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Cutting force reduction mechanism of lead-free brass cutting by measuring several different tool materials

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Abstract
Recently, in response to adverse health issues conventional free-cutting brass has been replaced with lead-free brass. However, the machinability of lead-free brass is lower than free cutting brass. Therefore, there is a demand for improvements to its machinability. In this research, optimum tool materials for the cutting of lead-free brass were investigated from the point of view of reducing the cutting force. The experimental results showed that using PCD tools results in the lowest cutting force. To investigate the cause of the reduced cutting force of PCD tools, the adhered material on the rake face of the PCD tool used in a cutting experiment was analyzed. Further, the high temperature wettability between the brass and the tool materials (PCD and carbide) was measured. From the results, it is concluded that the cutting force of lead-free brass can be reduced by using PCD tools, because of its low adhesion characteristics and low chemical affinity with lead-free brass.
Lead free brass, cutting force, wettability

1. Introduction

In general, copper-based alloys are widely used in industry because of their wide range of properties. Leaded brass is known as free-cutting brass and it is commonly used in plumbing fixtures used for water supplies. However, lead in brass has been regulated in several countries because lead causes human health problems. Therefore, in recent years, raw material suppliers have developed several types of lead-free brass alloys by adding bismuth or tin, however, the machinability of these lead-free brasses is not as good as conventional free-cutting brass. For example, the cutting force of lead-free brass is approximately 50% more than that of free-cutting brass, this causes serious trouble such as the stopping of the main spindle or cutting tool fractures.

In our previous study, the machinability of lead-free brass was investigated. The results showed the machinability was changed by changing the additive elements in brass alloy. [1] In this research, the effect of cutting tool materials on the cutting force during the cutting of brass alloy was investigated. In the experiment, outer turning experiments were executed and four tool materials, carbide, cermet, cBN, and PCD were tested.

2. Experiment equipment

In this research, outer turning experiments were conducted by using four different cutting tool materials. The composition of the lead-free brass used as test pieces is listed in Table 1. To forces cutting characteristics with changing tool materials, no additive elements brass alloy was used. An engine lathe with continuously variable transmission (OKUMA type LS) is used and a 4-component dynamometer (Kistler type 9272) is used to measure cutting forces in this experiment. The schematic illustration of the experimental set up is shown in Fig.1

Table 1 components of brass

Mas(%)	Cu	Pb	Zn
C6820(JIS)	58.0	0.17	Bal.

3.Experiment

3.1. Turning experiment

The cutting force is measured to investigate the machinability of lead-free brass using four kinds of cutting tool. Table 2 shows the experiment conditions. **Figure 2** shows the measured forces including the cutting, feed and thrust forces, these are the average value of the raw cutting forces recorded in two seconds. The cutting forces of carbide, cermet, and cBN tools are similar, while for the PCD tool, the cutting force is reduced by 37% and the feed force is reduced by 75%.

3.2 EPMA analysis experiment

Figure 3 shows the microscopic images of the rake faces of tools after the cutting test. As seen in the figure, adhesive material is observed on the carbide, cermet and cBN tools, but no adhesive material is found on the PCD tool.

To investigate the elemental composition on the rake face of the cutting tools, Electron Probe Microanalysis(EPMA) was

Table 2 Cutting condition

Cutting Speed *V*(m/min)	200
Feed *f*(mm/rev)	0.16
Depth *a*(mm)	0.5
Tool holder	PTGNR2020K16
Insert	TNGA160404
Tool material	Carbide Cermet cBN PCD
Atmosphere	Dry

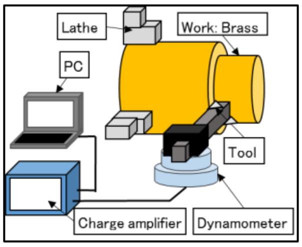

Figure 1turning experiment

adopted where, Cu, Zn, C, W, and Co were analysed respectively.

Figure 4 shows the elemental mapping of the rake face of cutting tools used in the cutting test. Because the major components of brass are Cu and Zn, the concentrations of these elements are rich on the carbide, cermet, and cBN tools. However, they are not observed on the PCD tool. As a result, adhesion elements on the tool are derived from brass, the work material; it is difficult for Cu and Zn to adhere to a PCD tool during the cutting process.

3.3 High temperature wettability experiment

The chemical affinity of PCD with brass alloy was investigated to clarify the cause of low adhesion to the PCD tool. The high temperature wettability between the brass and tool materials (PCD and carbide) was measured. **Figure 5** is the schematic illustration of the wettability measurement. A brass ball of about a 5mm diameter was placed on the tool material substrate and the temperature was raised by using an electric heater. When the brass melted, the contact angle was measured by a digital camera.

