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Fracture Toughness and Physical Properties of Zirconia Toughened Barium Ferrite

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Abstract**—***Barium ferrite ceramic known as ferromagnetic material, has been widely used for permanent magnet materials. The barium ferrite as ceramic magnet in application can experience to un-anticipate fracture, it has low fracture toughness. The fracture toughness of the barium ferrite can be improved by addition of zirconia. The barium ferrite specimens were added zirconia with various weight fractions i.e. 0%, 1%, 2%, and 3%. The specimens were produced by uniaxial compacting pressure of 30 MPa, and then were sintered at 1100 °C for 1 hours. The specimens were characterized by using scanning electron microscope (SEM) to observe the morphology of fracture surface. The mechanical properties were characterized by using Vickers Hardness and the biaxial strength by ball on three ball/B3B method. The fracture toughness of the specimen was calculated by biaxial strength (B3B-K_{Ic}) method. The result of the SEM photographs showed porosity increased with increasing zirconia content, it corresponded with relative density of spesimens. The relative density of spesimens decreased with incerasing zirconia content. The maximum hardness, biaxial strength and B3B-K_{Ic} were obtained at the specimen containing 1% weight of zirconia.*

Keywords**—** *Barium ferrite, ball on three balls, fracture toughness, magnet, zirconia.*

I. INTRODUCTION

Barium ferrite is specially material that much be used in engineering materials, it is ferrimagnetic material for permanent magnet ceramic. The barium ferrite belongs to a hexagonal M-type magneto plumbite ferromagnetic ceramic material. The barium hexaferrite ($BaFe_{12}O_{19}$/BaM) has advantages such as having a high Curie temperature, large coercivity, a high isotropic magnetic property, stability to chemicals, corrosion resistance and low production cost. Due to these advantages properties, BaM has a wide range of applications in the high performance permanent magnetic material. However, the BaM material has low fracture toughness. The low fracture toughness was caused the BaM has the plainest structure. The BaM structures was built up by stacking sequences of three basic blocks of crystalline structures.The Barium ferrite with ferromagnetic property is one of type the hexagonal ferrite that called barium hexaferrite [1]. The hexaferrites material have much more essentials application for, electric motors, speakers, microwave, and magnetic recording applications [2]. The fracture toughness of the BaM can be improved by doped a reinforcement material. Zirconia is one of a reinforcement material that can improve the fracture toughness of the material [3]. Zirconia stabilized with yttrium element known as yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP). The Y-TZP is a ceramic material that is most widely used because of excellent mechanical properties, such as hardness, strength, and fracture toughness [4]. This paper reported effect of zirconia to physical and mechanical properties of the barium hexaferrite, include stress intensity factor.

The stress intensity factor (K_{Ic}) determine the linear-elastic fracture toughness of a material at which a thin flaw in the material begins to grow. Fracture toughness is a property that describes the ability of a material containing a crack to resist fracture and is one of the most important properties of any material for many design applications.

The barium ferrite as ceramic materials are generally formed a disc or cylindrical shape. The cylindrical shape is difficult to determine mechanical strength of the materials by uniaxial testing. The one methode to determine the mechanical strength of disc shape specimens can use biaxial testing by using ball on three balls/B3B method. The B3B method consists of four balls in which a disc specimen was supported by three balls and the load by the fourth ball. Hence, the maximum tensile stress locates at the surface of the disc directly opposite to the centre ball. The illustration of biaxial testing by B3B can be seen in fig. 1 [5]. The biaxial testing has advantages compared uniaxial testing i.e. three or four-point bending (T/FPB). The T/FPB has disadvantages for specimen preparation, bars specimen must be cut off from bulk material and surface and edge preparation specimens have to be performed [6]. There are various advantages declared for biaxial testing of disc compared with uniaxial testing, entering easy of specimen preparation, use for sheet materials, specimen free from side defect, very stable against inaccuracies on small specimens, edge defects have no effect, and the incidence is very low friction. Many commercial product components at their application received a biaxial load hence the biaxial testing is more relevant for test condition at their application. The B3B is more tolerant to some out of flatness of the disc specimens then other test mentioned without special surface finishing [7].

