UDC 621.921.34-419:536.421.5

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Fabrication and wear performance of (Cu–Sn) solution/TiC_x bonded diamond composites

The Cu(Sn)–TiC_x bonded diamond composites were prepared by in situ reaction sintering of Cu, Ti_2SnC and diamond powders. Effect of Ti_2SnC content on the phase composition, microstructure and grinding properties were studied. The result shows that Ti_2SnC was decomposed to TiC_x and Sn. And then, Sn atom dissolved into the crystal lattice of Cu and formed Cu(Sn) solution. The rich C formed at the interface between diamond and the matrix. Excess Ti_2SnC inhibited the formation of Cu solid solution and reacted with Cu to form Cu_3Sn. Additionally, its matrix was mainly composed of TiC_x with better wear resistance, which may improve obviously the grinding performance of the composites. The grinding ratio value of copper-diamond composite was only 132. The grinding ratio value of the composite contained higher Ti_2SnC content in the raw materials was 636.

Keywords: *reaction synthesis, diamond, Cu, TiC_x.*

INTRODUCTION

There are three main types of diamond grinding tools: resin bonder, metal bonder and ceramics bonder [1]. Each tool possesses its own limitations and flaws. For example, the vitrified bonder has a large brittleness and poor elasticity. Resin bonder had a poor resistance and vulnerable to alkali erosion. Its bonding between the binder and the diamond particles is poor. Metal bonder has a poor self sharpness, easy to plug the heat and difficult dressing.

It is possible to solve these problems by using complex binders such as metal-ceramic, metal-resin. Many studies concentrate in the fabrication of the complex bonded diamond composites [2, 3]. For example, Zh. Wang et al. fabricated R_2O–B_2O_3–Al_2O_3–SiO_2 ceramic bonders with doping Ni, Co, Fe powders [4, 5]. Effect of these metals on the mechanical properties of ceramic bonders were studied.

Zhang X. H. et al. added Ti or Si powder in diamond and borosilicate glass. The thermal stability of diamond in the obtained composites was improved obviously [6, 7].

Metal-based complex bonders can be fabricated by adding ceramic powder to metal powders [8]. But directly adding ceramic particles especially nano particles into metal bonders are often not uniformly dispersed in the metal matrix. In addition to, the cost is relatively high. Therefore, metal and ceramic complex bonders need not only a strong interface between metal and ceramic, but also the strength effect of nano particles. This is what researchers have been pursuing.

Recently, some researchers fabricated Cu(Sn) solution/TiC_x composites by in situ reaction technology from Cu and Ti_2SnC powders. Due to the strong interfacial bonding between TiC_x and Cu(A1), Cu(Sn)/TiC_x composites have good bending strength and good grinding properties. J. Zhang et al. [9] studied the structural stability of Ti_2SnC in Cu prepared at different temperatures by high-resolution transmission electron microscopy and X-ray diffraction. Mengqi Li et al. [10] fabricated Cu–Al alloy matrix composites containing in-situ $TiC_{0.5}$ particles by sintering of a mixture of Cu and Ti_2AlC powders. Zhenying Huang et al. [11] prepared submicro-layered $TiC_{0.61}$/Cu(Al) composite has been by hot-pressing a mixture of 50 vol % Ti_2SnC and 50 vol % Cu powders. Xinhua Chen et al. [12] prepared Fe matrix composite reinforced by the in-situ generated TiC*x* grains using the element Fe and Ti_2SnC powders.

In this study, the TiC_x/Cu(Sn) solution complex bonded diamond composite was firstly prepared by in-situ reaction between Ti_2SnC, Cu and diamond. The effect of Ti_2SnC content on the phase composition, microstructure and mechanical properties of the composites were studied.

