Materials Science and Engineering A 509 (2009) 63–68

Contents lists available at ScienceDirect

Materials Science and Engineering A

journal homepage: www.elsevier.com/locate/msea

Microstructure and mechanical properties of ZrO_2/NiCr functionally graded materials

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ARTICLE INFO

Article history:
Received 9 November 2008
Received in revised form 24 December 2008
Accepted 26 January 2009

Keywords:
Functionally graded materials
Microstructure
Mechanical property
Interface

ABSTRACT

The microstructure and mechanical properties of ZrO_2/NiCr functionally graded materials (FGMs) fabricated by powder metallurgy are investigated experimentally. Microscopic examination exhibits that the material composition and microstructure of the FGMs vary gradually. The distributions of mechanical properties in the FGMs are obtained from the mechanical testing of homogeneous composite samples (non-FGM) with different volume fractions of ZrO_2. The experimental results show that the distributions of mechanical properties strongly depend on the variation of microstructure. It is found that hardness increases and ductility decreases with the increase of ZrO_2, which is attributed to the variation of the matrix phase from the metal to the ceramic. Bending strength and elastic modulus decrease as the volume fraction of ZrO_2 increase from 0% to 40%, however, increase as the volume fraction of ZrO_2 increase from 50% to 100%. These are mainly caused by the weakly bonded ceramic/metal interface.

1. Introduction

Functionally graded materials (FGMs) offer an advantageous mean of combining different materials and providing a spatial variation in composition and properties [1]. FGMs consisting of ceramics and metals are promising candidates for the future high temperature applications. Ceramic component in the FGMs offers thermal barrier effects and protects the metal from corrosion and oxidation, and the FGMs are toughened and strengthened by metallic component [2]. The investigation of mechanical response of the FGMs is significant to the optimal design and fabricating process. The varying mechanical properties are usually determined by the micromechanical method [3–5] or the finite element method (FEM) [6,7]. However, few experiments [8–10] have been conducted to investigate the relationship between the mechanical properties and the material composition as well as the microstructure in the FGMs.

Due to the high mechanical and thermal properties of the constituent materials, the ZrO_2/NiCr FGMs can exhibit good service performance under some severe environments, such as super-high temperature and great temperature gradient [11,12]. However, the experimental investigation on the mechanical response of the ZrO_2/NiCr FGMs is rare. Zhu et al. [13] conducted the mechanical testing on a six-layered ZrO_2/NiCr FGM sample, and found that the mechanical properties of the FGMs exhibit various gradient distributions with the composition change. Using powder metallurgy, Jin et al. [14] fabricated the ZrO_2/NiCr FGMs with the volume fraction of NiCr increasing from 0% to 50%. They found that the elastic modulus decreases and the fracture toughness increases with the increase of NiCr. But further research is needed to fully understand the influences of the material composition and varying microstructure on the mechanical response of the ZrO_2/NiCr FGMs.

In this paper, an eleven-layered ZrO_2/NiCr FGM sample is fabricated by powder metallurgy, and the microstructural characteristics of the FGMs are examined by the optical microscope. The distributions of mechanical properties in the FGMs are directly obtained by the mechanical testing conducted on the non-FGM samples. Finally, scanning electron microscope (SEM) is performed on the fracture surface to analyze the dominant failure mechanisms of the FGMs.

2. Materials and experimental procedures

2.1. Materials

Commercially available ZrO_2 powder and Ni-20 wt.% Cr alloy (NiCr) powder are used as the raw powders. The characteristics of the two raw powders are listed in Table 1. In this paper, an eleven-layered ZrO_2/NiCr FGM sample is fabricated by powder metallurgy, as shown in Fig. 1. The ZrO_2 and NiCr powders are mixed with different volume ratios according to the design. The mixtures are stacked, layer by layer, and compacted by cold-pressing at ~30 MPa in a steel die to form a disk-shaped green compact. To maintain the designed composition distribution, the stacked layer is

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0921-5093/$ – see front matter.
doi:10.1016/j.msea.2009.01.066

Table 1
Raw powders characteristics.

Materials	Particles size (μm)	Purity (%)	Manufacture
NiCr	<45	>98	Shanghai Institute of Ceramics, Shanghai, China
ZrO_2	1.5	>99.9	General Research Institute for Nonferrous Metals, Beijing, China

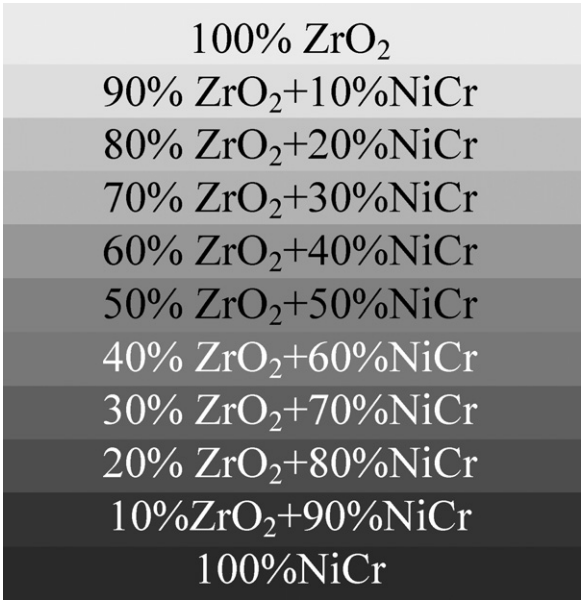

Fig. 1. Composition distribution model of the ZrO_2/NiCr FGMs.

