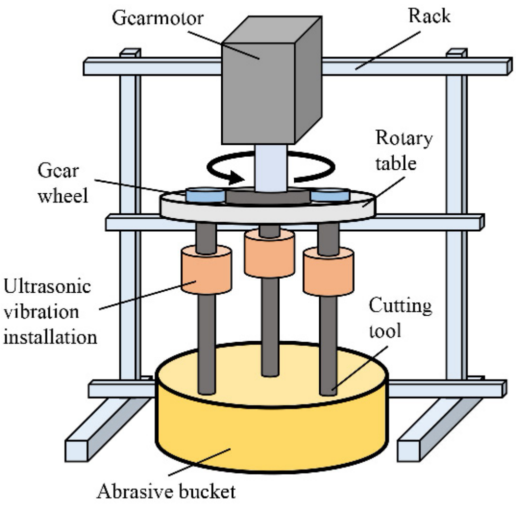


Fig. 20 Preparation of the cutting edge by ultrasonic vibration drag finishing.

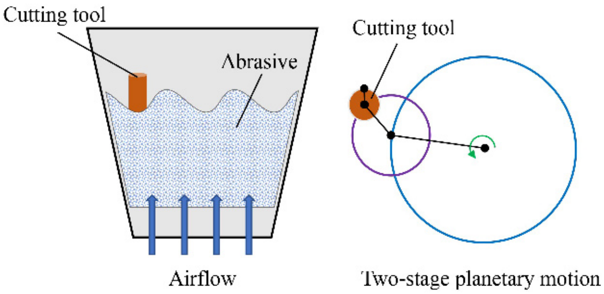


Fig. 21 Schematic of gas–solid two-phase flow abrasive machining.

improve the surface quality and edge consistency of the prepared edge.

Drag finishing has the advantages of low machining cost and high machining efficiency and can be used for batch-cutting edge preparation of rotary tools with complex cutting edges. For these reasons, drag finishing is currently used by tool manufacturers for the batch-cutting edge preparation of tools. The problems of high mechanical force and poor axial consistency of the edge in the machining process are urgent problems to be solved in the current research on edge drag finishing.

3.4 Abrasive jet machining

Abrasive jet machining (Fig. 22) is an edge preparation process that uses compressed fluid to mix abrasive particles to form a high-speed jet beam and sprays the tool edge at a certain angle to remove the edge material [43–45,56–67]. Abrasive jet machining is mainly categorized as abrasive blasting and abrasive water jet machining.

Fig. 22 Abrasive jet machining process [57], reproduced under the terms of CC BY license.

Abrasive blasting, including dry and wet abrasive blasting, is driven by compressed air. A small amount of water is added to the compressed air in wet abrasive blasting to prevent dust from flying. On the basis of the cutting edge shape data obtained after wet abrasive machining, Tiffe et al. [58] predicted the optimal edge shape of cutting tools with minimum wear in the cutting process by using finite elements to simulate the chip formation process. In drilling experiments on a GGG40 cast iron material with unprepared and wet abrasive blasted cemented carbide single reamers, Voina et al. [59] found that the wear resistance of the cutting edge was significantly improved after preparation. Furthermore, Krebs et al. [60] applied the wet abrasive jet machining method to prepare a micromilling tool edge with a diameter of less than 1 mm. The burrs of the cutting edge were removed to form the minimum edge radius after approximately 2 s of processing. This finding proves the feasibility of wet abrasive jet machining in the batch preparation of microtool edges.

To realize the specific design of the microgeometry of the cutting edge, Biermann et al. [61] used an industrial robot to control the nozzle and perform wet abrasive

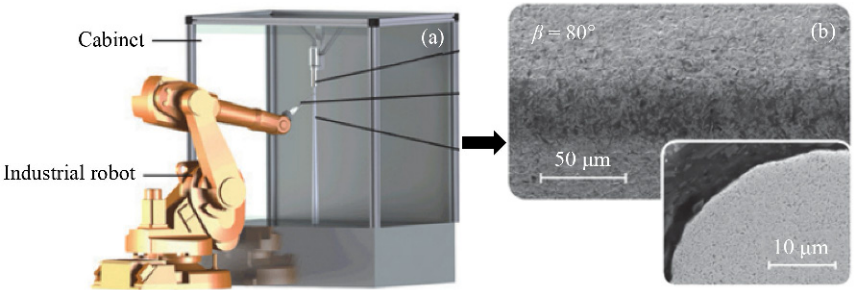


Fig. 23 Cutting edge preparation by an industrial robot guided nozzle [61]: (a) machining principle and (b) micromorphology of the prepared edge. Reproduced under the terms of the CC BY NC ND license.

machining on the cutting edge of a cemented carbide tool (Fig. 23). The method could achieve the preparation of specific shape cutting edges. The injection angle and injection pressure were the main influencing factors of the form factor *K* and the cutting edge radius. However, the poor surface quality of the cutting edge after processing and the poor batch processing ability limits the application of this method in cutting edge preparation for high-performance tools.

The excessive impact of abrasive particles in jet machining is accompanied by brittle fractures and subsurface damage of the tool surface materials. The flexible abrasive jet polishing method proposed by Shi et al [62]. can efficaciously reduce the probability of edge damage during machining. The abrasive particles are embedded into the surface of the flexible matrix to form a composite abrasive particle with vibration absorption. Composite abrasive particles are used to spray the rotating two-edged carbide spiral end-milling cutter. The surface grinding marks and microchips of the tool are removed after processing, and the excessive impact energy of the tool surface is absorbed by the composite abrasive matrix prior to preparing the cutting edge without damage.

Similarly, the SIRIUS-Z series edge polishing equipment developed by FUJI Research Institute of Japan uses the elastic abrasive blasting method to process the edge in a point-to-point manner [63,64]. Figure 24 illustrates the elasticity of the abrasive matrix material. The matrix has a buffer process when it impacts the cutting edge surface, allowing the prepared cutting edge to be almost free of damage. The abrasive recovers its shape after leaving the cutting edge and can be recycled, but implementing the process is extremely expensive.

In contrast to traditional abrasive blasting technologies, abrasive blasting using micron-sized abrasives, also called microabrasive blasting [79], has been developed. This method has good application prospects in tool edge preparation [17,65,66]. Zhang et al. [17] performed a cutting edge jet machining experiment on KT15 cemented carbide inserts by using micron-sized white corundum abrasives (Fig. 25). The removal mechanism of cutting edge materials in microabrasive blasting and the influence of different process parameters on the results of cutting edge preparation were systematically studied. The removal of cutting edge materials mainly relied on the impact of abrasives and microcutting. In this scheme, the surface materials are continuously broken and removed to form a round edge.

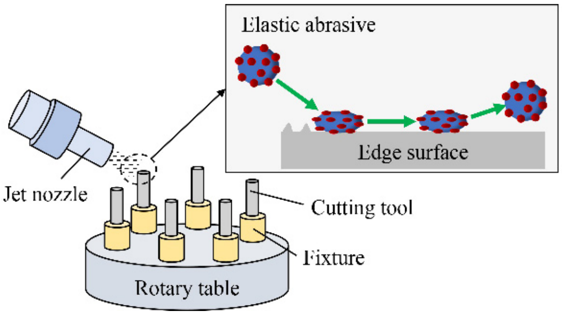


Fig. 24 Preparation of the cutting edge by elastic abrasive blasting.

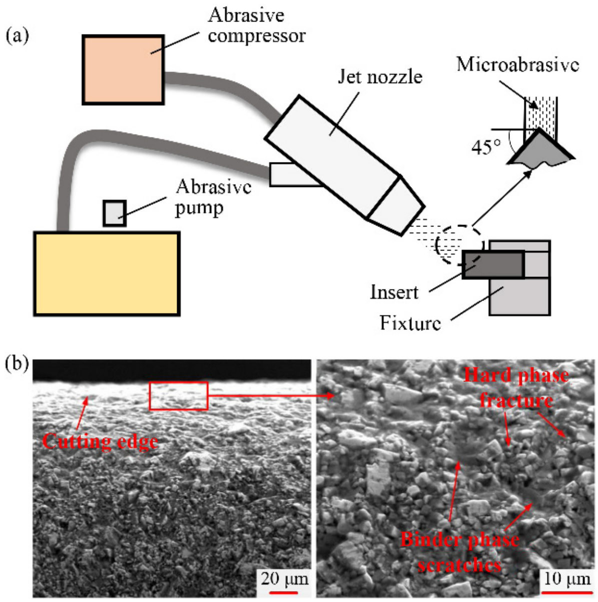


Fig. 25 Preparation of the cemented carbide insert edge by microabrasive blasting [17]: (a) machining principle and (b) micromorphology of the prepared edge. Reproduced under the terms of CC BY license.

Abrasive water jet machining is a jet machining method in which high-pressure water flow is used as an abrasive carrier [77]. The removal of the cutting edge material is mainly caused by the impact of erosion of the high-speed abrasive jet on the surface of the edge. A micron-sized abrasive was used by Yang et al. [67] in the abrasive water jet machining of a coated carbide insert edge (Fig. 26). The nozzle shape was transformed from a traditional circular nozzle to a rectangular nozzle, allowing a more appropriate jet area to be obtained. The removal of the surface coating ripple of the tool during processing and the formation of a round edge prove the feasibility of this method in the edge preparation of cutting tools.