Figure 6 showed melted brass alloy on the substrate. As in Fig.5, brass adhered on the carbide substrate. However, the melted brass retained a spherical shape on the PCD due to a repelling action. **Table 3** shows the measured contact angle. As shown in the table, the contact angle of the brass alloy and the carbide substrate is larger than that of brass alloy and PCD substrate. As the result shows the chemical affinity of brass and PCD was lower than that of brass and carbide.

4.Discussion

By consideration of these results, it is shown the chemical affinity of brass alloy and PCD is lower compared with that of brass and carbide, and adhering does not occur while cutting brass. It is reported that the contact angle between the tool and work material is related to the frictional force of the tool rake face in the cutting process [2]

As these examinations show, because the cutting force is reduced by using a PCD tool to cut the brass, the chemical affinity is low compared to carbide, and the friction force is reduced.

In our preceding study, during orthogonal cutting the friction force was the same between C6820 and a lead-free brass alloy (Sn adding Cu alloy) [1].

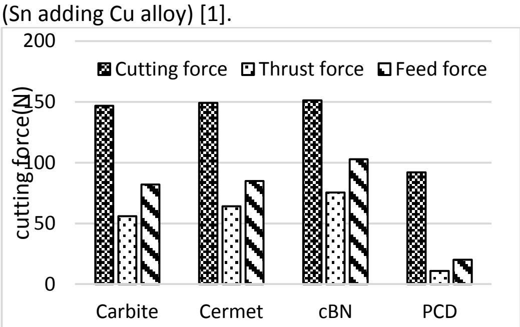

Figure 2 Result of cutting Experiment

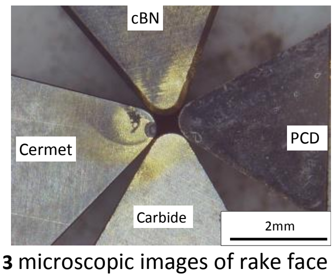

Figure 3 microscopic images of rake face of tool

It was concluded that the use of a PCD tool will improve the machinability of a lead-free brass alloy.

5.Conclusion

The following objective results are obtained by cutting experiments, EPMA analysis and high temperature wettability experiments to investigate the factors affecting the friction forces between brass alloy and tool materials during machining.

1) The lowest cutting force was observed by using a PCD cutting tool (compared to carbide, cermet and cBN tools).

2) After the cutting test, adhered material was observed on the carbide, cermet and cBN tools, however no adhered material was observed on the PCD tool.

3) From the result of high temperature wettability experiments, the contact angle between molten brass on a PCD substrate was larger than that measured on a carbide substrate.

4) Because the cutting force is reduced by using a PCD tool to cut brass, the chemical affinity is low compared to carbide, and the friction force is reduced. A PCD tool will improve the machinability of a lead-free brass alloy.

To clear chemical affinity, a section of cutting tool is now analyzed for investigating of adhesion property between copper alloy and carbide, diamond and cobalt binder.

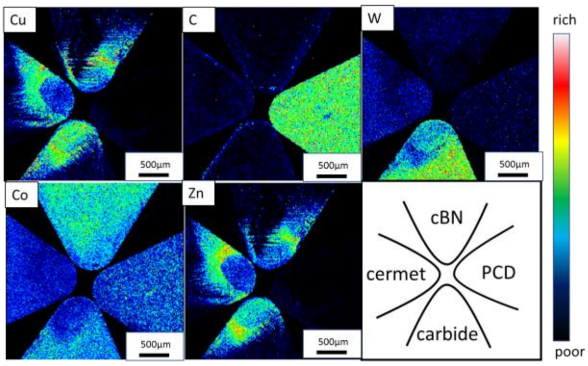

Figure 4 Result of EPMA observation

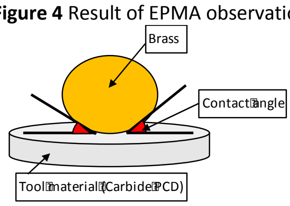

Figure 5 High temperature wettability experiment

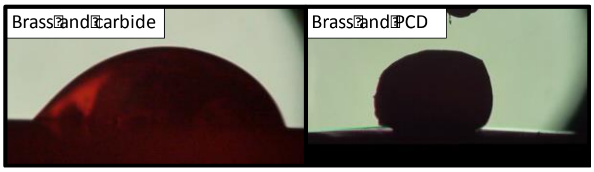

Figure 6 Melting brass on the tool material

Table3 Result of contact angle

[deg]	(1)	(2)	Ave.
Brass-carbide	134.4	117.1	125.8
Brass-PCD	36.2	40.2	38.2

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