MICRODRILLING AND MICROMILLING OF BRASS USING A 10 µm DIAMETER TOOL

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Abstract The microdrilling and micromilling of brass using a 10 µm diameter cutting tool were examined. The authors have previously examined the cutting of brittle materials such as silicon and glass; however, no study on metallic materials has been performed. The relaxation of the depth of cut and tool feed speed restrictions for such materials would suggest that a high machining rate could be expected. Cemented carbide tools were used in the experiments because of their high hardness, toughness and electrical conductivity properties. Both microtool fabrication and cutting were performed on a micro-electrodischarge machine. The microtools were fabricated by wire electrodischarge grinding and had a semicircular cross section for both drilling and milling applications. High-accuracy tool alignment was realized by the machining methods employed in the fabrication process. A 50 µm deep microhole was successfully drilled at a penetration of 0.2 µm/s. Holes of depth 20 µm were realized at a penetration of 26 µm/s, which was much higher than that achieved during the drilling of brittle materials. In the milling tests, a slot of length 100 µm and depth 20 µm was realized at an axial depth of cut of 1 µm and a horizontal feed speed of 10 µm/s. The large depth of cut enabled a high machining rate to be achieved.

Key words Microdrilling, Micromilling, Microtool, Brass, WEDG

1 INTRODUCTION

There have been many demands for the micromachining of three-dimensional parts for use in the production of microdevices such as tools, sensors, actuators and so on. Mechanical fabrication processes using a solid tool are useful in terms of realizing complex three-dimensional features; however, in the area of micromachining, there are problems caused by the small size of tools. One is difficulty in tool fabrication. Conventional tool fabrication processes including grinding, which apply large force to workpieces, cannot be used because of the low strength of small-sized tools. In general, the smallest diameter of commercially available drills or end mills is 50 µm. In order to make thinner tools, a non-conventional process has to be adopted.

Electrodischarge machining (EDM) is useful with respect to the force applied to the workpiece since the electrode and workpiece do not contact each other. Furthermore, high machining accuracy can be obtained by reducing the capacitance and voltage between the electrode and workpiece. EDM is capable of fabricating small pins with a diameter smaller than 10 µm, and thus is suitable for the fabrication of microtools. In the previous studies, the authors fabricated microtools by EDM and used them for the drilling and milling of brittle materials such as monocrystalline silicon and glass [1][2]. As a result, a microhole with a diameter as small as 6.7 µm and a slot of width 20 µm were successfully realized. However, the cutting of metallic materials, which is very common in the field of machining, was not performed. In the cutting of brittle materials, a small depth of cut and low tool feed speed are indispensable in avoiding the transition in the cutting mode from the ductile regime to the brittle regime, leading to a low machining rate. Such concerns can be neglected for metallic materials, which are ductile materials. The relaxation of depth of cut and tool feed speed restrictions would suggest that a high machining rate could be expected.

The microdrilling and micromilling of metallic materials have been widely performed by EDM, using a tool fabricated also by EDM. However, the tool wears rapidly and machined surfaces are of poor quality. Furthermore, the machining rate of EDM is generally lower than that of cutting. If such machinings are performed by cutting, these problems can be solved.

In this study, we perform the drilling and milling of brass using a microtool of diameter 10 µm. The machinable depth, permissible axial depth of cut and tool feed speed are investigated and compared to those for brittle materials.

2 EXPERIMENTAL METHOD

2.1 Experimental Setup

The experiments were carried out on a micro-EDM machine built at Matsushita Electric Industrial Co., Ltd. [3]. The machine is capable of wire electrodischarge grinding (WEDG) [4] and die-sinking EDM with a RC electric circuit. WEDG is one of the micro-EDM methods used for fabricating thin and small shapes.

The machine has X-, Y-, Z-axes that are driven by stepping motors and leadscrews, with a step feed of 0.1 µm and a feed speed range from 0.1 µm/s to 12000 µm/s. A working tank filled with working fluid is mounted on the XY stage. Inside the tank are a stage for mounting workpieces and a wire electrode of diameter 100 µm used for WEDG. An electrode material is set in the mandrel, mounted on the V-shaped bearing and rotated by the DC motor. The rotation run-out is less than 0.5 µm. The rotation speed is 3000 rpm and thus the cutting speed of a 10 µm diameter tool is approximately 0.1 mm/min. In most cases, the machine is used for the EDM of microholes or microslots, where a thin electrode is fabricated by WEDG and then the fabricated electrode is used in the EDM of those microshapes. Because of this on-the-machine electrode fabrication, a very accurate electrode alignment can be expected.

