Properties of Diamond Compacts Having Different Grain Sizes with MgCO_3 Sintering Agent

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Two sorts of diamond- MgCO_3 compacts with grain sizes of $6\sim 12\ \mu\text{m}$ (mean grain size: $7.5\ \mu\text{m}$) and $20\sim 40\ \mu\text{m}$ (mean grain size: $23\ \mu\text{m}$) were prepared and examined. The effects of diamond grain size on the amount of MgCO_3 and Knoop hardness were not remarkable. The coarser grained diamond compact with MgCO_3 sintering agent exhibited little better wear resistance than the finer grained one and showed tiny flaking on a rake face and small recession of a cutting edge in a cutting test of granite. When compared with a conventional diamond-Co system, the effects of a sort of a sintering agent on the properties of compacts were much more remarkable than those of diamond grain size. Namely, the diamond- MgCO_3 compacts showed much smaller amount of a sintering agent, higher hardness and better cutting performance for granite, irrespective of grain size.

[sintered diamond, non-metallic catalyst, cutting performance, granite, grain size]

1. Introduction

A polycrystalline diamond compact (PCD) is widely used as cutting tools, wear parts, etc. because of its excellent properties such as wear resistance, adhesion resistance and thermal conductivity. However, since the conventional PCD contains Co as a sintering agent, its mechanical properties deteriorate above about 1073 K due to catalytic graphitization of diamond and cracking caused by difference in thermal expansion coefficient between diamond and catalysis metal, which limits application temperature. It is desired to raise the temperature over about 1100 K in some applications such as an oil drilling bit.

Recently it was found by Akaishi et al. that carbonates of alkaline earth metals such as MgCO_3 can work as a sintering agent of diamond and that a PCD with such a sintering agent has high thermal stability[1]. It was also shown that it exhibits higher wear resistance than conventional one in a cutting test of an aluminum alloy with high silicon content and of cemented carbides[2]. Following these results, diamond- MgCO_3 compacts having different grain sizes of diamond were synthesized and the effects of grain size on some properties of them were evaluated.

2. Experimental

As starting materials, two sorts of natural diamond powder having grain sizes of $6\sim 12\ \mu\text{m}$ (mean grain size: $7.5\ \mu\text{m}$) and $20\sim 40\ \mu\text{m}$ (mean grain size: $23\ \mu\text{m}$), and MgCO_3 powder were used.

Diamond powder was layered on MgCO_3 powder and treated using a modified belt type high pressure apparatus as shown in Fig. 1. Treating condition was 7.7GPa and 2573K and a holding time was 1.8ks. During treatment, MgCO_3 melts and infiltrates into the diamond layer, and sintering proceeds.

The sample thus obtained (hereafter named as "DM") was ground and polished with diamond wheel. The polished sample was examined by X-ray diffraction analysis and optical microscopy. Knoop hardness was measured under the load of 9.8N. In order to easily observe the grain boundary and to estimate the amount of a sintering agent, the sample was dipped

in hot HCl for 14.4 ks and a sintering agent was removed. The amount of a sintering agent was measured with image analyzer. In order to elucidate cutting performance, the PCD was brazed on a carbide substrate and a round cutting insert with a diameter of $\phi 8\text{mm}$ was prepared. A cutting test was carried out using granite as a work material. Cutting condition was as follows; cutting speed: 150m/min, depth of cut: 0.3mm, feed rate: 0.1mm/rev, coolant: used. Flank wear was measured and a cutting edge was observed.

Fig. 1. A modified belt type high pressure apparatus.
(1) piston, (2) cylinder, (3) Ta capsule, (4) NaCl-10wt%ZrO₂, (5) graphite heater, (6) NaCl-10wt%ZrO₂, (7) steel ring, (8) gasket.

Two sorts of conventional PCD with Co sintering agent (GE, #1300 and #1500, hereafter named as "DC") were also used for reference. The grain sizes of #1300 and #1500 nearly correspond to $6\sim 12\ \mu\text{m}$ and $20\sim 40\ \mu\text{m}$, respectively.

3. Results and Discussion

X-ray diffraction analysis and optical microscopy on the polished DM surface showed that the sample was composed of

diamond and a small amount of MgCO_3 as reported before[1,2]. Figs.2 and 3 show Knoop hardness and indentations by optical microscopy, respectively. Hardness was measured on 5 points for each sample. The effect of diamond grain size on Knoop hardness was negligible, compared with that of the sort of a sintering agent. Mean hardness of DM was higher than that of DC, irrespective of grain size

Fig. 2. Knoop hardness under load of 9.8N.