Fracture toughness testing generally used single edge V notch bending (SEVNB) method, the method good performance result for bar specimens, but it dificult for disc specimens. The fracture toughness testing with a disc specimen can be determined with biaxial tension with B3B method. The method is known as a B3B-K_{Ic} method. Recently, several researchers have investigated the B3B-K_{Ic} method to

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determine of the fracture toughness, K_{Ic} with satisfactory result to compare with another i.e. SEVNB method.

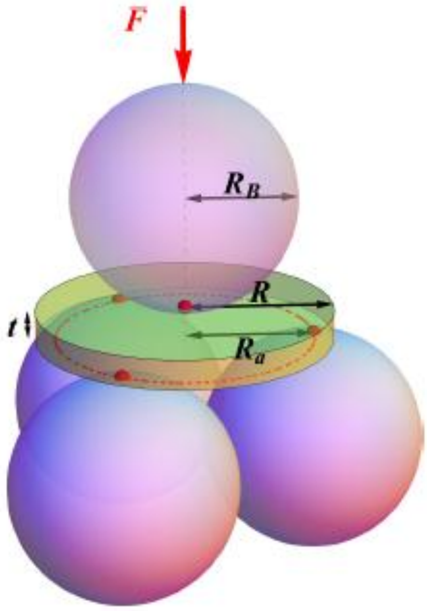

Fig. 1. The B3B testing methods with a disc-shaped test specimen with a radius *R* and the thickness *t*, *Ra* support radius (distance between the canter of the load to the supporting balls). Force *F* is applied through the ball parallel to the centre axis of the disc [5].

The B3B method composes of four balls in which a disc specimen was supported by three balls and the load by the fourth ball. Hence, the maximum tensile stress locates at the surface of the disc directly opposite to the centre ball. The maximum tensile stress σ_{B3B} expressed the flexural strength at specimen during loading. The σ_{B3B} determined from Eq. 1 [5] [8]:

$$\sigma_{B3B} = \frac{F}{t^2} f(\frac{Ra}{R}, \frac{t}{R}, V) \quad (1)$$

where, *f* is the dimensionless factor depends on the Poisson's ratio (υ) of the tested material and on the geometry of the specimen, *F* is the maximum load at failure, *t* is the thickness of specimen. The determination of σB3B can be performed through a web application of mathematical at home page http://www.isfk.at/en/960/ [5] [8]. From the web aplication, the parameters have to been filled to blank cells are radius (*R*) (mm) of specimen, disc tickness/disc radius (*t/R* = 0.035-0.5), ball radius/disc radius (R_B/R = 0.6-0.82), poisson ratio (υ = 0.1 -0.40), *F* = fracture force, Winbull modulus (*m*=1-50). General equation B3B-K_{Ic} fracture toughness in determining the stress intensity factor is expressed by Eq. 2:

$$K_{1c} = \sigma_{B3B} Y \sqrt{a\pi} \quad (2)$$

From Eq. 2, where *Y* is the geometric factor that depends on the geometry of crack and on the Poisson's ratio of the specimen. The maximum value of *Y* along the surface crack is determined by linear elastic theory approach. Strobl, *et al* (2014) has analyzed the dimensionless of geometry factor. Some of the parameters influence materials and geometry that limited. The constant *Y* is determined from a function at the Eq. 3 [5]

$$Y = Y(\frac{a}{c}, \frac{a}{t}, \frac{t}{R_a}, v) \quad (3)$$

The calculation of *Y* was performed using the commercial finite element program. The geometric factor *Y* was ploted of as a function of the crack shape *a/c* and the relative crack depth *a/t*. Analogy in SEVNB test, the initial crack was made as artificial surface crack. An artificial surface crack in the B3B-K_{Ic} was created in the centre of the tensile stress side of the disc by a knop indenter [5] or Vickers indenter [9]. The crack was approximated semi-circular, where *2c* is the full crack width at the surface and *a* is the crack depth. The surface crack by indentation Vickers can be seen in fig. 2.

