15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 2

DIAMOND DISPERSED CEMENTED CARBIDE PRODUCED WITHOUT USING ULTRA HIGH PRESSURE EQUIPMENT

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SUMMARY

We have developed a composite material of dispersed diamond particles in cemented carbide without using ultra high pressure equipment. The developed diamond dispersed cemented carbide combines the excellent properties of cemented carbide with diamond and also provides 1.5 times improved fracture toughness over that of cemented carbide. They also show 10 times higher wear resistance over that of cemented carbide in a wear resistance test against bearing steel, and 5 times greater grindability than diamond compacts. Because ultra high pressure equipment is not used to produce the developed material, large compacts over 100 mm in diameter can be manufactured. The developed material showed 10-25 times higher wear resistance in real use as wear-resistant tools such as centerless blades and work-rests.

KEYWORDS

Diamond particle, graphitization, ultra high pressure equipment, cemented carbide, fracture toughness, wear resistance, grindability, wear-resistant tools

1. Introduction

Cemented carbide is a composite material made of tungsten carbide (WC) and cobalt (Co). This material was invented by Schorter in 1938, and produced commercially under the brand name Wie Diamant. Since then this

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 2

material has been widely used as a material for cutting tools and wear-resistant tools because of its excellent hardness, strength, toughness, and Young's modulus [1].
In recent years, diamond compacts have come into greater use because of their extremely high hardness and wear resistance [2]. But diamond compacts have the disadvantages of being difficult to machine because of their high hardness, the inability to be formed into oversized or complex shapes because of the use of ultra high pressure equipment, and consequential high cost.

Therefore, a material combining the excellent properties of cemented carbides and diamond compacts, and offering the advantage of inexpensive fabrication without requiring ultra high pressure equipment would be of considerable industrial value. Newly developed diamond dispersed cemented carbides meet just such needs. This paper describes the properties of newly developed diamond dispersed cemented carbides.

2. Conventional technique and purpose of this study

Because diamond is the hardest material on the earth (9.8 GPa), a sintered compact made by dispersing diamond particles in cemented carbide should offer exceptional toughness and wear resistance. Actual fabrication of such materials, however, has encountered the problem of phase transformation of diamond, which is thermodynamically stable at high pressures, into graphite at high-temperature when sintering pressure is inadequate as shown in Fig. 1 [3]. Although Hall et al. have reported that diamond can be stable at temperatures below 1400 K, even if thermodynamically unstable at such temperatures [4], it is difficult to make diamond dispersed cemented carbides with dense cemented carbides under such conditions. It is possible but expensive to make dense diamond dispersed cemented carbides at the high temperatures and pressures at which diamond is stable due to the required use of ultra high pressure equipment.

Thermodynamically, diamond is unstable around 1600 K below 5 GPa. But it is necessary for diamond particles to have sufficient time to transform into graphite in view of kinetics. Therefore we attempted to produce diamond

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 2

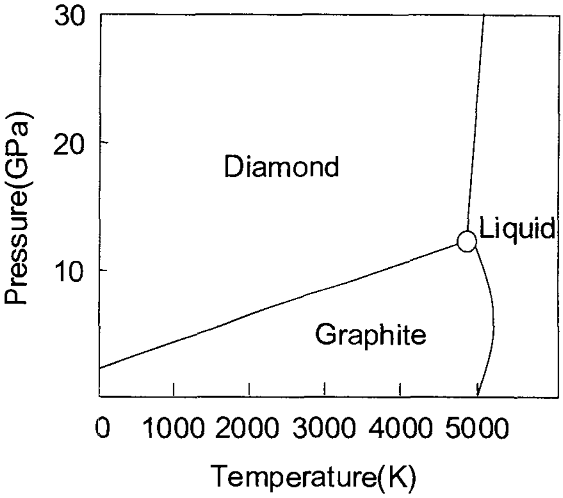


Figure 1 Phase diagram of diamond

dispersed cemented carbides by short time sintering around 1600 K preventing diamond particles from transforming into graphite without using ultra high pressure equipment. In this study, we used a new sintering technique applying pulse current directly into a carbon mold, thus making it possible to raise the temperature quickly and facilitate rapid sintering.

The purpose of this study was to produce diamond dispersed cemented carbides with sufficient density without using ultra high pressure equipment, and to compare the mechanical properties of diamond dispersed cemented carbides with cemented carbides and diamond compacts.

