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Influence of cobalt phase on thermal shock resistance of Al_2O_3–TiC composites evaluated by indentation technique[☆]

Shi Rui-Xia[a,b,*], Yin Yan-Sheng[b], Li Jia[a], Wang Dong-Zhi[a]

[a] *School of Materials Science and Engineering of University of Jinan, Jinan, Shandong 250022, China*
[b] *School of Materials Science and Engineering of Ocean University of China, Qingdao, Shandong 266100, China*

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Abstract

Cobalt-coated Al_2O_3 and TiC powders were prepared using an electroless method to improve resistance to thermal shock. The mixture of cobalt-coated Al_2O_3 and TiC powders (about 70 wt.% Al_2O_3–Co + 30 wt.% TiC–Co) was hot-pressed into an Al_2O_3–TiC–Co composite. The thermal shock properties of the composite were evaluated by indentation technique and compared with the traditional Al_2O_3–TiC composite. The composites containing 3.96 wt.% cobalt exhibited better resistance to crack propagation, cyclic thermal shock and higher critical temperature difference (ΔT_c). The calculation of thermal shock resistance parameters (*R* parameters) shows that the incorporation of cobalt improves the resistance to thermal shock fracture and thermal shock damage. The thermal physic parameters are changed very little but the flexure strength and fracture toughness of the composites are improved greatly by introducing cobalt into Al_2O_3–TiC (AT) composites. The higher thermal shock resistance of the composites should be attributed to the higher flexure strength and fracture toughness.

Keywords: A. Composites; B. Ceramics; C. Mechanical properties; D. Microstructure

1. Introduction

Ceramic materials possess excellent high temperature resistance. However, the brittleness, higher elastic modules, bad plastic deformation ability and lower thermal conductivity of ceramic materials lead them to be sensitive to environments in which the temperature fluctuates rapidly. Therefore, the full exertion of high temperature resistance of ceramic materials depends on the resistance to thermal shock. Al_2O_3–TiC (AT) composites are a kind of important engineering ceramics and have been widely used in various engineering fields [1–3]. In many applications the Al_2O_3–TiC composites are often exposed to rapid temperature changes, which might cause severe thermal stress and thermal shock damage due to their lower strength and bad thermal properties. Consequently, how to improve the thermal shock resistance of AT composites has been an important issue in their structural applications.

It has been known that the incorporation of metal phase into alumina matrix can bring about improvement on mechanical properties, including thermal shock performance [4–7]. Yet, in order to guarantee the higher hardness the

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* Corresponding author at: School of Materials Science and Engineering of University of Jinan, Jinan, Shandong 250022, China. Tel.: +86 531 82765983; fax: +86 531 87974453.
E-mail address: mse_shirx@ujn.edu.cn (R.-X. Shi).

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Table 1
Thermal physic parameters of Al_2O_3, TiC and cobalt

Materials	α ($\times 10^{-6}$ K^{-1})	k (W/m K)	E (GPa)	ν
Cobalt	12.5	100	210	0.31
TiC	7.4	22	462	0.19
Al_2O_3	8.8	26	380	0.26

content of metal phase is very low. The few metal phases cannot be homogeneously dispersed in matrix by using traditional technology, which results in serious metal particles agglomeration. The powder coating technique has been proved to be an effective method in processing ceramic–ceramic composites [8,9]. It was found to greatly improve the homogeneity and sinterability of composites, and consequently their mechanical properties and thermal shock resistance.

Comparing with Al_2O_3 and TiC, cobalt possesses a unique set of thermal physical properties (see Table 1), e.g. higher thermal conductivity and lower Young's modulus, which contributes to the improvement of thermal shock resistance of Al_2O_3–TiC–Co composites (ATC). In the research, the ATC composites were prepared from the cobalt coating powders that were obtained by a newly developed coating technique, which was expected to improve the mechanical and thermal shock resistance.

The thermal shock resistance of ATC composite was evaluated by indentation-quench technique and parallel reference experiments were conducted with AT composites. In order to assess specially the effects of cobalt phase on thermal shock behavior, four thermal shock parameters (R parameters) were introduced for the two composites in terms of their mechanical and physical properties.

2. Experimental procedures

2.1. Material preparation and mechanical properties

The Al_2O_3 (average particle size ~[illegible] nm) and TiC (average particle size ~130 nm) powders were coated with cobalt film (about 3.96 vol.%) by using electroless method, respectively. In the chemical deposition method, $CoSO_4 \cdot 7H_2O$ is reduced by NaH_2PO_2 to form a thin film of cobalt on the surface of Al_2O_3 and TiC, respectively. The two kinds of ceramic powder were mixed at a ratio of 70 wt.% Al_2O_3–Co to 30 wt.% TiC–Co and homogenized by ultrasonic dispersion as the starting powder (provided by copartners of Ningbo Lingri Surface Engineering Co. Ltd., Zhejiang, China). Then the starting powders were hot-pressed in vacuum at 1650 °C for 30 min under a pressure of 30 MPa (Model HIGH MULTI [illegible], FUJI DENPA, Japan). As a comparison study, Al_2O_3–TiC composites (about 70 wt.% Al_2O_3 + 30 wt.% TiC) were prepared in the same sintering process. The hot-pressed bodies were cut into bars, ground and polished to 1 μm finish before flexure strength and fracture toughness testing. Five samples were tested for either flexure strength or fracture toughness. The flexure strengths were measured in three-point test (3 mm × 4 mm × [illegible] mm in size), fracture toughness tests were performed by the single edge notched beam (SENB) method ([illegible] × 4 mm × [illegible] mm in size) at a loading rate of 0.5 mm/min with a notch (2 mm in depth and 0.25 mm in width) and a span of [illegible], and HD-187.5 Brinell tester was used to test hardness. Relative density was measured by Archimedes method. The phase composition of the polished samples was identified using X-ray diffractometry (XRD; Model D/Max-[illegible], Rigaku Co., Japan) using Cu Kα radiation.

2.2. Indentation thermal shock

The indentation thermal shock technique developed by Andersson and Rowcliffe [10] was used to study the thermal shock and thermal fatigue behavior of the materials. In this technique, the thermal shock resistance is measured by studying the propagation of median/radial cracks around a Vickers indentation after single or repeated quenching. The specimens for thermal shock were disk shaped, with a diameter of ~30 mm and a thickness of 3 mm (Fig. 1a), with parallel 1 μm polished surfaces. Three specimens were tested for each composite. The four indentations were made uniformly, using a load of 294 N, on polished surfaces of each specimen. The holding time of each indentation was 5 s, and the interval between successive indentations was 60 s. Each indentation comes into being four cracks (Fig. 1b).