II. METHOD

The barium ferrite as powder material was produced by calcination of a mixture of hematite and barium carbonate that was calcined at a temperature of 1100 °C for 2 hours. The calcined powders were mixed with zirconia reinforcement with various composition 0%, 1%, 2% and 3 %. The mixed powder were shaped by uniaxial compacted to produce green compacts with a pressure of 30 MPa with a cylindrical moulding with an inside diameter of 20 mm and approximately 3 mm in thickness. The green compacts were then sintered at a temperature of 1100 ºC for 1 hour [10] to produce sintered composite discs. The sintered composite discs were prepared by using abrasive paper and then were polished.

The mechanical properties testing on the composite of the barium ferrite with various addition of zirconia include the hardness testing and the fracture toughness testing by using the biaxial strength method to determine the stress intensity factor. The maximum tensile stress by using B3B methode. The intensity stress of fracture toughness (K_{Ic}) was calculated by using the maximum tensile stress $\sigma_{B3B,}$ that known as B3B-K_{Ic} method. An initial crack in B3B-K_{Ic} method as artificial surface crack was created by using Vickers indentation (Fig. 2 (a)). The Vickers indentation was used to make a crack with load applied at 30 kg (HV30). Fig. 2 (b) and 2 (c) shows one representative example for a crack in a specimen. After testing of B3B the crack shape of pre-crack was determined the values of *a* and *c*, respectively. The B3B testing method used the balls with radius R_B = 6 mm, R_a = (2/√3) R_B, hence *Ra* = 6.93 mm, R_B/R = 0.5–0.82, hence the radius of specimen was required *R* = 7.3–12 mm. The sintered barium ferrite specimens with disc radius *R* = 8–9 mm. The thick of specimens were required (*t/R* = 0.035–0.5), if average disc radius *R* = 8.5 mm, hence t = 0.3–4.25 mm. The initial crack was placed opposite with the load of balls when testing, the schematic of the B3B testing can be seen at fig. 3.

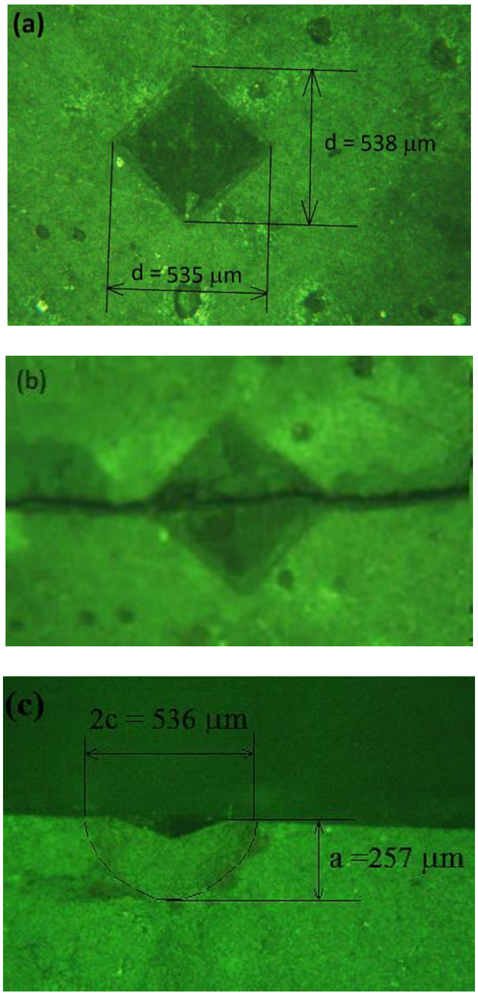

Fig. 2. (a) Vickers Indentasion to determine initial crack on the B3B–K_{Ic} methode, (b) the fracture of the specimen after B3B biaxial testing (c) The surface crack by Vickers indentation in form a semi-circular to determine *2c* and *a*, from cross section side.

