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Ceramic Membrane Fabrication from Industrial Waste: Effect of Particle Size Distribution on the Porosity

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Abstract: Industrial waste from sanitary company is chosen in this study as a precursor to fabricate ceramic membrane. It has been reported that enormous rejects being generated every year by this company. A preliminary characterization of this industrial waste shows the presence of quartz mineral, which is one of the main and suitable elements for the formation of ceramic products. Extrusion method was applied in fabricating tubular type ceramic membrane. In this present study, the effect of three different particle size distribution of the powder waste on the porosity is presented. The characterization of the porosity was performed in order to gain the insights in preparing ceramic membrane with good permeability. Results show that almost 40% porosity is able to be obtained using higher particle size distribution. However, further improvements in working conditions should be optimized in order to have a ceramic membrane with good physical properties.

Key words: Ceramic membrane, extrusion, industrial waste, porosity, particle size

INTRODUCTION

In the last years, many different industrial sectors have been mentioned as source of contamination and pollution of environment, due to enormous quantity of rejects generated. Very often these rejects are thrown directly in ecosystems without an adequate treatment process.

The recent environmental approach in Malaysia aims to achieve sustainable development by minimizing the discard of materials. In addition to that, the increasingly high waste disposal problem such as limited secured landfill, leachate and air pollution have pushed to new alternatives techniques of preparation processes to separate valuable materials from waste for recycling purposes.

A formidable amount of industrial waste from sanitary company is generated every year due to the enormous quantity of rejects. Little of the past work has focused on high-value added or highly technical development of the treatment to the waste. Therefore, in this project, it is intended to evaluate the suitability of the industrial waste in the fabrication of ceramic membrane using extrusion process.

The materials that have been used in the commercial manufacture of ceramic membrane support are silica, zirconia, titania and alumina (Leger *et al*., 1996). These materials are considered as the main and suitable ceramic materials for the formation of the asymmetric structures (Benito *et al*., 2005). In accordance with this finding, it may be possible to manufacture ceramic membranes from inexpensive waste materials which contain these materials compositions (Jo *et al*., 1996).

Porous ceramic membranes are widely used over recent decades due to their excellent mechanical strength and tolerance to solvents, as well as pH, oxidation and high temperature (Khemakhem *et al*., 2004). Their unique ability to operate under extreme environments and operating conditions give them significant advantages over polymeric membranes, stainless steel membranes and conventional filtration techniques in many applications (Sondhi *et al*., 2003). The continuous improvement in the development and manufacturing of these materials has resulted in increased commercial applications of ceramic membranes in recent years.

Ceramic pastes are often processed as high volume fraction of solids in a liquid binder solution (Amarasinghe and Wilson, 1999). The requirement of liquid and binder arises from the fact that ceramic powders cannot always be effectively extruded in their dry powder state, as they offer a very high friction at the interface of the bulk material and the processing equipment (extruder) (Khan *et al*., 2001). These ceramic pastes are normally extruded and formed into desired products.

Extrusion processes have been widely used for industrial manufacturing of various ceramics (Isobe *et al*., 2006). This process is advantageous in the production of rods and tubes, which has regular and constant

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cross- section bodies. For extrusion process, the paste has to be in plastic state, so that it shall be able to be extruded.

Plasticity is defined as the property that enables a material to be changed in shape without rupturing by the application of an external force and to retain that shape when the force is removed or reduced below a certain value (Baran *et al*., 2001). The plasticity behavior of an extrudable ceramic paste is controlled by few factors such as volumetric fraction, shape and size distribution of the particles and surface chemistry (Ribeiro *et al*., 2005).

MATERIALS AND METHODS

Preparation of the waste powder: The raw waste sample used was an unspecified product collected from Saniton Ceramic (M) Sdn Bhd, Pasir Gudang, Johor. Figure 1 shows the X-ray diffraction spectrum of the industrial waste indicating the present of silica (quartz). The result indicated that the industrial waste from the sanitary company could be used as initial material for the production of a porous ceramic support (Leger *et al*., 1996).

