Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2019
(ICMERE2019) 11-13December, 2019, Chittagong, Bangladesh

ICMERE2019-PI-158

EVALUATION OF DIAMETRAL TENSILE STRENGTH AND POROSITY OF CLASSICALLY SINTERED ZINC OXIDE CERAMIC

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Abstract*-This paper represents the variation of diametral tensile strength(DTS) with the change of porosity of Zinc Oxide ceramic prepared by solid oxide reaction method. Corn flour was used as a pore former of varying proportion and Polyvinyl Alcohol (PVA) as a binder material. Mean porosity and diametral tensile strengths (DTS) were calculated for each composition. Porosity was increased from 1.4% to 3.98% with increasing percentage of corn flour from 0 to 5% without adding binder whereas porosity was increased from 1.19% to 3.86% with binder material at same percentage of corn flour. Diametral tensile strengths was decreased from 9.87MPa to 3.94 MPa with increasing the porosity from1.4% to 3.98% without adding binder while DTS was decreased from 15.43MPa to 6.85 MPa with binder material with increasing the porosity from 1.19% to 3.86%.*

Keywords: Zinc oxide, Corn flour, Porosity, Diametral tensile strength (DTS).

1. INTRODUCTION

The fast progress of modern high technology requires more and more new materials with various special properties or functions. Ceramic–metal composites (or cermets) are widely used for the manufacture of high performance wear parts and cutting tools. Ideally, cermets display physical properties that combine the hardness of a ceramic phase with the toughness of a metal-based matrix [1~3]. Porous ceramics have received considerable attention due to the unique combination of a low thermal expansion coefficient, excellent thermal shock, and high-temperature creep resistance, good mechanical and chemical stability at elevated temperatures as well as large specific surface area and high fluid permeability. Highly porous ceramics are desirable for use as catalyst supports, particle filters, and gas membranes under severe conditions [4~6]. At present porous ceramics with porosity up to 92.9%were fabricated by the conventional process. The sintering behavior, open porosity, and mechanical strength of porous ceramics were investigated [7~10]. The aim of the work is to fabricate ZnO ceramic with and without Polyvinyl Alcohol (PVA) and different corn flour percentage and evaluate porosity and diametral tensile strength.

2. MATERIALS AND METHOD

Zinc Oxide, corn flour and polyvinyl alcohol were used for fabricating ZnO ceramic metal. 5% corn flour was used for increasing porosity and binder for increasing strength. Several cylindrical specimens were fabricated for porosity and DTS test. Raw materials and their manufacturers are given in Table 1. Chemical properties of raw materials are given in Table 2.

Table 1: Materials and Manufacturer

Component	Manufacturer
Zinc Oxide(98.5% pure)	Merck Specialties private Limited(India)
Corn Flour	Local company (Bangladesh)
Polyvinyl Alcohol	Loba Private Company Limited (India)

Table 2: Properties of raw materials [11]

Component	Melting Point (℃)	Molecular Weight (gm/mol)	Density (gm/cc)
ZnO	1975	81.38	5.61
Polyvinyl Alcohol	200	44.05	1.19

The conventional method of manufacturing ceramics involves weighing, blending or mixing, compaction and sintering.

It is important to mix appropriate amount of required raw materials for correct reaction. At first, ZnO ceramics were prepared with and without PVA and corn flour. To increase the porosity 5% corn flour was added as a pore former to both with and without PVA conditions. Mass of raw materials are given in Table 3. Polyvinyl alcohol

(2-3 ml) was used as a binder with ZnO. A digital weight machine was used for weighing raw materials [12~14].

Table 3: Mass of raw material

Percentage corn flour (wt)	Mass of ZnO (gm)	Mass of corn flour (gm)	Total mass
0%	15	0	15
	20	0	20
5%	14.25	0.75	15
	19	1	20

The next step is mixing, eliminating aggregates and reducing the particle size. Mixing is important because it controls the final distribution of reinforcement particle and porosity in green compacts after compaction. All the measured powders were taken in a smaller pot. The pot consisted of polymer. Zirconia ball of two size (diameter of 5 mm and 11 mm) were used acting as a grinding medium. A motor driven ball mill (Model: G91-e.J. Payne, UK) was used for the mixing of powders. The speed of rotation was kept about 600 rpm. For each cycle, the milling time was kept between 4-6 hours. Then the mixture is dried in an oven (Model: JISICO, J-300S, Japan) for 5 minutes at 80℃ to remove the moisture.

