Development of Highly-Wear-Resistant, High-Strength Polycrystalline Diamond "SUMIDIA DA1000"

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The newly developed SUMIDIA DA1000 grade, which is applicable for machining of non-ferrous alloy parts that are hard to cut, has been developed as a solution to environmental problems in various industries such as automobile and machine manufacturing. DA1000 is made by densely sintering the fine grains of diamond and provides the highest level of wear resistance and toughness as well as excellent surface roughness. The SUMIDIA DA1000 grade realizes higher productivity and excellent surface roughness in machining of various hard-to-cut non-ferrous alloy parts. This paper describes the features of DA1000 and its cutting performance.

1. Introduction

Polycrystalline diamond (PCD) tools featuring excellent wear resistance and long tool life are made by sintering diamond powders. They are being used in the automotive and electronics industries as the tools that realize high speed, high efficiency and high precision machining of non-ferrous metals and nonmetals. The SUMIDIA series PCD tools developed by Sumitomo Electric Hardmetal Corporation contribute to the improvement in productivity and cost reduction.

Recently, the machining trends in various industries are toward productivity improvement, use of hard-to-cut materials as environmental measures, and higher required precisions in finish specifications such as finish roughness. As a result of these trends in machining, there are growing needs for cutting tools made of PCD [(1)].

To respond to such needs, the authors have developed SUMIDIA DA1000, the new highly-wear-resistant and high-strength grade in the SUMIDIA series. The features and cutting performance of SUMIDIA DA1000 are described in this report.

2. Features of SUMIDIA DA1000

Table 1 shows the features of DA1000 and conventional PCD grades. **Figure 1** shows the relationship between the transverse rupture strength and the relative ratio of wear resistances of various kinds of grades when the wear resistance of DA2200 is assumed 1. PCD consists of diamond particles and Co compounds. DA90 consists of large diamond particles whose average diameter is 50 μm, so it is densely sintered and excellent in wear resistance but has low strength. On the other hand, high-strength DA200 consists of small diamond particles whose average diameter is 0.5 μm and has low wear resistance because its diamond content is low. SUMIDIA DA2200 having a high diamond particle density was developed to offer both high chipping resistance and high wear resistance [(2)]. In order to achieve better toughness and higher wear resistance than DA2200, SUMIDIA DA1000 has been developed.

Table 1. Characteristics of DA1000

	DA1000	DA2200	DA200	DA150	DA90
Average diamond particle diameter (μm)	**~0.5**	0.5	0.5	5	50
Hardness Hv (GPa)	**110-120**	90-100	80-100	100-120	100-120
Transverse rupture strength (GPa)	**2.60**	2.45	2.15	1.95	1.10

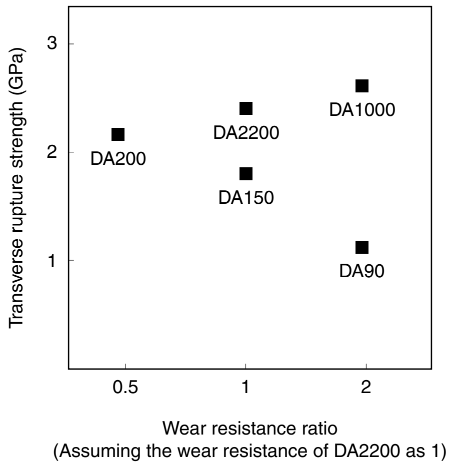


Fig. 1. Grade map

Figure 2 shows the microstructure of DA1000 (with the Co binder phase leached out). As shown in **Fig. 2**, DA1000 has higher diamond particle density than DA2200. DA1000 has excellent wear resistance equal to that of coarse-grained diamond DA90, or two times that of DA2200, and also has excellent transverse rupture strength.