The waste was first crushed using a jaw crusher (Restch, Germany) to produce a fine powder, for which the particle size was less than 100 µm. Then, it was classified using different sieve sizes to obtain narrow powder particle size distributions. Three powder size distributions were prepared; <45, 56-62 and 71-89 µm.

Paste preparation: Waste ceramic-pastes have been prepared using fine ground industrial waste powder, ball clay and polyethylene glycol with a molecular weight of 6000 g mol^{-1} which acts as binder and distilled water (range from 19-21%) using a laboratory mixer. The X-ray diffraction spectrum for ball clay is given in Fig. 2 and it also shows the present of quartz mineral. The ratio of waste powder to ball clay is 3:2 for all the experiments in this study. The mixtures were mixed at 230 rpm for 1 h to form the paste, then the paste was left overnight for ageing process. The particle sizes distribution of the waste ceramic-paste was measured by Malvern Mastersizer. Pfefferkorn method was used to determine and derived the most suitable moisture content for shaping in extrusion process.

Pfefferkorn method: In the Pfefferkorn method, a plate having a defined weight is dropped onto a measurement cylinder having a standard size of both initial height and diameter of 38 mm (H_o), whereby the specimen is compressed to a height H_d. The water content of the sample corresponding to when the compression ratio

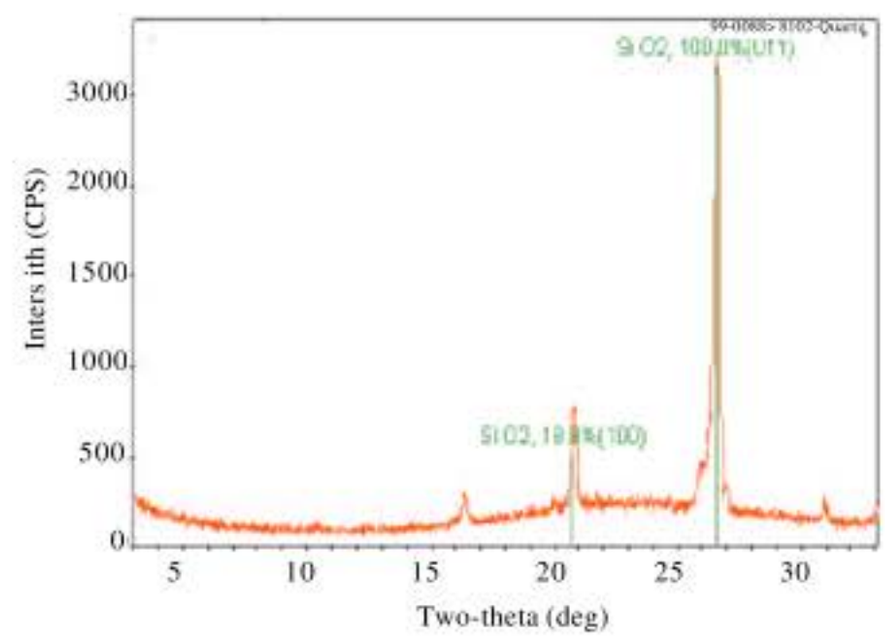

Fig. 1: Typical X-ray diffraction spectrum of industrial waste

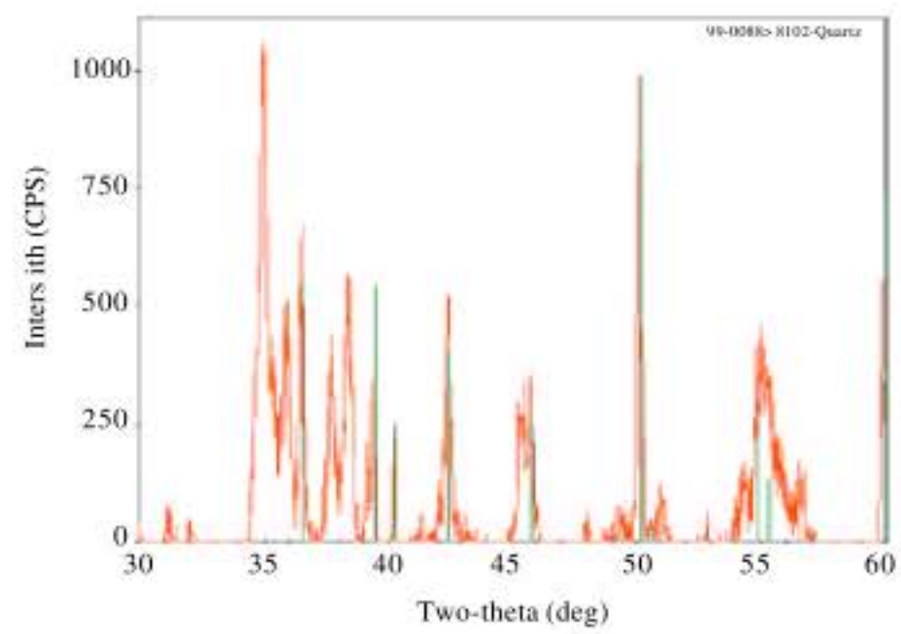

Fig. 2: X-ray diffraction spectrum of ball clay used

H_o:H_d = 3:1 is taken to be the Plasticity Index (PI) according to the Pfefferkorn method. For an extrudable paste, the compression ratio falls in the range of 1.25 to 2. In this study the compression ratio for preparing an extrudable paste was fixed at 1.5.

Extrusion and sintering processes: The resulting paste was molded using a pug-mill (Shimpo, USA). The extruded green bodies were dried at 110°C for 24 h in an oven. The specimens were then sintered at three different temperatures which are 918, 978 and 1008°C.

Characterization techniques: Characterization of the membrane was based on properties important to the potential application in separation processes. Among the important properties are pore size, porosity and mechanical strength. The property presented in this study is porosity.

Porosity was determined via boiling the samples in water for 5 h using an ASTM Standard C373. After 5 h of boiling, the specimens were allowed to soak for an

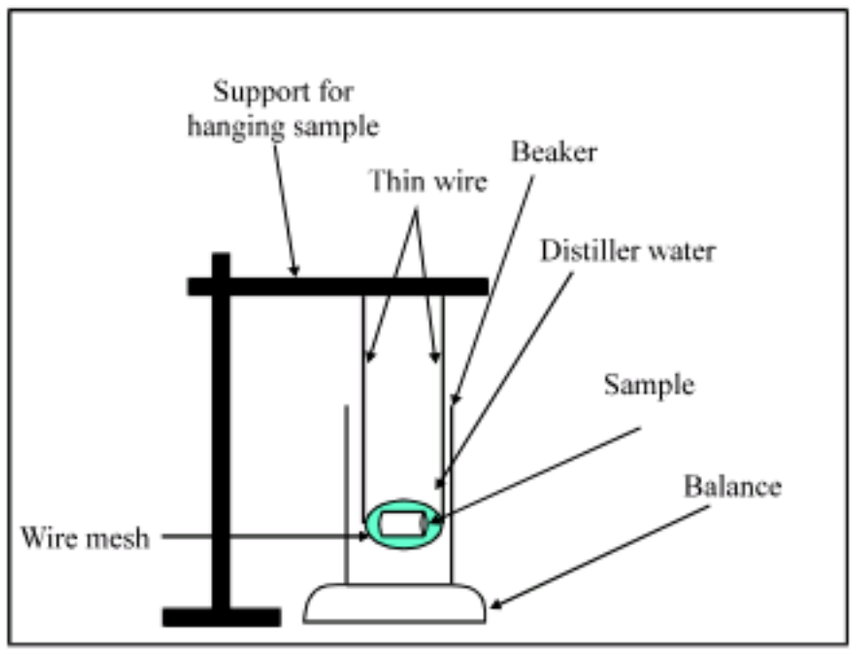

Fig. 3: Schematic diagram for determining porosity of specimens

additional 24 h. The porosity values of the specimens were identified by weighing the specimens while suspended in water using the diagram shown in Fig. 3.

