Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of the European Ceramic Society 25 (2005) 1119–1132

www.elsevier.com/locate/jeurceramsoc

Hertzian crack analysis in alumina–chromium composites

G. Geandier [a,*], S. Denis [b], A. Hazotte [c], A. Mocellin [b]

[a] E.S.R.F. (European Synchrotron Radiation Facilities), 6 rue Jules Horowitz, BP 220 38043 Grenoble Cedex 9, France
[b] L.S.G.2M. (Laboratoire de Science et Génie des Matériaux et de Métallurgie), UMR CNRS INPL no 7584 Ecole des Mines de Nancy, Parc de Saurupt, 54042 Nancy Cedex, France
[c] L.E.T.A.M. (Laboratoire d'Etude des Textures Appliquées Aux Matériaux), UMR CNRS/Université de Metz no 7078, LETAM ISGMP, Ile de Saulcy, 57045 Metz Cedex 1, France

Received 11 November 2003; received in revised form 2 April 2004; accepted 22 April 2004
Available online 3 July 2004

Abstract

Ceramic metal composites are of interest for their good resistance to crack propagation. We have prepared different kinds of alumina chromium composites, observed their microstructures and made an analysis of Hertzian cracks in order to identify the principle parameters of crack propagation in relation with the metallic phase size and distribution in the matrix. The crack is analysed at two scales, a macroscopic one to estimate the fracture toughness from the overall crack and a microscopic one to study, at the local level, the influence of the metallic phase on crack propagation. Using macroscopic models the fracture toughness estimation highlights the benefit of the presence of chromium particles. Observations and measurements made on the crack path and metallic phase, from the microstructure analysis, combined with the knowledge of the residual stress state, provide the principal parameters governing crack propagation in these composites.

Keywords: Ceramic Matrix Composite; Hertz crack; Fracture toughness; Microstructure; Al_2O_3/Cr

1. Introduction

Al_2O_3–metal composites are known for their improved mechanical properties as compared to pure alumina. Their production by hot pressing of mechanosynthesized nanocomposite powders allows obtaining dense, homogeneous ceramic-metal materials containing high metal contents.[1] The optimisation of the properties of these materials requires controlling the size and morphology of the reinforcing phase but also a good knowledge of the interaction between a propagating crack and the microstructure. In this work, we analyse Hertzian cracks made in alumina chromium composite which are heterogerenous material, to investigate their mechanical behaviours. The analysis takes into account all error sources due to specificity of the materials. Hertzian indentation is used for its experimental simplicity and well defined crack geometry compared to other techniques, such as Vickers indentation.[2] Hertzian indentation is also a technique that has not been tested on heterogenous materials. Results from indentations and micromechanical analysis[3] are used for the interpretation of relations between microstructure, mechanical state and crack paths in the composites.

The first part of the paper will describe the samples, their elaboration and a microstructural analysis of the different types of composites. The second part deals with the experimental set-up and a reminder of the Hertzian test. The third part presents the results of crack analysis at a macroscopic and a microscopic scale and analyses the crack propagation in relation with the microstructure and the local residual state of stress.

2. Sample preparation

The materials under study here are composites prepared by mechanical alloying.[1,4] The starting powders are metallic aluminium, alumina and chromium oxide. High-energy milling is carried out in a planetary ball mill with steel balls. This mechanical process allows to synthesize a chromium-alumina composite through the following reaction:

$$2Al + Cr_2O_3(+Al_2O_3) \rightarrow 2Cr + Al_2O_3$$

* Corresponding author.
E-mail address: geandier@esrf.fr (G. Geandier).