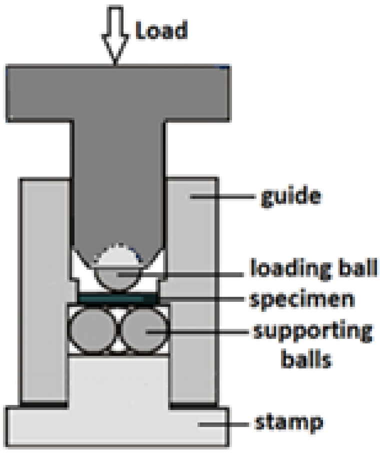

Fig. 3. Schematic of test equipment biaxial strength by the B3B method

The shcematic of the test equipment biaxial strength can be seen at fig. 3. The testing used universal teting machine with load from up side. The maximum load of failure was recorded from display on the machine and the load was used to determine biaxial strength at the Eq. 1.

The physical properties of specimens were determined by using Scanning Electron Microscope/SEM photographs to observe fracture surface morphologies and the relative density of specimen was measured by Archimedes method.

III. Results and Discussion

A. SEM Photographs

The photographs of fracture surface morphologies by using SEM are shown in fig. 4. The SEM photographs of specimens showed the increased zirconia phase to increase the porosity of the composite specimens. It can be seen in fig. 4 (a), that the particles of barium ferrite sintered without the addition of zirconia show densification and the porosity reduced. Fig. 4 (d) shows the specimen with of 3% by weight of zirconia, it has much more porosity than the specimen with 1% by weight of zirconia in fig. 3 (b).

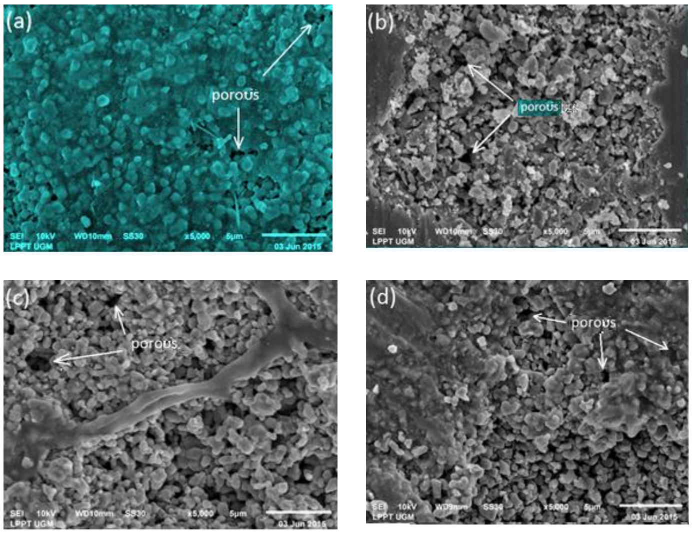

Fig. 4. SEM Photograph of barium ferrite phase with the various addition of zirconia by weight %, (a). barium ferrite phase, (b). 1% ZrO2, (c). 2% ZrO2, (d). 3% ZrO2.

B. Density

Fig. 5 present relative density barium ferrite with addition various weight % zirconia by using Archimedes method. It shows that the addition of zirconia cause reduction the relative density of the composite due to the amount of porosity increases. The sintering temperature of barium ferrite-zirconia composite was lower than densification of zirconia that required. The zirconia phase requires sintering temperature according to the densification between the zirconia particles, it at suitable for densification with range sintering temperature of 1350 °C until 1550 °C [11]. The relative density by using Archimedes method showed corresponding with the porosity of composite zirconia toughened barium ferrite with various addition zirconia specimens that was observed by SEM. By SEM observed the porosity of specimens increased with increasing the addition of zirconia.