Following the mixing operation, the mixture was then pressed at room temperature using a Pellet press machine (Model: PP25, Retsch, Germany) into pellet by keeping pressure around 2.50-3 tons for 15 grams pellet (diameter-32mm) and 3.5-4 tons for 20 grams pellet (diameter-40 mm) and pellets were held there for 2 minutes for better compaction. The both surface of the die was cleaned carefully with ethanol and tissue paper so that nothing troubled in getting smooth surfaced pellet. The samples were usually cylindrical in shape as desired. After ejecting the pellets from the dies, the pellets were placed into a sample holder made of refractory brick. This process is called cold compaction and the pellets are called green briquette [1~3, 6, 8, 16].

Sintering is a process in which fine grains or powders are converted to dense products after heating to an appropriate temperature (below the melting point of the materials). The pellets were sintered in air in a high temperature furnace (Model: Nabertherm GMBH, UK). Sintering profile of the pellet is illustrated in Figure 1. At first slow heating rate (6.67°C /min) was kept up to 600°C for 1hour and 30minutes. Then the pellets were hold there for 30 minutes and temperature was raised to 1200°C at a rate of 6.67°C/min in 1hour 30 minutes and holds it for 3 hour and 30 minutes. Finally cooled (cooling rate 10°C/min) to room temperature. The sintering process starts with bonding among particles as the materials heats up. There is four stages in sintering. The sintering process starts with bonding among particles as material heats up. Bonding involves diffusion of atoms where there is intimate contact between particles leading to development of neck formation. During the next stage, the newly formed bond areas called “necks” grow in size, followed by pore rounding. This is shown schematically in Figure 2. The last stage is pore shrinkage or randomization [1~3, 6, 8].

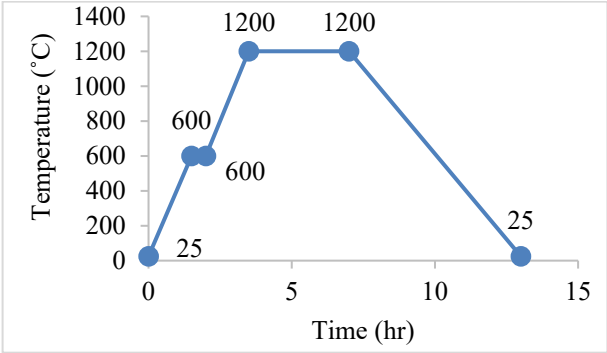

Figure 1: Sintering graph of Zinc Oxide

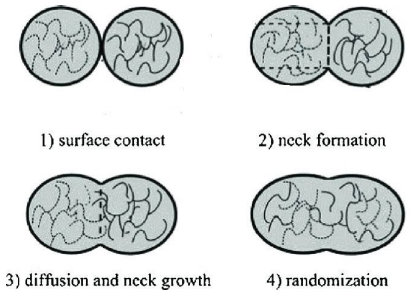

Figure 2: Neck growth process [17]

Porosity is a measure of the void spaces in a material. Any solid material that contains cavities, channels or interstices may be regarded as porous. Porosity influences the physical exchanges and chemical reactivity of solids with gases and liquids. Porosity is of great industrial concern as it influences the behavior of gas adsorption and fluid flow within materials.
Examples of materials that porosity is of importance include catalysts, construction materials, ceramics, pharmaceutical products, metal powders, membranes, active components in batteries and fuel cells, and oil and gas bearing reservoirs [4, 5,16].

For determination of porosity, at first dry weight of the sample was measured in digital mass weighing machine. Then the sample was immerged in wtare for 24 hours to get saturated. Then the saturated weight was measured. After that we calculated suspended weight by hanging the sample with the help of a wire shown in Figure 3.

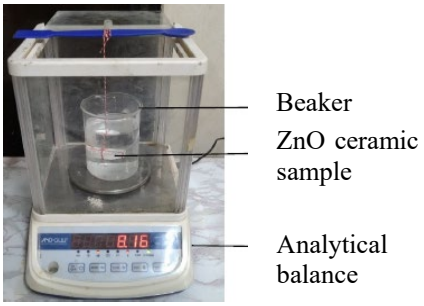

Figure 3: Suspended weight of pellet

After determining the various weights, porosity was calculated by Archimedes law. Three samples were selected for each composition for calculating their porosity.
Equation (1) states the Archimedes law by which porosity can be calculated.

$$\text{Porosity, } \varphi = \frac{\text{saturation weight} - \text{dry weight}}{\text{saturation weight} - \text{suspended weight}} \times 100\% \quad (1)$$