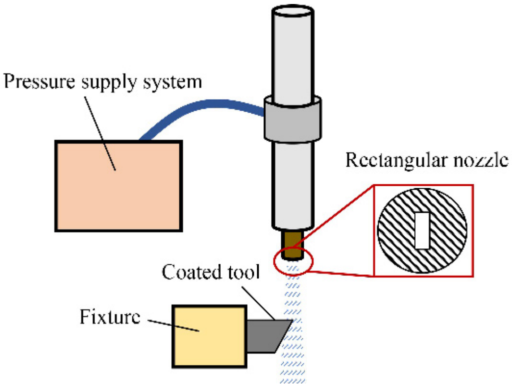


Fig. 26 Preparation of the coated tool edge by rectangular nozzle abrasive water jet machining.

Abrasive jet machining is also commonly used for the batch processing of various types of tools owing to its simple equipment, flexible process, and low cost. However, the process parameters that need to be controlled in this process are risky for the cutting edge shape customization process. Compared with general abrasive jet machining methods, microabrasive blasting and elastic abrasive blasting are more effective approaches to improve the quality of edge preparation of cutting tools. Elastic abrasive blasting is also a current research hotspot. However, only a few studies apply the abrasive waterjet machining method for cutting edge preparation. The effect of this method on cutting edge preparation also needs to be further verified.

3.5 Abrasive flow machining

Abrasive flow machining uses a high-viscosity polymer fluid that carries abrasive particles to finish the workpiece surface in enclosed and pressurized environments [79]. As shown in Fig. 27, material removal on the surface of the processing object occurs while the fluid flows alternately along the work surface under appropriate pressure and temperature. In addition to deburring, polishing, and chamfering of the inner contour surface of mechanical parts [80], the application of abrasive flow machining includes the surface polishing and edge preparation of cutting tools [11,43,68–69].

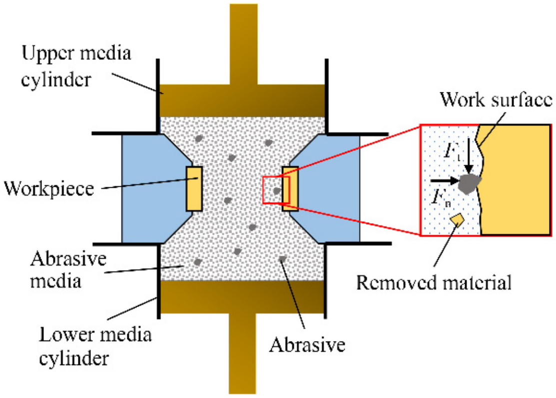


Fig. 27 Schematic of the material removal mechanism in abrasive flow machining.

Tang et al. [68] implemented a method that could rotate a tool in a closed channel during abrasive flow machining (Fig. 28). The rotation motion of the tool increases the contact frequency between the abrasive particles and the tool surface. At this time, the abrasive particles move randomly on the tool surface, removing the surface material efficiently and evenly. After the deep-hole drill is processed for approximately 30 min, the grinding marks and serrated chippings on the surface are removed to form a well-consistent round edge. However, the influence law of different rotation directions and speeds on the shape of the cutting edge and processing efficiency of using this method needs to be further explored.

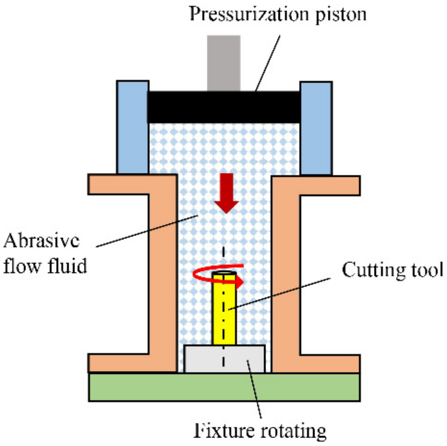


Fig. 28 Preparation of the cutting edge by tool rotation abrasive flow.

Combining abrasive flow machining and drag finishing, a tool rotary abrasive flow polishing (R-AFP) method was proposed by Gao et al. [69]. Two new viscoelastic abrasive media [80], WS and GC, were used for the rotary abrasive flow polishing of a high-speed steel tap (Fig. 29). Multistation-rotating abrasive flow polishing

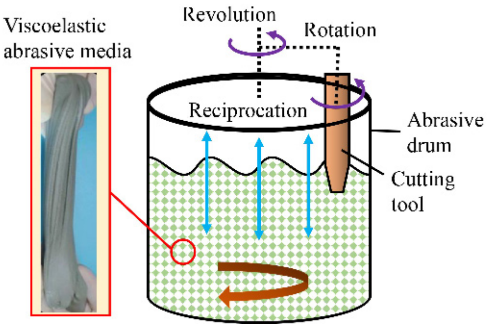


Fig. 29 Tool edge preparation by rotating abrasive flow polishing. The viscoelastic abrasive media (left part) is reprinted with permission from Ref. [80] from Elsevier.

equipment was developed to achieve high-quality and efficient preparation. This new machine can drag the tool into the viscoelastic abrasive flow. The processing is divided into three steps (rough, semifinish, and finish), but they can be performed simultaneously. Under the optimized parameters, the tool surface roughness was reduced from 0.73 to 0.26 μm in 2 min, and the edge radius was controlled within 5 μm.

In abrasive flow machining, the tool surface can be in complete contact with the abrasive. This method is highly suitable for preparing tool edges with complex shapes. Abrasive flow machining has the advantage of low machining cost, but its cutting edge preparation efficiency is low. The tool (R-AFP) method can improve the edge preparation efficiency in abrasive flow machining, but the surface quality of the edge in this method should still be improved.

3.6 Vibration machining

Vibration machining for cutting edge preparation can be employed via high-stress collision between the tool and the abrasive to remove the most vulnerable part of a material at the cutting edge [54,70,71]. In this scheme, a tool is placed into a container filled with abrasives, and vibration is applied at a certain amplitude and frequency. The vibration frequency and fixture method are the main influencing factors of the edge preparation effect.

Wang et al. [71] studied the influence of process parameters, such as the clamping method, abrasive particle size, and processing time, on the edge preparation effect in a vibration processing experiment of a cemented carbide insert edge (Fig. 30). The notch at the edge was significantly reduced after preparation. The edge radius increased with increasing abrasive particle size and processing time. Free clamping helped to improve the edge consistency.

Vibration machining and drag finishing can be processed in dry abrasive environments, and both methods are suitable for combining different cutting edge preparation methods of a tool. For example, the edge preparation method proposed by Zou et al. [54] combined ultrasonic vibration with drag finishing to improve the efficiency and consistency of cutting edge preparation. The combination of vibration machining and other processing methods (except DF) may also obtain better processing effects compared with that of a single processing method. More attempts and studies are expected in this aspect.

Vibration processing equipment was the mainstream processing equipment for cutting edge preparation in the 1970s. Vibration machining offers the benefits of low cost, simple equipment, and high processing efficiency; it can also effectively reduce the residual stress on tool surfaces. However, the continuous random collision between the abrasive and the tool could easily damage the tool surface. This issue can explain why this method was rarely applied to the edge preparation of precision tools. This processing method is commonly used by tool manufacturers to prepare tool edges in batches, but it has rarely appeared in the research of edge preparation in the last ten years.

3.7 Shear thickening polishing

Shear thickening polishing is a new flexible finishing method for curved surface polishing that relies on the shear thickening effect of non-Newtonian fluids [81,82]. The principle of this process is illustrated in Fig. 31. The non-Newtonian power fluid is used as the matrix to mix the abrasive particles with other auxiliary media to form

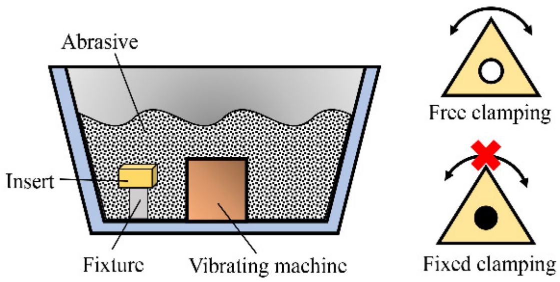


Fig. 30 Preparation of the cemented carbide insert edge by vibration machining.

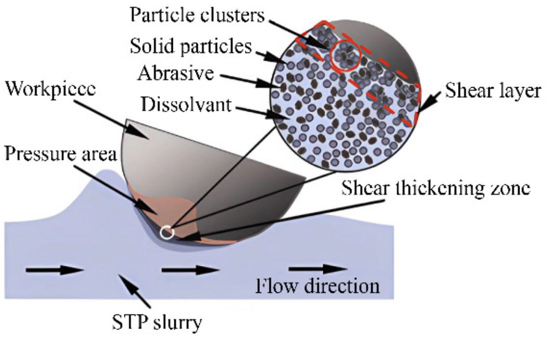


Fig. 31 Principle of shear thickening polishing (STP) [81], reproduced with permission from Elsevier.

the shear thickening polishing fluid. The viscosity of the matrix rises sharply because of the occurrence of the shear effect when the polishing fluid moves relative to the workpiece. At this moment, the dispersed abrasive particles in the polishing fluid are aggregated and form “flexible fixed abrasive tools” to continuously microcut the workpiece surface, eventually achieving precision finishing of the workpiece surface. Span et al. [28] applied the shear thickening polishing method in the edge preparation test of high-speed steel blades. After 5 min of processing, the edge radius increased from 5 to 39 µm, proving the effectiveness of the method in tool edge preparation.

