Cutting Performance of Electroplated Diamond Drill with V-Shaped Groove and through Coolant Hole in Drilling Cemented Carbide

Tadahiro Wada

***Abstract*—Micro-electrical discharge machining (EDM) is one of the most effective methods for making holes in machining difficult-to-cut materials, such as tungsten carbide, because the hardness is not a dominant parameter in EDM. However, as die sinking EDM requires the use and subsequent production of tool electrodes, the machining time is longer and costs higher than in cutting methods such as milling by a machining center. The method with a diamond drill is considered one of the most effective methods for making holes. In this study, cemented carbides were holed by electroplated diamond drills with a through coolant hole. Two types of drills with different flute shape, namely with a V-groove and without a V-groove, were used to drill two types of cemented carbides of different hardness. The following results were obtained: (1) No drilled holes showed noticeable burrs or corner dullness. (2) The main tool failure of the electroplated diamond drill was the flaking of the diamond layer on the drill tip. (3) The addition of the V-groove on the drill tip extended the tool life by 1.7 times. (4) Both the drilled hole's diameter of the entrance side and that of the outlet side decreases with the increase of the drilled hole length. (5) The tool life of the electroplated diamond drill was dependent on the hardness of the cemented carbide.**

***Index Terms*—Cutting performance, electroplated diamond drill, cemented carbide, unique flute.**

I. Introduction

Cemented carbides have been developed as a material for cutting tools. They was first demonstrated at the Spring Fair at Leipzig in 1927, cutting cast-iron and 12% manganese steel at 2-3 times the normally accepted cutting speeds [1]. Due to the excellent mechanical properties of cemented carbides, such as compressive strength, hardness and toughness they are used for wear resistant material [2], such as drawing dies, molds, rolling rolls etc., in addition to the cutting tool. Cemented carbides are generally machined to improve the dimensional accuracy after sintering. Owing to the high material hardness, machining is generally performed with diamond grinding wheels [3]. Resin-bonded diamond wheels are usually used for grinding various cemented tungsten carbides [4].

For machining difficult-to-cut materials, such as tungsten carbide, micro-electrical discharge machining (EDM) is one of the most effective methods for making holes because the hardness is not a dominant parameter in EDM [5]. However, as die sinking EDM requires the use and subsequent production of tool electrodes, machining time is longer and costs higher than cutting methods such as milling by a machining center [6]. The method with a diamond drill is considered one of the most effective methods for making holes. There have been many studies on drilling ceramics by diamond drills [7]-[9]. However, few studies on drilling cemented carbides have been reported.

In this study, cemented carbides were holed by electroplated diamond drills with a through coolant hole. Two types of drills with a different flute shape, namely with a V-groove and without a V-groove, were used in order to clarify the effect of the unique flute (V-shaped groove) at the drill tip on the tool life of an electroplated diamond drill. Furthermore, two types of cemented carbides of different hardness were used in order to clarify the effect of the hardness of the workpiece on the tool life of the drill.

II. Experimental Procedure

Fig. 1 shows an electroplated diamond drill with a V-shaped groove and a through coolant hole. This drill has a length of 80 mm and a diameter of straight shank of 16 mm. The length of the electroplated diamond, which is the cutting part, is 15.5 mm as shown in Fig. 1. The diamond particle size is about 0.4 mm, and the thickness of the electroplated diamond, which has a single diamond layer, is about 0.5 mm. So, the diameter of the electroplated diamond is about 17 mm. The material of the drill body is high-speed steel. Furthermore, to clarify the effectiveness of the V-shaped groove for drilling cemented carbide, an electroplated diamond drill with a through coolant hole only, namely without the V-shaped groove, was used, too. These diamond drills can drill both through and blind holes. This unique flute, namely the V–shaped groove, can take the chip smoothly and supply the cutting liquid to the cutting part.

The workpieces used were a cemented carbide WC-5mass%Co plate for cutting tools and a WC-16mass%Co plate for wear resistant tools. The thickness of the WC-5mass%Co plate and the WC-16mass%Co plate was 15 mm and 20 mm, respectively. Table I shows the mechanical properties of two types of the cemented carbides. In this table, the lower part indicates the case of WC-16mass%Co alloy, and the upper part indicates the case of WC-5mass%Co.