EXPERIMENTAL PROCEDURE

Powders of Ti_2SnC (99.0 % pure, ~ 10 μm), Cu (99.0 % pure, ~ 53 μm) and diamond (74/100 μm) were mixed with a different raw materials ratio (Table 1). Then, these powders were ball-milled in a planetary ball mill (XM-405) for 3 h using agate balls to achieve homogeneous mixed mixtures. Finally, the mixtures were put in a 20 mm graphite mold and subsequently spark plasma sintered at 1000 °C with holding time of 15min under a vacuum environment with a pressure of 20 MPa. The sintered samples were ground and analyzed by The X-ray diffraction (XRD) experiments were performed in a rotating anode X-ray diffractometer (Rigaku Ultima IV) with Cu*K*α radiation. Scanning electron microscopy was conducted using a FE-SEM with an energy-dispersive spectroscope (EDS).

Material composition, wt %

Sample	Cu	Ti_2SnC	Diamond
1	80		20
2	70	10	20
3	60	20	20
4	40	40	20
5	20	60	20

RESULT AND DISCUSSION

Figure 1 shows that XRD patterns of different composites. From Fig. 1, sample 2 composed of Cu, TiC and diamond. Ti_2SnC diffraction peaks were not observed, indicating that it was decomposed to Sn and TiC_x. The theoretical composition of the resulting TiC_x should be $TiC_{0.5}$. Here the lattice parameter of TiC_x is 4.3102 Å in this sample, while that of standard TiC is 4.3287 Å. The tendency that the lattice parameters data of TiC_x increase with x in the very wide non-stoichiometric range agrees with the previous reported data result [13].

Sn peaks from decomposed Ti_2SnC were not observed. Meanwhile, Cu peaks moved to small angle. These results show that Cu(Sn) solid solution was formed because of its' larger lattice parameters.

These phenomena were the same as the results of the literature [9–11]. The reason was that Ti_2SnC was decomposed to Sn and nonstoichiometry $TiC_{0.5}$. Thus, The Cu(Sn) solid solution were formed by solid solution of Sn into Cu lattice, which leads to the increase of lattice constant and the decrease of diffraction angle of Cu. The reaction formula (1) was as followed:

$$Ti_2SnC + Cu \rightarrow 2TiC_{0.5} + Cu(Al). \quad (1)$$

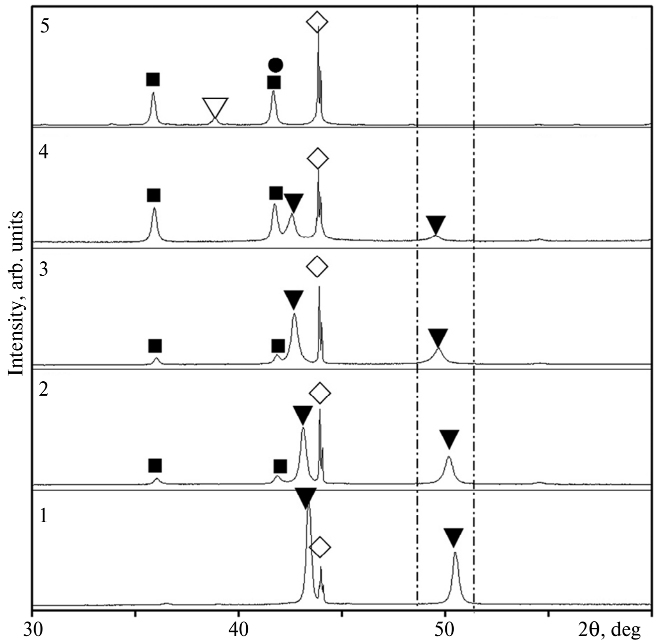

Fig. 1. XRD of the composites: diamond (◇), Cu (▼), Cu_3Sn (●), Sn (▽), NiC_x (■).

Cu peaks gradually moved to small angle as Ti_2SnC content increases in the composites, indicating that solid solution degree of Cu was increased. Additionally, TiCx diffraction peaks were also gradually increased. But the sample 5 composed of Cu_3Sn, Ti_2SnC, Sn, TiC_x and diamond when Ti_2SnC content was excess. This result shows that chemical reaction was occurred between Cu and Sn. Excess Sn element may remain in the product.

