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Wear Resistance of TiB_2-TiC Solidified Ceramics Using for Cutting Tools Fabricated through Combustion Synthesis in the High-Gravity Field

Yujun Yin, Jing Zhang, Chuanzeng Pan and Bing Zhu

Army Engineering University, 97 Heping west road, Shijiazhuang, 050003, China
E-mail: zhjj116@163.com

Abstract. TiB_2-TiC solidified ceramics were fabricated by taking combustion synthesis with the blends of (B_4C+Ti) powders and (CrO_3+Al) thermite in the high-gravity field of 300 g. XRD, FESEM and EDAX results showed that the composites mainly were consisted of fine plate-like TiB_2, irregular TiC and $(Cr, Ti)_3B_2$ solids and Al_2O_3 inclusion particles. The introduction of high-gravity field was thought to bring about pure Ti-Cr-B-C liquid. Rapid solidification was a key factor for the achievement of fine-grained microstructure, which in turn was responsible for the improved wear properties of the composites.Vickers hardness, fracture toughnessandmaximum wear rate of the composites were measured 20.8GPa, 13.4MPa $m^{0.5}$ and 2.5×10^{-7}g $(N\ m)^{-1}$, respectively.The excellent wear resistance of the composites was considered resulting from the contribution of the high-toughness, high-hardness, fine-grained TiB_2 plate-like primary phases.

1. Introduction

Apart from the extremely high hardness and elastic modulus, TiB_2-TiC also exhibits high electrical conductivity, high melting point and strong wear resistance, low density and relatively good chemical stability [1-4]. These properties are especially appropriate for the fabrication of high wear resistant and temperature resistant components such as cutting tools [5].However; it is difficult to obtain the fully dense TiB_2-TiC bodies because of their rather low self-diffusion coefficients caused by the character of covalent bond [6]. Additionally, relatively high cost of monolithic TiB_2 used to fabricate TiB_2-TiC also limits their wide use as cutting materials in machining engineering application [7]. All these shortcomings have triggered research interest to improve the production of TiB_2-TiC with good sinterability [7].In the past decades, extensive studies have focused on the combustion synthesis of TiB_2-TiC composites using the Ti-B_4C system. Nevertheless, the reaction and densification process were rather difficult as a result of the low adiabatic combustion temperature for Ti-B_4C system.

To control the reaction and densification process, the thermite was adopted to Ti-B_4C reactants, which was shown to play an import role. Meanwhile, Al_2O_3 formed in the aluminothermic reaction will be removed from the final products in the high-gravity field in this experimental, and thus improve the hardness and wear resistance properties of the composites. In this study, we investigated the synthesis of TiB_2-TiC composites by taking (CrO_3+Al) thermitein (B_4C+Ti) reactants in the high-gravity field, and then discussed relationship between wear resistance and microstructure of TiB_2-TiC solidified ceramics.

2. Experimental

Raw materials were prepared from commercial powders of Ti (99.5% purity, ~ 25 μm), B_4C (98% purity, ~3 μm), CrO_3 (99% purity, ~ 45 μm) and Al (99% purity, ~ 63 μm). The molar ratio (Ti: B_4C) of

3:1 was chosen as the starting composition, as shown in the equation (1). In order to ensure full-liquid products after combustion reaction, the adiabatic temperature of the whole combustion system was designed as 3500 ℃, and (CrO_3+Al) subsystem was added as the activator for increasing the adiabatic temperature according to the equation (2).

$$B_4C + 3Ti \rightarrow 2TiB_2 + TiC \quad (1)$$

$$CrO_3 + 2Al \rightarrow Al_2O_3 + Cr \quad (2)$$

The above reactant powders were mixed sufficiently and then dried in a furnace for 2 h at 120 ℃ to remove adsorbed water. Then the dried powder blend was pressed in graphite crucibles of 100 mm in diameter with a green density ranging between 55% ~ 65% theoretical density. Finally, the graphite crucibles were inserted into two reaction chambers at the end of the rotating arms of the centrifugal machine. The high gravity field was induced by centrifugation, with an acceleration of 300 *g*, where *g* means the gravitational acceleration, 9.8m·s^{-2}. Then, the combustion systems in the combustion chambers were ignited with the W wire (diameter of 0.5 mm) and completed after about 5s. Finally, the ceramic discs of 100 mm in diameter and about 20 mm in thickness were produced.

The reaction products were identified by X-ray diffraction (XRD, Rigaku D/max 2550PC, Japan). The density of the products was measured by the volume displacement method. Microstructure observations were carried out on polished surfaces by field emission scanning electron microscope (FESEM, Sirion200, Japan) equipped with a energy disperse spectroscopy (EDS, LinkISIS-300, Britain). Vickers hardness was measured using a hardness tester (HVS-50, China). The dry-sliding wear testing of the products was performed with diamond grinding wheels of 100 mm in diameter. Different value of normal loads (in the range of 9.8N~ 39.2N), sliding speed (7.33m·s^{-1}) and sliding distance (2 km) were used for sliding wear tests. Weight loss due to wear was measured by using an electronic balance with an accuracy of 0.01mg.