Because the average diamond particle diameter of DA1000 is 0.5 μm or less, DA1000 can be applied in finishing applications where smooth surface is required. **Figure 3** shows the surface roughness of 17% Si-Al alloy cut using either DA1000 or DA150 at Vc = 1,000 m/min, and **Fig. 4** shows the end cutting edge of each insert. As shown in **Fig. 3**, the surface machined using DA150 has a maximum height of 5.8 μm and shows a random and non-uniform feed mark pattern, while the surface machined using DA1000 has a maximum height of 3.6 μm, which is close to the theoretical surface roughness of 3.5μm, and shows a smooth and regular feed mark profile. This difference is due to different sizes of diamond particles that constitute sintered bodies. The cutting edge of DA150 has irregularities of about 3 μm, but the cutting edge of DA1000 is smooth.

Especially in machining of highly-ductile work materials, the sharpness of cutting edge is important because the machined surface gets plucked when the cutting edge is worn into a round shape. The sharpness of cutting edge is affected by the size of diamond grains. Because DA1000 contains diamond particles of under 0.5 μm in size, it can keep the cutting edge sharpness during the cutting operation and therefore shows excellent performance in this application.

3. Cutting performance

To evaluate the cutting performance of DA1000, the cutting test was carried out with Si-Al alloy containing either 12% or 17% Si. The result obtained with each Si-Al alloy is shown in **Fig. 5** and **Fig. 6**, respectively.

In machining of 12% Si-Al alloy at a cutting speed of Vc = 2,000 m/min, the flank wear width of DA1000 is smaller than that of DA2200 by about 30%, and only 15 μm after a cutting length of 5km. On the other hand, in machining of 17% Si-Al alloy containing hard particles, even at a low cutting speed of Vc = 800 m/min, the flank wear width is 80 μm after a cutting distance of 5 km. This is due to the facts that hard Si particles cause abrasive wear and that diamond in PCD becomes graphite when heated to 700°C or higher. A partial increase in the temperature of the cutting edge while cutting Si accelerates the wear of a PCD tool. Even in cutting of hard-to-cut materials such as Si, DA1000

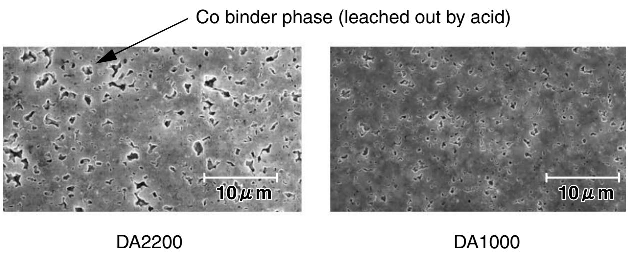
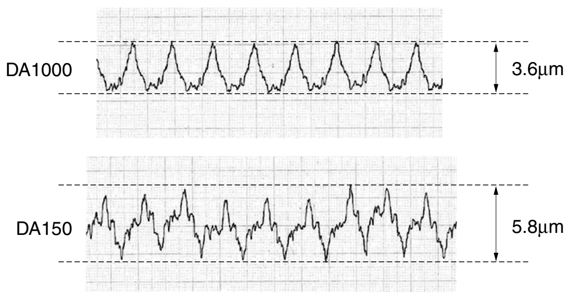


Fig. 2. Microstructure of acid treated PCD



Work material: 17% Si-Al alloy, Insert: TPGW160308
Cutting conditions: Vc = 1,000 m/min, f = 0.15 mm/rev, a_p = 0.2 mm, WET

