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In situ toughening of pressureless liquid phase sintered α-SiC by using TiO_2

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Abstract

In-situ TiC particles were introduced into the SiC matrix by using TiO_2 particles as a Ti source, which was beneficial for the improvement of the fracture toughness of liquid phase sintered SiC ceramics. The in-situ reaction between TiO_2 and SiC resulted in the formation of TiC during the sintering process. Compared with the SiC ceramic by adding ready-made TiC particles as reinforced phase, the SiC ceramic had higher density, higher fracture strength and Vickers' hardness with in situ synthesized TiC. In addition, the fracture toughness of SiC ceramic was also improved by the in-situ introduction of TiC. The fracture toughness of SiC ceramic was enhanced due to the in-situ introduction of small amount of TiC particles, which induced the formation of trace elongated SiC particles. The residual thermal stress field originating from the thermal expansion mismatch between SiC and TiC promoted the crack bridging and deflection, resulting in the improvement of fracture toughness as well.

Keywords: A. Sintering; C. Fracture; D. SiC; D. TiO_2

1. Introduction

Silicon carbide (SiC) is an important structural material due to its superior properties such as high hardness, high strength and excellent resistance to oxidation and corrosion [1–3]. However, the wide range of industrial application of SiC ceramics is restricted by its poor sinterability and limited fracture toughness [4–6]. In order to improve the sinterability of SiC ceramics, several sintering techniques have been utilized including reaction bonding sintering, gas pressure sintering, hot pressing sintering, pressureless sintering, etc. [7–11] By comparison, pressureless sintering is the most promising method because it imposes relatively low requirement on the equipment and yields products with high performance and desired shapes. According to sintering additives used during the sintering process, the pressureless sintering can be classified into pressureless solid state sintering and pressureless liquid phase sintering (PLPS). The pressureless liquid phase sintering, by contrast, requires lower densification temperature and results in higher mechanical performance of SiC ceramics. As a matter of course, the pressureless liquid phase sintering is of great potential to be extensively applied in improving the sinterability of SiC ceramics.

Another unresolved issue is the limited fracture toughness, which is the common problem of structural ceramics [12]. Although much progress has been achieved in improving the fracture toughness of SiC ceramics by means of liquid phase sintering, it is still barely satisfactory. Therefore, it is always a research focus to improve the fracture toughness of SiC ceramics. An effective way to address this problem is introducing reinforcing phase into the SiC matrix [5,13,14]. Ideal reinforcing phases should have similar advantages of SiC and do not degrade the performance of the composite. As one of the transition metal carbide, titanium carbide (TiC) is famous for the high performance, such as high hardness and

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elastic modulus, high stability to corrosion and wear. In addition, due to the thermal expansion coefficient mismatch ($\Delta\alpha = \sim 2.6 \times 10^{-6}\ ^{\circ}C^{-1}$) [15] between SiC and TiC, TiC is often used as a reinforcing phase to improve the fracture toughness of SiC ceramics [16]. However, the hot pressing sintering method is often adopted to achieve the densification of SiC–TiC composites because of the low self-diffusion coefficient of both SiC and TiC [6,16,17]. But the hot pressing sintering method imposes high requirement on equipment and is unable to fabricate products with complex shapes [5]. So it is desired to improve the fracture toughness of SiC ceramics in a facile way, i.e. pressureless liquid phase sintering. With this premise in mind, in-situ synthesis of TiC is considered to be a good solution.

In the present work, small amount of TiO_2 was used as the Ti source to introduce in-situ TiC into the SiC matrix. And the most widely used combination of Al_2O_3 and Y_2O_3 [18–20] was employed as the liquid phase sintering additives to achieve the densification of SiC ceramics.

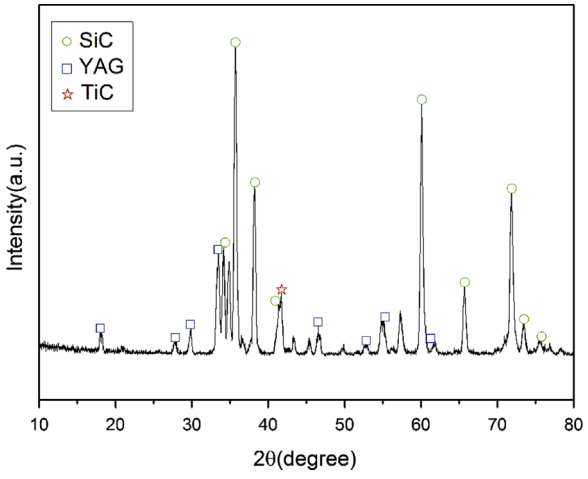

Fig. 1. XRD pattern of sample SiC/TiO_2.