Lyu et al. [72] further applied the shear thickening polishing method to the finishing of the complex cutting edges of a tool (Fig. 32). Under optimized process parameters, the surface roughness *Ra* of the cemented carbide thread tool with V-shaped tooth characteristics was reduced to < 10 nm after polishing for 15 min. However, when this method was used to polish the cemented carbide comb cutter with U-groove characteristics, the surface defects of the tool groove could hardly be removed due to the blockage of the polishing liquid at the multiedge gap. This issue was addressed by introducing a brush tool-assisted shear thickening polishing method to polish the thread comb cutter [73]. As shown in Fig. 33, the brushes drive the polishing fluid to smoothly enter and exit the comb tooth gap, allowing the surface between the teeth to be efficiently polished. Lyu et al. [72,73] proved the feasibility of the shear thickening polishing method in the finishing of complex tool edges, but the changes in the radius and shape of cutting tool edges were not considered in the finishing process. Subsequently, experiments on the edge preparation of cemented carbide inserts by flexible fiber-assisted shear thickening polishing were conducted by Shao et al. [74],

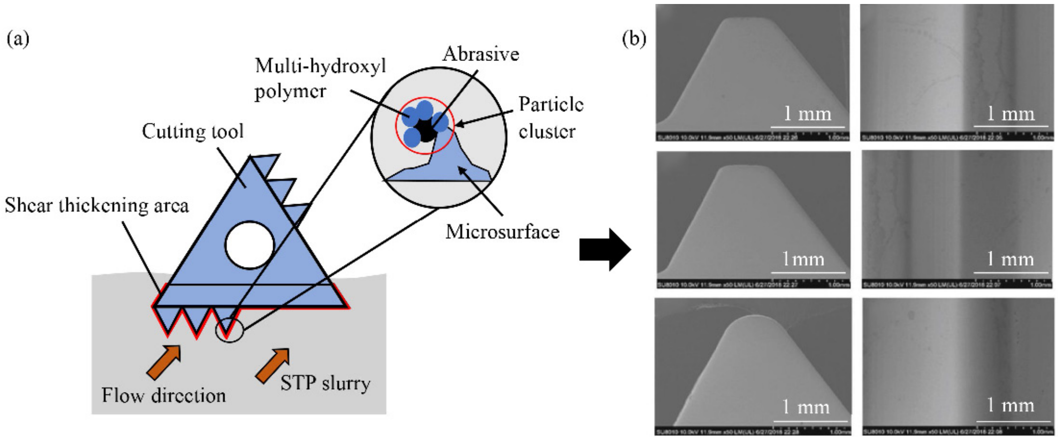


Fig. 32 Shear thickening polishing (STP) of a complex shape tool [72]: (a) processing mechanism and (b) micromorphology of the prepared edge. Reproduced with permission from Springer Nature.

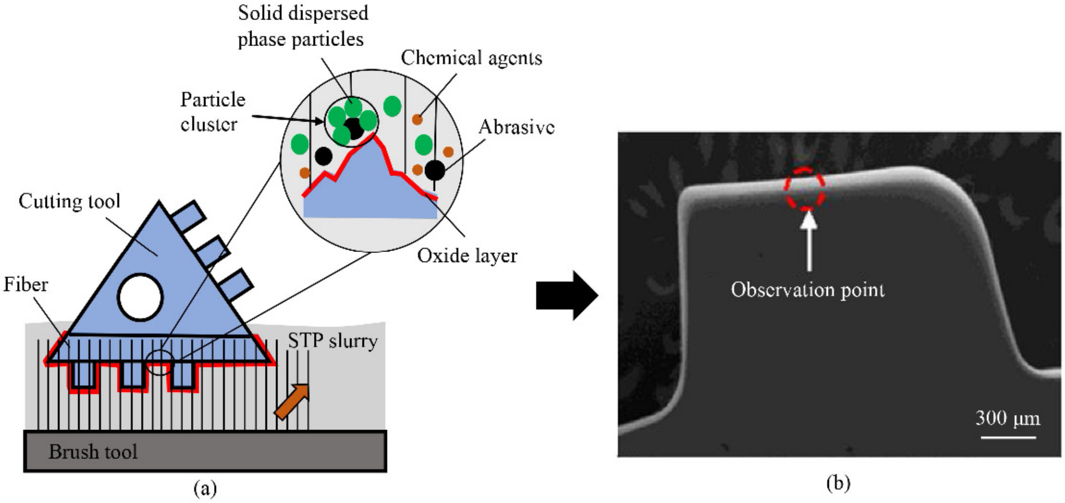


Fig. 33 Brush tool-assisted shear thickening polishing (STP) of a tool with a complex shape [73]: (a) processing mechanism and (b) micromorphology of the prepared edge. Reproduced with permission from Springer Nature.

and the influence of the polishing speed and polishing angle on the edge preparation results was investigated. The polishing speed mainly affected the increase rate of the edge radius, and the polishing angle functioned as the key influencing factor of the edge shape. This method was also used to prepare the cutting edge of core drills. The experimental results showed that the cutting edge radius r = 14 μm had the best cutting heat load distribution [75].

Chan and Koshy [76] used the shear thickening polishing method to prepare the cutting edges of high-speed steel inserts and twist drills, cemented carbide ball-nosed inserts, and cemented carbide conical spiral end-milling cutters. After processing, the cutting edges of different tools formed varying rounded shapes. Considerable removal of the cutting edge material occurred only when the polishing fluid flow and the tool rotation occurred simultaneously. The change in shape of the cutting edge was primarily caused by the changing trend of the tool rotation.

The shear thickening polishing method has the advantages of simple processing and low processing cost. In contrast to other cutting edge preparation schemes, the cutting tool in this method can achieve ultrahigh surface quality. With the help of tools such as brushes and flexible fibers, the complex edges of cutting tools can be prepared, and the efficiency of edge preparation can be improved. This method has great application potential in tool edge preparation.

3.8 Others

In addition to the abovementioned typical mechanical cutting edge preparation methods, researchers have also applied other surface finishing methods to the study of tool edge preparation [83–86].

In the case of ultrahard material tools, such as cubic boron nitrification (CBN) tools, ultrahigh hardness and traditional mechanical processing methods can hardly remove the edge materials of tools. Kuruc et al. [83,84] prepared a CBN cutting edge tool by rotary ultrasonic machining, through which round and chamfer edges can be prepared. However, given the low machining accuracy of this method, the feasibility of customizing edge shapes needs to be further studied and verified.

The hard-grinding wheel grinding tool edge easily causes secondary damage to the tool edge. Yao [85] proposed a method of using a flexible polishing pad as an abrasive tool to prepare the cutting edge. The processing principle is shown in Fig. 34. The tool is constantly swayed around the center of the circular arc of the tool tip, and part of the edge is in contact with the soft damping cloth polishing pad pasted on the high-speed rotating grinding disc. The edge material is continuously removed during the contact process to form the round edge. Abrasives may also be added to the polishing pad to further improve the efficiency of edge preparation processing. However, this method can only be used for the edge preparation of cutting tools with simple shapes.

Denkena et al. [86] proposed a new method for preparing tool edges by using flexible diamond tools. As shown in Fig. 35, the polishing tool is an impeller with diamond abrasives embedded in plastic blades. The polishing tool is controlled by a five-axis linkage machine tool so that it is parallel to the tool edge. Various symmetrical and asymmetrical edges can be obtained by

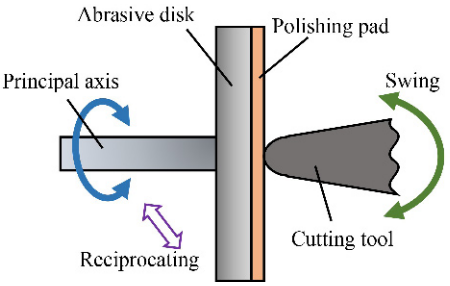


Fig. 34 Flexible polishing pad as a machining tool to prepare the cutting edge: (a) processing principle and (b) micromorphology of the prepared edge.

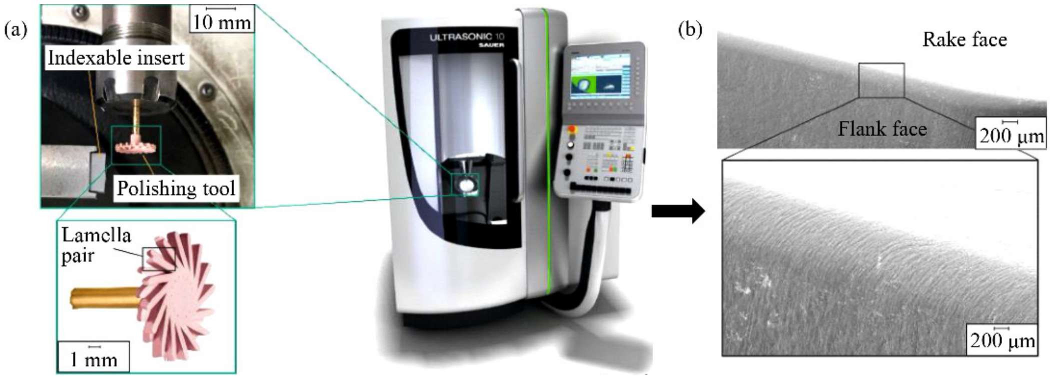


Fig. 35 Cutting edge preparation with flexible diamond tools [86]: (a) processing principle and (b) micromorphology of the prepared edge. Reproduced under the terms of CC BY NC ND license.

changing the angle between the polishing tool and the indexable insert during polishing, but the surface quality of the edge is poor after processing. The scheme is also unsuitable for preparing tool edges with complex shapes. The polishing tool tends to wear continuously during the machining process, resulting in poor machining repeatability of the edge.