Figure 2 shows that the fracture morphology of the composites. From Fig. 2, *a*, there were bigger pores between Cu and diamond in sample 1, which indicates Cu had a bad bonding with diamond. The matrix showed typical dimples morphology of Cu. From Fig. 2, *b*, some smaller holes were existed in the local interface between diamond and the matrix in sample 2. It indicates that the matrix had a good adhesion with diamond. The combination between diamond and matrix in samples 4 and 5 was very close (Figures 2, *c*, *e*). From Fig. 2, *d* (enlarge zones in the circle of the Fig. 2, *c*), one transition layer with a thickness of about 4μm can be observed on the interface in sample 4. The C, Sn, Ti and Cu element contents were 93.42, 0.67, 4.62 and 1.30 at %, respectively. From this data, it can be concluded that the C atoms on the surface of the diamond were diffused into the matrix, and a rich C transition layer is formed on the interface. Compared with sample 4, the surface of diamond in sample 5 was much straighter and thinner with a thickness of about 0.5 μm (Fig. 2 (6)). These transition layer may improve the holding fore of the matrix to diamond, which ensures that diamond is not easy to fall off during the grinding process. It may probably improve the grinding properties of these composites.

Figure 3 shows the grinding properties of the composites. From Fig. 3, all composites contained Ti_2SnC in the raw materials had a much higher grinding ratio value than that of sample without contained Ti_2SnC (sample 1). The grinding ratio value of the composites gradually increased with the increase of Ti_2SnC content. The sample 5 had a maximum grinding ratio value of 636. These values were about 4.8 times that of sample 1.