Fig. 2 shows a schematic view of the drilling test. The drilling tests of two types of the cemented carbide plates were carried out by the helical milling test method. Table II shows the drilling conditions of the helical milling test. In Table II, through holes were formed in two types of cemented carbide plates, and the tool life of the drill was investigated.

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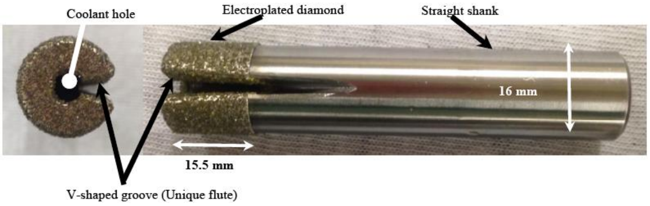


Fig. 1. Electroplated diamond drill with unique flute and through the coolant hole.

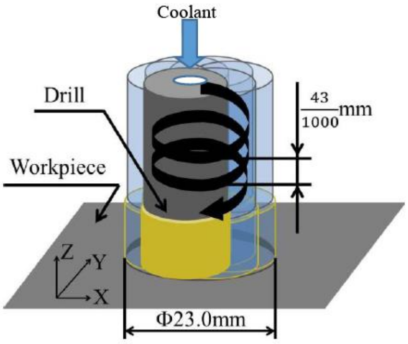


Fig. 2. Schematic view of the drilling using helical milling.

TABLE I: MECHANICAL PROPERTIES OF CEMENTED CARBIDE

Workpiece material	Density [Mg/m^3]	Thermal conductivity [W/mK]	Thermal expansion coefficient ×10^{-6}[K^{-1}]
WC-5mass%Co	14.9	80	4.9
WC-16mass%Co	14.0	82	5.9
Hardness [HRA]	**Young's modulus [GPa]**	**Fracture toughness value [MPa·m$^{1/2}$]**	**T.R.S. [GPa]**
92.5	630	10	2.0
87.0	520	21	3.3

T.R.S.: Transverse rupture strength

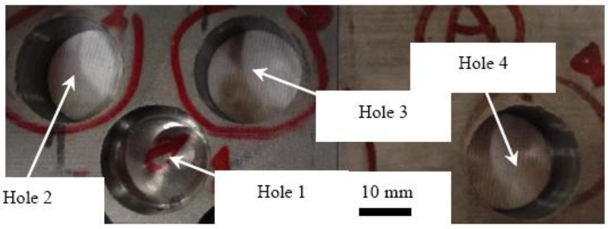
TABLE II: DRILLING CONDITIONS OF THE HELICAL MILLING TEST

Cutting speed	216.1 m/min (Spindle rotational speed: 4300 min-1)
Feed speed	86 mm/min (0.020 mm/rev)
Z-axis depth for one helical	0.043 mm/rev
Tool overhang length	40 mm
Hole type	Through hole
Coolant (Cutting fluid)	Emulsion of oil and water type (Yoshiro Chemical Industry Co., Ltd. FGE360 (5%))

The drilling test of the cemented carbide WC-5mass%Co was conducted on a vertical machining center (Type AJV-25/405N, Yamazaki Mazak Corporation). The driving power of Type AJV-25/405N machining center is AC 18.5/14.8 kW and the maximum rotational speed is 5000 min^{-1}. The drilling test of the cemented carbide WC-16mass%Co was conducted on a vertical machining center (Type VKC45 II, Hitachi Seiki Co., Ltd.). The driving power of Type VKC45 II machining center is AC 11/7.5 kW and the maximum rotational speed is 12000 min^{-1}. Both Type VKC45 II and Type AJV-25/405N machining center have the through-spindle coolant supply system.