2. Experimental procedure

According to the thermodynamic analysis by a commercial software package (HSC Chemistry 6.1 Outokumpu Research Oy, Pori, Finland), TiC was introduced into the SiC matrix by the following reaction presumably taking place at 1800 °C:

$$TiO_2\ (s) + 3SiC\ (s) \rightarrow TiC\ (s) + 3Si\ (s) + 2CO\ (g)\uparrow \quad (1)$$

Commercially available α-SiC (FCP 15C, SIKA Tech., Lillesand, Norway), Al_2O_3 (Fenghe Ceramic Co., Ltd., China), Y_2O_3 (Yuelong Chemical Co., Ltd., China), and TiO_2 (Sinopharm Group Co., Ltd., China) were used as the starting powders in the present work. For a comparative study, another batch of powders with the addition of TiC (Changsha Langfeng Metallic Material CO., Ltd., China) instead of TiO_2 was prepared. The mixture of 88 wt%-SiC–3.06 wt% Al_2O_3–3.94 wt% Y_2O_3–5 wt % TiO_2 (TiC) was ball-milled in ethanol for 4 h with silicon carbide media in a planetary mill at 300 rpm. After milling, the resultant slurries were dried in a vacuum evaporator at 60 °C for 24 h. Then these powders were sieved through a 100 mesh screen to avoid the agglomeration. Then the as-received powders were compacted by cold uniaxial pressing at a pressure of 20 MPa followed by cold isostatic pressing at 200 MPa. Before sintering, all the green bodies were slowly heated to 1000 °C with dwell time of 1 h to remove the binder.

Subsequently, sintering was carried out under Ar atmosphere up to 1920 °C at a heating rate of 10 °C/min below 1600 °C and 2 °C/min above 1600 °C. The samples were held at 1800 °C for 30 min to allow the reaction between SiC and TiO_2 to take place and fully convert TiO_2 into TiC.

The as-sintered samples (henceforth denoted as SiC/TiO_2 and SiC/TiC were machined into rectangular bars with a dimension of 4 mm × 3 mm × 36 mm and the surfaces of the bars were polished using polishing machinery with diamond slurries. In order to minimize the stress concentration induced during the machining process, the edges of all the bars were chamfered.

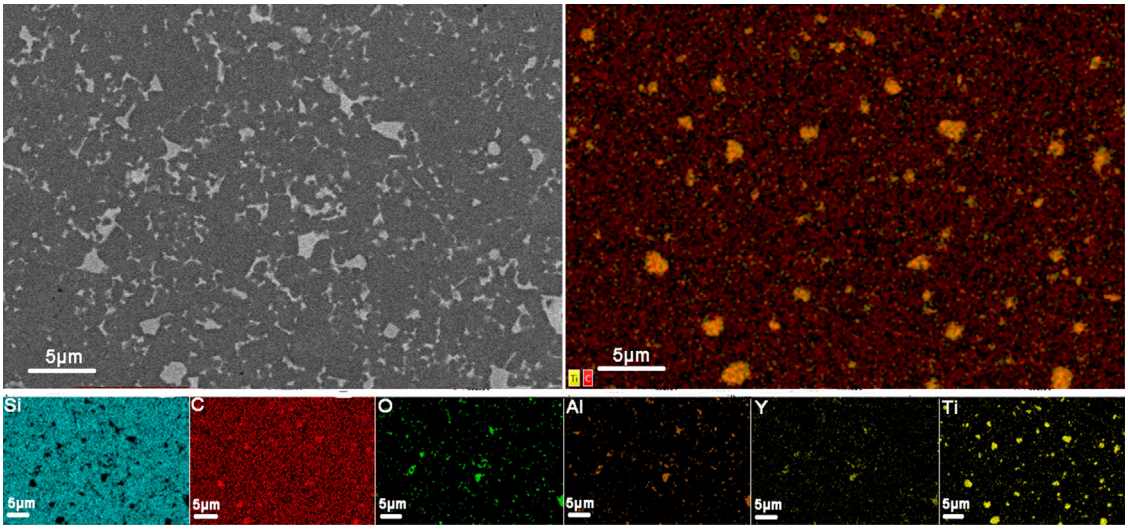

Fig. 2. EDS compositional mapping of sample SiC/TiO_2.