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Effect of Initial Green Samples on Mechanical Properties of Alumina Ceramic

I Nyoman Sudiana

Material Physics Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Halu Oleo University, Kampus Bumi Tridharma Anduonohu Kendari 93232, Indonesia

Seitaro Mitsudo

Research Center for Development of Far-Infrared Region, University of Fukui 3-9-1 Bunkyo, Fukui-shi 910-8507, Japan

Muhammad Zamrun Firihu

Theoretical and Computational Physics Laboratory, Department of Physics Faculty of Mathematics and Natural Sciences, Halu Oleo University, Kampus Bumi Tridharma Anduonohu, Kendari 93232, Indonesia

Abstract

Initial microstructure of samples before sintering is very sensitive in microwave processing. Effect of initial green samples on densification curve of microwaved sintered alumina have been reported previously by authors. In this paper the effect of initial green samples on the mechanical properties (micro hardness and fracture toughness) of alumina after sintering is considered. The experimental results were taken from a series of investigations to study the effect of very high frequency microwave on properties of alumina ceramics. The sub-millimeter wave experimental results are presented and discussed.

Keywords: Cold Isostatic Pressing (CIP), microhardness, gyrotron, alumina

1 Introduction

Alumina, Al_2O_3, is one of the most sintered ceramic materials. It offers a combination of good mechanical and electrical properties leading to a wide range of applications. Alumina can be produced in a range of purities with additives and various processing methods designed to enhance its properties [1-2]. Production of alumina for specific application requires a careful control of each step of ceramic processing, from powder synthesis to the final sintering stage for finding desired properties. Moreover, each step may have an effect on the following one. Sintering alumina, despite several decades of lasting research effort, still remain many questions because such a complexity process during sintering in the material[3-5]. Especially for microwave processing, until now there are lack of theoretical basis yet to explain the effect of microwaves on the atomic transport of alumina ceramics. Sintering alumina by using various microwaves frequencies have been reported [5-8] as well as silica [9-11].

One of the main propertie of alumina ceramics for application is mechanical property. The common methods for hardness testing of ceramics are by using a Vickers hardness testing [12-13]. The basic principle of this method is to observe the questioned material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all ceramics and metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV). The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not a pressure. Vickers hardness test uses a square-base diamond pyramid as the indenter with the included angle between opposite faces of the pyramid of 136º. Vickers hardness number (HV) is determined by Equation [12],

$$HV = \frac{F}{S} = \frac{2F \sin \theta/2}{d^2} \approx 1.8544 \frac{F}{d^2} \quad (1)$$

where F is the force applied to the diamond (in kilograms-force) and S is the surface area of the resulting indentation in square millimeters, d is the average length of the diagonal left by the indenter in millimeters.

Another mechanical property testing is fracture toughness is a property which describes the ability of a material containing a crack to resist fracture, and is one of the most important properties of any material for applications [4]. There are two kind of fracture toughness:

1. Linear-elastic fracture toughness: determined from the stress intensity factor at which a thin crack in the material begins to grow and denoted by K_{Ic} in $MPa.m^{1/2}$.
2. Plastic-elastic fracture toughness where denoted by J_{Ic}, with the unit of J/cm^2.

There are several ways for fracture toughness measurement methods. Due to its simplicity, its non-destructive nature, and the fact that minimal machining is required to prepare the sample, the use of the Vickers hardness indentations to measure fracture toughness (K_{IC}) has become quite popular.
The fracture toughness then calculated by equation [12],

$$Kc(Mpa \cdot m^{1/2}) = 0.016 \times \left(\frac{E(Pa)}{HV(Pa)} \right)^{1/2} \times \left(\frac{P(N)}{c(m)^{3/2}} \right) \quad (2)$$

where P is the indentation-applied load, c is length of the crack arising from the corners of the impression and E and HV are respectively the Young`s modulus and Vickers hardness.

In this paper will present effect of initial samples properties to hardness and fracture toughness of sintered alumina.