III. RESULTS AND DISCUSSION

First, the WC-5mass%Co cemented carbide was drilled by the electroplated diamond drill with a V-shaped groove and through the coolant hole. Fig. 3 shows the drilled hole and the tool wear of the drill tip. Fig. 3(i) and (ii) show the photograph and the tool wear of the drill tip, respectively. In Fig. 3(i), no drilled holes have noticeable burrs or corner dullness. The drilling test was stopped at a drilled hole length of 5 mm as indicated by "Hole 1" shown in Fig. 3(i)(a), and the wear of the drill tip was investigated. There was no remarkable flaking of the electroplated diamond layer. So, the drilling test was carried out 4 times as indicated by the "Hole 2" to "Hole 4" shown in Fig. 3(i). In Fig. 3(ii), no remarkable flaking of the electroplated diamond layer was found at the drilled hole length of 35 mm. However, at the drilled hole length of 50 mm remarkable flaking of the electroplated diamond layer (area of "A" indicated in Fig. 3(ii) was found.

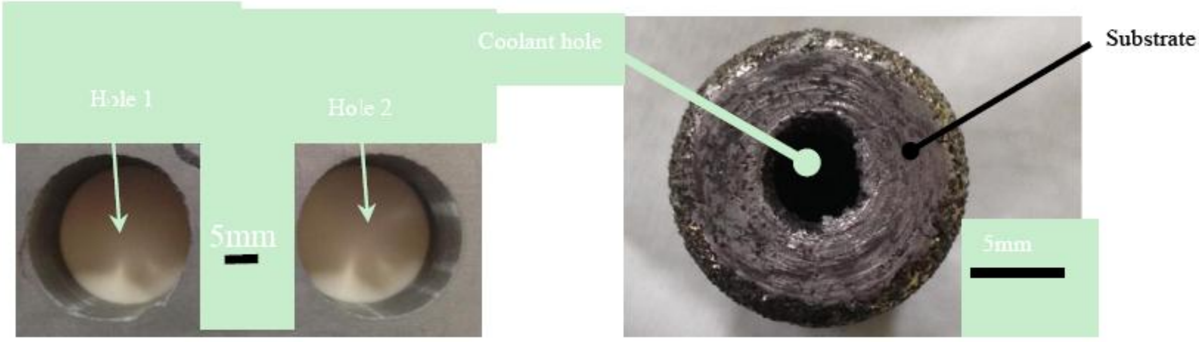


(i) Photograph of drilled hole

(a) Drilled hole length of 35 mm (b) Drilled hole length of 50 mm
(ii) Tool wear of the drill tip
Fig. 3. Drilled hole and the tool wear of the tip in drilling WC-5mass%Co cemented carbide with a V–shaped groove.

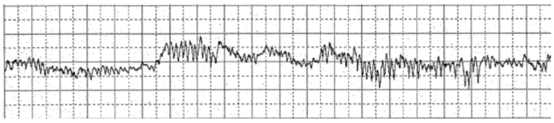
The above results indicate that the main tool failure of the electroplated diamond drill was the flaking of the diamond layer on the drill tip, and in drilling the WC-5mass%Co cemented carbide a hole can be drilled to a length to 50 mm.

Next, the WC-5mass%Co cemented carbide was drilled by the electroplated diamond drill without a V-shaped groove and through the coolant hole. Fig. 4 shows the drilled hole and the tool wear of the drill tip. Fig. 4(i) and (ii) show a photograph and the tool wear of the drill tip, respectively. In Fig. 4(i), none of the drilled holes have noticeable burrs or corner dullness. In the case of drilling without the V-shaped groove drill, at the drilled hole length of 30 mm remarkable flaking of the electroplated diamond layer was found, and the substrate of the drill appears on the drill tip. Thus, adding a V-shaped groove to an electroplated diamond drill is effective for improving the tool life. Namely, the addition of the V-groove on the drill tip extends the tool life by 1.7 times. Fig. 5 shows the profile curve of the drilled hole along the feed direction. In Fig. 5, the lower part of the profile curve is the workpiece. As compared with the drill with a V-shaped groove shown in Fig. 5(i)(a) and the one without a V-shaped groove shown in Fig. 5(ii) at the drilled hole length of about 30 mm, it is possible to improve the surface quality by adding a V-shaped groove. Furthermore, in the case of the drill with a V-shaped groove, as the drilled hole length is longer, the surface quality becomes lower like the drill without a V-shaped groove.