2.2 Experimental Procedure

In choosing the tool material, hardness, strength and toughness must be taken into account to carry out cutting effectively and prevent tool breakage. Moreover, the material must be conductive in order to be processed by EDM. Considering these facts, cemented carbide was chosen.

Figure 1 illustrates the experimental procedure involving microtool fabrication and cutting. The tool material of a 300 µm diameter pin was set in the mandrel and mounted on the machine, then processed to a microtool by WEDG. The fabricated microtool was then moved to be above the workpiece mounted on the stage. Since the stage was inside the working tank, cutting was carried out in the working fluid. Contact between the tool and workpiece was detected by electrical conduction. Tool breakage could also be detected by monitoring the tool-workpiece conduction. The cutting force was not measured due to the lack of a dynamometer. Brass, which has good cutting machinability, was

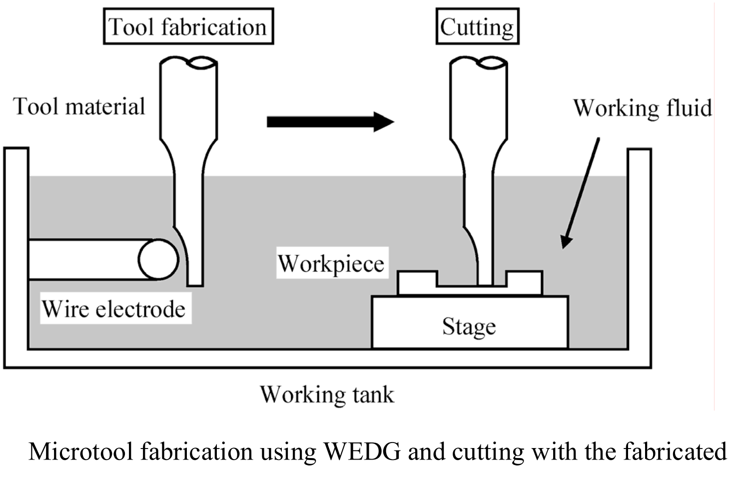

Fig. 1 Microtool fabrication using WEDG and cutting with the fabricated tool

chosen for the workpiece.

Figures 2 (a) and (b) show respectively the scanning electron microscope (SEM) micrographs of the overview and close-up view of a 10 µm diameter microtool. It has a semicircular cross section and is similar to a square end mill with one straight flute. It is capable of both drilling and milling. Although the tool surface is covered with craters generated by electrodischarge and the cutting edge is not as straight or as smooth as that of a tool fabricated by precise polishing, cutting is possible, as shown in the next section.

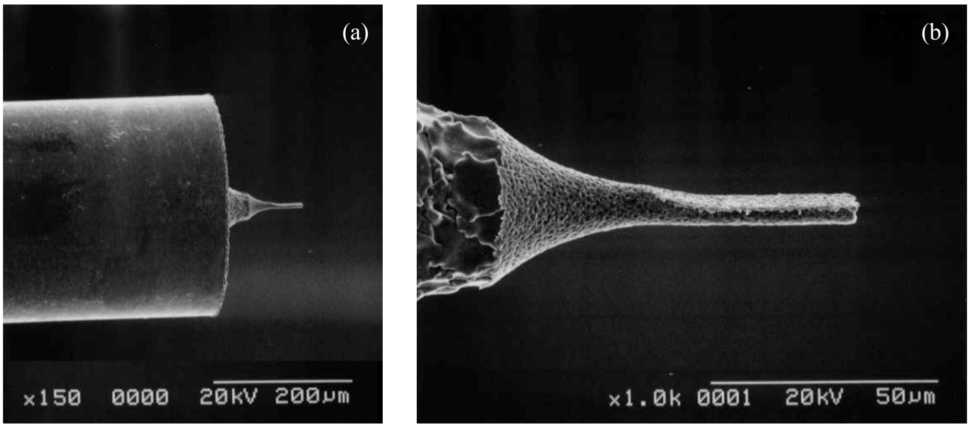

Fig. 2 (a) Overview and (b) close-up view of a 10 µm diameter microtool

3 RESULTS OF MICRODRILLING

Figure 3 shows a 20 µm deep microhole drilled under the machining conditions shown in Table 1. It does not have noticeable burrs or corner dullness. Its diameter is one of the smallest diameters obtained in drilling using a cutting tool.