3. Results and discussion

Reaction product was examined by XRD and the result was presented in Figure 1. It was clear that the major phase in the products was TiB_2, except for minor TiC, $(Cr, Ti)_3B_2$ and a minute amount of Al_2O_3. FESEM image for the reaction product was shown in Figure 2. It could be easily found that a large number of randomly-orientated, fine plate-like TiB_2 phases (presented by the dark areas in Figure 2) with their thickness close to even smaller than 1 μm. Irregular TiC phases (presented by the grey areas in Figure 2) and $(Cr, Ti)_3B_2$ (presented by the white areas in Figure 2), and only a few inclusions of Al_2O_3 (presented by the isolated black particles in Figure 2) were also observed.

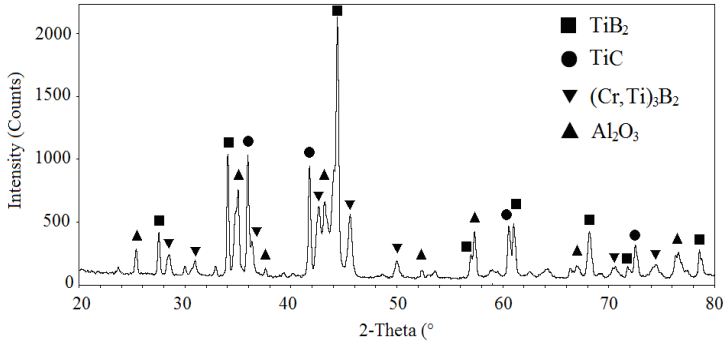

Figure 1. XRD patterns of the powdered sample of TiB_2-TiC ceramics

Presence of full-liquid products after combustion reaction was ensured due to the adiabatic combustion temperature designed as 3500 ℃ which was above melting point of all possible reactive products. Meanwhile, rapid liquid-liquid separation was thought to occur for the full-liquid products consisting of immiscible Al_2O_3 liquid and Ti-Cr-B-C liquid, which was accelerated in high-gravity field due to the presence of density difference [8, 9]. Rapid solidification was considered asa key

factor for the achievement of fine-grained microstructure as shown in Figure 2, which in turn was responsible for the improved properties of theseTiB_2-TiC ceramics. Relative density, Vickers hardness and fracture toughness of the ceramics were measured 98.3%, 20.8GPa and 13.4MPa $m^{0.5}$, respectively.

FESEM images of fracture morphologies of TiB_2-TiCceramics presented a mixed mode of intergranular fracture along TiB_2 platelets and transgranular fracture in TiC irregular grains, and the grooves of TiB_2 platelets were clearly remained at fracture surface of the ceramics after they were pulled out of the matrix of composite, as shown in Figure 3. TiB_2 platelets had important effects on the strengthening and toughening of composites because of their high elastic modulus, high volume fraction, and highly-random distribution, especially refined microstructure. With the propagation of the crack and debonding at the interface of TiB_2 platelets, the secondary microcracks, as shown at the arrow in Figure 4, also developed along the boundary of TiB_2 platelets. Those secondary microcracks was thought to further result in the presence of crack bridging along with the fractionally interlocking, as shown in Figure 4.Therefore, high toughness value of 13.4 MPa $m^{0.5}$ of the composites was achieved by the cooperation action of crack-deflection, crack-bridging and frictionally-interlocking toughening mechanisms by a number of fine TiB_2 platelets.