4 Nontraditional processing methods for edge preparation

Nontraditional processing methods (NPMs) for edge preparation use light, electric, or magnetic energy in addition to mechanical energy to prepare the cutting edge with the melting, dissolving, or evaporating effect. Figure 36 [12] shows the main nontraditional cutting edge preparation methods, including magnetic abrasive machining (MAM) [43–44,87–94], laser machining (LM) [11,43,95–99], electrochemical machining (EM) [100–103], and electrical discharge machining (EDM) [104–106].

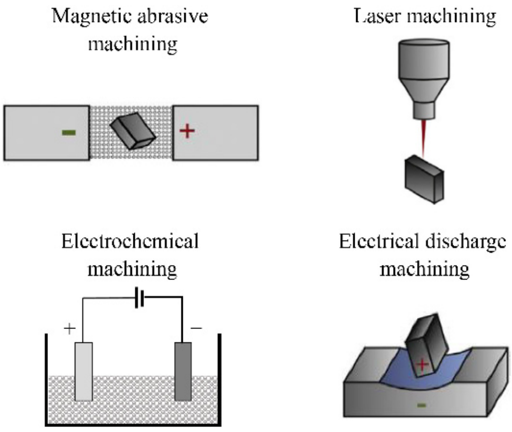


Fig. 36 Nontraditional processing methods for edge preparation [12], reproduced with permission from Elsevier.

4.1 Magnetic abrasive machining

Magnetic abrasive machining uses a magnetic field to drive abrasive to finish the surface of parts. The availability of this method in the edge preparation of cutting tools has been proven in the literature [43–44,87–94]. Figure 37 [43] shows the magnetic abrasive processing equipment. The magnetic abrasives filled in the magnetic field are arranged along the direction of the magnetic field line under the action of a strong magnetic field, and an “abrasive brush” is formed on the magnetic pole. As the magnetic pole drives the “abrasive brush” to continuously scratch the tool surface, the material of the tool surface and cutting edge are gradually removed.

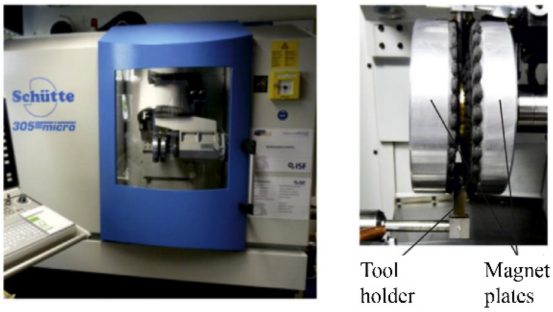


Fig. 37 Magnetic abrasive machining equipment [43], reproduced with permission from Elsevier.

Karpuschewski et al. [89] applied magnetic abrasive machining to the edge preparation of a high-speed steel twist drill. The surface quality of the tool was improved during processing, and a rounded edge with good repeatability and consistency was observed. In subsequent cutting experiments, the radius of the rounded edge served as the primary factor affecting the service life of the drill. Denkena et al. [90] found that magnetic abrasive particles continue to break up and form dense agglomerations during edge preparation. The irregular slip of magnetic abrasive particles on the cutting edge also deteriorates the consistency of the cutting edge. The movement of magnetic abrasive particles along the cutting edge improved the consistency of the cutting edge.

Yamaguchi et al. [91] used a magnetic field to control magnetic abrasive particles to finish the surface of triangular titanium alloy inserts. A hard and nonmagnetic material was used to manufacture the fixture. In the machining process, the tool edge was positioned lower than the fixture installation to ensure that the magnetic abrasive particles would concentrate in removing the tool surface material. Two kinds of magnetic materials (iron and steel) were mixed as abrasive particles for magnetic abrasive machining [92]. The results of polishing the titanium alloy tool surface showed that the best ratio of the two kinds of abrasive particles is 3:2. The average life of the tool after preparation was 1.5 times longer than that of the initial tool.

Zhao et al. [93] proposed a double-disk magnetic preparation method based on magnetic abrasive machining. The machining principle is shown in Fig. 38. Magnetic abrasive particles are adsorbed on both sides of the disk to form a flexible “abrasive brush.” The tool rotates between the two disks, and the rotation of both disks drives the “abrasive brush” to process the tool surface. Tool speed, disk spacing, and disk speed are the main factors influencing the edge shape. Magnetoelastic abrasives can also be introduced into the double-disk magnetic preparation. By embedding abrasives and magnetic media into the elastic polymer matrix material, two new types of composite magnetoelastic abrasives (silica gel-type and epoxy resin-type abrasives) can be produced. Compared with traditional magnetic abrasives, magnetoelastic abrasives can better improve the material removal rate and reduce the surface roughness of the cutting edge.

Magnetorheological finishing is a special magnetic abrasive machining method that uses magnetorheological fluid, inducing a rheological effect to polish the surface of the workpiece [107]. Guan et al. [94] proposed a novel controllable preparation method based on magnetorheological finishing and applied it to nonuniform cutting edges. Figure 39 illustrates the principle of this method. The tool is placed horizontally in the magnetorheological fluid and rotated. Then, the abrasive particles gather under the action of the magnetic field to form a flexible abrasive tool to grind the edge. However, the removal rates vary because of the different relative velocities and pressures at certain positions for the cutting edges. By adjusting the installation position of the tool and the magnetic field parameters, the nonuniform cutting edge can be controllably prepared.

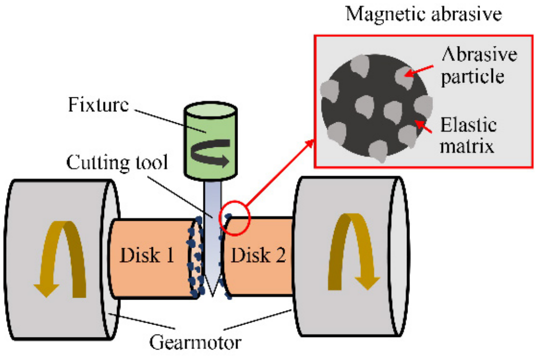


Fig. 38 Double-disk magnetic machining to prepare the cutting edge.

Magnetic abrasive machining is suitable for preparing the complex cutting edges of cutting tools. After processing, high surface quality can be obtained. However, apart from the high processing cost, the magnetic properties of abrasive particles continue to degrade during processing, resulting in a poor effect of edge preparation.

4.2 Laser machining

Laser machining for edge preparation (Fig. 40 [43]) can achieve the ideal edge shape by enabling the laser radiation to produce high heat on the tool surface and melt part of the edge material [11,43,95–99]. As laser ablation can accurately remove almost any material while maintaining a minimum thermal shock to the adjacent

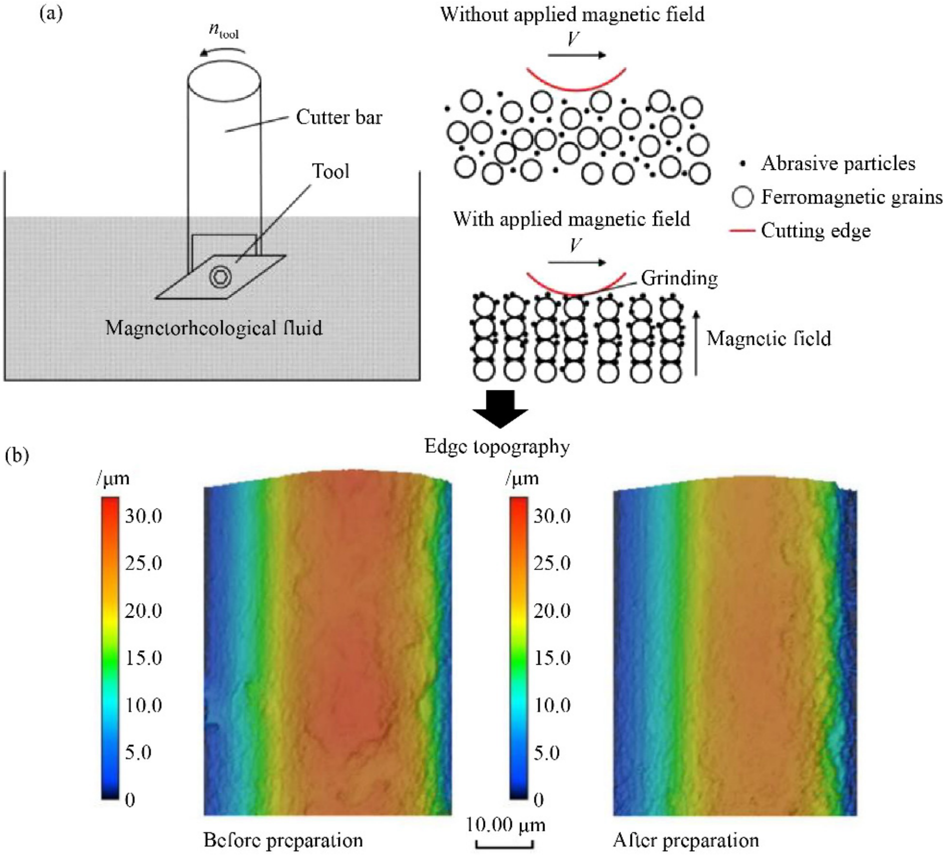


Fig. 39 Magnetorheological preparation for cutting edge [94]: (a) processing mechanism and (b) edge topography. Reproduced under the terms of CC BY license.

area and without tool wear, laser machining is suitable for preparing cutting edges of tools with any material.