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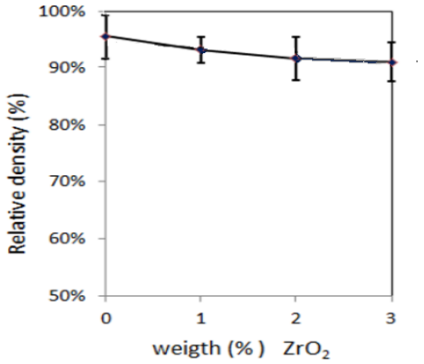

Fig. 5. The relative density barium ferrite with various weight % zirconia was tested by using Archimedes method.

C. Hardness

The result of the hardness testing is shown in fig. 6. It exhibits the increase the hardness and the biaxial strength by the addition of 1% zirconia. The addition of zirconia more than 1% by weight decreased the mechanical properties. The hardness of the barium ferrite of 277 HV without the addition of zirconia. The hardness increased by the addition zirconia, the maximum hardness up to 550 HV at addition weight 1% of zirconia.

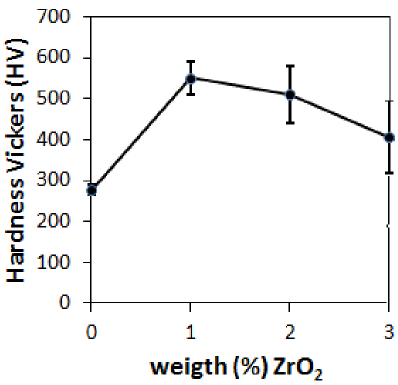

Fig. 6. The effect addition of zirconia to the hardness of barium ferrite. The zirconia has given strengthening to barium ferrite as ceramic matrix composite.

D. Biaxial Strength and Kic

Fig. 7 and 8 shows biaxial strength and stress intensity factor of barium ferrite with addition of zirconia. The result of biaxial strength and the stress intensity factor reached maximum at the addition by weight 1% of zirconia, they are 220 MPa and 3.76 MPa $m^{0.5}$, respectively. The effect of zirconia that was incerased more than 1 % of weigth would to decrease in hardness, biaxial strength and K_{Ic}. The addition of more than 1% weight of zirconia was influenced by the amount of porosity, which porosity increases. It corresponded with SEM photograph and relatif density at fig. 4 and 5, respectively. Increased porosity can be seen in fig. 4, where the addition of 3% (Fig. 4 (d)) the number and the size of the porosity increases. Weak bonds between particles of barium ferrite and zirconia caused the porosity increases, which it was required a higher sintering temperature for the densification between the particles [12]. Increased solidification can be done by increasing the sintering temperature. However, the higher sintering temperature can lose of ferromagnetic properties of the barium ferrite [13] [14]. Therefore, the sintering temperature was limited at temperature of 1100 °C.

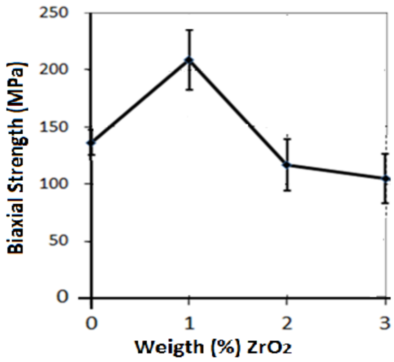

Fig. 7. The effect of zirconia to the biaxial strength of barium ferrite.

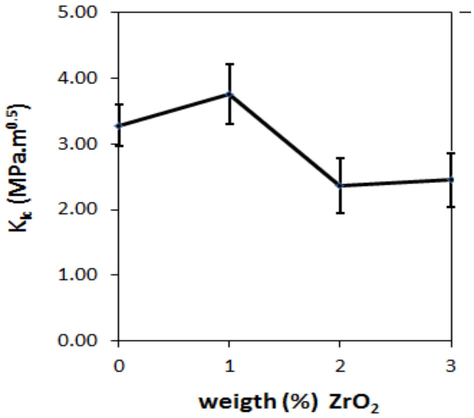

Fig. 8. The effect of zirconia to the K_{Ic} of the barium ferrite.

