Study on Hot-pressing Sintering Process of Diamond/metal Composites of Super-abrasive Wheels

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Abstract. Hot-pressing sintering process of metal/diamond composites of super-abrasive wheels is focused in this paper. The matrix consisting of copper-based bonded (60wt% Cu, 15wt% Sn, 15wt% Fe,10wt% Ni) and diamond micro-powder (average particle size W40) was prepared by hot-pressing sintering. The effect of hot-pressing temperature, pressure and isothermal holding time on the properties of matrix such as bending strength, hardess and density has been investigated by means of orthogonal experiment (L9(3)4). Then its structure and the bonding strength between the matrix and diamonds were analyzed by optical microscope diffraction. The results showed that the porosity observed by optical microscope declined obviously with the increase of sintering temperature from 550 ^{o}C to 650 ^{o}C. The best integrated performance was obtained at the sintering temperature of 650 ^{o}C , sintering pressure of 25 MPa and isothermal holding time of 150 s.

1.Introduction

Diamond or CBN is usually used as super-abrasive in grinding process, which extends the application scope of super-abrasive wheel to almost all processed materials with high perfomance of hardness, brittleness and toughness. The use of super-abrasive can prolong the life of the grinding wheel and improve the dimensional stability of the machining parts. The diamond wheel is the best abrasive tool for grinding high hairdness and brittleness materials, such as carbide, optical glass, ceramics, sapphire, etc. Although resin bonded diamond tools are composed of resin matrix and diamond fillers with desired particle size distributions, the cutting and grinding performances is rapidly degradated in spite of good cutting and grinding abilities [1]. Comparatively speaking, Metal bond diamond grinding wheels have higher bonding strength between the diamond grits and the bonding matrix than that of resin bond wheels, and, consequently, longer tool life [2]. The conventional metal bond diamond wheel is usually sintered with high temperature and high pressure. It is very important to forming metal bond diamond wheel at low temperature as the low diamond graphitization temperature causes a sharp decline in performance at 900 ^{o}C [3].

Hot-pressing sintering is a very effective low temperature molding process whose sintering temperature is 100 ^{o}C ~150 ^{o}C lower than that of conventional sintering [4]. At present, hot-pressing sintering is mainly applied in the field of carbide, especially in the nanoscale carbide powder sintering, it is being more widely used at home and abroad [5]. Metal bond diamond wheel was prepared by hot-pressing sintering in this paper,which can reduce the sintering temperature, shorten the sintering time, inhibit the excessive growth of grain, and obtain good mechanical properties finally [6]. The effect of sinterting temperature, sintering pressure and isothermal holding time on both physical and mechanical properties of matrix has been investigated by means of orthogonal experiment ($L9(3)^4$), and its fracture surface morphology was analyzed by optical microscope diffraction, which provide both theoretical practical basis and for metal bonded diamond wheel.

2.Experimental procedure

2.1 Preparation of raw matiral

The MBD-6 type of diamond is used in this experiment with mean size W40 and concentrantion 150%. The composition of metal powder used in this experiment was showed in Table 1.

Table 1

Composition of metal powder

Bond component	Cu	Sn	Fe	Ni
wt.%	10%	60%	15%	15%
Mean size （μm）	18	48	38	10

2.2 Manufacturing processes of sintered metal/diamond composites

The size of the sintered metal/diamond composites is 40×20×10 mm. Table 2 shows three factors and three levels of orthogonal experiment (L9(3)4).

Table 2

Factors and levels for orthogonal test

Variable	Level		
	1	2	3
A[^{o}C]	550	600	650
B[MPa]	15	20	25
C[s]	120	150	180

A: sintering temperature; B: sintering pressure; C: isothermal holding time.

2.3 Measurement of properties of sintered metal/diamond composites.

The composite block specimens were buffed, then their bending strength were measured by three-point bending method. The structure and the bonding strength between the matrix and diamonds were analyzed by optical microscope diffraction (VHX-1000) magnified 500 times. The hardness of each sintered specimen was performed using Rockwell hardness tester (HR-150DT). The density was measured by drainage method.

3. Results and discussions

3.1 Results of the experiment

Table3 shows the effect of sintering temperature,sintering pressure and isothermal holding time on both physical and mechanical propeties of sintered metal/diamond composition, which obtained from orthogonal experiment ($L9(3)^4$).