Laser devices used to emit lasers can be divided into nanosecond laser devices and picosecond devices according to the pulse duration. Bouzakis et al. [66] performed a laser processing experiment on coated tools and found that a picosecond pulse and large tool feed speed can eliminate the negative effects of heat-affected zone thickness, material properties and adhesion on the service life of coated tools. Microblasting on the tool after laser processing can effectively enhance the adhesion of the coating. Zimmermann et al. [97] obtained results similar to those derived by Bouzakis et al. [66] when preparing cemented carbide-coated tool edges by laser processing. Their findings showed that the main influencing factor of the tool preparation effect is pulse time. As the processing duration of the picosecond pulse is shorter than that of the nanosecond pulse, the laser causes less damage to the tool surface material, and the laser does not extend to the nonprocessing area.

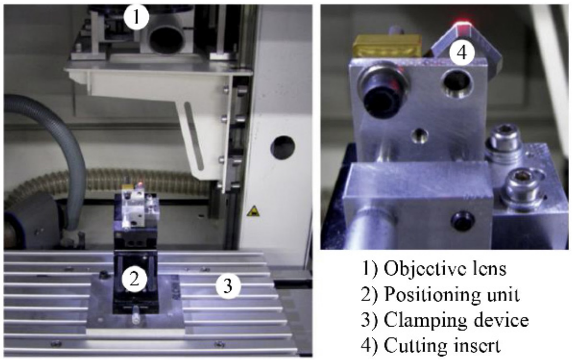
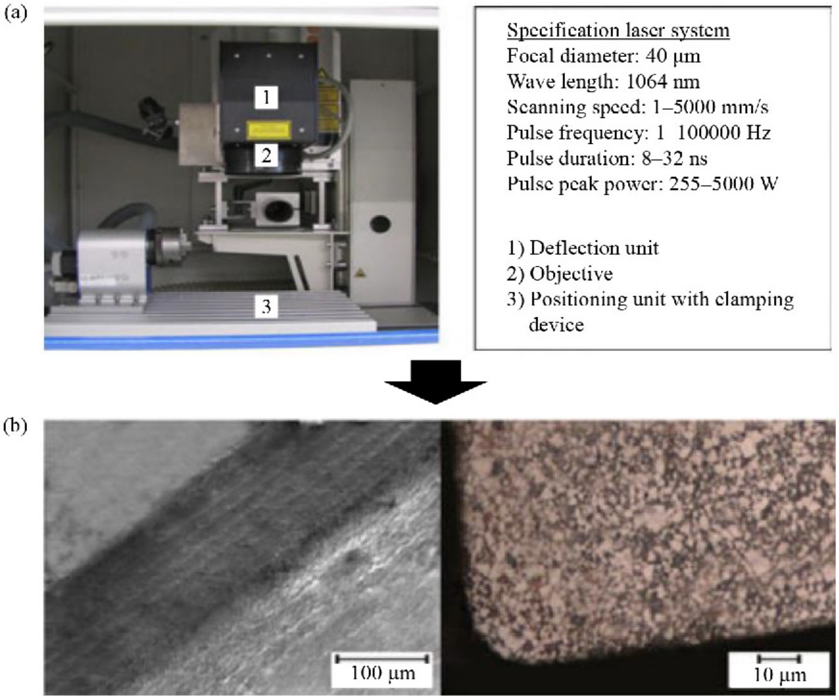


Fig. 40 Edge preparation by laser machining [43], reproduced with permission from Elsevier.

Laser emitting picosecond pulses are extremely expensive. Consequently, Aurich et al. [98] proposed a method of using a low-cost marker laser to prepare the tool edge. Figure 41 shows the processing equipment and the results of cutting edge preparation. The laser beam produced by the laser device has a Gaussian energy distribution on the spot diameter. This energy distribution ensures a smooth transition between the laser processing area and the nonlaser processing area. The ablation efficiency of the material is improved by the increased deposition energy per unit area, and the surface integrity of the edge is enhanced. In their work, the radius of the prepared edge was 9–47 μm, but the edge surface showed obvious burn marks.

Kang et al. [99] introduced a method of cutting edge preparation by jetting auxiliary gases (helium and oxygen) on the surface of tool edges in the laser irradiation process (Fig. 42). They found that the auxiliary gas had a negligible effect on the edge preparation of the cutting tools. The influence of process parameters on the effect of edge preparation in laser processing was also investigated. Under the optimal process parameters, a clear outline cutting edge with a surface roughness *Ra* of < 0.15 μm and a radius of 20–40 μm was obtained. However, the machining parameter setting was somewhat unreasonable,



Specification laser system
Focal diameter: 40 μm
Wave length: 1064 nm
Scanning speed: 1–5000 mm/s
Pulse frequency: 1 100000 Hz
Pulse duration: 8–32 ns
Pulse peak power: 255–5000 W

1) Deflection unit
2) Objective
3) Positioning unit with clamping device

Fig. 41 Cutting edge preparation by laser marking [98]: (a) processing equipment and (b) micromorphology of the prepared edge. Reproduced under the terms of CC BY license.

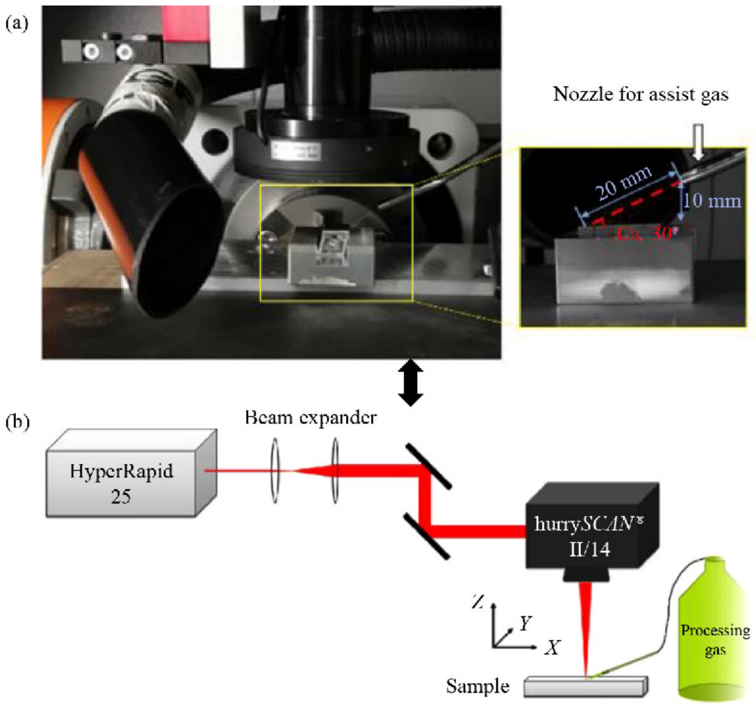


Fig. 42 Principle of cutting edge preparation by laser ablation with processing gas [99]: (a) processing equipment and (b) machining principle. Reproduced with permission from Laser Institute of America.

and the edge surface was prone to defects, including microholes.

Laser machining offers high processing efficiency in the preparation of tool edges, but it also causes surface burns on the edge and surface defects, such as microholes caused by different laser burning efficiencies of different materials on the edge. Thus, the tool to be used after laser processing needs to be processed at least once (i.e., blasting) to eliminate the influence of the surface metamorphic layer.

4.3 Electrochemical machining

Electrochemical machining, also known as electrolytic machining or electrolytic polishing, uses the cutting tool as the anode to match the corresponding cathode (usually graphite) in the preparation of the cutting edge [100–103]. Two electrodes are externally connected with direct current and placed in the electrolyte. As tip dissolution affects the anode metal, the tip of the cutting edge quickly dissolves to form a rounded corner in the removal of defects, such as burrs, on the edge surface [108]. The edge preparation of tools by electrochemical machining mainly includes two stages. In the first stage, the edge material dissolves to form a rounded corner due to the tip effect after the initial energization. In the second stage, when the edge fillet reaches a certain degree, the tip effect is weakened. At this time, the metal ions precipitated by the anode form a metal salt film at the edge to inhibit the continuous dissolution of the edge.