2 Experimental Setup

Two initial green samples, Cold Isostatic Pressed (CIP) and un-Cold Isostatic pressed (un-CIPed) were prepared and sintered. To determine mechanical property, alumina samples were cut and grinded after sintered by microwave 300 GHz. The grinded surface then prepared for Vickers hardness testing . The testing was performed only for very high sintering temperatures: 1500-1700^{o}C where at these temperatures alumina already achieved high density or only small percentage of pores remains inside compact as found. The Vickers hardness tester was performed by using a micro Vicker hardness tester (Akashi MVK-EII). Testing was performed every 200μm from the surface to the center of samples by adjusting the position of samples as shown in Figure 1.

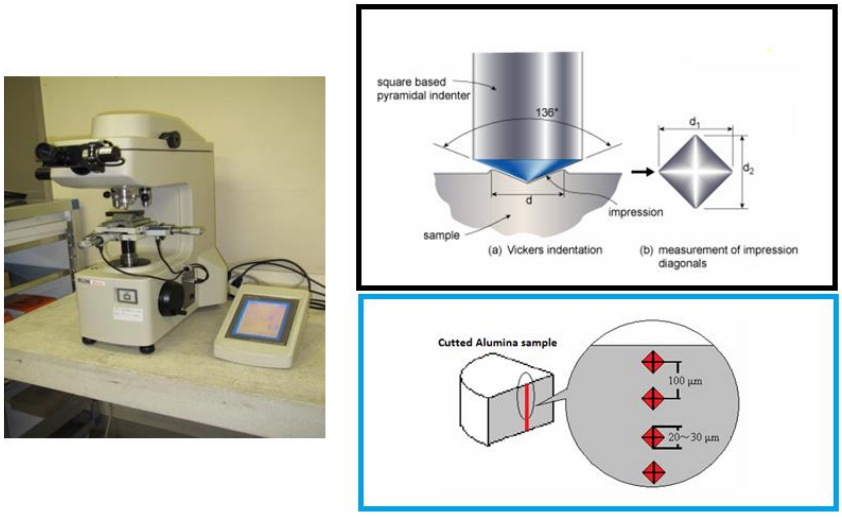

Fig. 1 Experiment for Vickers hardness

The average of the micro Vickers hardness as well as fracture toughness values are determined from this measurements by using Equations 1 and 2.

3 Experimental Results and Discussion

The effect of initial green samples to micro Vickers hardness results are shown in Figure 2. The hardness of the sintered alumina ranged from approximately 1700 to 2400 kgf/mm^2.

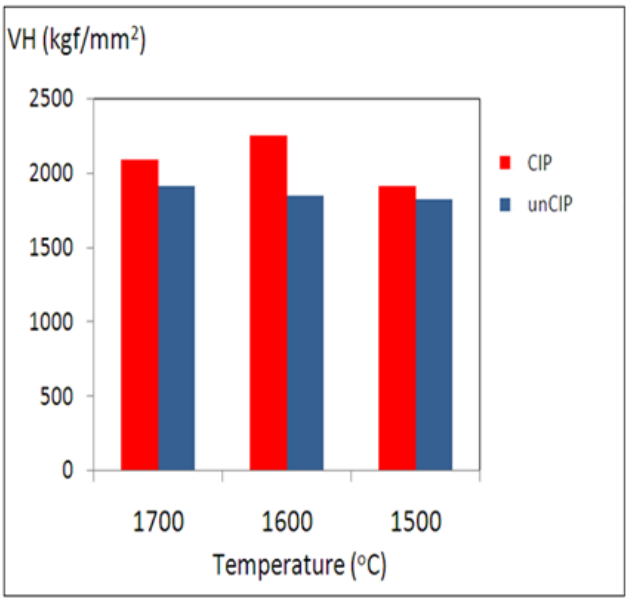

Fig. 2 Micro Vickers hardness of microwave sintered alumina
For CIP and unCIP samples

Figure 3 shows the fracture toughness for CIPed and un-CIPed alumina samples. The effect of green samples on the mechanical properties of microwaves processed alumina is vividly. The CIPed alumina samples had a higher strength at all temperatures. Such a higher strength was due to the CIPed samples' higher density and finer grains. However, density and grain size alone seem to be unable to explain such a fracture toughening behavior.