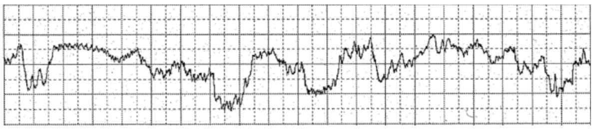


(a) Photograph of drilled hole (b) Tool wear of the drill tip

Fig. 4. Drilled hole and the tool wear of tip in drilling WC-5mass%Co cemented carbide without a V-shaped groove after drilled hole length of 30 mm.

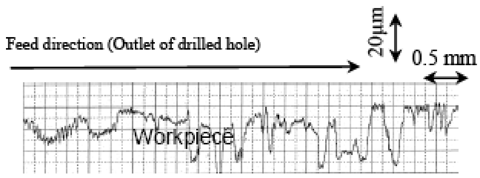


(a) Drilled hole length of 35 mm



(b) Drilled hole length of 50 mm

(i) With V-shaped groove



(ii) Without V-shaped groove (Drilled hole length of 30 mm).

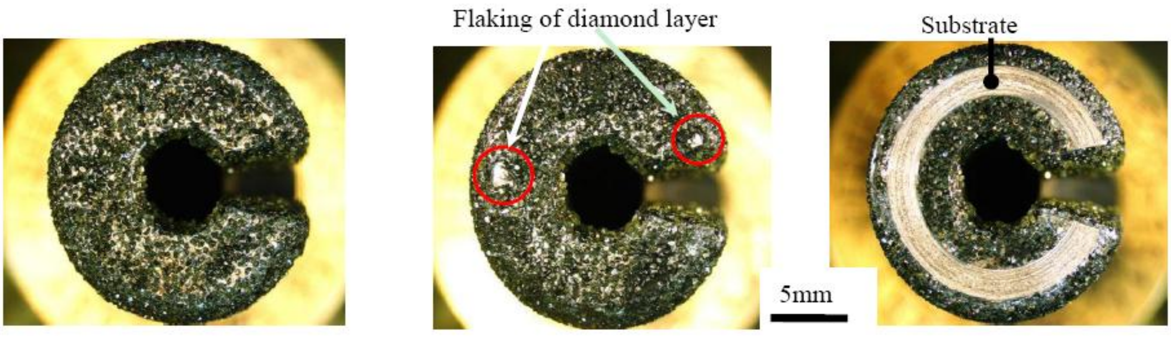
Fig. 5. Profile curve of drilled hole in drilling WC-5mass%Co cemented carbide.

The above results show that the addition of a V-shaped groove is effective for prevention of the flaking of the diamond layer and the tool life can be improved.

Finally, the cemented carbide WC-16mass%Co plate was drilled by the electroplated diamond drill with a V-shaped groove and through the coolant hole. Fig. 6 shows the tool wear of the drill tip. In the case of Drilled Hole 1 as shown in Fig. 6(a), no remarkable flaking of the electroplated diamond layer was found. And, in the case of Drilled Hole 2 as shown in Fig. 6(b), slight flaking of the electroplated diamond layer was found. As the drilled hole increases, the flaking of the electroplated diamond layer on the drill bit was remarkable as shown in Fig. 6(c). As compared with the WC-5mass%Co cemented carbide shown in Fig. 3 and the WC-16mass%Co cemented carbide shown in Fig. 6, the tool life, which is the drilled hole length, of the WC-5mass%Co cemented carbide and that of the WC-16mass%Co cemented carbide was 50 mm and 60 mm, respectively. Namely, the tool life of the WC-16mass%Co cemented is longer than that of the WC-5mass%Co cemented. The hardness of the WC-16mass%Co cemented is considered smaller than that of the WC-5mass%Co cemented shown in Table I. Therefore, it is clear that the tool life of the electroplated diamond drill is dependent on the hardness of the cemented carbide.

Fig. 7 shows a photograph of the drilled hole. In Fig. 7(i), no drilled holes have noticeable burrs or corner dullness.

Fig. 8 shows the profile curve of the drilled hole. In Fig. 8, the lower part of the profile curve is the workpiece.



(a) 1 hole (L=20 mm) (b) 2 holes (L=40 mm) (c) 3 holes (L=60 mm)

Fig. 6. Tool wear of the drill tip in drilling WC-16mass%Co cemented carbide with a V-shaped groove (L: drilled hole length).