Next, the drilling characteristics were investigated. Figure 4 shows the relationship between the tool length and penetration in the drilling of holes with a depth 5 µm smaller than the tool length. Drilling was carried out at various penetrations using tools with lengths of 25 µm, 35 µm, 45 µm and 55 µm. Solid squares indicate the highest penetration at which the drilling of at least one hole was possible and hollow squares the lowest penetration at which drilling was impossible due to tool breakage. Using a tool of length 25 µm, the penetration could be increased to 26 µm/s, while the highest penetration was 0.3 µm/s in the drilling of a 50 µm deep hole in silicon using a 20 µm diameter tool [2]. Without the problem of transition in the cutting mode, the penetration can be increased to be much more than that for brittle materials. The deepest possible drilling depth was 50 µm, which was realized at a penetration of 0.2 µm/s, while it was impossible to drill 30 µm or deeper in glass using a 9 µm diameter tool [5]. The reason for the possible drilling depth being deeper than

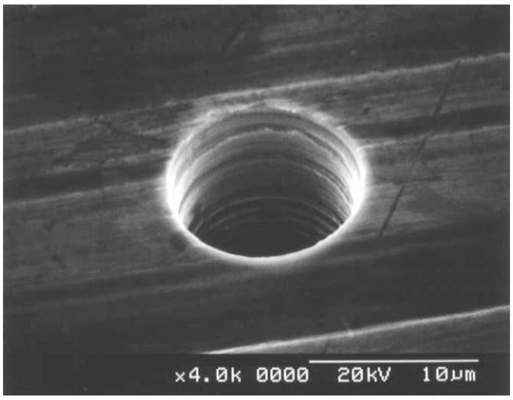

Fig. 3 Microhole of depth 20 µm

Table 1 Machining conditions for drilling

Tool diameter	10 µm
Cutting speed	0.1 m/min
Penetration	6.4 µm/s
Drilling depth	20 µm

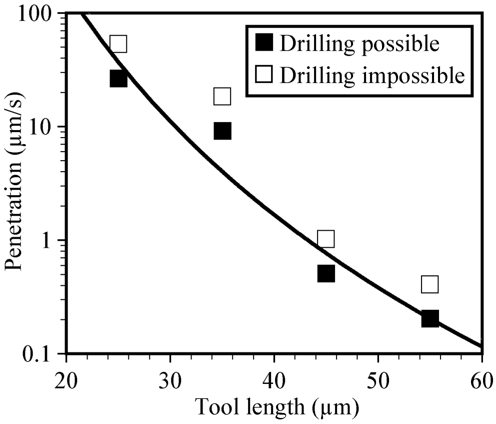

Fig. 4 Relationship between tool length and penetration in drilling (drilling depth = 5 μm smaller than tool length)

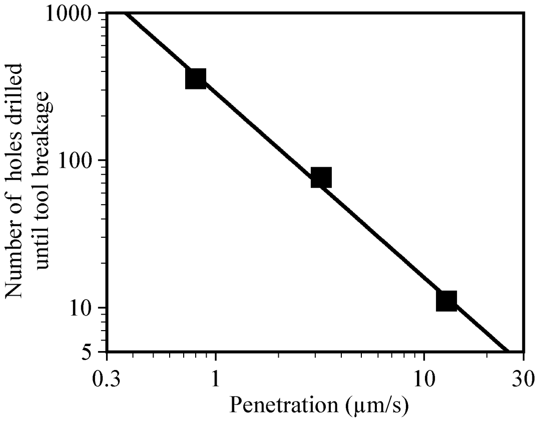

Fig. 5 Relationship between penetration and tool life in drilling (drilling depth = 20 μm, tool length = 25 μm)

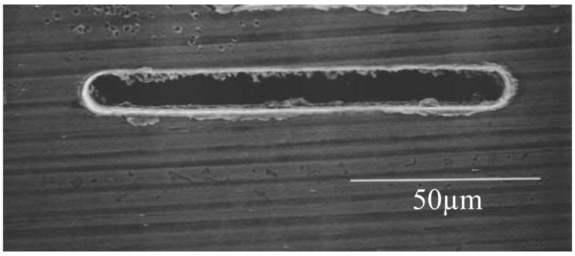

Fig. 6 Microslot of depth 20 μm

Table 2 Machining conditions for milling

Tool diameter	10 μm
Cutting speed	0.1 m/min
Axial depth of cut	1 μm
Horizontal feed speed	10 μm/s
Milling depth	20 μm
Horizontal feed length	100 μm

that of glass may be that the tool wears less because of lower hardness of brass, leading to a smaller increase in cutting force. From the approximate curve, the highest permissible penetration was proportional to the tool length to the power of approximately –6.6.