RESULTS

Particle sizes distribution of paste: Particle size distribution of the waste ceramic used in the fabrication process is shown in Fig. 4, where three different types of particle size distribution are applied.

Particle sizes distribution on deformation ratio: The effect of three different particle size distribution of the waste ceramic powder on the deformation ratio is presented in Fig. 5.

Particle size distribution on porosity: Figure 6a-c presents the effect of particle size distribution on the porosity using different concentration of binder.

DISCUSSION

Particle sizes distribution of paste: The particle size distributions of three different size ranges for industrial waste ceramic-pastes are presented in Fig. 4. It can be illustrated that all of the prepared waste ceramic-pastes are well-distributed and significant difference can be seen for all of the curves. This means that the mixing process of the industrial waste ceramic-paste is homogenous and shown the coherent dispersed mass which is suitable for extrusion processing.

The result also proves that binder is required in preparing an extrudable paste. According to Reed (1995), plastic consistency can be produced using clay binder, a polymeric organic binder or a mixture

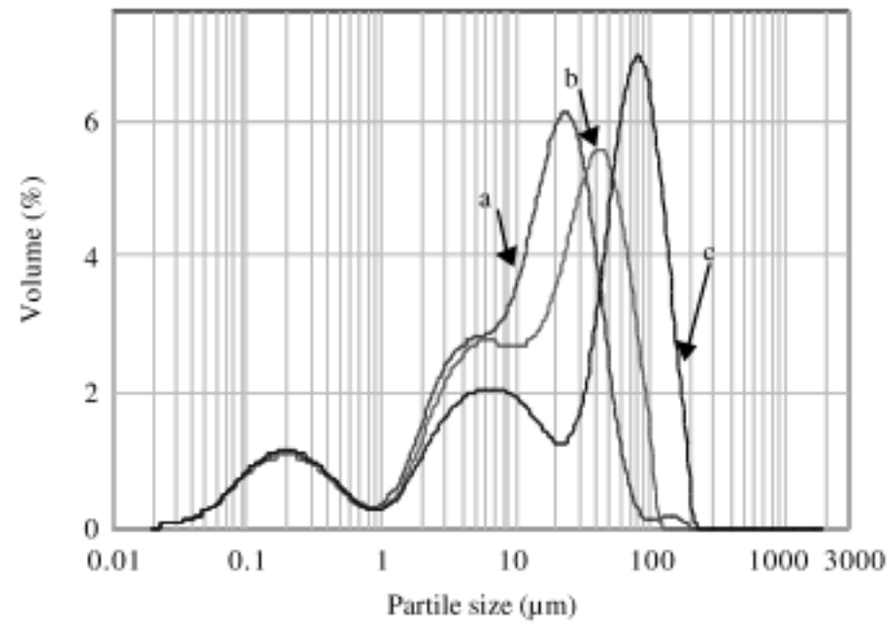

Fig. 4: Particle sizes distribution for waste ceramic-paste using different powder sizes of a) <45 µm, b) 56-62 µm and c) 71-89 µm

