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Fracture Toughness Properties of Mullite-Magnesia-Yttria Stabilized Zirconia System

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Abstract**:** *This study evaluated the additional 1 to 9% by weight Yttria into the Mullite- Yttria Stabilized Zirconia-Magnesia system resulted high hardness and high fracture toughness. The specimens of Mullite-Yttria Stabilized Zirconia-Magnesia were prepared, and the indented crack was measured. The measured crack length represents the criteria of c/a parameter less than 3.0 that follow Palmqvist crack criteria. The specimen that contains 8% by weight of Yttria in the Mullite 10%-Yttria Stabilized Zirconia-Magnesia showed the highest value of fracture toughness at about 5.58 MPa.m^{½} while compared with the lower content of Yttria. However, the highest hardness value of 16.26 GPa was belonged to specimen with 9% by weight of Yttria. An increase of Yttria content in the range of 1 to 9% by weight leads to improve the hardness and fracture toughness properties of Mullite-Yttria Stabilized Zirconia-Magnesia system.*

Keywords: *Brittleness index, Fracture toughness, Mullite-Yttria, Palmqvist crack, Zirconia-Magnesia*

1. Introduction

The zirconia based ceramic material has advantages among other similar materials due to its high hardness, modulus of elasticity, and mechanical strength properties. The study of indentation test on the ceramics material gives clear characteristic of ceramic hardness level. From this point, the mechanical parameter of fracture toughness has been studied by researchers. The previous work shows that Mullite content tends to reduce the hardness and fracture toughness of the 3Y-TZP-Mullite-Magnesia system [1].

In this study, the toughness material may relevant with study of Palmqvist crack were reported [2-5]. Although the Palmqvist crack material is not considerable for high toughness material, however this criterion may better fit to represent the ceramic material at the short distance level of Palmqvist crack criteria. In this case, the Japanese Standards Association established the requirement of this type of ceramic material [6]. The Palmqvist crack criterion was satisfied in which the c/a parameter was less than 3.0 [7].

In parallel, the study of more toughness material was reported by several researchers [8-9]. In the same time, an improved definition of the toughness was proposed [10]. Later, some researchers reported their study regarding about crack on the ceramics material [11-14]. In the last years, the study of ceramics was still developed [15-16]. The median crack criteria prevail while the c/a parameter was more or equal than 3.0 [7].

2. Experimental Procedure

This study employed the raw material partially synthesized in laboratory scale at the Ceramic Technology laboratory - Bandung Institute of Technology, namely Zirconia. The Zirconia was processed from $ZrSiO_4$ as a side product of tin mining in Bangka Island. The zirconate ($ZrSiO_4$) powder with 3% mole of Yttria (Y_2O_3) and poly vinyl butyrate were mixed at proper quantity, blended homogeneously, calcinated, dried and finally grinded to obtain 3Y-TZP powder. The 3Y-TZP powder was then casted with applied maximum load of 4 tons/ cm^2 and

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then sintered at temperature of 1500 ^{o}C for 4 hours. The other materials were obtained commercially include Yttria (Y_2O_3), alumina (Al_2O_3), silica (SiO_2), and magnesia (MgO).

The Mullite was synthesized by additional silica into alumina at molarity proportion. The specimens were prepared in pellet and plate shapes. With refer to ASTM C1161; the specimens were shaped in pellet in 8 mm diameter and 3 mm thickness (Fig. 1). The hardness was tested using Micro Vickers equipment (Fig. 2), whereas the ceramic morphology was analyzed using infrared to identify the crack propagation.

Fig. 1: Mullite-3YSZ sample

Fig. 2: Micro Vickers

The ceramics samples were analyzed using Micro Vickers and also by means of the infrared thermography imager. Both measurement will be compared to obtain precisely crack length of indented samples. The crack length from all four sides of indented tip will be calculated in an average value of crack length.