3. Experimental procedure

The WC powder with an average grain size of 1.9 μm, Co powder with an average grain size of 1.4 μm, and diamond powder with an average grain size of 10 μm were used as starting materials. These powders were combined with a mixture of WC and 10 % Co by weight, and wet-mixed in a ball mill for 15 hours and dried. Then this WC-10wt%Co powder and 20 % diamond powder by volume were dry-mixed in a ball mill for 2 hours. In

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 2

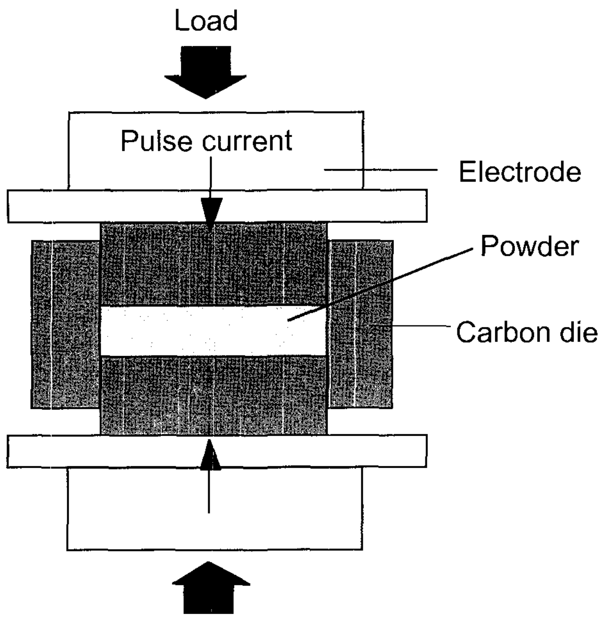


Figure 2 Apparatus of the new sintering technique

addition, the surface of the diamond powders were coated with an SiC layer having a thickness of 100nm by chemical vapor deposition in order to prevent contact with molten Co during sintering [5]. Because molten Co is very reactive to diamond, diamond transforms easily into graphite. The mixed powders were poured into the carbon die having an inside diameter 30 mm, and pre-pressed at 1.4 MPa. The quantity of mixed powder was adjusted to a 4 mm thickness after sintering. Then the pre-pressed sample in the carbon die was set in the sintering furnace using pressurizing and direct resistant heating by pulse current as shown in Fig. 2. As a result, carbon die was heated quickly by Joule heat, thus making it possible to facilitate rapid sintering. The load of 41 MPa was applied to the green compact during sintering. The temperature was measured by an optical pyrometer at the point of the carbon die surface located near the sample. This temperature is about 200 K lower than the real temperature of the specimen. Thereafter the sample was vacuum sintered under the following conditions: heating rate:

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 2

6 K/minute, keeping time: 3 minutes. The sintering temperature was selected between 1243-1543 K.

To evaluate the densification level and microstructure of the sintered samples, a cross section of the sample was ground with a # 200 diamond grindstone. The samples were observed using an optical microscope and scanning electron microscope. To evaluate the mechanical properties of the sintered samples, the hardness and fracture toughness were measured by the indentation fracture method using a Vickers hardness gauge at a load of 490N.

4. Results and discussion

4-1. Sintering test results

The relation between sintering temperature and specific gravity is shown in Fig. 3. The specific gravity of samples sintered between 1400-1500 K were in near agreement with the theoretical density. In this sintering temperature, it was possible to satisfy both prerequisites of minimizing the graphitization of diamond particles and promoting the densification of cemented carbides. The microstructure of diamond dispersed cemented carbides sintered between 1400-1500 K is shown in Photo. 1. As can be seen in this photograph,