Table 3

The test results of matrix propeties

Specimen number	Density [g/cm^3]	Hardness [HRB]	Bending strength [MPa]
1	6.72	56.67	155.70
2	6.80	75.50	197.98
3	6.76	84.50	189.98
4	6.78	81.83	244.40
5	6.81	84.92	264.23
6	6.78	89.13	247.45
7	6.78	84.50	184.53
8	6.79	87.94	295.22
9	6.89	92.50	304.83

The specimen No. 9 achieved the optimal comprehensive propeties under conditions of sintering temperature of 650 ^{o}C , sintering pressure of 25 MPa and isothermal holding time of 150 s.

3.2 Effect of sintering parameters

3.2.1 Effect of sintering temperature

The density,hardness and bending strength improved with the increase of sintering temprerature from 550 ^{o}C to 650 ^{o}C and reached their maximum respectively at 650 ^{o}C , as shown in figure 1.

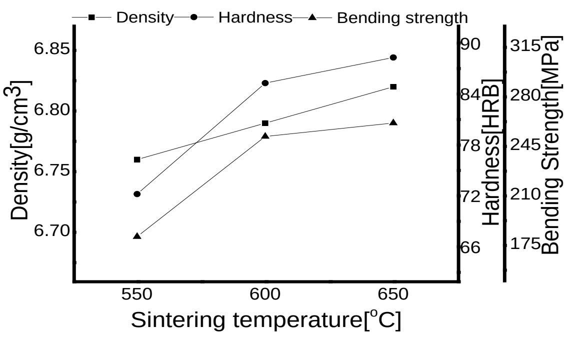

Fig. 1-Effect of sintering temperature

Figure 2 shows the results of optical microscope diffraction for fracture morphology.

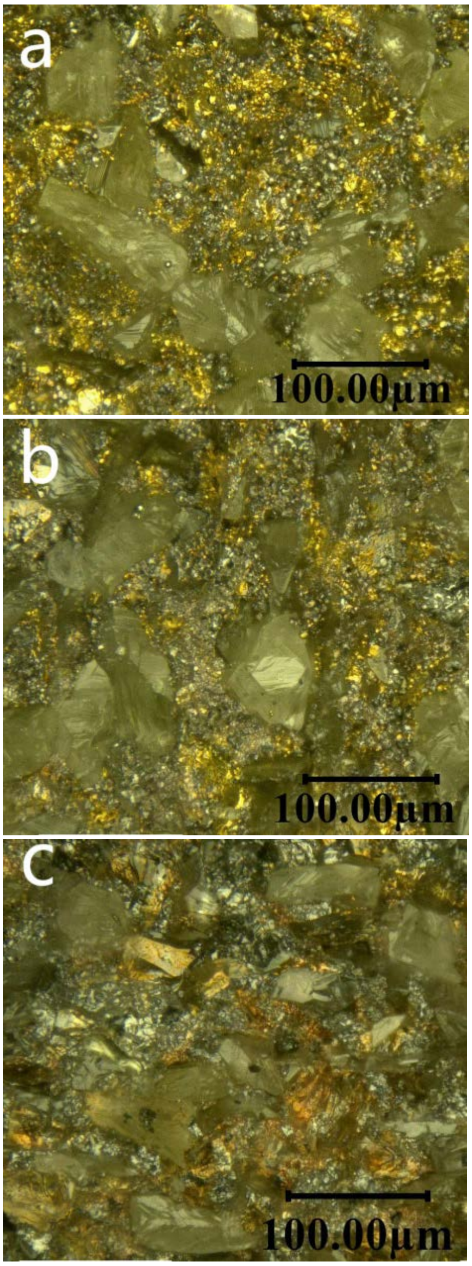

Fig. 2- Fracture morphology of bulks of diomand/metal composites sintered at different tempearure. (a) 550 °C , (b) 600 °C , (c) 650°C .

