



Effects of particulate metallic phase on microstructure and mechanical properties of carbide reinforced alumina ceramic tool materials

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Abstract

Alumina-based composite ceramic tool materials reinforced with carbide particles were fabricated by the hot-pressing technology. Choice of metallic phase added into the present composite ceramic was based on the distribution of residual stress in the composite. The effects of metallic phase on microstructure and mechanical properties of composites were investigated. The metallic phase could dramatically improve room temperature mechanical properties by refining microstructure, filling pores and enhancing interfacial bonding strength. However, it also led to sharp strength degradation at high temperature because the metallic phase was easier to be oxidized and get soft at high temperature in air. The effects of metallic phase on strengthening and toughening were discussed. The improved fracture toughness of composite with metallic phase was attributed to the lower residual tensile stress in the matrix and the interaction of more effective energy consuming mechanisms, such as crack bridged by particle, crack deflection and intragranular grain failure.

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1. Introduction

Alumina ceramics possess some attractive properties of high hardness, chemical stability, excellent wear resistance and high temperature oxidation resistance. These properties make it possible to be applied in the environments of high temperature, wear and corrosive conditions. However, it is brittle at low temperature because of a fundamental lack of dislocation mobility and insufficient slip systems, which seriously limits its application as engineering material. So improving the flexural strength and fracture toughness is crucial for the use of Al₂O₃ ceramics as the cutting tools. In order to solve this problem, many approaches have been proposed. The strength and toughness can be improved either by the manipulation of microstructural features, such as control of grain size and shape (Si₃N₄ self-toughening and ZrO₂ phase transformation

toughening) [1,2], or by use of various second phases, e.g., multi-scale particles [3–5], whiskers [6], rare earth oxides [7] and ductile phase [8–9]. Among the various toughening methods, the ductile reinforcement toughening is one of the most promising toughening mechanisms. Many studies [10–15] have shown that the flexural strength and fracture toughness of composite ceramics can be greatly improved by the inclusion of a small quantity of metallic phase (Ni, Mo, Co and Fe).

Microstructure of the current metallic phase toughened ceramics can be classified into two types such as a particulate distribution microstructure and a continuous (or partially continuous) network microstructure. The addition of the particulate metallic phase into a brittle matrix is now well established as a method for increasing toughness, but in many cases the toughening contribution is small. The main limitation to toughening is lack of plastic deformation of the metallic phase [15]. Toughness increment achieved by the continuous (or partially continuous) network of metallic phase is generally higher than that of the particulate metallic phase. However, the materials toughened by the metallic particles have the

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advantages of material homogeneity isotropy and particularly better high temperature properties [16].

In the present work, the micro-scale (W,Ti)C particles, nano-scale TiC particles and the particulate metallic phase were added into the Al_2O_3 matrix in order to fabricate the composite ceramic tool material with high flexural strength and fracture toughness. Choice of metallic phase was based on the distribution of residual stress in the composite. Effects of metallic phase on the room temperature mechanical properties and high temperature flexural strength were investigated. Effects of metallic phase on strengthening and toughening were discussed.

2. Choice of the metallic phase

The level and nature of the internal stresses in the composite is one of the important factors that influence strengthening and toughening [17]. The distribution of residual stress in each phase of the composite ceramic containing metallic phase, which was induced by the mismatch of thermal expansion coefficients, was quite different from that of the composite without metal [18]. The elements Ni, Mo and Co are commonly added into the carbide particles reinforced ceramics due to their good wettability to the carbide particles. The metallic phase is usually distributed at the interface between the matrix

and reinforcing particle, so the residual stress in the composite can be calculated according to the four-layer thermal stress model [19]. When cooled from 1650 °C to the room temperature, the distribution of residual stress in each phase of the Al_2O_3 -30 vol% (W,Ti)C composites with/without metallic phase was shown in Fig. 1. As the very low content of nano-TiC in the present composite and small difference of thermal expansion coefficient between TiC and Al_2O_3 , so the residual stress induced by nano-TiC was ignored.