Fig. 9 shows the relationship between drilled hole length and the drilled hole's diameter. Both the drilled hole's diameter of the entrance side and that of the outlet side decrease with the increase of the drilled hole length. As the crushing or falling of diamond particles becomes large with the increase of the drilled hole length, the hole's diameter becomes small with the decrease of the outer diameter of the drill. Furthermore, as compared with the drilled hole's diameter of the entrance side and that of the bottom side, the drilled hole's diameter of the entrance side is larger at the same drilled hole length. The hole's diameter at the drill tip becomes small with the decrease of the outer diameter of the drill tip because of the crushing or falling of diamond particles at the tip of the drill side.

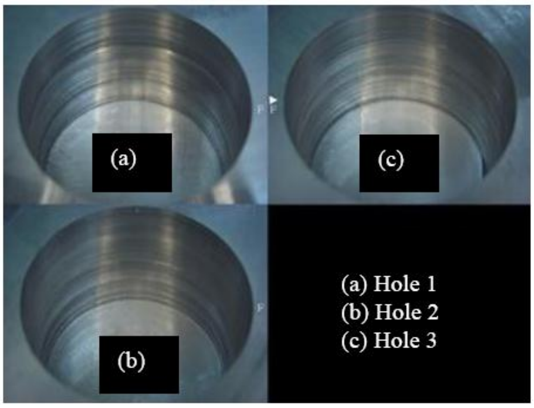
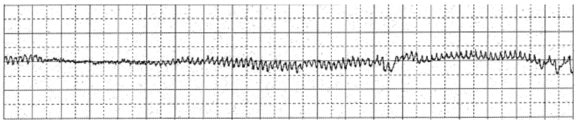
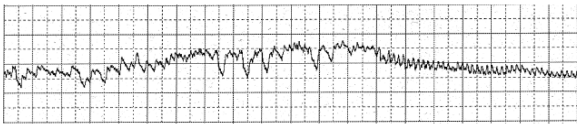


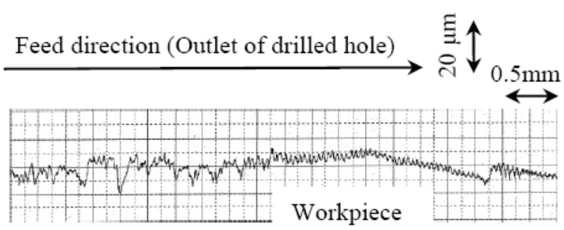
Fig. 7. Photograph of drilled hole in drilling WC-16mass%Co cemented carbide with a V-shaped groove.



(a) Hole 1



(b) Hole 2



(c) Hole 3

Fig. 8. Profile curve of the drilled hole in drilling WC-16mass%Co cemented carbide with a V-shaped groove.

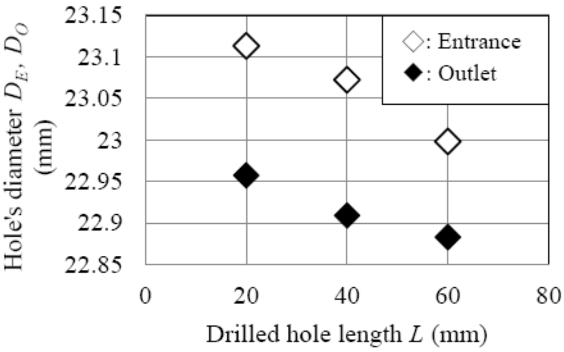


Fig. 9. Relationship between drilled hole length and drilled hole's diameter.

IV. CONCLUSION

In this study, cemented carbides were holed by electroplated diamond drills with a through coolant hole. Two types of drills with different flute shape, namely with a V-groove and without a V-groove, were used. Furthermore, two types of cemented carbides with different hardness were used, too.

The following results were obtained:

1) None of the drilled holes showed noticeable burrs or corner dullness.
2) The main tool failure of the electroplated diamond drill was the flaking of the diamond layer on the drill tip.
3) The addition of the V-groove on the drill tip extended the tool life by 1.7 times.
4) Both the drilled hole's diameter of the entrance side and that of the outlet side decreased with the increase of the drilled hole length.
5) The tool life of the electroplated diamond drill was dependent on the hardness of the cemented carbide.

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