Li et al. [101] developed an electrolytic-abrasive cutting edge preparation process based on electrochemical machining. Figure 43 [101] shows the machining principle of this method. An oxide film forms first at the cutting edge during the electrolysis, and the high-speed flowing electrolyte is introduced at the cathode to drive the abrasive to scrape the oxide film to continue the electrolysis. Various shapes of cutting edges can be prepared by changing the position of the cutting edge. Combined with this method, a brushing–polishing machine is used to prepare the cutting edge of carbide cutting tools. Previous experimental results showed that the cobalt accumulation area is preferentially electrolyzed, resulting in micron-level corrosion micropits on the surface of the tool. The processing efficiency of this method is 2.3 times that of the brushing–polishing machine. However, the elements in the electrolyte remain in the micropits, indicating the need for the tool to undergo further surface cleaning after processing.

Vopát et al. [102] proposed a novel edge preparation method for using plasma discharge in an electrolyte. As shown in Fig. 44, the method entails electrolysis, and a plasma film with an air gap is added to the cutting edge of the tool. The ions in the electrolyte enter the air gap filled with the plasma film and replace the metal ions dissolved in the edge material of the tool, eventually replacing the metal ions in the electrolyte to achieve the ideal cutting edge shape. The plasma film is the key factor in this process, as it determines the size of the current during processing.

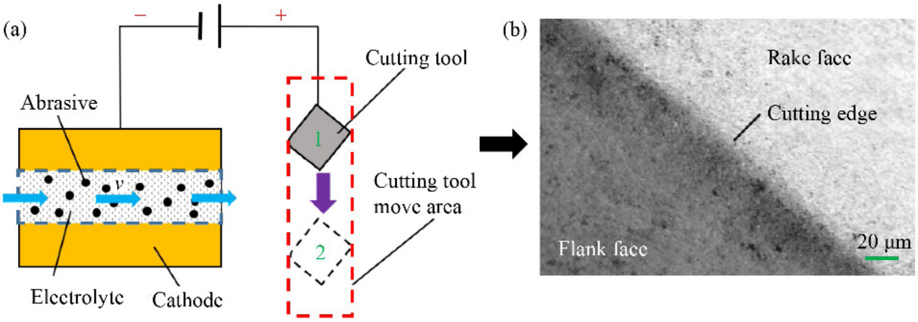


Fig. 43 Process of cutting edge preparation by electrolytic abrasion [101]: (a) machining principle and (b) micromorphology of the prepared edge. Reproduced under the terms of CC BY license.

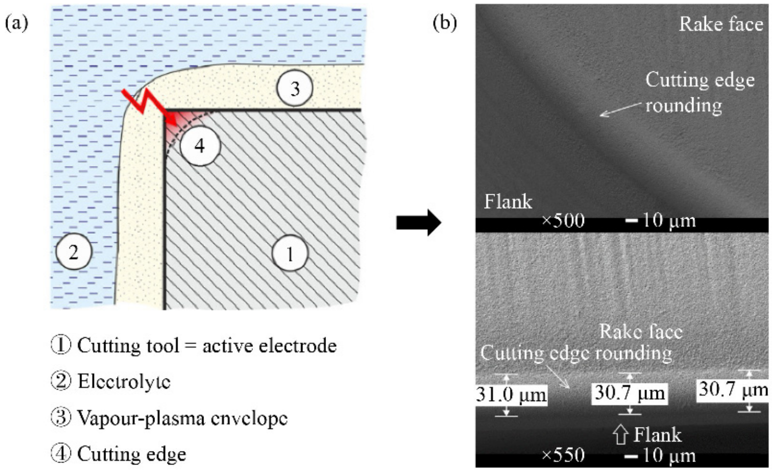


Fig. 44 Cutting edge preparation of cutting tools by using plasma discharges in electrolyte [102]: (a) machining principle and (b) micromorphology of the prepared edge. Reproduced with permission from Elsevier.

In the process of electrolytic machining, different degrees of electrolysis occur at varying positions on the cutting edge due to the different distances from the cathode. However, the consistency of the complex curve cutting edge is poor after electrochemical machining. Consequently, a method of indentation cathode electrolysis was proposed by Wu et al. [103] to prepare the complex shape edge of cutting tools. Figure 45 shows a layer of tin foil paper attached to the clay to produce a tool electrode. The indentation consistent with the shape of the cutting edge can be pressed owing to the plasticity of the clay. The tool edge and the indentation are controlled to maintain a certain gap for electrolysis, and each position of the cutting edge has the same distance from the opposite electrode. During electrolysis, the tiny pits on the edge surface gradually develop into cracks, which will gradually fall off as the electrolysis continues to form a dense oxide film. The Co ions in the electrolyte will also form cobalt salt attached to the edge surface. After completing this process, another process is needed to scrape away the cobalt salts.

Electrochemical machining has shown good applicability in the cutting edge preparation of metal material tools, such as cemented carbide and high-speed steel. However, electrochemical machining requires electrical conductivity as the primary condition. This processing method cannot be used in the cutting edge preparation of nonmetallic material tools, such as diamond tools and ceramic tools. Excessive corrosion of the tool edge surface always occurs in the electrochemical machining process, and the surface quality of the cutting tool is poor after processing.

4.4 Electrical discharge machining

Electric discharge machining based on electroerosion, also known as electroerosion, removes excess materials on the surface of parts caused by pulsed spark discharge between positive and negative electrodes [109]. This machining method can meet the predetermined machining requirements of workpiece size, shape, and surface quality. As shown in Fig. 46 [105], multiple electrodes are typically used during processing to form the required geometric shape of the cutting edge. As the shape of the tool electrode deteriorates, the sharp points on the tool material gradually become round. This EDM feature is reported to be highly suitable for tool edge preparation [104–106].

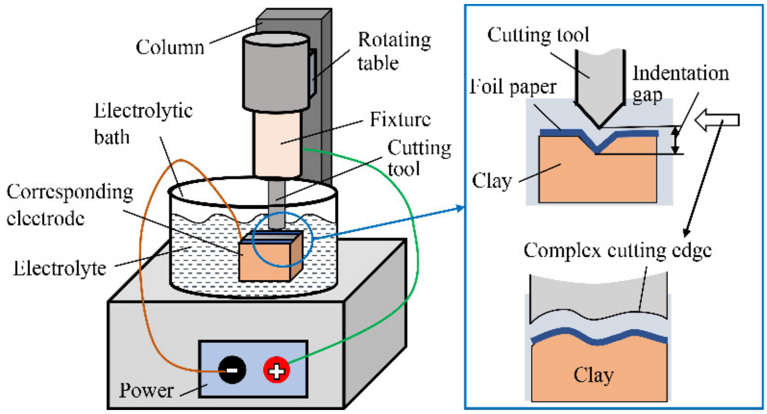


Fig. 45 Cutting edge preparation by indentation cathode electrolysis.

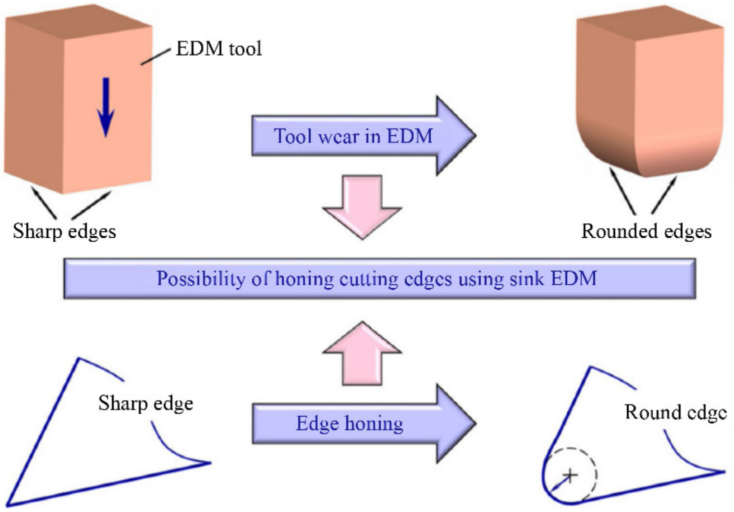


Fig. 46 Principle of electroerosion edge honing [105], reproduced with permission from Elsevier. EDM: electrical discharge machining.

A method for preparing tool edges by sinking EDM was first proposed by Yussefian et al. [104]. As shown in Fig. 47, the tool is sunk as an electrode to the corresponding electrode for EDM. After machining, the material at the tip of the high-speed steel and cemented carbide tool is removed to form rounded edges. Compared with the conventional preparation of edges, the tool after sinking EDM has less edge variability. However, the edge material is easily affected by local wear during the machining process, resulting in edge deterioration.

To obtain a uniform round edge, Yussefian and Koshy [105] further proposed a processing method of using foil as the corresponding electrode of the edge, preventing

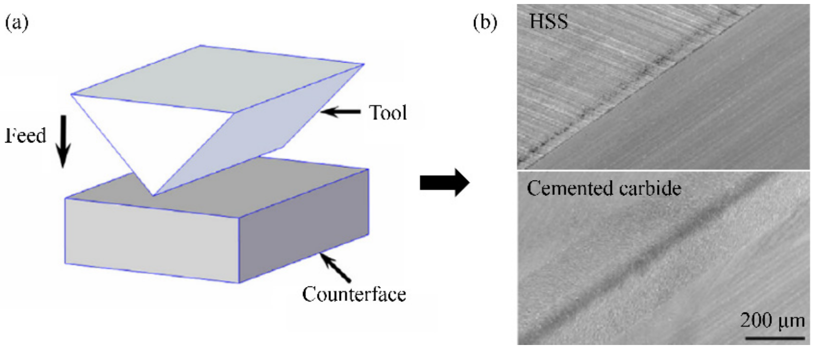


Fig. 47 Cutting edge preparation by sinking electrical discharge machining [104]: (a) machining principle and (b) micromorphology of the prepared edge. Reproduced with permission from Elsevier. HSS: high-speed steel.

edge materials from being removed when foil melting is reached. Figure 48 [105] shows the edge wrapped by foil after sinking during processing. The shape and size of the edge after processing are only related to the thickness of the foil. As a result, the radius of the edge after processing is uniform, and the variability of the radius of the round edge of the prepared cemented carbide insert is less than 15% [105].