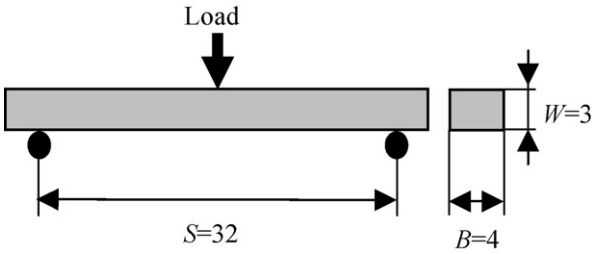

Fig. 2. Schematics of the three-point bending test. (Dimensions in mm).

pre-compacted at a lower pressure before stacking the next layer. Then the green compact is sintered under the hot-pressing condition of 1300 °C and 5 MPa for 1.5 h. With the same process, eleven non-FGM samples with different volume fractions of ZrO_2 are also fabricated. For microstructure inspection and mechanical testing, the samples are cut by a diamond saw, and their surfaces are ground and polished.

2.2. Mechanical testing

The distribution of Vickers hardness in the FGMs is directly determined by indenting with a load of 10 kgf on each layer of the FGM sample. The distributions of bending strength and elastic modulus in the FGMs are obtained from three-point bending test conducted on the non-FGM samples, as shown in Fig. 2. The three-point bending test is conducted on an Instron 5569 universal testing machine under the displacement control condition at the rates of 0.5 mm/min. For each material composition, five samples are tested.

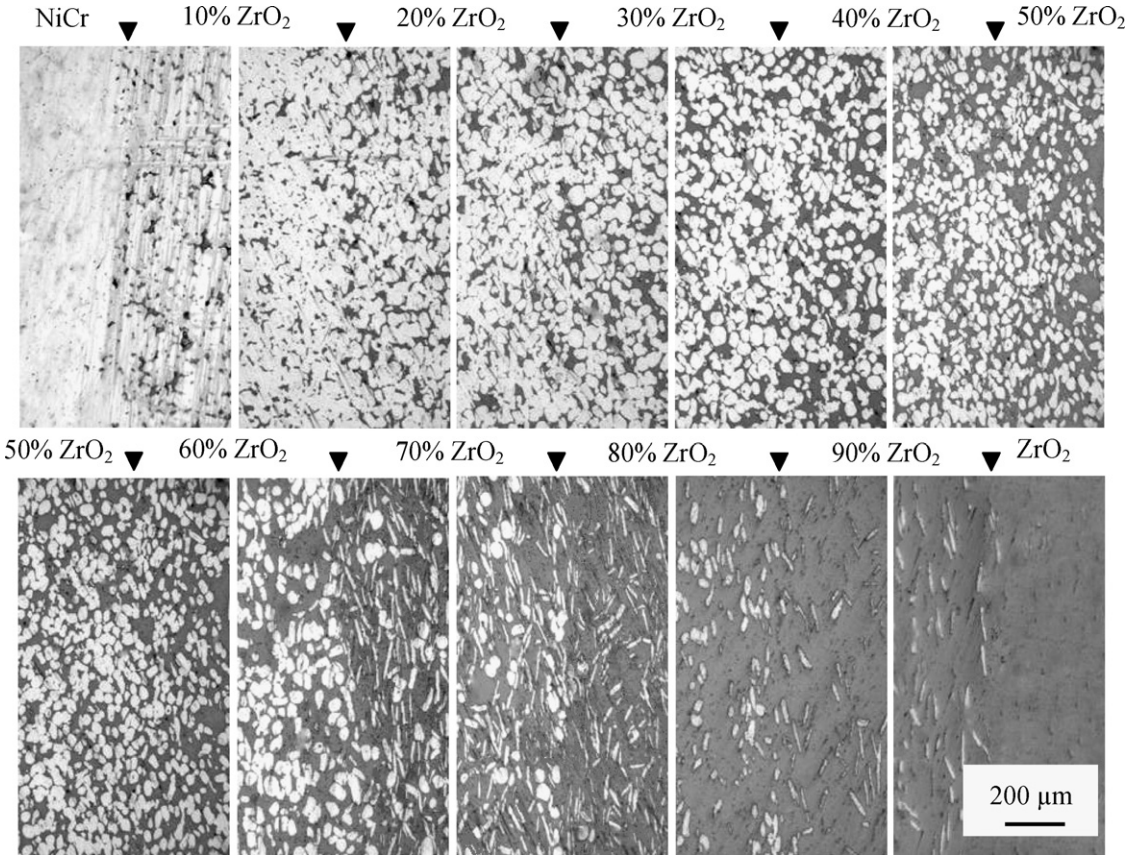

Fig. 3. Microstrcture of the ZrO_2/NiCr FGMs fabricated by powder metallurgy.