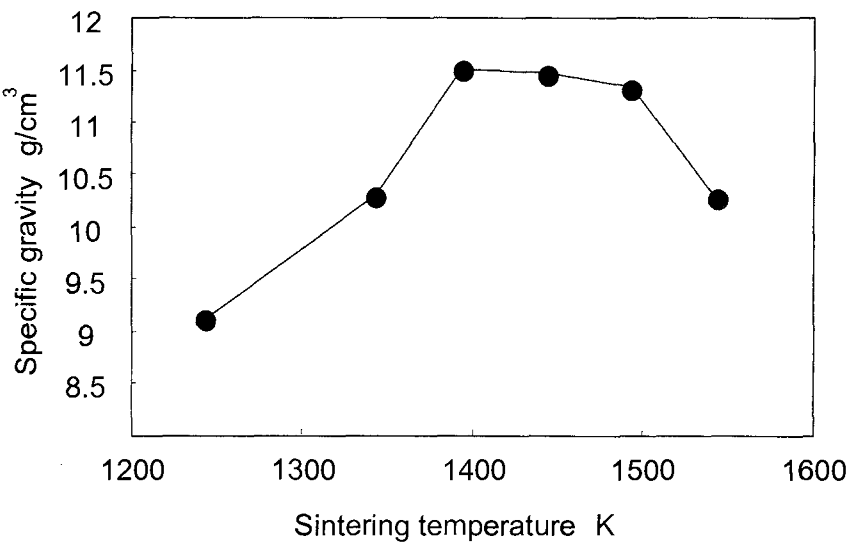


Figure 3 Relation between sintering temperature and specific gravity

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 2

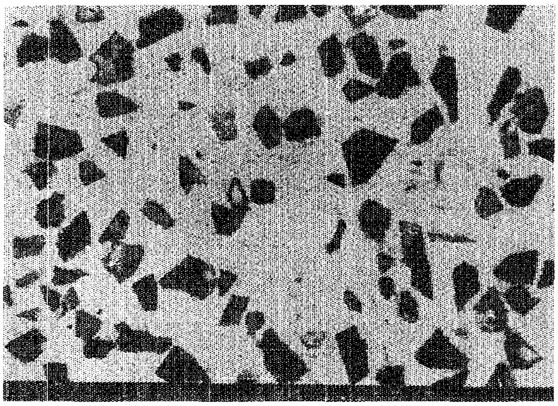


Photo1. Microstructure of diamond dispersed cemented carbide

diamond particles having an average diameter of 10 μ m are uniformly dispersed in the dense cemented carbide. Sintered under 1373 K, diamond particles did not transform into graphite, but cemented carbide matrix was porous. Sintered over 1500 K, cemented carbide matrix was dense, but the surface of diamond particles transformed into graphite. Thus, we succeeded in making diamond dispersed cemented carbides minimized the transformation of diamond particles into graphite and with sufficient density without using ultra high pressure equipment.

Furthermore a large-sized diamond dispersed cemented carbide with 100 mm diameter, which can not be produced by ultra high pressure equipment, can be produced with pressurizing and direct resistant heating by pulse current.

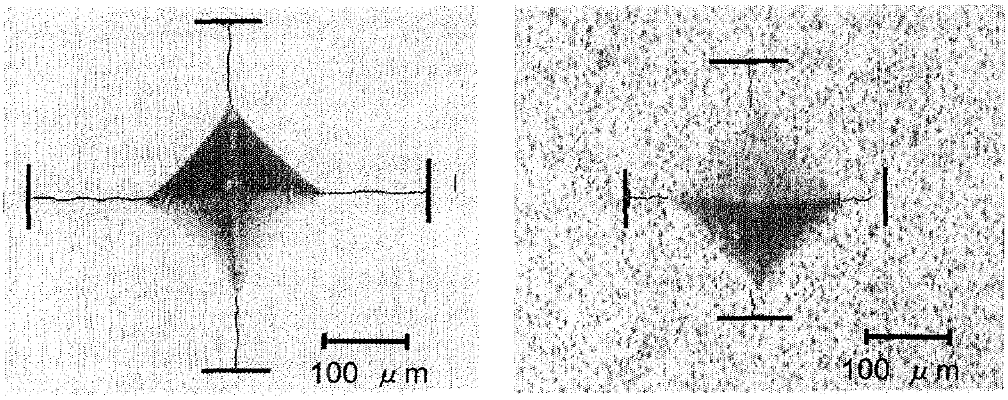
4-2. Mechanical properties

The mechanical properties of developed diamond dispersed cemented carbides are shown in Table 1. The table shows that diamond dispersed cemented carbides have superior fracture toughness compared with that of conventional 10 wt % Co cemented carbides. Since the diamond dispersed cemented carbides have over 50 % better fracture toughness, the crack lengths are shorter than that of cemented carbides having the same amount of Co binder as can be seen in Photo 2. Photo 3 shows the propagation of a

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 2

crack induced by a Vickers hardness gauge around the diamond particles. Thus, the superior fracture toughness of diamond dispersed cemented carbides is most likely the result of the crack deflection effect by the diamond particles, wherein the energy of crack propagation is absorbed.

The dynamic coefficient of friction of diamond dispersed cemented carbides was measured by a pin-on-disk device against alumina balls. (Rotation speed: 3 m/min, load: 10 N, atmosphere: dry). Diamond dispersed cemented carbides have an extremely low dynamic coefficient of friction: roughly one-fifth of that of conventional cemented carbides, comparable to that of diamond compacts.



