Development of fixed-abrasive tool without loading

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Abstract

To eliminate or decrease the loading of swarf in fixed-abrasive tools, it is necessary to develop a tool with pores whose size and position can be continuously controlled as a replacement for conventional tools with randomly positioned pores with discrete sizes. If pores are continuously placed, an infinite chip pocket is formed that enables the continuous discharge of swarf, realizing long-life fixed-abrasive tools that require no supportive processes such as dressing. In this study, the occurrence of loading was compared between our proposed fixed-abrasive tool and general-purpose tools. It was found that the causes of loading were (1) the formation of a chip pocket due to a high abrasive-grain density, (2) an increase in the contact area between the tool and the workpiece, and (3) the absence of infinite continuous pore owing to the non-spiral structure. Moreover, swarf larger than the grain size were observed for the tool with loading, whereas no such swarf were observed for the tool without loading even when the tool contained fine abrasive grains. In the manufacture of fixed-abrasive tools, therefore, the abrasive grains percentage in the tools should be 55% or lower, regardless of their grain size.

1 Concept of the tool with continuous spiral pore

To suppress the occurrence of loading, a method that combines grinding with electrolytic has been effectively used [1][2]. But the improvement of machines is expensive and increases their environmental impact. So in order to overcome the matter of loading, the fixed-abrasive tool of spiral structure was proposed (Figure 1). The discharge ability of metal swarf is related to the contact area between the tool and the workpiece; it is

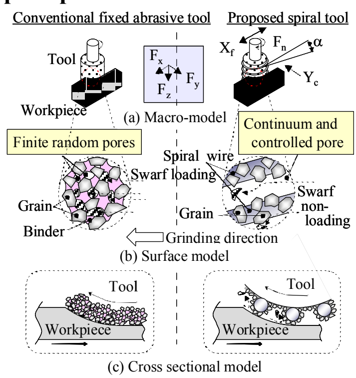


Figure 1: Proposed spiral tool

considered that the smaller the contact area, the higher the swarf discharge ability.
To increase the swarf discharge ability, it is essential to form an infinite chip pocket that enables the continuous discharge of metal swarf. When a thin wire is wound around a metal rod along a spiral groove formed on the rod with a predetermined angle, the contact region between the tool and the workpiece during grinding is near a point or a line, minimizing the contact area. In addition, a continuous spiral pore is formed between the adjacent turns of the spirally wound thin wire. This pore is connected with the circumference of abrasive-grains, which contribute to machining, allowing metal swarf to be immediately discharged. A nickel sulfamate bath was used for electroplating during the manufacture of the tool. For the spirally grooved base material and the wire, SUS304, which has high adhesion to nickel, was used. Because the diffusion layer of the cathode surface can be thinned by rubbing the cathode during electroplating and ions can be actively supplied [3], a brush was vertically fixed on the inner side of the bath parallel to the cathode so that the brush came into contact with the cathode.

2 Loading and grinding force

We examined the relationship between loading and grinding force by fixing the grain diameter, spiral angle, and wire diameter. Table 1 shows the grinding conditions, and Table 2 shows the specifications of the tool. Workpieces made of aluminum, which easily clogs, were used (thickness 2.2 mm). To measure the force applied to the workpiece during grinding, a load cell was attached to the lower end of the workpiece (Figure 2). The side of the workpiece was cut by 1 μm/pass in the Y_c direction and ground by feeding the tool ±5 mm in the X_f direction. Figure 3 shows a comparison of the grinding force F_Y between tool (a), in which loading occurred at a total depth of cut of 98 μm, and tool (b), in which no loading occurred even at a total depth of cut of 200 μm. During each revolution of the tool, both tools were alternately in contact and not in contact with the tool was in contact with the workpiece, the direct current and alternating current components of the grinding force were measured. On the other hand, when the tool and workpiece were not in contact, the system including the load cell was vibrated by the grinding force that was generated during grinding. This phenomenon was

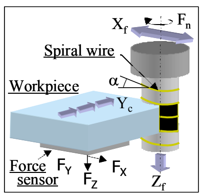


Figure 2: Schematic

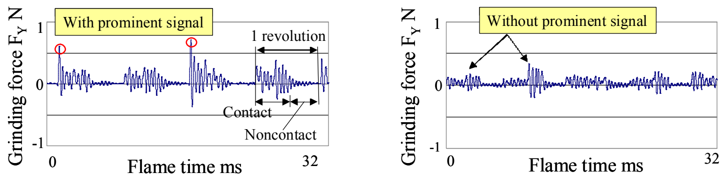
similarly observed regardless of the occurrence of loading. However, a distinct difference between tools (a) and (b) was observed in terms of the amplitude of grinding force obtained during grinding. A spike in amplitude appeared for tool (a), for which loading occurred, but was not observed for tool (b). This maximum in amplitude resulted from the vibration of the system owing to the loading of the tool rather than the grinding force. The grinding force was found to be 0.1 N or smaller from the average direct current. The occurrence of loading in tools can be detected easily by initial detecting this spike in amplitude.