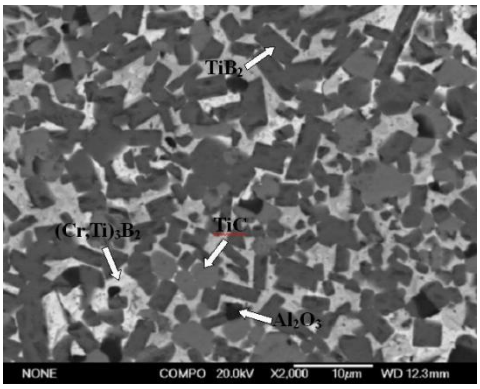

Figure 2. FESEM image of the microstructure of TiB_2-TiC composites

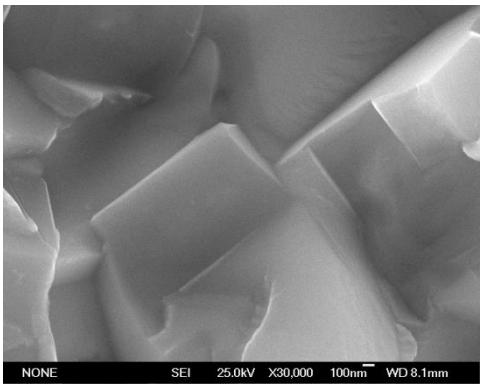

Figure 3. Pulling-up fracture of TiB_2 platelet grains

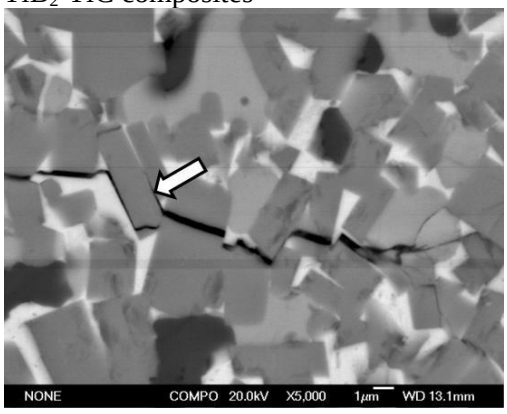

Figure 4. Crack bridging and fractionally interlocking of TiB2 platelet grains

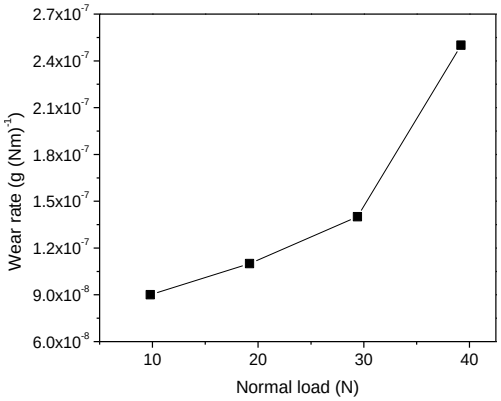

Figure 5. Variation of wear rate with normal load for sliding speed of 7.33 m·s-1

The wear resistance of TiB_2-TiC ceramics was evaluated upon the wear rate which was calculated in terms of weight loss per unit normal load per unit sliding distance. The wear rate was plotted against applied normal loads in Figure 5, where the wear rate showed a gradual increase tendency along with loads. The maximum wear rate of 2.5×10^{-7}g $(N\ m)^{-1}$ was measured when the load of 39.2N was used. The wear resistance of TiB_2-based composites was superior to that of a number of ceramic cutting materials [5]. The rise in wear rate was possible due to the fact that the wear mechanism changed from abrasive wear to brittle fracture, cracking and total removal of the ceramics with

increase in normal load[10]. FESEM observations were employed to examine the morphology of worn surface of the composites as shown in Figure 6. The worn surface showed the exposure of unbroken TiB_2 platelet primary phases and the fragmentation and removal of TiC. Therefore, it was considered that the excellent wear resistance of the TiB_2-based composites was attributed to the high-toughness and high-hardness, fine-grained TiB_2 plate-like grains.

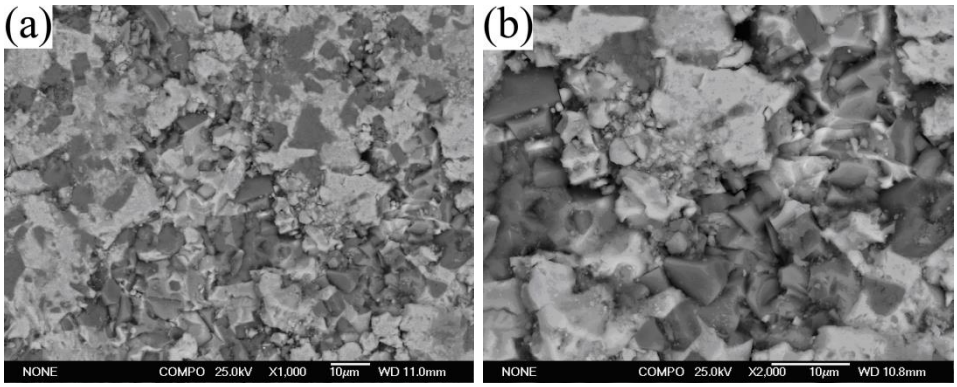

Figure 6. FESEM images of worn surface of TiB_2-based composites under normal load of 39.2 N for sliding speed of 7.33 $m \cdot s^{-1}$. (a) worn surface (b) magnified view

4. Conclusion

TiB_2-TiC solidified ceramics were fabricated by taking combustion synthesis with the blends of (B_4C+Ti) powders and (CrO_3+Al) thermite in the high-gravity field of 300g. XRD, FESEM and EDAX results showed that the composites mainly were consisted of fine plate-like TiB_2, irregular TiC, $(Cr, Ti)_3B_2$ solids and Al_2O_3 inclusion particles. The introduction of high-gravity field brought about pure Ti-Cr-B-C liquid, whereas rapid solidification was a key factor for the achievement of fine-grained structure, which in turn was responsible for the much improved wear properties of the composites.Vickers hardness, fracture toughness and maximum wear rate of the composites were measured 20.8GPa, 13.4MPa $m^{0.5}$ and 2.5×10^{-7}g $(N\ m)^{-1}$, respectively.The excellent wear resistance of the composites was considered resulting from the contribution of the high-toughness, high-hardness, fine-grained TiB_2 plate-like primary phases.

5. Acknowledgments

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6. References

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