IV. CONCLUSION

The result of the SEM photographs showed porosity increased with increasing zirconia content. The relative density of specimens decreased with increasing zirconia content. The mechanical properties of the Vickers hardness, the biaxial strength, and B3B-K_{Ic} are 550 HV, 220 MPa and 3.76 MPa $m^{0.5}$ respectively, it achieved maximum at the specimen containing 1% weight of zirconia.

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REFERENCES

[1] I. Ştefan, R. Chiriac, C. Nicolicescu, and M. Ciobanu, "Research on synthesis of barium hexaferrite powders processed by mechanical alloying," *Journal Optoelectronics and Advanced Materials*, vol. 13, pp 883-886, 2011.
[2] Samikannu, K., Jesurani S., Sivakumar M., Thirupathi C., dan Kalaivani T., "Synthesis and magnetic properties of conventional and microwave

calcined strontium hexaferrite powder," *Journal Materials Sciences and Applications*, vol. 2, pp. 638-642, 2011.

[3] G. Roebben, B. Basu, J. Vleugels, O. V. der Biest, "Transformation-Induced Damping Behavior of Y-TZP zirkonia ceramics," *Journal of the European Ceramic Society*, vol. 23, pp. 481-489, 2003.

[4] E. S. Elshazly, M. El-Sayed A., and S.M. El-Hout, "Alumina effect on the phase transformation of 3Y-TZP ceramics," *Journal Materials Science and Technology*, vol. 24, issue 6, pp. 873-877, 2008.

[5] S. Strobl, S. Rasche, C. Krautgassera, E. Sharova, and T. Lube, "Fracture toughness testing of small ceramic discs and plates," *Journal of the European Ceramic Society*, vol. 34, pp. 1637-1642, 2014.

[6] C. T. Badur, "Biaxial strength testing of ceramics using square and rectangular specimens," *Journal of the Australian Ceramic Society*, vol. 50, issue 2, pp. 126–134, 2014.

[7] A. Börger, P. Supancic, and R. Danzer, "The ball on three balls test for strength testing of brittle discs -stress distribution in the disc," *Journal of the European Ceramic Society*, vol. 22, issue 8, pp. 1425-1436, 2002.

[8] A. Börger, P. Supancic, and R. Danzer, "The ball on three balls test for strength testing of brittle discs: Part II: Analysis of possible errors in the strength determination," *Journal of the European Ceramic Society*, vol. 24, pp. 2917-2928, 2004.

[9] S. Rasche, S. Strobl, M. Kuna, R. Bermejo, and T. Lube, "Determination of strength and fracture toughness of small ceramic discs using the small punch test and the ball–on –three–balls test," *20th European Conference on Fracture (ECF20), Procedia Materials Science,* vol. 3, pp. 961–966, 2014.

[10] T. Rusianto, M. Waziz Wildan, Kamsul Abraha, and Kusmono, "Characterizations of ceramic magnets from iron sand," *International Journal of Technology*, vol. 5, pp. 336-343, 2015.

[11] A. Marinis, "Fracture toughness of yttrium stabilized zirconia sintered in conventional and microwave ovens," A Thesis at Master of Science Degree in the Graduate Collage of the University of Iowa, 2011.

[12] N.A. Abbas, M. Noorbakhsh, M. Nourbakhsh, M. Shaygana, and K. J. D. Mackenzie, "The effect of nano sized $SrFe_{12}O_{19}$ additions on the magnetic properties of chromium-doped strontium-hexaferrite ceramics," *Journal of Materials Science: Materials in Electronics*, vol. 22, pp. 1297–1302, 2011.

[13] P. Shepherd, K. K. Mallick, and R. J. Green, "Magnetic and structural properties of M-type barium hexaferrite prepared by co-precipitation," *Journal of Magnetism and Magnetic Materials*, vol. 311, pp. 683-692, 2007.

[14] M. Ahmad, I. Ali, F. Aen, M.U. Islam, M. N. Ashiq, S.Atiq, W. Ahmad, and M.U. Rana, "Effect of sintering temperature on magnetic and electrical properties of nano-sized Co_2W hexaferrites," *Journal Ceramics International* vol. 38, pp. 1267–1273, 2012.