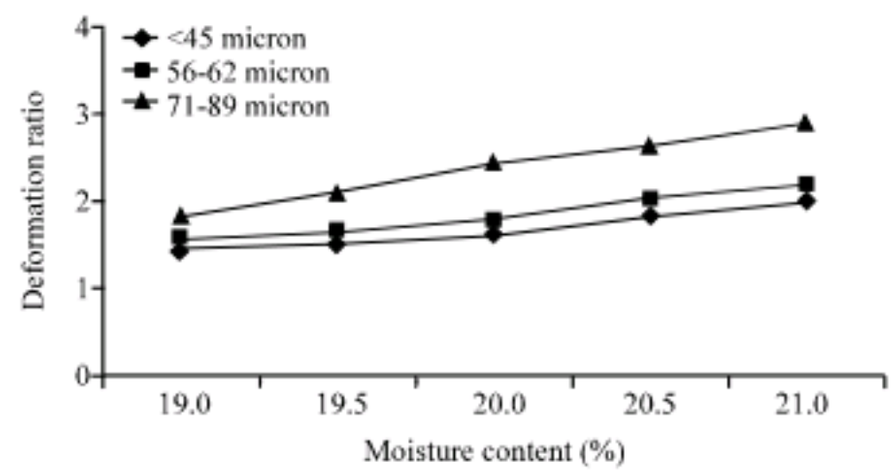

Fig. 5: Deformation ratio of the ceramic waste-paste prepared using different particle size distribution

of the two types. This is because the paste produced which contain ceramic powder and water alone will normally dewater or phase-separate during extrusion process and become non-extrudable (Khan *et al*., 2001).

Particle sizes distribution on deformation ratio: Figure 5 represents the deformation ratio for three different particle sizes distribution of industrial waste ceramic-paste against the amount of moisture content of the paste. It shows a similar trend of moisture content requirement for different particle sizes distribution. As the moisture content increase, larger particle sizes distribution tends to have higher deformation ratio.

Principle of impact deformation, which in this study is calculated as deformation ratio, is a way of measuring plasticity of paste. At 21% of moisture content, the particle range of <45, 56-62 and 71-89 µm has deformation value of 1.98, 2.17 and 2.89, respectively. Results also shows that the plasticity behavior of an extrudable ceramic paste is controlled by sizes distribution of the particles. This is because big particles do not have the ability to slide over each other due to water retained in the

