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Study on sequential machining of EDM and grinding for the end face of cemented carbide round bar using EC-PCD tool

Yoji YAMADA[1)], Shinichi NINOMIYA[1)], Fumio KOGA[2)], Manabu IWAI [3)]

[1]*Nippon Institute of Technology*
[2]*KOGA Co. Ltd.*
[3]*Toyama Prefectural University*

yoji@yamada-mt.co.jp, *ninomiya@nit.ac.jp*, *iwai@pu-toyama.ac.jp*

Abstract
A sequential machining method of EDM (Electro discharge machining) and grinding has been proposed by rotating a PCD (polycrystalline diamond) segment made of conductive diamond particles for machining cemented carbide materials. In this study, in order to achieve the on-machine forming of the end face of a cemented carbide round bar material used as a cutting tool for rotary cutting with a 5-axis multi-tasking lathe, sequential machining experiments are performed by rotating the cemented carbide round bar without rotating the PCD tool. First, in basic experiments using Die-sinking EDM machine, the end face of a rotating cemented carbide round bar is EDMed using a fixed arc PCD as an electrode, and then the rotating cemented carbide round bar is pressed against the PCD surface. As results, it is clarified that the heat-affected layer due to electric discharge remaining on the cemented carbide surface is removed by grinding action using PCD. In addition, it is shown that when an electro discharge function is installed in 5-axis cutting machine, on-machine forming of a cemented carbide round bar tool in the cutting machine is possible.

sequential processing combining EDM and grinding, PCD tool, cemented carbide round bar material, 5-axis cutting machine

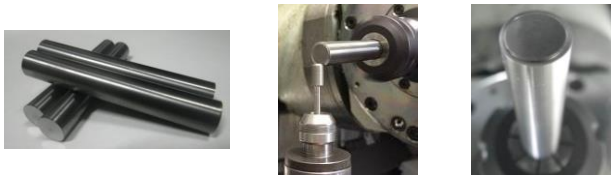
1. Introduction

The authors have proposed a method of sequential machining of cemented carbide materials by EDM and grinding using a PCD segment composed of electrically conductive (hereafter EC) diamond particles as a rotating tool [1, 2]. This method is characterized by the process where a hard workpiece such as cemented carbide is first processed by EDM using a rotating PCD electrode and then the heat affected layer remained on the carbide surface as a result of EDM is removed by grinding to produce a good surface condition. In this case use of PCD plays two important roles. One is to minimize the electrode wear by its use as an EDM electrode and the other is to perform efficient removal of the carbide by its use as a grinding tool.

In this study, in order to achieve on-machine forming of the end face of a cemented carbide round bar used as a rotary cutting tool on the 5-axis multi-tasking lathe, sequential machining experiments were performed by rotating the cemented carbide round bar without rotating the PCD segment tool. Firstly, basic experiments were carried out using a die-sinking EDM machine in oil. Next, possibility of the on-machine forming by this method with water supply was investigated.

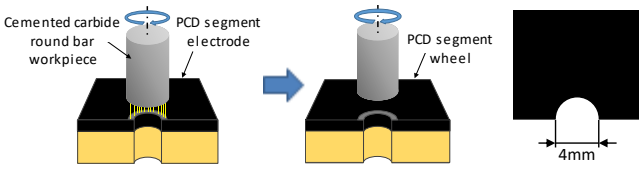
2. On-machine forming of end face of rotary cutting tool

In recent years, a power-driven rotary cutting technology has received attention for its capability to realize high precision and high efficiency machining of hard to process materials. By using a built-in function of the 5-axis multi-function machine to control a cutting edge position, the end face periphery of a simple round bar can be used as a cutting edge. The authors have realized rotary cutting of hardened steel materials using an uncoated cemented carbide round bar tool, and have shown that on-machine forming/ regrinding of the tool is possible [3]. On-machine tool forming with a small diameter mounted diamond wheel enables easy achievement of the minimized tool rotational runout and rake face forming (Figure 1). However, the mounted wheel provides only a small number of the active cutting edges and easily loses its shape, which requires



(a) Cemented carbide round bar tool (b) Situation of tool forming by wheel (c) Appearance of tool

Figure 1. On-machine forming of rotary cutting tool with small diameter grinding wheel



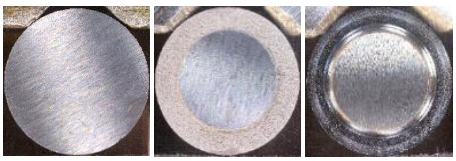
(a) EDM (b) Grinding (c) PCD tool

Figure 2. Sequential machining of EDM and grinding using PCD segment tool

Table 1. Experimental conditions on Die-sinking EDM machine

EDM machine	AP1L (Sodick)
PCD tool	EC-PCD segment: Grain size 25μm, Thickness 0.6mm
Workpiece	Cemented carbide round bar: A1, ϕ6mm×L50mm
EDM conditions	Polarity: PCD (+), carbide (-), E0 = 90V, SV = 80V, IP = 3A, te/to = 20μs/20μs, N = 200rpm, processing time 5h, in oil
Grinding conditions	Total machining depth: H1 = 20μm, F = 1μm / min, N = 200rpm, dry machining

complicated operational managements such as continual checking of the wheel condition and frequent operation of trueing and dressing. To solve these problems in the on-machine tool forming, the authors came to a solution in which the sequential processing combining EDM and grinding with a PCD tool would be functional, and then decided to investigate its fundamental characteristics.