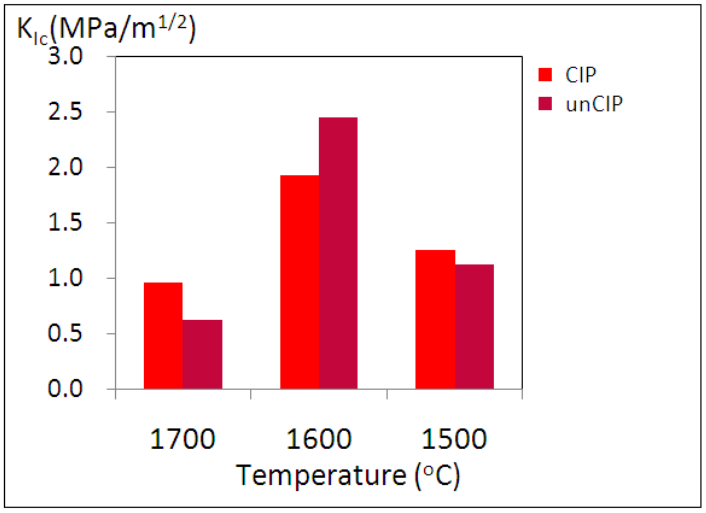

Fig. 3 Fracture Toughness of microwave sintered alumina
for CIP and unCIP samples

Mechanisms for hardening of alumina in this study maybe because of increasing in grain boundaries areas with increasing grain size and promote grain boundary micro cracking [14-15]. The CIP increases contact between grains and increases grain boundaries areas as shown in Figure 4. [15-16]. Moreover microwaves couples stronger in grain boundary.

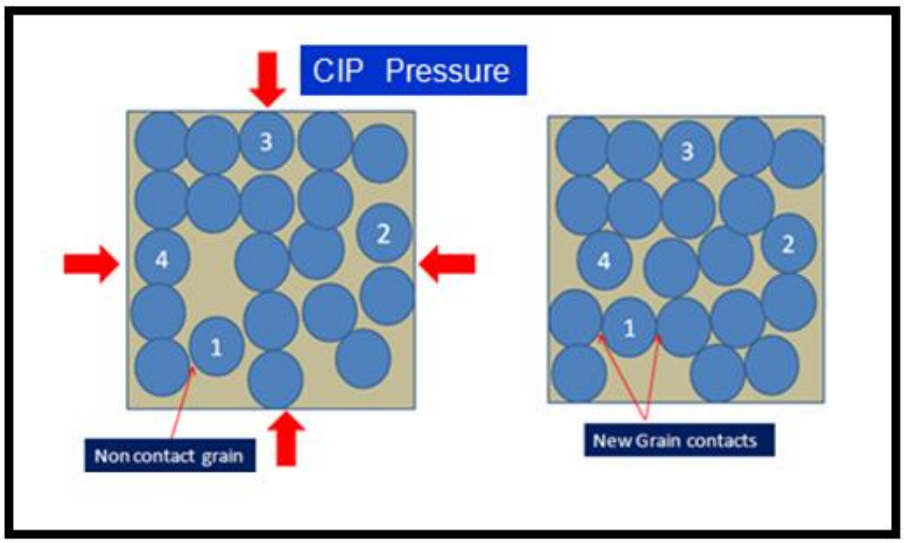

Fig. 4 Effect of CIP on grains contact

Conclusion

The evaluation on the effects of green compact on densification demonstrated that cold isostatic pressing (CIP) treatment significantly increased densification in microwave sintering. The effect was higher than that both in other microwave frequencies and in conventional, as well. This suggested that the CIP was effective to enhance densification in microwave sintering. In this investigation, effect of CIP pressing increased mechanical properties of microwaves sintered alumina was also found. That is because of the higher densities and smaller grains of the CIPed green samples at same sintering temperatures. It suggested that CIP can be one of appropriate technologies for ceramics processing.

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