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Thermo-Mechanical Processes in Sapphire Crystals with Different Orientations

P. H. Otsuka[1], V. N. Gurarie[2] and I. V. Andrienko[3]

MARC, School of Physics, University of Melbourne, Melbourne 3010, Australia,
[1]p.otsuka@physics.unimelb.edu.au
[2]v.gurarie@physics.unimelb.edu.au
[3]iva@physics.unimelb.edu.au

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Abstract. The present study deals with thermo-mechanical behaviour of aluminium oxide single crystals under thermal stress. In the experiments the (0001), $(11\bar{2}0)$ and $(1\bar{1}02)$ faces are tested under pulse heating in plasma of varying intensity. The peak temperature on the sample surface is determined by measuring the separation between fragments formed by cracks during the cooling stage of the heating-cooling cycle. The fracture morphology and fracture threshold are analysed experimentally and theoretically on all three crystal faces tested in plasma.

A theoretical model is based on the continuum mechanics approach which takes into account anisotropy of elastic, plastic and thermal properties of sapphire crystals. The thermal stress resistance parameter is theoretically analysed for the faces under investigation. The parameter allows one to determine the resistance to fracture and plastic deformation for various crystal faces in sapphire and thus to identify the most resistant crystal face under thermal shock loading. The theoretical results on fracture morphology and fracture threshold proved to be consistent with the experimental ones. The $(1\bar{1}02)$ face in sapphire crystals is demonstrated to be most resistant to fracture, and the (0001) face most resistant to plastic deformation under the plane state of stress applied. The model is shown to be suitable for determining the temperature threshold of fracture and plastic deformation and predicting the fracture morphology in brittle crystals with various faces.

Introduction

The brittle nature of ceramic materials is one of their main limitations in many high temperature applications for which metals are not appropriate. Identifying and quantifying major properties responsible for fracture under dynamic loading, especially thermal shock, are important considerations in finding ways to improve their performance. Thermal shock resistance of ceramic single crystals represents a special problem because of the anisotropic nature of their elastic, plastic, thermal and fracture properties.

The thermal stress resistance of rhombohedral single crystals with different crystallographic faces has been previously investigated experimentally and theoretically [1]. It was found that a fracture criterion based on an interplay between the surface energy and the tensile stress acting normal to the cleavage plane was adequate to account for the fracture propagation in sapphire single crystals. However, the effect of plastic deformation that occurs during the heating stage was not considered. In the present study, the thermo-mechanical processes are further investigated using the stress-temperature diagram which includes the effect of plastic strain during the heating stage.