3. Result and Discussion

3.1. Vickers Hardness

Set of specimens were prepared for indentation test to obtain the hardness value of ceramic specimen. The average distance of cracks were measured to define the value of *l* and *a* (Fig. 3 and 4). This study employs parameter of *c/a* to define the crack types either comply to the Palmqvist or median crack criteria. Fig. 5 shows that all of the crack specimens measurement comply to Palmqvist criteria with the values of *c/a* parameter are between 2.1 to 2.9. The reference line was determined to comply the Plamqvist criteria at the value of *c/a* less than 3.0 and turns to the median crack criteria while the value of *c/a* more or equal to 3.0. Fig. 6 herein shows the value of hardness of specimens far higher than the expected values of these mechanical parameters.

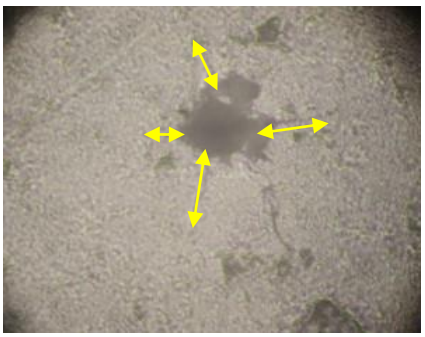

Fig. 3: Visual Micro Vickers

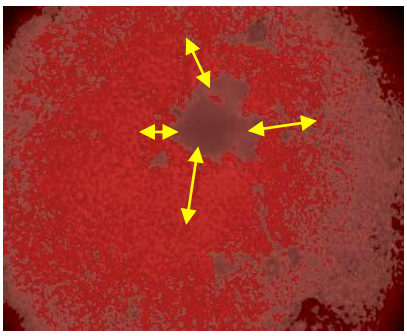

Fig. 4: Infrared Imaging

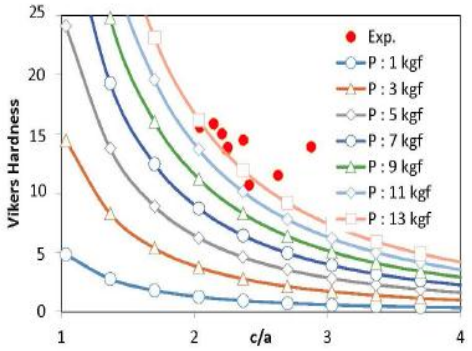

Fig. 5: HV vs c/a

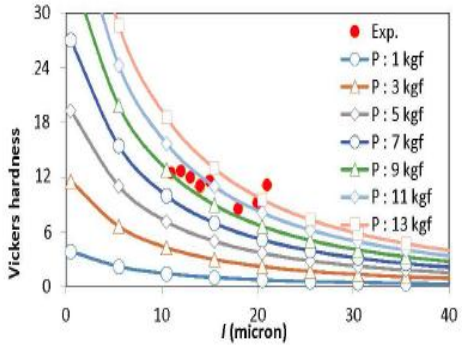

Fig. 6: HV vs lf

The figure represents the *c/a* value at about 2.1 owned by Mullite 10% mole into 4YSZ system, resulted the lowest fracture toughness of ceramic material at the value of 3.99. However, the lowest value of ceramics hardness at about 10.97 GPa was obtained from specimen Mullite 10% mole into 1YSZ system.

3.2. Fracture Toughness

The K_{IC} value of specimen with refer to the length of cracks after indentation test was shown at Fig. 7 and 8 show. All specimen show higher value than the reference line at the applied indented load at about 1.5 kgf. The specimens contain the Mullite at about 10% mole, and the Yttria content into Stabilized Zirconia as much as 1, 2, 3 until 9% by weight, respectively. The values of fracture toughness of the Mullite-3YSZ-Magnesia system were at the range of 3.99 to 5.58 MPa.m^{½}. The figure shows that the specimen having the highest crack length of 21 μm correlates with the lowest fracture toughness at 3.99 MPa.m^{½}.

