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Biaxial strength and slow crack growth in porous alumina with silica sintering aid

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Abstract

Biaxial strength, fracture toughness and subcritical crack growth are reported for coarse grained porous alumina ceramics. The materials were prepared with a varying amount of a silica sintering aid, which resulted in the formation of a glassy secondary phase at the grain boundaries. Crystalline mullite was additionally found in the material with the highest silica content. The biaxial strength, measured by Ball-on-Ring and Ball-on-3-Balls, was highest for the material without mullite at the grain boundaries, and the biaxial strength decreased with increasing porosity. The fracture toughness of the materials was in the range of 1.7-1.9 $MPam^{0.5}$. Measurements of subcritical crack growth by a modified lifetime method in air and aqueous environments demonstrated a higher crack growth rate in water and acid relative to in air. The effect of porosity and grain boundary phase were discussed in relation to subcritical crack growth and fracture mode in the coarse grained alumina ceramics.

Keywords: Porous alumina, Biaxial strength, Fracture toughness, Subcritical crack growth

1. Introduction

Alumina ceramics are widely used today due to its excellent properties such as high hardness [1], chemical inertness [2, 3], thermal stability [4] and low electrical conductivity [5]. In most of these applications dense ceramics are desired, and MgO is mostly used as a sintering aid for sintering of high performance dense alumina ceramics [6–8]. Porous alumina ceramics on the other hand, where the porosity can be tailored by the use of pore forming agents or by using coarse grained powders, have also potential applications such as in filters, catalyst support and in membranes [9, 10]. In many of these applications the porous alumina material can be exposed to a mechanical load in various aqueous or chemical environments, which address the importance of understanding subcritical crack growth and fracture mode in the porous materials.

The mechanical performance of alumina ceramics such as strength and fracture toughness have been studied extensively due to the technical importance of alumina ceramics [4, 11–13]. The mechanical performance depends on porosity, the presence of other phases at the grain boundaries and also humidity. Biaxial strength and effect of environment on the mechanical performance of alumina-based ceramics have been measured on ceramic plates by Ball-on-Ball (BOB) or Ball-on-3-Balls (B3B) methods [14–16]. Subcritical crack growth (SCCG) may occur when cracks grow under an applied stress intensity factor, K_I, well below the fracture toughness, K_{IC} [17]. SCCG is related to presence of humidity in ceramics [11, 14, 18, 19]. Polar molecules, such as water, may interact with the strained crack tip, which will weaken the bond at the crack tip. With presence of humidity, SCCG may also influence the determination of fracture toughness as recently addressed by Krautgasser et al. and Quinn and Swab for low-temperature co-fired ceramics and glasses, respectively [20, 21]. Though in case of high purity alumina with submicron grain size no effect of humidity has been reported [14]. In alumina ceramics fast fracture often propagates by a transgranular mode, whereas slow crack growth propagates by intragranular mode, especially for materials with

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