Fig. 3. Comparison of machined surfaces

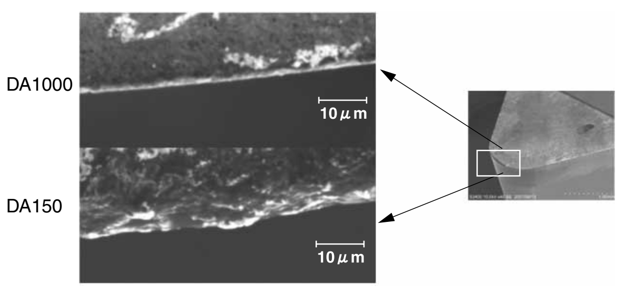
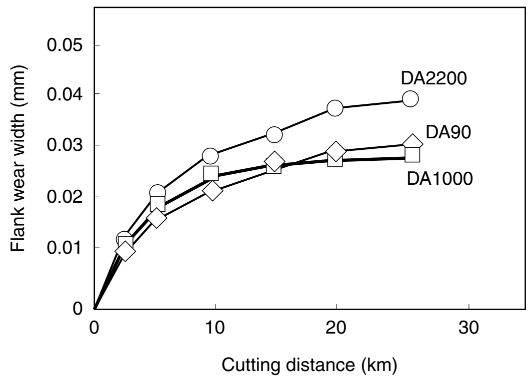
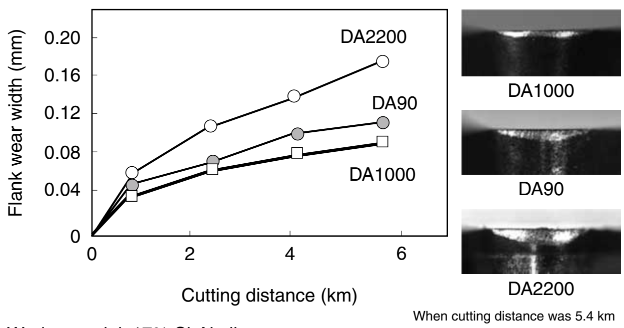


Fig. 4. End cutting edge of insert



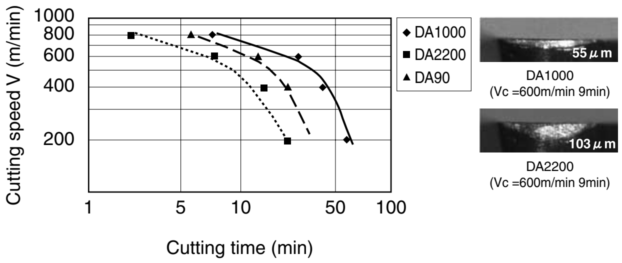
Work material: 12% Si-Al alloy, Insert: TPGN160304
Cutting conditions: Vc = 2,000 m/min, f = 0.15 mm/rev, a_p = 3.0 mm, WET

Fig. 5. Wear resistance in turning of 12% Si-Al alloy



Work material: 17% Si-Al alloy
Insert: TPGN160304
Cutting conditions: Vc = 800 m/min, f = 0.12 mm/rev, a_p = 0.5 mm, WET

Fig. 6. Wear resistance in turning of 17% Si-Al alloy



Work material: 17% Si-Al alloy, Insert: TPGN160304
Cutting conditions: *Vc* = 200-800 m/min, *f* = 0.12 mm/rev, a_p = 0.5 mm, WET
Criterion: Vb = 0.1mm

Fig. 7. V-T curve in turning of 17% Si-Al alloy

shows excellent wear resistance

Figure 7 shows the V-T curve in machining of 17% Si-Al alloy using the flank wear width of 0.1 mm as a criterion of tool life. As shown in the figure, At Vc = 800 m/min, the tool life of DA1000 is 7.5 minutes, which is three times longer than that of DA2200 (2.5 minutes). At Vc = 200 m/min, the tool life of DA1000 is 54 minutes, which is twice longer than that of DA2200 (27 minutes). As just described, DA1000 has a longer tool life in a wide cutting speed range from low to high speed compared with the conventional grades such as DA90 and DA2200.

To evaluate the cutting performance of DA1000 in milling applications, the cutting test was carried out with

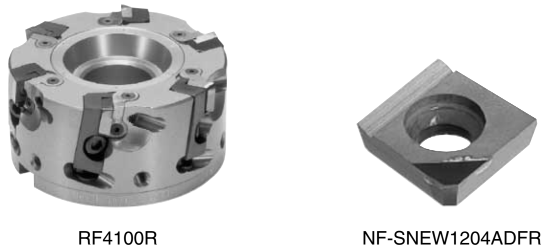
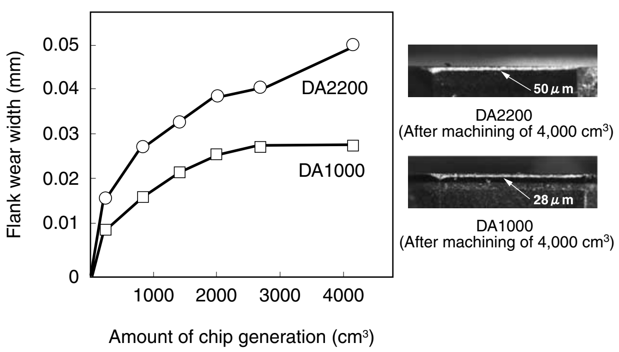