(a) Before (b) EDM only (c) EDM+G

Figure 3. Cemented carbide surface before and after processing (In Oil)

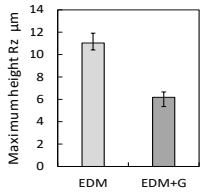
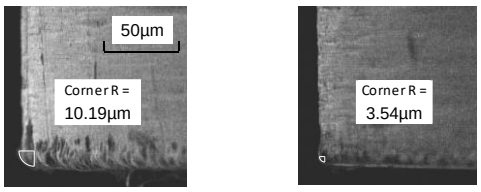


Figure 4. Surface roughness of workpiece

3. Sequential forming by EDM and grinding on EDM machine

An EC-PCD plate with a semicircular cut of R2mm was fixed to the machine table side and a step processing was performed to give a ring groove of 1mm onto the edge face periphery of the φ6mm rotating carbide round bar (Figure 2). After the end face of the rotating carbide round bar was processed in oil on the die-sinking EDM machine using the fixed PCD as an electrode, the working oil was ejected and pressing the rotating carbide round bar straightly to the PCD, infeed grinding was performed. The experimental conditions are shown in Table 1.

Figure 3 shows the conditions of the cemented carbide surface before and after processing. The surface after just EDM was a pear skin finish, but successive grinding of 20μm in depth turned the surface to a mirror finish. Though maximum value of roughness height was relatively large in both cases due to the concentric grooves produced by the infeed grinding, it is clear that the roughness value of the ground surface was halved in comparison with that of the surface after just EDM (Figure 4). On the surface processed by just EDM, surface deterioration due to discharge effects and drop-off of the carbide particles can be seen on the corner regions, resulting in the corner R of 10μm or more of the edge section (Figure 5). On the other hand, it was found that the corner radius improved to R3.5 μm and the traces of the particle drop-off could be removed by adding the grinding process. PCD wear was little or nothing after machining.

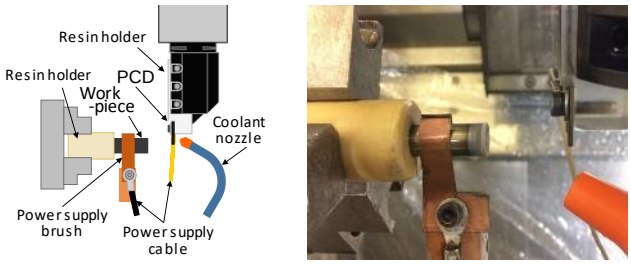


(a) EDM only (b) EDM+Grinding

Figure 5. State of corner part on cemented carbide after processing (In Oil)

4. Sequential forming by EDM and grinding on 5-axis lathe

By adding a function to control a discharge gap, the 5-axis multi-tasking lathe was upgraded to the special machine which enabled EDM processing of a carbide round bar tool. To simplify the experiment, an R4 arc shaped PCD tool was fixed to the machine head and a cemented carbide round bar of φ 12 mm was gripped to the main spindle chuck and rotation was given (Figure 6). Ion-exchange water was supplied as a working fluid. EDM processing was conducted on the conditions shown in Table 2, and then infeed grinding was carried out.



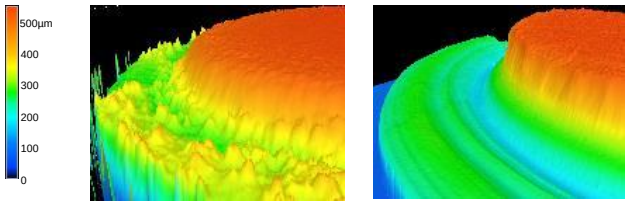
(a) Schematic diagram (b) Experimental setup

Figure 6. Experimental setup on 5 axis multi-tasking lathe

Table 2. Experimental conditions on 5 axis multi-tasking lathe

5-axis machine	INTEGREX 100-Ⅲ (Mazak)
Power supply	SUE-87(Sodick)
PCD tool	EC-PCD segment: Grain size 10μm, Notch R=4mm
Workpiece	Cemented carbide round bar: A1, ϕ12mm×L73mm
EDM conditions	Polarity: PCD (+), carbide (-), E0 = 90V, SV = 80V, IP = 6A, te/to = 20μs/30μs, N = 100rpm, processing time 0.5h, Ion-exchange water supply: 9L/min
Grinding conditions	V=1.9m/min, a=0.005mm/pass (Dwell time 10min/pass), H1 =0.08mm, Ion-exchange water supply: 9L/min

Surface conditions of the cemented carbide after experiments are shown in Figure 7. On the surface of the cemented carbide discharge processed by PCD electrode, melted and solidified discharge wastes were adhered. In contrast after grinding the surface exhibited a mirror finish without adhered matters all of which had been removed. However, it was found that the PCD did wear during the EDM processing. While the processing on the die-sinking EDM machine was performed in oil, in this experiment on the 5-axis multi-tasking lathe ion exchange water was used instead of oil. Therefore, the effect to protect the PCD surface by the oil decomposed carbon produced during the EDM process didn't work. It seems this is the reason why the PCD wore. It was confirmed that the grinding with this PCD could remove the discharge affected layer on the carbide surface and the shape of the PCD was copied.



(a) EDM only (b) EDM+Grinding

Figure 7. Surface state of cemented carbide using a laser microscope VK-9710: Keyence (Ion-exchange water supply)

5. Conclusion

In order to perform on-machine forming of a cemented carbide rotary cutting tool, sequential processing method combining EDM and grinding was proposed. In this method the rotation was given to a carbide round bar but not to PCD tool. It was shown that the EDM processed cemented carbide surface could be turned to mirror finish by on-machine processing using the same PCD tool on both die-sinking EDM machine and a 5-axis multi-tasking lathe equipped with EDM function.

In addition, it was found that use of oil is desirable as a working fluid for EDM since the use of ion exchange water did not produce the oil carbon decomposition to protect the PCD, leading to a wear of the PCD electrode.

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