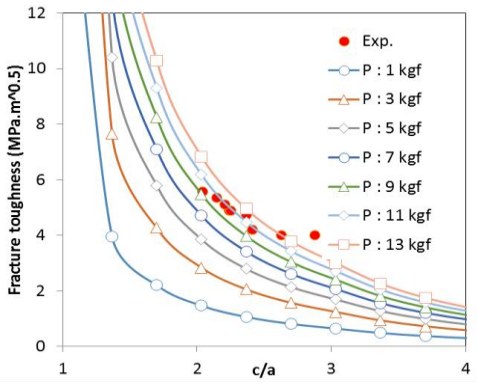

Fig. 7: K_{IC} vs c/a

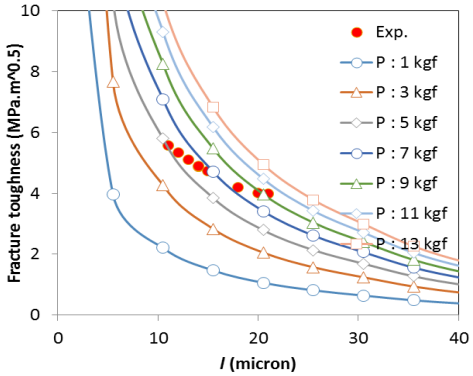

Fig. 8: K_{IC} vs *l*

3.3. Brittleness Index

The study of brittleness index was shown at Fig.9 herein. The figure shows that specimen with the lowest toughness of 3.99 MPa.m^{½} has the highest value of brittleness index at about 559. Whereas the highest toughness specimen of 5.58 MPa.m^{½} has the lowest brittleness index at about 320. The highest toughness specimen was the Mullite-3YSZ-Magnesia system with Yttria content of 8% by weight. It can be said that the increase of Yttria content into the Mullite-3YSZ-Magnesia system leads to increase the fracture toughness.

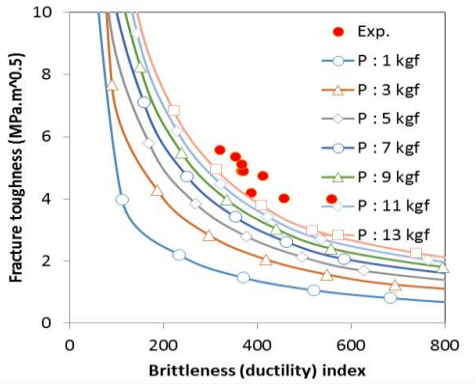

Fig. 9: K_{IC} vs BI

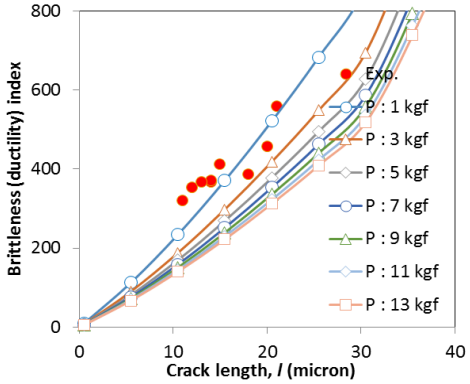

Fig. 10: BI vs *l*

Fig.10 shows the tendency of an increase of the crack length will increase of the brittleness index. The specimen with highest brittleness index of 559 show crack length at average of 21 µm. In the other hand, the specimen with lowest brittleness index of 320 show crack length at about 11 µm. In this case the brittleness index correlates with the length of formed crack after the application of the indentation load during test.

4. Conclusion

This experiment proved than the indented crack of specimens of Mullite-Yttria Stabilized Zirconia-Magnesia follow the Plamqvist crack criteria, instead of mean radial crack criteria. The measured crack length represents the criteria of *c/a* parameter less than 3.0. It was studied that Yttria content in the range of 1 to 9% by weight into the Mullite-Stabilized Zirconia-Magnesia showed high value of hardness and fracture toughness. The specimen with the highest value of fracture toughness at about 5.58 MPa.$m^{½}$ contains 8% by weight of Yttria into Mullite 10%-Yttria Stabilized Zirconia-Magnesia. However, the highest hardness value of 16.26 GPa was belonged to specimen with 9% by weight of Yttria into Mullite 10%-Yttria Stabilized Zirconia-Magnesia. It means, an increase content of Yttria leads to increase the hardness and fracture toughness of Mullite-Yttria Stabilized Zirconia-Magnesia system.

5. Acknowledgement

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