Table 1: Grinding conditions

Revolution F_n	8000rpm	Grain	WA= #600, #2000, #4000
Feed rate X_f (±5mm)	0.4mm/sec	Fluid	Water-insoluble
Depth of cut Y_c	1 μm/1pass	Workpiece	Aluminum

Table 2: Specifications of tool

Substrate	SUS304, ϕ10mm
Wire (mm)	SUS304, ϕ=0.7, 0.4, 0.2
Spiral angle	α11.3°

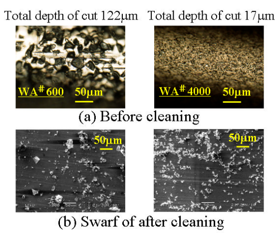


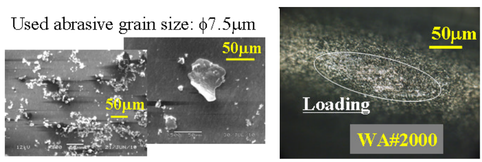
Tool (a) Tool (b)

Figure 3: Comparison of grinding force between tool (a) and tool (b)

3 Relationship between loading and swarf

To identify the causes of the loading of the tool, we examined the swarf obtained after grinding. The total depth of cut was set at a value fivefold greater than the diameter of the abrasive grains used. When the wire diameter was fixed at 0.4 mm and two types of abrasive grains with different diameters were used (Figure 4), no loading occurred for either type of grain. Then, the tool used for grinding was immediately cleaned with ethanol to obtain the swarf. No swarf larger than the grain diameter were observed after cleaning; therefore, the occurrence of loading was considered to be related to the grain density. Abrasive grains were reasonably evenly





Swarf of after cleaning After used of tool (a)

Figure 5: Loading of Swarf

distributed on the surface of the tool with no loading. This indicates that loading was suppressed because the abrasive grains did not coagulate during composite plating and no chip pocket in which swarf could accumulate was formed. The reason for the loading of tool (a) in Figure 3 is the formation of a chip pocket owing to the high abrasive-grain density. For this tool, swarf larger than the grain diameter (7.5 μm) was observed (Figure 5).

4 Grain volume percentage and tool life

Figure 6 shows the grain volume percentage in the tools used in the grinding experiment. Open circles represent the values for tools (a) and (b), and filled circles represent the values for tools with different grain diameters. From Figure 6, the grain volume percentage at which no loading occurs is 55% or lower, regardless of the grain diameter. Moreover, the tool life was compared between tools (a) and (b), which have different grain volume percentages (Figure 7). The tool life is defined as the total depth of cut at which loading starts to occur. The tool life of tool (b), for which no loading occurred even at a total depth of cut of 200 μm, is at least one order of magnitude greater than that of tool (a), and is expected to be greater than the value shown in Figure 7.

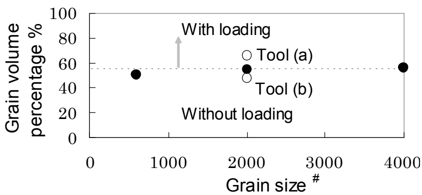


Figure 6: Grain volume percentage of tools

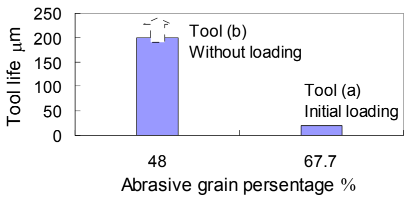
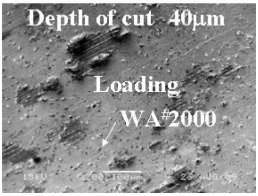


Figure 7: Comparison of tool life

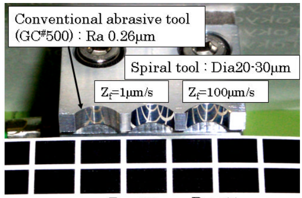
5 Factors causing loading

The formation of a chip pocket owing to a high abrasive-grain density was found to be a cause of loading. However, for the tool without a spiral wire, obtained by directly applying composite plating to the ϕ10 mm base material, loading occurred even though the abrasive-grain density was low and no chip pocket was formed (Figure 8). The total depth of cut was 40 μm. The reasons for loading in this case may be the increase in contact area between the tool and the workpiece and the absence of a continuous pore for the structure without a spiral wire. The contact region between the proposed tool and the workpiece is an ellipse because of the continuous spiral pore. This is considered to improve swarf discharge ability. In summary, the causes of loading were (1) the formation of a chip pocket owing to a high abrasive-grain density, (2) the increase in contact area between the tool and the workpiece, and (3) the absence of infinite continuous pore for the structure without a spiral wire. Therefore, it is possible to realize abrasive-grain tools that are free from loading by taking countermeasures against these factors. The mirror grinding example of aluminum surface shows in figure 9. The abrasive grain was used diamond. The tool was moved by Z_f in the vertical direction (Figure 2).



ϕ10mm SUS304

Figure 8: Loading of non-spiral tool



Ra=32nm Ra=41nm

Figure 9: Mirror grinding of aluminum

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