The tool life at penetrations of 0.8 μm/s, 3.2 μm/s and 12.8 μm/s is shown in Fig. 5, where 20 μm deep holes were drilled using a 25 μm long tool. The tool life is shown as the number of holes drilled until tool breakage. 355 holes could be drilled at a penetration of 0.8 μm/s. The number of holes drilled was proportional to the penetration to the power of approximately –1.3.

4 RESULTS OF MICROMILLING

Figure 6 shows a 20 μm deep microslot milled under the machining conditions shown in Table 2. Since the axial depth of cut was 1 μm, the tool was scanned repeatedly until the milling depth reached 20 μm.

Figure 7 shows the relationship between the axial depth of cut and horizontal feed speed in the milling of 100 μm long slots using a tool of length 25 μm. Milling was performed at various horizontal feed speeds and axial depths of cut of 2 μm, 4 μm, 6 μm and 8 μm. Solid squares indicate the highest horizontal feed speed at which the milling of at least one slot was possible and hollow squares the lowest horizontal feed speed at which milling was impossible due to tool breakage. In the ductile-regime cutting of brittle materials, the depth of cut has to be generally smaller than 1 μm; however, it could be increased to 8 μm or more for brass. The highest permissible horizontal feed speed was proportional to the axial depth of cut to the power of approximately –2.3.

Figure 8 shows the tool life at horizontal feed speeds of 3.2 μm/s, 6.4 μm/s and 12.8 μm/s in milling at an axial depth of cut of 4 μm using a 25 μm long tool. The tool life is indicated as the milling length until tool breakage. The milling length was 600 μm at a horizontal feed speed of 3.2 μm/s. It was proportional to the horizontal feed speed to the power of approximately –2.8.

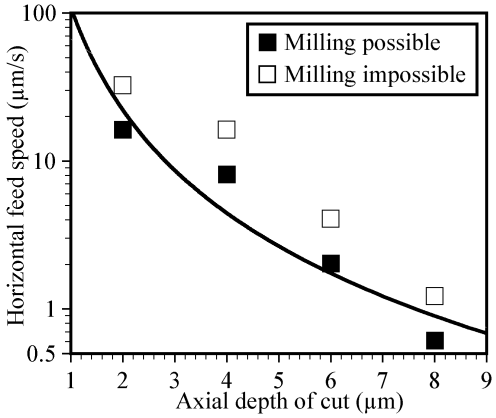

Fig. 7 Relationship between axial depth of cut and horizontal feed speed in milling of 100 μm long slot (tool length = 25 μm)

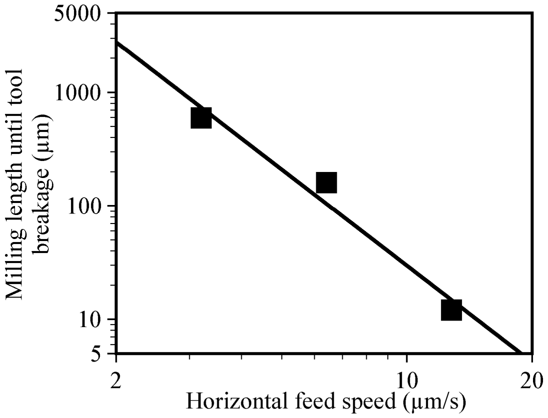

Fig. 8 Relationship between horizontal feed speed and tool life in milling (axial depth of cut = 4 μm, tool length = 25 μm)

5 CONCLUSIONS

The microcutting of brass was carried out. Drilling and milling were performed using a tool of diameter 10 μm fabricated by WEDG. The following results were obtained.

(1) A microhole of depth 50 μm was successfully drilled at a penetration of 0.2 μm/s. In drilling a hole of depth 20 μm using a tool of length 25 μm, drilling was possible at a high penetration of 26 μm/s, and 355 holes were drilled at a penetration of 0.8 μm/s until tool breakage.

(2) A microslot of length 100 μm and depth 20 μm was successfully milled at an axial depth of cut of 1 μm and a horizontal feed speed of 10 μm/s. Using a tool of length 25 μm, the milling of a 100 μm long slot was possible at a large axial depth of cut of 8 μm and a horizontal feed speed of 0.6 μm/s, and the milling length until tool breakage was 600 μm at an axial depth of cut of 4 μm and a horizontal feed speed of 3.2 μm/s.

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