At 500 °C, a lot of pores could be observed in the microstructure due to insufficient firing. With the increase of the sintering temperature, the amplitude of the atomic thermal vibration and the gravitation between atoms in atomic coupling surface were enhanced. The bonding surface was formed with more and more atoms intrude the atomic force range during the process of atomic diffusion. The strength of sintered metal/diamond composites improved with the expansion of bonding surface. As the sintering temperature elvated, the liquid phase amount increased as well as the wettability of metal bond, as a result, the density of sintered metal/diamond composites is significantly improved, as shown in figure 6 (b), (c).

3.2.2 Effect of sintering pressure

As the sintering pressure increased from 15 MPa to 25 MPa, both density and hardness enhanced continuously and reached their maximum of 6.89 g/cm^3 and 92.5 HRB respectively at 25 MPa. By contrast, the relationship between sintering pressure and bending strength of matrix is nonlinear, as shown in figure 3.

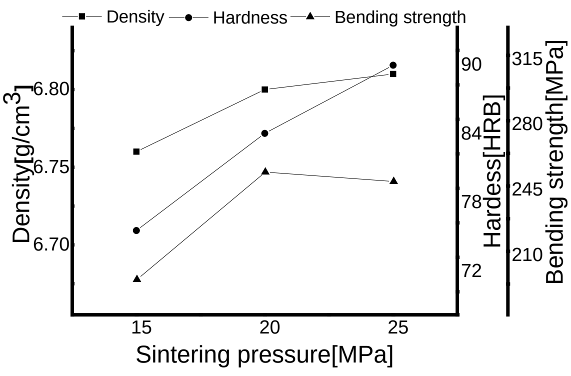

Fig. 3- Effect of sintering pressure

By analyzing the above data, it is known that the plastic flow of powder became more significant with the sintering pressure increased, which causes the aggravation of the displacement and rearrangement of powder, as a result, the density of sintered bulks of metal/diamond composites as well as their hardness increased. However, excessive high pressure can lead to different degrees of material flow behavior, thus the bending strength of these metal/diamond composites weakened.

3.2.3 Effect of sintering pressure

Figure 4 shows the relationship between isothermal holding time and propoties of sintered metal/diamond composites. As shown in figure, insufficient flowability of Sn with lower melting point (about 230 ^{o}C) as well as some alloy leaded to poor density of alloy microstructure at the isothermal holding time of 120 s. As the isothermal holding time increased, The sintering process was sufficient to eliminate the pores in the sintered matrix gradually, and the densification of the sintered matrix was simultaneously promoted, Accordingly, improved mechanical performance was possessed and reached their maximum at the isothermal holding time of 150 s. Nevertheless, as the isothermal holding time increased, the microstructure of sintered matrix became coarse and its density did not change significantly. Furthermore, the bending strength of sintered matrix decreased as a result of serious graphitization.

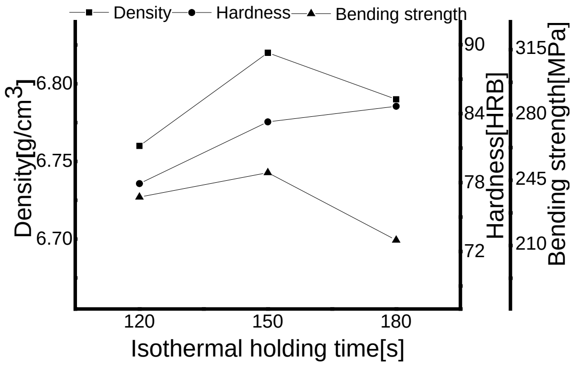

Fig. 4- Effect of isothermal holding time

4. Conclusions

Through the orthogonal experiment (L9(3) 4), a sintering temperature of 650 ^{o}C , a sintering pressure of 25 MPa and an isothermal holding time of 150 s were found to be optimal in achieving an optimal combination of bond density, bond hardness and bond bending strength(6.899 g/cm^3, 92.5 HRB and 304.83 MPa respectively).

As the sintering temperature increased, both the physical and mechanical properties of sintered metal/diamond composites were improved. The relationship between sintering pressure and bending strength of sintered body was nonlinear and reached the maximum of 252.47 MPa at the sintering pressure of 20 MPa. As the isothermal holding time increased, the hardness of sintered body shown the same trendency, while both the bending strength and density of sintered body first increased and then decreased and reached their peak value respectively at the isothermal holding time of 150s.

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