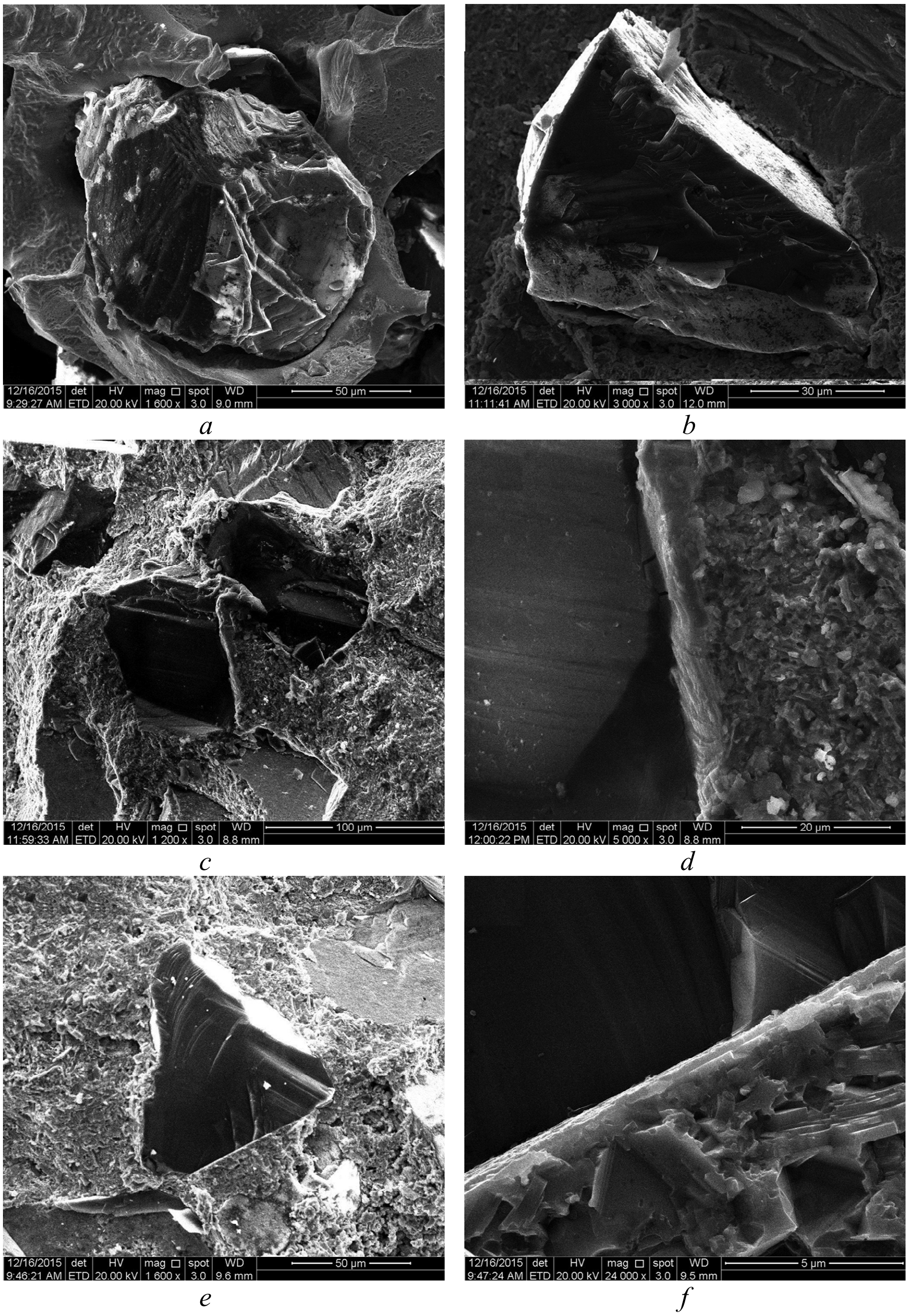

Fig. 2. Fracture morphology of the composites: samples 1 (*a*), 3 (*b*), 4 (*c*, *d*), 5 (*e*, *f*).

Based on the above study, Ti_2SnC content had an obvious affect on the composition, microstructure and grinding performance of the composites. We did some discussion on this as followed.

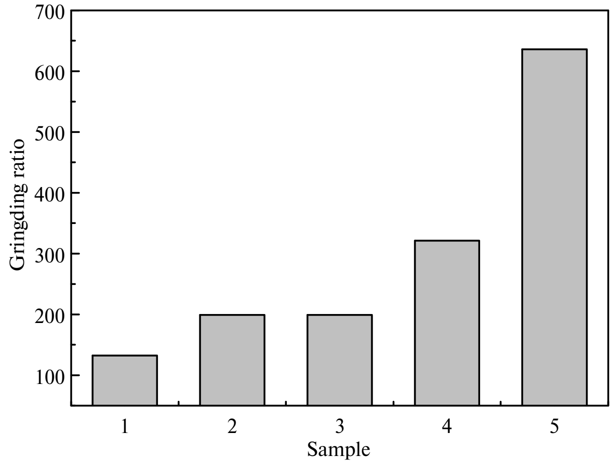

Fig. 3. Grinding performance of composites.

Because Cu had bad wetting ability and large difference in coefficient of expansion to diamond, bigger pores between diamond and Cu were formed in sample 1. Therefore, these diamonds were easy to fall off in the process of grinding, which can reduce the grinding performance. When the Ti_2SnC was added to the raw materials, non stoichiometric TiC_x and Sn were obtained by reaction of Cu and Ti_2SnC. On the one hand, Sn atom dissolved into the crystal lattice of Cu and form Cu(Sn) solution. On the other hand, the C atoms on the surface of the diamond diffused into the matrix, and the rich C transition layer formed at the interface between diamond and the matrix. And then, C atoms probably react with TiC_x to form C-rich TiC_y. It is helpful to promote the combination of matrix and diamond. With the increase of the content of Ti_2SnC, TiC_x and Sn content were increased. This will more promote the combination.