Cemented carbid Diamond dispersed cemented

Photo 2. Crack length of diamond dispersed cemented carbide

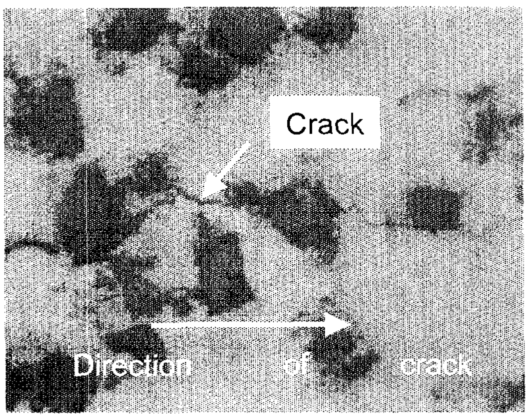


Photo 3. Crack propagation of Diamond Dispersed cemented Carbide)

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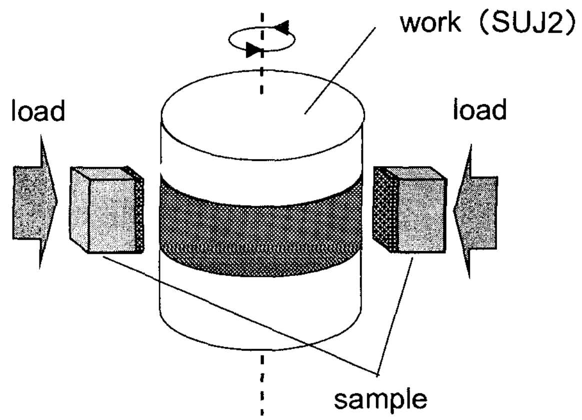

Figure 4. Wear resistance testing machine

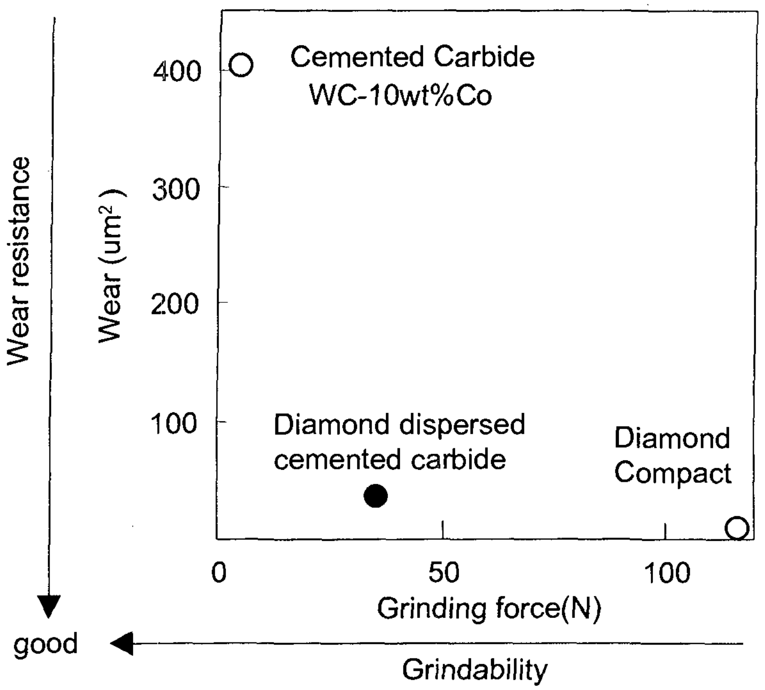

Figure 5 Relation between wear resistance and grinding force

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 2

The wear resistance of diamond dispersed cemented carbides against bearing steel (i.e., SUJ2) was investigated by using friction and wear testing equipment which is shown in Fig. 4 (Tsuya tribometer). The conditions were as follows: rotation speed: 19 m/min, load: 30 MPa, time: 2 hours, atmosphere: dry. The results are shown in Fig. 5. The grindability of diamond dispersed cemented carbides was compared by measuring the grinding force with a surface grinder with a # 230 diamond grindstone. The conditions were as follows; rotation speed of grindstone: 1,500 m/min, cutting depth: 20 μ m, feed rate: 6 m/min. The results were also shown in Fig. 5. These results show that diamond dispersed cemented carbides have ten times higher wear resistance than conventional cemented carbide, and diamond dispersed cemented carbides have five times better grindability than diamond compacts.