As shown in Fig. 49 [106], chamfered or rounded edges of different shapes can be obtained by adjusting the relative position of two discharge electrodes of the EDM equipment and the shape of the corresponding tool electrode. Based on a previous work, Yussefian and Koshy [106] proposed a geometric model that could accurately predict the formation of symmetrical and asymmetric contours during machining by simulating the process of edge preparation by EDM.

The material removal efficiency of EDM is notably high; it only takes a few seconds to complete the edge preparation. The material removal mechanism of EDM is represented by the melting and evaporation of materials, allowing the tools to be processed by materials with arbitrary hardness. Nonconductive materials can also be processed by coating conductive materials on their surfaces. However, this method inevitably causes tool surface burns and cannot meet the requirements of high-quality edge preparation.

4.5 Others

In contrast to conventional cutting tools, the cutting tools used for ultra-precision machining are manufactured from superhard materials to achieve nanoscale thickness cutting, but the cutting edge needs to be as sharp as possible. A method combining mechanical lapping and ion beam polishing to prepare the sharp edge of a nanotwinned cubic boron nitride (nt-cBN) tool was proposed by Wang et al. [110]. First, the nt-cBN tool edge is mechanically lapped by experimental equipment (Fig. 50(a)); then, the edge is further sharpened by Ar + ion beam polishing (Fig. 50(b)). The cutting edge prepared by this method has good consistency and entails less residual stress. However, ion beam polishing requires vacuum conditions, and the processing efficiency is relatively low. In addition, this method is unsuitable for preparing cutting edges with complex shapes.

5 Comparison of the cutting edge preparation methods

Edge preparation methods are difficult to compare because of the varying objects of edge preparation experiments in the literature. To systematically compare the processing effects of different edge preparation methods, many researchers [43–45] have used a variety

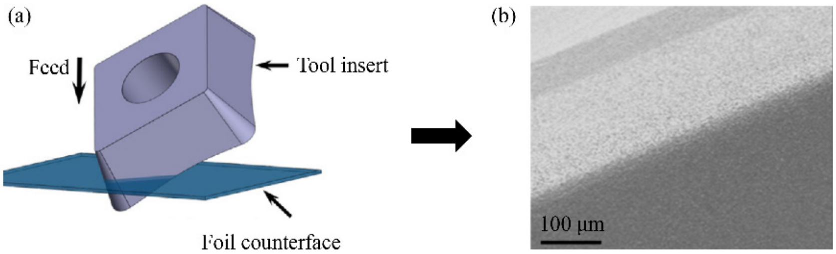


Fig. 48 Cutting edge preparation by foil counterface electrical discharge machining [105]: (a) machining principle and (b) micromorphology of the prepared edge. Reproduced with permission from Elsevier.

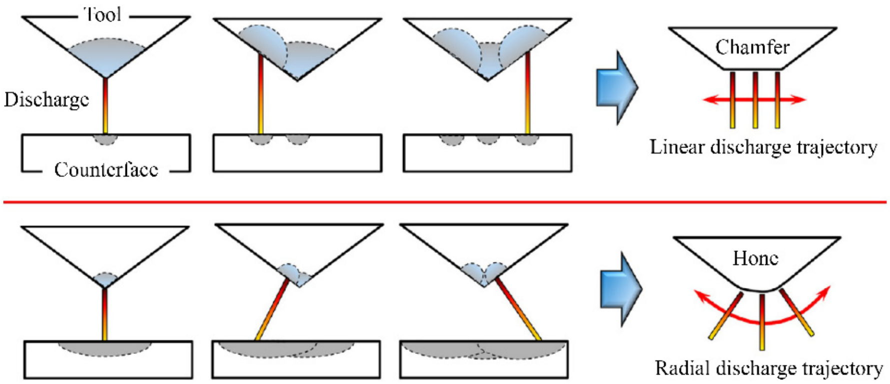


Fig. 49 Shape generation of honed and chamfered edges in electrical discharge machining [106], reproduced with permission from Elsevier.

of methods to perform edge preparation experiments on the same tool.

Seven processing methods (abrasive blasting, AFM, abrasive magnetic machining, drag, abrasive slurry (AS), B, and LM) were used by Bouzakis et al. [43] for the edge preparation of cemented carbide-coated tools. Similar to drag finishing, abrasive slurry is a machining method that allows the tool to perform a two-stage planetary rotation movement in a liquid-abrasive mixed medium. Figure 51(a) compares the radius of the cutting edge after machining by these different methods; the findings showed that brushing can obtain a larger cutting edge radius under similar process conditions. The cutting experiments of four different metal materials (42CrMo4QT, AISI 304L, Inconel 718, and Ti–6Al–4V) were conducted using the prepared tools, and the effects of different cutting edges on the cutting performance of the tool were compared. Figure 51(b) summarizes the effect of different edge preparation methods on cutting tool performance during the cutting of different materials. The results indicate that the edge preparation of cutting tools is closely related to the cutting process. In particular, the inserts machined by DF have the longest life in cutting, whereas the tools machined by LM are the most fragile. Uhlmann et al. [44] prepared microend-milling cutter edges by brush polishing, polish blasting, magnet finishing, and immersed tumbling. The morphology of the prepared edges is shown in Fig. 52. The experimental results showed that the cutting tools prepared by immersed tumbling and magnet finishing have better cutting performance in milling. Wang et al. [45] used brushing, drag finishing, and wet abrasive jet machining to prepare the cutting edge of K313 uncoated carbide inserts. The roughness *Ra* of the edge surface increases only in wet abrasive jet machining. The cutting experiments were performed using unprepared and prepared tools. The tool prepared by drag finishing had the longest life under the same cutting conditions.

A fuzzy comparison of these edge preparation methods from six aspects (edge consistency, surface quality, efficiency, processing difficulty, machining cost, and general availability) was performed; the results are shown in Table 1 [17,28–42,46–77,87–106]. Compared with the NPM, the MPM has obvious advantages in terms of processing difficulty and processing cost. Cutting edge preparation by NPM (except MAM) easily forms edge surface damage, which can explain why it is rarely used in mass production. At present, the most commonly used

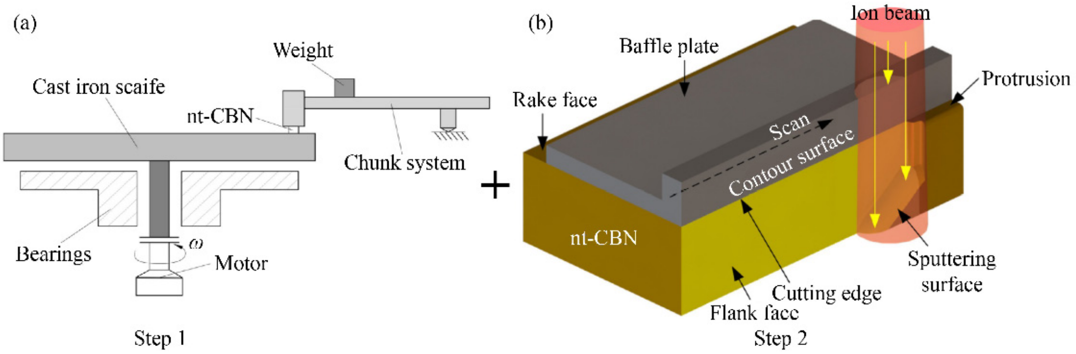
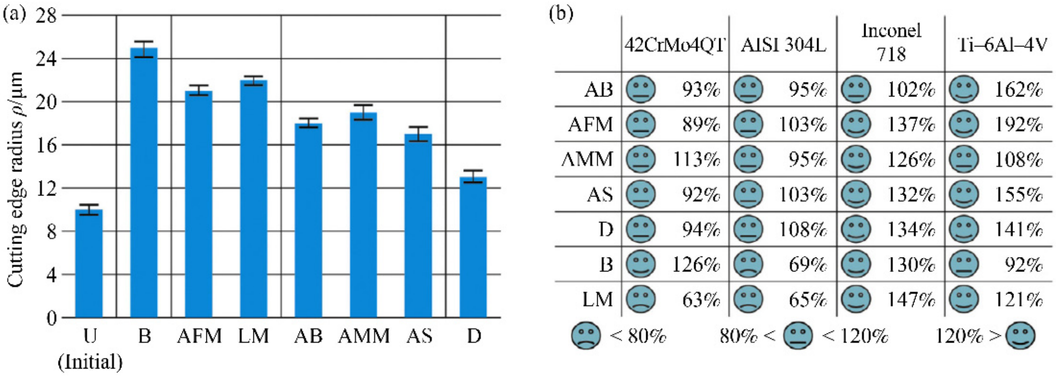


Fig. 50 Preparation of the nanotwinned cubic boron nitride (nt-cBN) cutting edge by combining (a) mechanical lapping and (b) ion beam polishing [110], reproduced with permission from Elsevier.



