crystals

MDPI

Review

Mechanical Properties of CaO–Al_2O_3–SiO_2 Glass-Ceramics Precipitating Hexagonal $CaAl_2Si_2O_8$ Crystals

Kei Maeda [1,*], Kosho Akatsuka [2], Gaku Okuma [3] and Atsuo Yasumori [1]

[1] Department of Materials Science and Technology, Tokyo University of Science, Tokyo 125-8585, Japan; yasumori@rs.tus.ac.jp
[2] AGC Inc., Yokohama Technical Center, Kanagawa 230-0045, Japan; kosho.akatsuka@agc.com
[3] Research Center for Structural Materials, National Institute for Materials Science, Ibaraki 305-0047, Japan; OKUMA.Gaku@nims.go.jp
* Correspondence: kei.maeda@rs.tus.ac.jp

Abstract: Fracture behavior via a flexural test for a newly found CaO–Al_2O_3–SiO_2 (CAS) glass-ceramic (GC) was compared with that of enstatite GC and mica GC, which are well-known GCs with high-fracture toughness and machinability, respectively. By focusing on the nonelastic load–displacement curves, CAS GC was characterized as a less brittle material similar to machinable mica GC, compared with enstatite GC, which showed higher fracture toughness, K_{IC}. The microcrack toughening mechanism in CAS GC was supported by the nondestructive observation of microcracks around the Vickers indentation using the X-ray microcomputed tomography technique. The CAS GC also showed higher transparency than mica GC due to its low crystallinity. Moreover, the precursor glass had easy formability due to its low-liquidus temperature.

Keywords: glass-ceramics; fracture toughness; brittleness

check for updates

Citation: Maeda, K.; Akatsuka, K.; Okuma, G.; Yasumori, A. Mechanical Properties of CaO–Al_2O_3–SiO_2 Glass-Ceramics Precipitating Hexagonal $CaAl_2Si_2O_8$ Crystals. *Crystals* **2021**, *11*, 393. https://doi.org/10.3390/cryst11040393

Academic Editors: Araceli De Pablos Martin and Giulio Gorni

Received: 4 March 2021
Accepted: 6 April 2021
Published: 8 April 2021

1. Introduction

After the discovery of toughened zirconia ceramics in the 1970s [1], studies to increase the toughness of ceramic materials have received a great deal of attention [2]. Many mechanisms of toughening, including phase transformation [2], microcracking [3,4], crack deflection [5,6], and crack bridging [7], were suggested and are well accepted. For characterizing the toughness of ceramics, the fracture toughness (K_{IC}), which describes the critical stress intensity on the crack tip, is mostly used as an index of material toughness. However, the so-called "resistant-curve (R-curve)" behavior, which indicates the increase of fracture resistance as the crack extends, is regarded as another important factor and inherent for understanding the toughness of ceramics [2].

One of the simple and easy methods to evaluate the toughness of ceramic materials is a flexural test using samples introducing various types of notches including chevron notch or a single notch. From load–displacement curves of the flexural test, R-curve behavior can be evaluated [8,9]. Figure 1 illustrates the concept of R-curve behaviors and the related load–displacement curves. Brittle materials break at a critical load in linear elastic behavior. There is no mechanism to increase the resistance against the propagation of cracks; hence, the R-curve is flat (Figure 1A). However, if the resistance increases as the crack extends, the load–displacement curve shows nonelastic behavior and the material gradually breaks (Figure 1B). As a result, one feels the material as "less brittle" or "tough".

Oxide glass is a typical brittle material with a K_{IC} of 0.6–1.0 MPa $m^{1/2}$ [10,11], because it does not have secondary phases and grain boundaries that can affect the propagation of cracks. Therefore, many studies have been conducted for glass-ceramic (GC) materials to improve the brittleness of oxide glass. A recent article defined GCs as "inorganic, non-metallic materials prepared by controlled crystallization of glasses via different processing methods" [12]. GCs contain some amounts of crystalline phases; therefore, their fracture