To measure the diametral tensile strength of the samples, the compressive load was applied by a flat plate against the side of a short cylindrical specimen. It was measured by computer interfaced Universal Testing Machine (UTM). The vertical compressive force along the side of the disk produces a tensile stress that is perpendicular to the vertical plane that passes through the center of the disk. In such a situation, the tensile stress is directly proportional to the compressive load applied [4, 5]. DTS is computed by equation (2)

$$\text{Diametral tensile strength} = \frac{2P}{\pi DT} \quad (2)$$

Where: P= load applied; D= diameter of the cylinder, T= thickness of the cylinder, π= 3.14 (constant)
For the diametral tensile test, 3 cylindrical specimens were fabricated from each material (26±0.1mm in diameter × 5±0.1mm in height). The dimensions of specimens were checked using a digital caliper. The crosshead speed of UTM was set at 0.5 mm/min [5, 15, 18].

Figure 4: Fracture pellet after DTS test

3. RESULTS AND DISCUSSION

Figure 5 shows the change of porosity with and without PVA and corn flour. From the figure it was found that porosity is increased with the increase of corn flour and slightly decreasing during addition of PVA. As porosity is inversely proportional with density, by adding 5% corn flour with zinc oxide the density of the specimens decreased respectively due to vaporization of corn flour at 250°C [19] as a result the porosity increased. But during addition of binder the density of the specimens slightly increase with respect to same composition without PVA, as density increase porosity slightly decreased for those specimens.

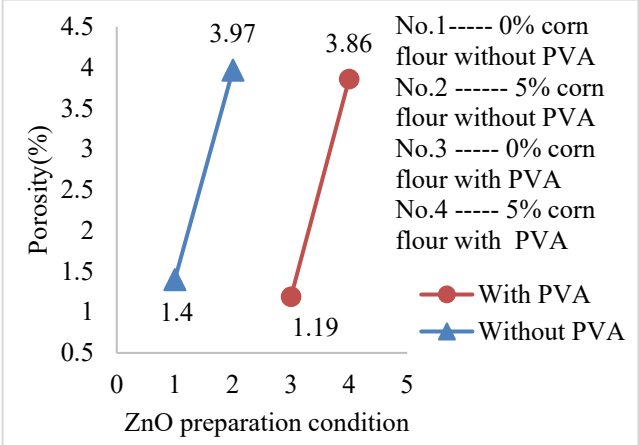

Figure 5: Change of porosity

Figure 6 shows the change of diametral tensile strength with increase the porosity. It reveals that with the increase of corn flour the diametral tensile strength (DTS) is decreased because of the formation of high amount of porous phase, this phase has low strength. But by adding PVA to those specimens diametral tensile strength (DTS) is increased, the value of DTS is higher, 15.45 MPa for ZnO with PVA, which is slightly decreased for ZnO without PVA. The minimum value of DTS found for 5% corn flour is 3.94 MPa without adding PVA.

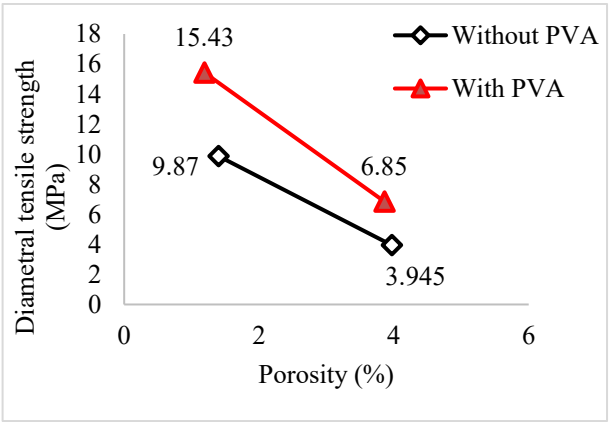

Figure 6: Strength vs porosity

4. CONCLUSION

In this study Zinc oxide (ZnO) ceramic was fabricated with different porosity with corn flour as a pore forming agent and reinforced by the addition of PVA. After preparing specimens porosity and diametral tensile test was performed and it was possible to approach the following conclusions.

1. Porosity is increasing from 1.4% to 3.98% with the increase of corn flour percentage (0 to 5%) without adding binder. After adding binder porosity slightly decreased and varied from 1.19% to 3.86% at a same change in corn flour percentage.

2. Diametral tensile strengths was decreased from 9.87 MPa to 3.94 MPa with increasing the porosity from1.4% to 3.98% without adding binder while DTS was decreased from 15.43 MPa to 6.85 MPa adding binder material with increasing the porosity from 1.19% to 3.86%.

5. ACKOWLEDGEMENT

We would like to express our sincere gratitude to Md. Saiful Islam, Technical Officer, Department of Mechanical Engineering (ME), RUET for his cooperation to conduct this work.

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