	42CrMo4QT	AISI 304L	Inconel 718	Ti–6Al–4V
AB	😐 93%	😐 95%	😐 102%	☺ 162%
AFM	😐 89%	😐 103%	☺ 137%	☺ 192%
AMM	😐 113%	😐 95%	☺ 126%	😐 108%
AS	😐 92%	😐 103%	☺ 132%	☺ 155%
D	😐 94%	😐 108%	☺ 134%	☺ 141%
B	☺ 126%	☹ 69%	☺ 130%	😐 92%
LM	☹ 63%	☹ 65%	☺ 147%	☺ 121%

☹ < 80% 80% < 😐 < 120% 120% > ☺

Fig. 51 Comparison of edge preparation methods [43]: (a) cutting edge radius and (b) cutting performance. Reproduced with permission from Elsevier. AB: abrasive blasting; AFM: abrasive flow machining; AMM: abrasive magnetic machine; AS: abrasive slurry; B: brushing; D: drag; LM: laser machining; U: unprepared.

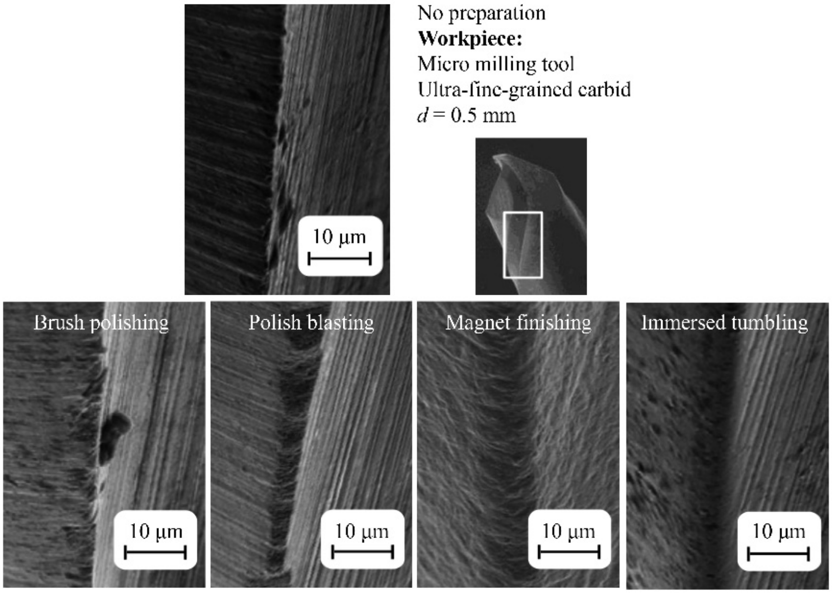


Fig. 52 Edge morphology of the micromilling tool processed by four methods [44], reproduced under the terms of CC BY license.

Table 1 Comparison of mainstream cutting edge preparation methods

Type	Methods	Edge consistency	Surface quality	Efficiency	Processing difficulty	Machining cost	General availability
MPM	G [29–36]	★★★	★★★	★★	★★★★	★★★★	★★★
	B [37–42]	★★	★★★	★★★★★	★★★★★	★★★★★	★★★★★
	DF [46–55]	★★★	★★★	★★★★★	★★★★★	★★★★★	★★★★★
	AJM [17,56–66]	★★★	★★★	★★★★★	★★★	★★★★	★★★★★
	AFM [67–69]	★★★	★★★	★★★	★★★★	★★★★	★★★★
	VM [54,70–71]	★★	★	★★★★	★★★★★	★★★★★	★★★★
	STP [28,72–74]	★★★★★	★★★★★	★★★	★★★★	★★★	★★★★
NPM	MAM [87–94]	★★★★	★★★★	★★★★	★★	★	★★★★
	LM [95–99]	★★★	★★	★★★	★★★	★★★	★★★★
	EM [100–103]	★★★	★	★★★★	★★★★	★★★★	★★
	EDM [104–106]	★★★	★★★	★★★	★★★	★★★	★★★★

Notes: The best: ★★★★★, the worst: ★.

edge preparation methods for cutting tool production are B, DF, and AJM, which are suitable for the batch preparation of cutting edges, but their processing qualities are poor. The cutting edge prepared by STP has good consistency and high surface quality, and its processing difficulty and processing are relatively low; thus, it has good application prospects in the edge preparation of cutting tools.

6 Conclusions and prospects

Edge preparation is an effective approach for improving the performance of cutting tools. This study systematically reviewed the development of tool edge preparation technology. It briefly introduces typical cutting edge characterization methods and systematically classifies and summarizes various edge preparation methods for cutting tools. The new edge preparation methods developed on the basis of the existing processing methods were analyzed comprehensively. Then, these methods were compared in different aspects to intuitively reflect the characteristics of the different edge preparation methods for cutting tools. For a specific tool, a reasonable edge preparation method must be suitably selected according to its matrix material, geometry, and use requirements. An edge preparation method with high quality, high efficiency, suitability for green economy, customizable microgeometry, and good repeatability is the direction of cutting edge preparation technology. In the future, cutting edge preparation technologies are expected to develop from the following aspects:

1) Cutting edges with a high surface quality should be prepared in a flexible manner (e.g., flexible material tool processing or staged processing) to reduce the edge damage in the machining process and improve the surface quality and consistency of the tool edge.

2) The advantages of nontraditional and mechanical processing methods can be combined to prepare cutting edges with much higher quality and efficiency. Nontraditional edge preparation methods, such as laser machining, electrical discharge machining, and electrochemical machining, have high processing efficiency, but the probability of cutting edge damage is high. After the cutting edge is prepared by these methods, a mechanical processing procedure should be adopted to remove the surface damage of the cutting edge and ensure the performance of the tool.

3) Studying cutting edge preparation is necessary in two aspects. On the one hand, the influence law and mechanism of different process parameters on edge shape consistency and tool surface quality (roughness and tool surface residual stress) during cutting edge preparation needs to be further investigated. On the other hand, cutting experiments should be conducted, and tools must be used after edge preparation. The influence of cutting edge shape and surface quality on mechanical and thermal loads during the cutting process of the tool, the service life of the tool under the action of different processing parameters, and the influence on the processing quality of the parts should be further explored.

4) The high-quality and efficient preparation of cutting edges requires high-performance equipment. Highly advanced and intelligent equipment must be developed to achieve high-quality and efficient tool edge preparation. Examples include equipment that can realize multistage continuous processing of cutting edges, multitechnology composite batch-processing equipment, equipment for automatic and immediate detection after cutting edge preparation, and equipment for the automatic upper and lower clamping of multiple cutting tools.

Nomenclature

Abbreviations

AFM	Abrasive flow machining
AJM	Abrasive jet machining
AMM	Abrasive magnetic machine
AS	Abrasive slurry
B	Brushing
CBN	Cubic boron nitrification
CFRP	Carbon fiber-reinforced polymer
DF	Drag finishing
EDEM	Extended distinct element method
EDM	Electrical discharge machining
EM	Electrochemical machining
G	Grinding
LM	Laser machining
MAM	Magnetic abrasive machining
MPM	Mechanical processing method
nt-CBN	Nanotwinned cubic boron nitride
NPM	Nontraditional processing method
PCBN	Polycrystalline cubic boron nitride
R-AFP	Rotary abrasive flow polishing
STP	Shear thickening polishing
VM	Vibration machining

Variables

A_α	Plough area
B_f	Cutting edge width
D_α	Distance from the intersection of the flank face extension line and the horizontal line at the vertex of the cutting edge to the flank surface
D_γ	Distance from the intersection of the rake face extension line and the horizontal line at the vertex of the cutting edge to the rake surface
f_a	Degree of cutting edge preparation
h	Uncut chip thickness
h_0	Undeformed chip thickness during tool machining is denoted
K	Form factor
l_β	Length of the chamfer edge
n	Cutting edge vertex
p	Area to the left of the cutting edge
P_α	Transition point of the cutting edge on the flank face during cutting process
P_γ	Transition point of the cutting edge on the rake face during cutting process
q	Area to the right of the cutting edge
r	Cutting edge radius
r_0	Arc radius of the edge
r_1, r_2	Transition radii
r_a	Radius of curvature of the highest point of the cutting edge
r_β	Fitted cutting edge radius
Δr	Distance between the line connecting the highest point of the edge arc and the theoretical tip
Ra	Surface roughness
s	Edge separation point
S	Edge symmetry
S_a	Degree of asymmetry of the contour
S_f	Extension area of the cutting edge relative to the flank face

S_r	Extension area of the cutting edge relative to the rake face
S_γ	Distance between the ideal tool tip and the transition point of the rake face
S_α	Distance between the ideal tool tip and the transition point of the flank face
α	Flank angle
γ	Macro rake angle
γ_e	Effective rake angle
γ_β	Angel between the chamfer edge and the rake face
θ	Angle between the symmetry axis of the cutting edge curve the bisector of the ideal tool tip angle
φ	Area between the line connecting the ideal tip to the highest point of the edge
φ_0	Cutting edge inclination angle

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Conflict of Interest The authors declare that they have no conflict of interest.

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