Precipitation of SiC on superhard diamond particles and its spark plasma sintering combined with WC

As the hardest material, diamond has been used to enhance the hardness and fracture toughness of other cutting materials such as tungsten carbide or alumina. However, the using of Co sintering aid for WC would like to induce the phase transformation of diamond to graphite and lead to a volume expansion resulting in cracking and low hardness of the products. In the present study, SiC nanoparticles were precipitated on diamond by rotary MOCVD to increase the sinterability, and consequently improve the mechanical properties and reliability of diamond-based cutting tools.

Diamond has been widely used for cutting tools or as a reinforcing phase to enhance the hardness and wear resistance of other cutting materials, such as WC, Al_2O_3 and so on. However, these composites can hardly be densified by the traditional pressureless sintering or hot pressing because of the strong covalent bond and the easy phase transformation to graphite occurring at high temperatures, low pressure and long sintering time.

The recent literature indicates SiC is beneficial as a sintering aid for Diamond[1]. In the present study, the SiC nanolayer was precipitated on diamond powders by a rotary CVD apparatus[2, 3] using hexamethyldisilane (Si_2(HMDS) as a precursor. The HMDS precursor was heated to a vaporization temperature of 303 K and carried into the reactor by Ar gas at a flow rate of 1.7×10^{-7} m^3s^{-1}, and the supply rate of precursor vapor was 6×10^{-7} kgs^{-1}. The reactor chamber was rotated at 15 rpm with a total pressure in the reactor chamber at 400 Pa, the deposition temperature was 953 K, and the deposition time was varied from 10.8 to 14.4 ks. Fig. 1 shows that the SIC nanolayer was about 20-50 nm in thickness was successfully precipitated on Diamond.

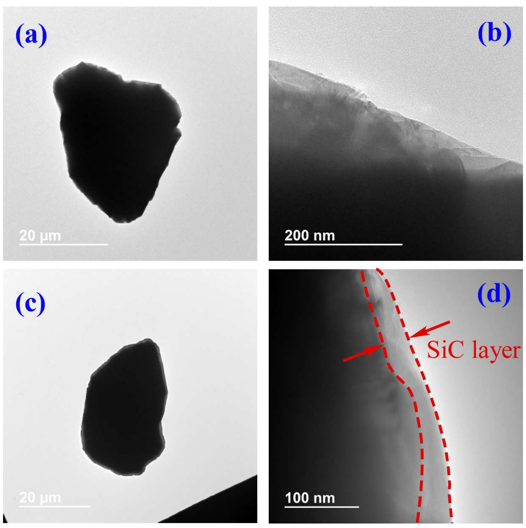

Fig. 1 TEM images of (a, b) Diamond and (c, d) SiC-precipitated Diamond

The as prepared SiC-precipitated Diamond was mixed with WC by hand and consolidated by spark plasma sintering (SPS-210LX, SPS Syntex Inc.) at 1673 to 1973 K under a pressure 70 MPa and a holding time of 5 mins. The more obvious shrinkage of WC-20 vol% Diamond/SiC composites compared to that of WC-20 vol% Diamond was found due to the incorporation of SiC nanolayer. And the shrinkage ended after a holding time of about 60s at a sintering temperature of 1873 K, indicating that the sintering process completed.