Fig. 8. Milling cutter and insert



Work material: 12% Si-Al alloy
Cutter: RF4100R (6-flute)
Insert: NF-SNEW1204ADFR
Cutting conditions: *Vc* = 2,000 m/min, *f* = 0.15 mm/rev, a_p = 3.0 mm, WET

Fig. 9. Milling performance of DA1000

12% Si-Al alloy. **Figure 8** shows the milling cutter (FR4100) used in the evaluation. The results of the test are shown in **Fig. 9**. From the figure, it is understood that at a cutting volume of 2,800 cm^3, the flank wear width of DA1000 is 27 μm and that of DA2200 is 40 μm. At a cutting volume of 4,000 cm^3, the flank wear width of DA2200 rapidly increased to 50 μm, indicating that the wear was accelerated due to the occurrence of chippings. Hence, it is proven that DA1000 shows excellent wear resistance and excellent chipping resistance in milling.

4. Recommended cutting conditions and application areas

Table 2 shows the recommended application areas of SUMIDIA DA1000. DA1000 shows better wear resistance than DA150. This means that DA1000 is applicable for cutting of all types of Al alloys including hard-to-

Table 2. Recommended application areas

Aluminum

Machinability	Work material	Turning: Rough	Turning: Finish	Milling	Part example
Good	Sintered alumina		DA1000		Piston liner
↕	Aluminum die-cast (ADC12)	DA2200			Transmission case Oil pan Cylinder block Aluminum wheel HDD
	Low silicon (AC2B-T6, AC4C-T6)				Cylinder head
Poor	High silicon (A390-T6)		DA150		Cylinder block

Non-aluminum

Machinability	Work material	Turning: Rough	Turning: Finish	Milling	Part example
Good	Non-ferrous sintered alloy	DA2200	DA1000		Bushing
↕	Zinc bronze				Connecting rod
	Carbon				Electrode
	Carbide		DA90	DA150	Roll
Poor	Combination with Fe				Cylinder block Bearing cap

Table 3. Recommended cutting conditions of DA1000

Work material	Cutting speed *Vc* (m/min)	Feed rate *f* (mm/rev)	Depth of cut a_p (mm)
Aluminum alloy (Si content ≦13%)	3,000 max.	0.2 max.	3 max.
Aluminum alloy (Si content >13%)	800 max.	0.2 max.	3 max.
Copper alloy	1,000 max.	0.2 max.	3 max.
Reinforced plastic	1,000 max.	0.4 max.	2 max.
Wooden or inorganic board (cutting, etc.)	4,000 max.	0.4 max.	–
Carbon	100 - 600	1	2 max.

cut high-silicon Al-alloy. DA1000 also shows excellent performance in machining of zinc bronze and non-ferrous sintered alloys such as copper alloy. For machining of ferrous alloys such as carbide and combinations with Fe, DA150 and DA90 are recommended, because the fine diamond particles contained in DA1000 easily react with ferrous materials. **Table 3** shows the recommended cutting conditions. It is recommended that an Al-alloy having a Si content of 13% or less is machined at a cutting speed of not more than 3,000 m/min, while an Al-alloy having a Si content of more than 13% is machined at a cutting speed of not more than 800 m/min. In addition, it is recommended that copper alloys and reinforced plastics are machined at a cutting speed of not more than 1,000 m/min.