The residual stress distribution in the composites containing different metal phases is quite different as shown in Fig. 1(a) and (b). This is mainly ascribed to the difference in the mismatch of thermal expansion coefficients among the matrix, reinforcing particle and metallic phase. The coefficient of thermal expansion of Mo is about $4.8 \times 10^{-6} \text{ K}^{-1}$, which is lower than those of Al_2O_3 and (W,Ti)C. It can be seen that large compressive stresses are distributed in the (W,Ti)C particle and Mo layer as shown in Fig. 1(a). The compressive stress can restrain cracks initiation and propagation, which is beneficial for enhancing the flexural strength and fracture toughness of composite ceramics. However, large tensile stress also exists in Al_2O_3 matrix. The tensile stress can accelerate the cracks propagation in the matrix, causing the negative effect on the mechanical properties. The coefficients of thermal expansion of Ni and Co are about $13 \times 10^{-6} \text{ K}^{-1}$, which are higher than those of Al_2O_3 and (W,Ti)C. Although the tensile stress still exists in Al_2O_3 matrix (Fig. 1(b)), the numerical

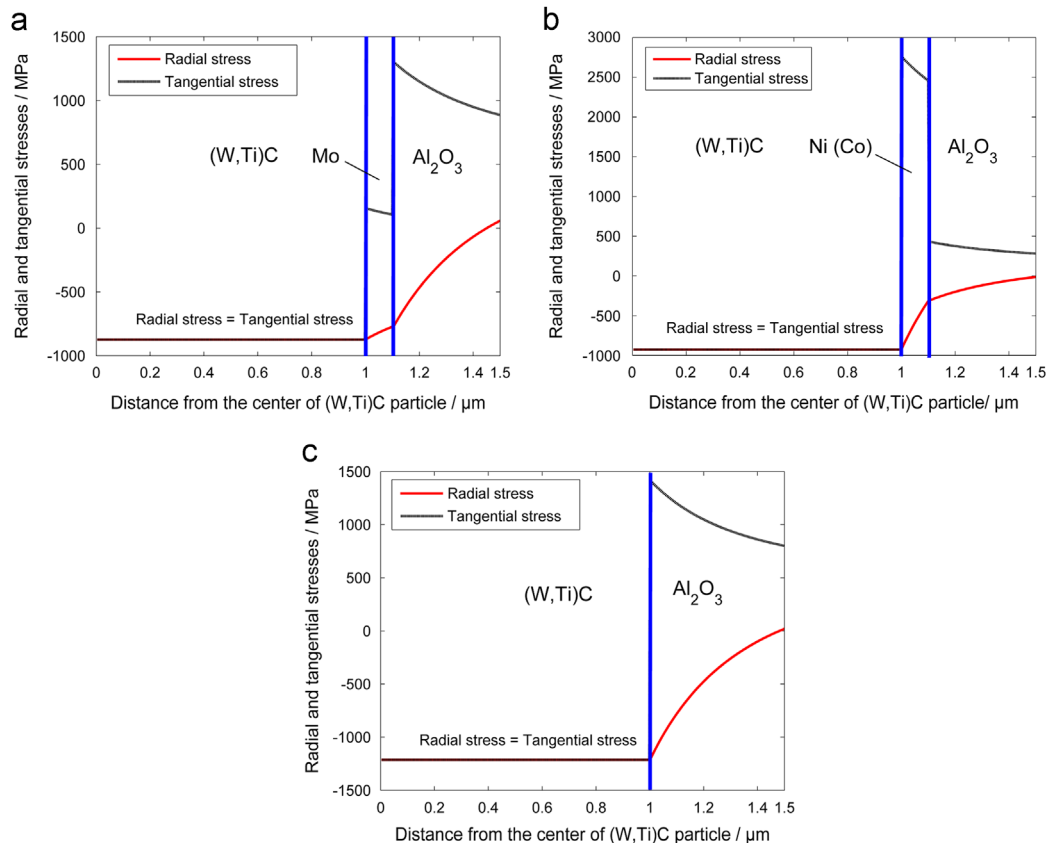


Fig. 1. The distribution of residual stress in the composites with/without metallic phase.

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