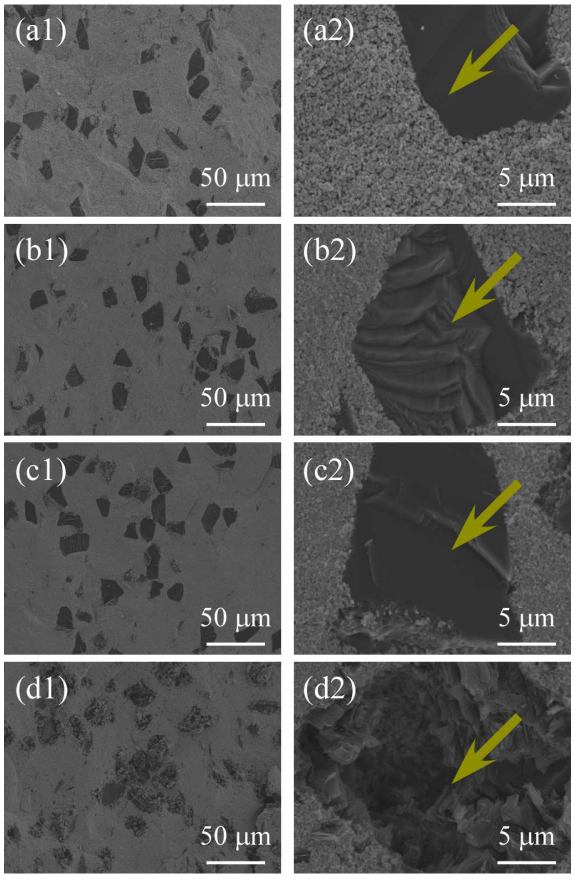

Fig. 2 SEM images of the fracture surface morphology of WC-20 vol% Diamond/SiC sintered at (a1, a2) 1673 K, (b1, b2) 1773 K, (c1, c2) 1873 K, (d1, d2) 1973 K.

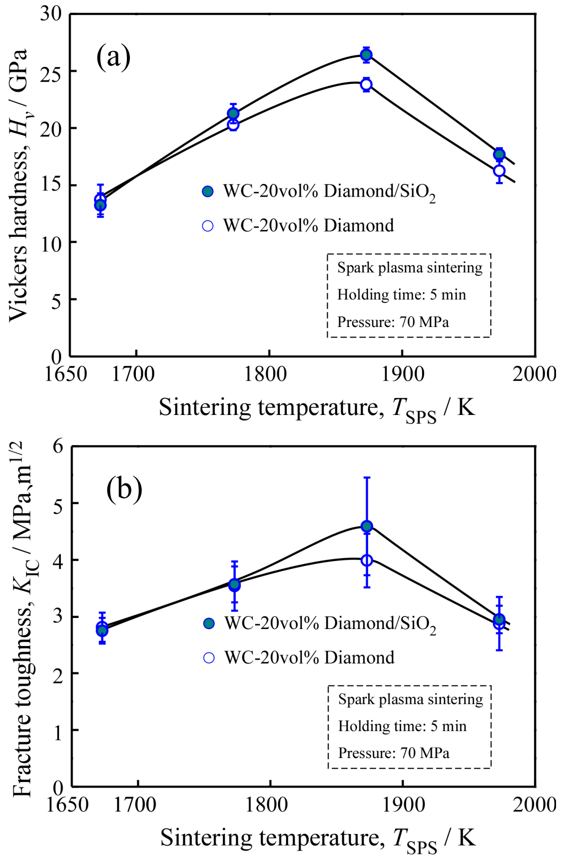

Fig. 3 Mechanical propertie4s of WC-diamond/SiC composites
(a) Vickers hardness, (b) Fracture toughness

The X-ray diffraction patterns indicate that the phase transformation of Diamond started from 1873 K in WC-20 vol% Diamond, but from 1973 K in WC-20 vol% Diamond/SiC indicating the SiC nanolayer coating elevated the phase transformation of Diamond about 100 K.

The SEM images of the fracture surface morphology of WC-20 vol% Diamond/SiC sintered also indicate the beneficial effect of SiC nanolayer coating. At 1673 to 1873 K, the mophology of Diamond kept similar due to the low or even less phase transformation of Diamond. Even at 1973 K, only a little transformation traces can be observed due to the hindering effect of SiC additive.

Just due to the successful incorporation of SiC nanolayer on Diamond, the mechanical properties of WC-Diamond/SiC were apparently improved compared to those of WC-Diamond. As shown in Fig. 3 (a) and (b), the maximum hardness and fracture toughness of WC-20vol% Diamond/SiC composite were 26.4 GPa and 4.59 MPa $m^{1/2}$, about 3 GPa and 0.6 MPa $m^{1/2}$ higher than those of WC-20vol% Diamond composite, respectively.

References

[1]M. Kitiwan, H. Katsui, and T. Goto, Science of Advanced Materials, 9, 1–6, 2017

[2] J. Zhang, H. Katsui, Z. He and T. Goto, J. Asian. Ceram. Soc. 2, 204-209, 2014.

[3] J. Zhang, R. Tu and T. Goto, Journal of the European Ceramic Society, 34, 435-441, 2014

Keywords: Powder coating; Diamond; Spark plasma sintering; Phase transformation
Jianfeng Zhang, College of Mechanics and Materials, Hohai University,
Xikang Road-1, Nanjing 210098, P.R. China
E-mail: jfzhang@hhu.edu.cn