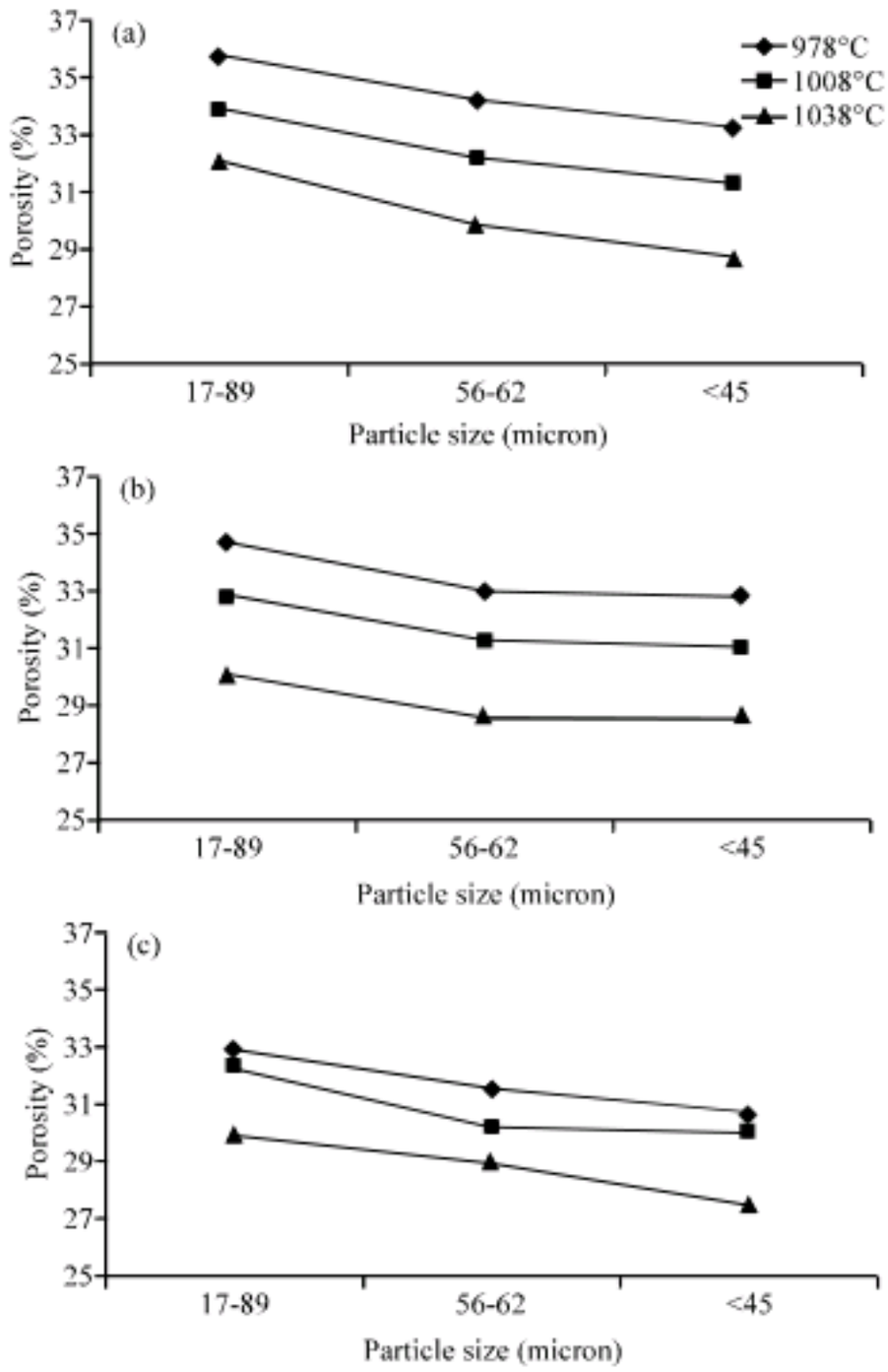

Fig. 6: (a) The porosity behavior for ceramic membrane fabricated using PEG 6000 at an amount of 80 g; (b) The porosity behavior for ceramic membrane fabricated using PEG 6000 at an amount of 50 g and (c) The porosity behavior for ceramic membrane fabricated using PEG 6000 at an amount of 20 g

interstitial spaces. Besides, flow resistance tends to reduce as the particle size decreases (Reed, 1995).

Particle size distribution on porosity: The effect of particle size distributions on the water absorption test, which presented as porosity value in this study, is presented in Fig. 6a-c, using different concentration of the binder.

The porosity recorded by particle size distribution of 71-89 µm with a PEG concentration of 80 g at sintering temperature of 978, 1008 and 1038°C are 34.77, 33.46 and 31.38, respectively, while for 56-62 µm and <45 µm the values recorded for that conditions are slightly lower compared to that of 71-89 µm in a range of 0.77 to 3.38.

As the particle size increases, the number of pores and void spaces increases. This is because large particles exhibit low-density compaction, which contains packing defects; apparent as a few large pores (German, 1996). The other reason of lower porosity of smaller sample compared with bigger one, as mentioned by Badawy and Hussain (2004), may be attributed to the ability of the fine particles to fill in the voids between the particles. Therefore, from these data, it can be concluded that the higher the amount of the pore, the greater the porosity.

CONCLUSION

The preparation of a ceramic membrane from industrial waste was studied in order to assess this process as a potential high-value waste product. The ceramic membrane was prepared using an extrusion process. It was found that particle size distribution of the paste affects the porosity of the fabricated ceramic membrane. At smaller particle size distribution a lower porosity was obtained. Meanwhile, higher plasticity index is obtained at small particle size distribution. However, smaller particle size requires more moisture (water). Therefore, the suitable moisture required for waste ceramic paste extrusion process, would be 18.3-21.4% for paste <45µm and only 17.9-19.3% for paste >71 µm, respectively.

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