5. Application examples

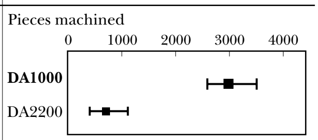
Table 4 shows the application examples of DA1000. Internal turning of bushings made of copper alloy is conducted to obtain a surface roughness of 3.2S under the wet cutting condition at Vc = 300 m/min, f = 0.07 mm/rev, and a_p = 0.08 mm. The end of life of DA2200 is when the surface roughness deteriorates as a result of the breakage of cutting edge due to the cumulation of micro-chippings. On the other hand, DA1000 can reduce the deterioration of surface roughness because it shows a small flank wear width and does not have micro-chippings. DA1000 can stably machine no less than 2,500 workpieces, meaning that its tool life is successfully extended by three times or more.

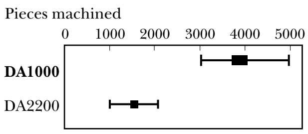
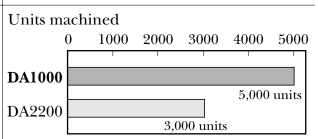
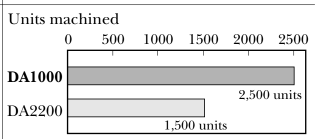
Machining of oil pump covers made of 12% Si-Al alloy is conducted under the wet cutting condition at Vc = 1,400 m/min, f = 0.3 mm/rev, and a_p = 0.02 mm. The end of life of DA2200 is when it needs to be replaced after 1,000 workpieces because of the occurrence of burrs. DA1000 has excellent wear resistance and has achieved machining of 3,000 workpieces or more, realizing a tool life 3 times that of DA2200.

In milling of cylinder blocks and the upper surfaces of cylinder heads, when DA2200 is used, the generation of burrs shortens the tool life. However, DA1000 has excellent wear resistance and can keep the cutting edge sharpness during the cutting process, so it can reduce the generation of burrs, realizing machining of 5,000 cylinder blocks or 2,500 cylinder heads. Accordingly, the use of DA1000 reduces the tooling cost to 60%, and DA1000 can contribute to the improvement of productivity because the frequency of tool replacement is decreased.

Table 4. Application examples

<table>
<tr><th>Machining description</th><th>Machining specifications</th><th>Results</th></tr>
<tr><td>Internal machining of bushing

Cutting distance: 73 m/piece</td><td>Work material: Copper alloy
Vc = 300 m/min,
f = 0.07 mm/rev,
a_p = 0.08 mm, WET
NF-TPGN160308
Surface roughness: 3.2S</td><td></td></tr>
<tr><td>Machining of oil pump cover

Cutting distance: 62 m/piece</td><td>Work material: 12% Si-Al alloy
Vc = 1400 m/min,
f = 0.3 mm/rev,
a_p = 0.2 mm, WET
NF-CNGX120408
Criterion: Burr</td><td></td></tr>
<tr><td>Milling of cylinder block's upper surface
</td><td>Work material: 12% Si-Al alloy
Vc = 2,800 m/min,
f = 0.14 mm/rev,
a_p = 2 mm, WET
NF-SNEW1204ADFR
Criterion: Burr</td><td></td></tr>
<tr><td>Milling of cylinder head's upper surface
</td><td>Work material: Al alloy
Vc = 1500 m/min,
f = 0.2 mm/rev,
a_p = 3 mm, WET
NF-SNEW1204ADFR
Criterion: Burr</td><td></td></tr>
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6. Conclusion

Highly-wear-resistant, high-strength PCD grade SUMIDIA DA1000 has been developed. In the field of machining, the trend is toward the increased use of hard-to-cut materials such as high-silicon al-alloy, copper alloy and CFRP. DA1000 can be used for machining of these hard-to-cut materials and for machining of the parts that have high precision requirements in finish specifications such as finish roughness, realizing longer tool life. The use of SUMIDIA DA1000 PCD tools having excellent cutting performance can contribute to cost reduction and productivity improvement.

References

(1) Tomohiro Fukaya: 8. Nonferrous metals, Diamond technology general statement, p.480 (2007)

(2) Yasuyuki Kanada, et al.: Development of SUMIDIA DA2200, High-strength PCD tool, SEI Technical Review, No. 151, p,119, (1997)

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