However, too much Ti_2SnC content in the raw materials may promote the form larger amounts of Sn. From Fig. 1 results, excess Sn inhibited the formation of Cu solid solution and reacted with Cu to form Cu_3Sn. Thus, the matrix was mainly composed of TiC_x with better wear resistance. Therefore, the grinding performance of sample 5 was obviously further improved compared with sample 4.

In this study, Cu–TiC_x bonded diamond composites were prepared by in-situ reaction sintering of Cu, Ti_2SnC and diamond. It provides a new idea for fabrication of metal ceramic complex bonded diamond composite material. In the further research, we will consider that other MAX phase materials such as Ti_2AlC, Ti_3AlC_2 or Cr_2AlC may be used to combination of Cu, Fe or Al based metal matrix. Thus different kinds of new metal ceramic matrix composites can be obtained.

CONCLUSION

The Cu–TiC_x bond diamond composites were prepared by in situ reaction sintering from Cu, Ti_2SnC and diamond powders. Ti_2SnC was decomposed to TiC_x and Sn. And then, Sn atom dissolved into the crystal lattice of Cu and formed Cu(Sn) solution. TiC_x may react with C atom on the surface of diamond to form TiC_x, which promotes the bind between the matrix and diamond. The grinding ratio value of Cu-diamond composite was 132. The grinding ratio value of the composite contained higher Ti_2SnC content in the raw materials was 636.

ACKNOWLEDGMENTS

The authors would like to thank the Natural Science Foundation of Henan (No. 17A430034, No. 142106000193 and No. 14A430007), Henan university innovation team project (15IRTSTHN004) , the Project of International Science and Technology Cooperation and Exchange of Zhengzhou (No. 153PGJHZ209).

Вивчено вплив змісту Ti_2SnC на фазовий склад, мікроструктуру і шліфувальні властивості алмазних композитів зі зв'язуючим $Cu(Sn)–TiC_x$, отриманих in situ реакційним спіканням Cu, Ti_2SnC і алмазних порошків. Показано, що Ti_2SnC розкладається на TiC_x і Sn, потім атом Sn проникає в кристалічну решітку Cu і утворюється розчин Cu(Sn). Багатий вуглецем перехідний шар утворюється на кордоні розділу між алмазом і матрицею. Надлишок Ti_2SnC уповільнює утворення твердого розчину Cu і взаємодіє з Cu, утворюючи Cu_3Sn. Матриця в основному складалася з TiC_x, якій має кращий опір зносу, що може поліпшити ефективність шліфування композитів. Коефіцієнт шліфування мідно-алмазного композиту дорівнював всього лише 132, а коефіцієнт шліфування композиту з високим вмістом Ti_2SnC в сировині – 636.

***Ключові слова**: реакційний синтез, алмаз, Cu, TiC_x.*

Изучено влияние содержания Ti_2SnC на фазовый состав, микроструктуру и шлифовальные свойства алмазных композитов со связующим $Cu(Sn)–TiC_x$, полученных in situ реакционным спеканием Cu, Ti_2SnC и алмазных порошков. Показано, что Ti_2SnC разлагается на TiC_x и Sn, затем атом Sn проникает в кристаллическую решетку Cu и образуется раствор Cu(Sn). Богатый углеродом переходный слой образуется на границе раздела между алмазом и матрицей. Избыток Ti_2SnC замедляет образование твердого раствора Cu и взаимодействует с Cu, образуя Cu_3Sn. Матрица в основном состоит из TiC_x, имеющего лучшее сопротивление износу, что может улучшить эффективность шлифования композитов. Коэффициент шлифования медно-алмазного композита имел значение всего лишь 132, а коэффициент шлифования композита с высоким содержанием Ti_2SnC в сырье – 636.

***Ключевые слова**: реакционный синтез, алмаз, Cu, TiC_x.*

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Received 05.04.17