Fig. 3. Differential interference micrographs of Knoop indentations (load: 9.8 N).

Fig.4 shows optical microstructures after treatment in hot HCl. The sintering agent of MgCO_3 or Co is leached out and is observed as black spots in the figure. They exist at diamond-diamond boundary. In the case of DM, homogeneous dispersion

of MgCO_3 phase is also revealed and diamond-diamond direct bonding is observed [1,2], irrespective of grain size. Thickness of MgCO_3 phase is under $1 \mu\text{m}$ in the both DM samples. In the case of DC, the coarser the grain size, the thicker the Co phase. Thickness of the Co phase is over $1 \mu\text{m}$ up to about $10 \mu\text{m}$. The amount of a sintering agent was measured at 3 points on the etched surface. Mean values are listed in Table.1. The amounts of a sintering agent in the both DM samples were much lower than those of DC, irrespective of grain size. When the grain size was considered, the finer grained sample had higher amount than the other to some extent in both DM and DC samples.

Fig. 4. Optical micrographs after treatment in hot HCl for 14.1ks.

Table 1. The amount of a sintering agent measured on an etched surface. (vol%)

Sample	Grain size	
	Fine	Coarse
DM	5	4
DC	14	10

Fig.5 is flank wear after cutting test of granite. Flank wear of the coarser grained DM was little smaller than that of the finer grained one, while flank wear of DM was about half of that of DC, irrespective of grain size. Appearance of a cutting edge is shown in Fig.6. The coarser grained DM showed tiny flaking on a rake face and small recession of a cutting edge which appears as a dark area in the flank wear. The finer grained DM showed neither flaking nor recession. In the both DC samples, large flaking and remarkable recession were observed.

Above results of a cutting test will be briefly discussed. Granite is composed of various minerals with different properties. Thus, even in a continuous cutting test, a cutting

edge crushes the minerals discontinuously. This would result in discontinuous cutting force on it, giving microscopical impact force together with abrasive wear. Therefore, this cutting test is considered to be able to evaluate toughness as well as wear resistance at the same time.

Fig. 5. Flank wear after cutting of granite. Cutting speed: 150m/min, depth of cut: 0.3mm, feed rate: 0.1mm/rev, coolant: used, cutting time: 1.8ks.

Fig. 6. Cutting edges of DM and DC after cutting of granite. Cutting speed: 150m/min, depth of cut: 0.3mm, feed rate: 0.1mm/rev, coolant: used, cutting time: 1.8ks.

Between the DM samples, the finer grained compact showed

better appearance of a cutting edge and little larger flank wear than the other. Following reasons were considered to be possible though any conclusion could not be obtained. (1) In the coarser compact, larger gaps among diamond grains generate larger concentrated stress which facilitates crack formation and thus the bonding between coarser grains are easily broken. (2) The bonding strength between diamond grains is different according to grain size due to the difference in facility of solution/re-precipitation. Namely, it is higher in the finer grained compact. (3) The coarser compact is easily fractured intragranularly.

The DM samples exhibited higher wear resistance and smaller flaking and recession than DC as shown in Figs. 5 and 6. The reasons for these results were considered as follows. (1) As shown in Fig. 4 and Table 1, DM has smaller amount of a sintering agent, i.e. larger amount of diamond, than DC. (2) This would result in formation of larger area of strong diamond-diamond bonding. (3) Besides, DM has higher thermal stability.

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4. Conclusions

Two sorts of diamond-MgCO₃ compacts with grain sizes of 6 ~ 12 μ m and 20 ~ 40 μ m were prepared and examined, referring to conventional diamond-Co compacts. The effects of diamond grain size on the amount of a sintering agent and Knoop hardness were negligible. In a cutting test of granite, the coarser grained compact with MgCO₃ sintering agent showed little higher wear resistance than the finer grained one and exhibited tiny flaking on a rake face and small recession of a cutting edge, while the other exhibited neither flaking nor recession.

However, the effects of the sort of a sintering agent on the properties were much more remarkable than those of diamond grain size. Namely, diamond-MgCO₃ compacts had much smaller amount of a sintering agent, higher hardness and better cutting performance for granite than conventional diamond-Co compacts, irrespective of grain size.

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References

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