6. Performance of diamond dispersed cemented carbides

Applications of diamond dispersed cemented carbides include centerless blades as shown in Photo 5, bearing tools, work-rests, work-stopper, and other tools requiring superior wear resistance. Results of user testing in such

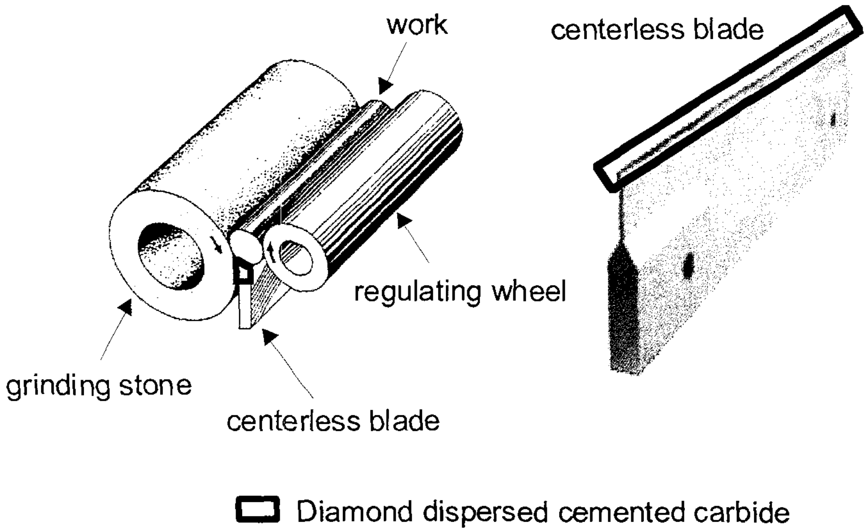

Photo 4 Centerless Blade

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applications show that work-rest applied diamond dispersed cemented carbides had about 25 times higher wear resistance against ultra fine grained cemented carbide than that applying low binder cemented carbide as shown in Fig 6.

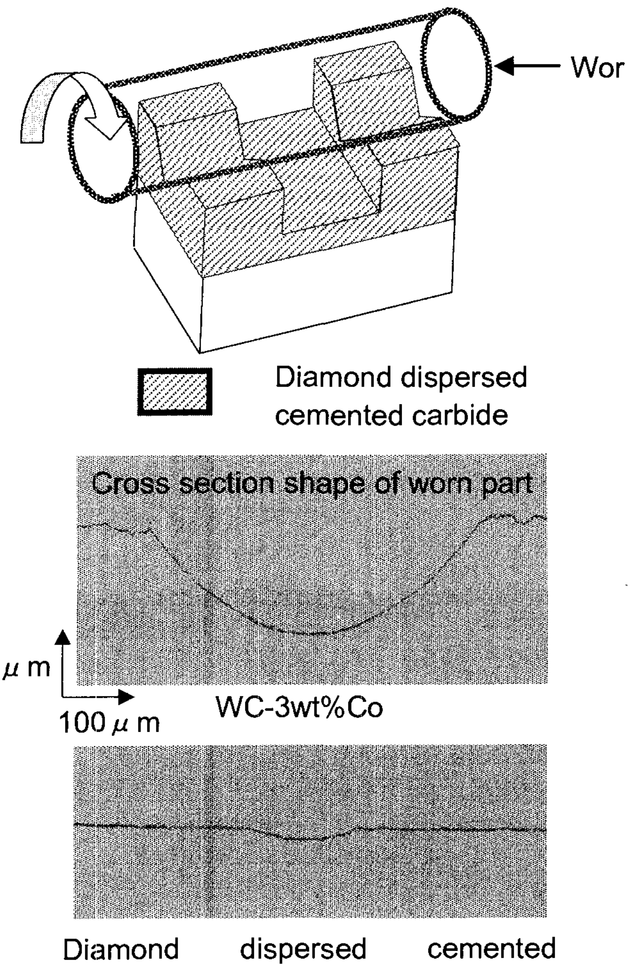

Figure 6 Test result of diamond dispersed cemented carbid

7. Conclusions

Diamond dispersed cemented carbides were successfully produced at a low sintering temperature around 1600 K while reducing the sintering time to

15th International Plansee Seminar, Eds. G. Kneringer, P. Rödhammer and H. Wildner, Plansee Holding AG, Reutte (2001), Vol. 2

several minutes as compared to several hours, thereby satisfying both prerequisites of minimizing the transforming into graphite of diamond particles and making cemented carbides with sufficient density without using ultra high pressure equipment. Diamond dispersed cemented carbides possess the following superior properties in comparison with conventional cemented carbides and diamond compacts.

(1) Superior wear resistance:
10 times higher than conventional cemented carbide
(2) Superior fracture toughness:
1.5 times higher than conventional cemented carbide
(3) Superior grindability: 5 times higher than diamond compact
(4) No requirement for ultra high pressure equipment:
Compacts 100 mm or more in diameter can be fabricated and used in applications unsuited for ordinary diamond compacts.

With such superior properties, diamond dispersed cemented carbides can be used for precision machining, reducing tool costs and shortening down time (e.g., time required for tool changes), thus promoting advancement of the machining industry.

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