0955-2219/$ – see front matter.
doi:10.1016/j.jeurceramsoc.2004.04.022

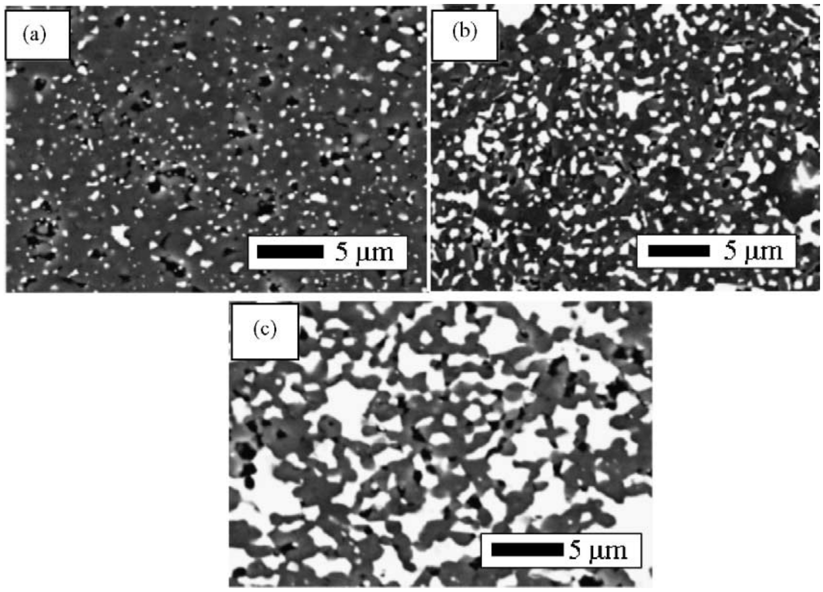

Fig. 1. SEM images of alumina chromium composites: (a) 9%, (b) 21%, and (c) 36% type I.

The proportion of powders is chosen to yield various volume fractions of metallic phase between 9 and 36%. In order to obtain dense samples, the powders are hot pressed in a graphite die at 1450° C in argon atmosphere. X-ray analysis has confirmed that the composites are made of an alumina matrix and metallic chromium particles. Chromium has been chosen due to the direct reduction of chromium oxide by aluminium leading to metallic chromium and alumina as outlined above. The complete solubility of Al_2O_3 and Cr_2O_3 is favourable to obtain highly dense composites with

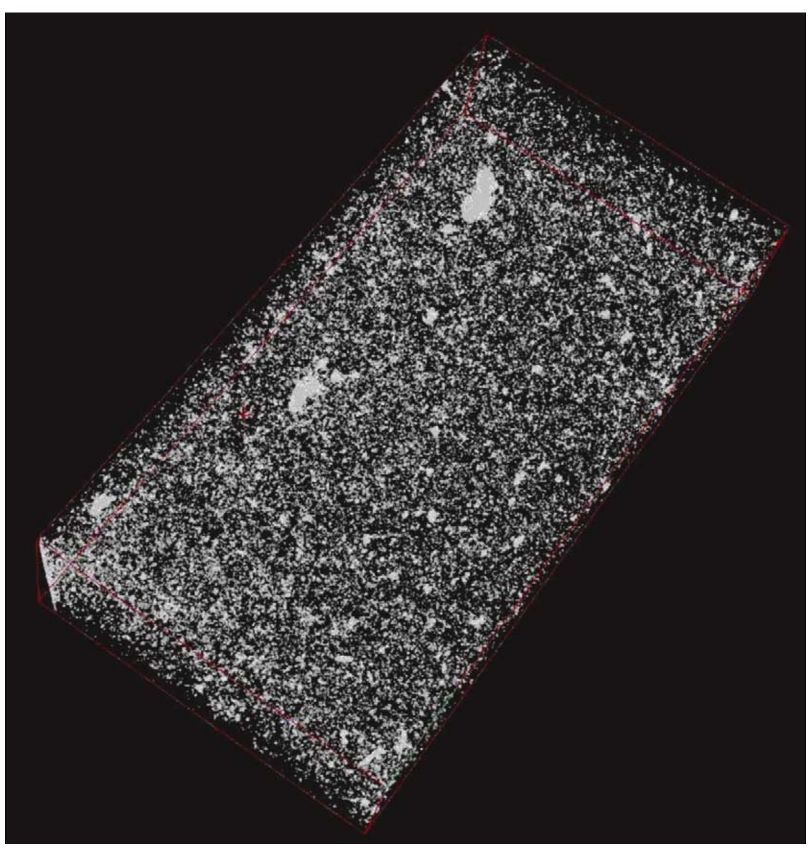

Fig. 2. X-ray microtomography of a composite containing 21 vol.% of chromium, volume size: 408 μm ×800 μm ×151 μm.