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Influence of Porosity on Flexural Strength and Flexural Modulus of an Eco-ceramic Membrane

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Abstract

This paper deals with the relationship between porosity and flexural strength along with flexural modulus of an eco-ceramic membrane. The eco-ceramic membrane is made of kaolin, feldspar and sawdust (pore former) along with two binders i.e. sodium metasilicate and boric acid. The membrane is prepared using uniaxial dry compaction process by applying two different pressures (7.84 and 11.76 MPa) followed by sintering in a muffle furnace at 850°C. Volumetric porosity is determined by gravimetric analysis of water. The evaluation of modulus of rupture (MOR) test (flexural strength and flexural modulus) has been done using three-point bend test (ASTM D790) at room temperature. Based on these results, it has been observed that with decrease in porosity from 28% to 11%, flexural strength increases from 4.46 to 13.29 MPa along with an increase in flexural modulus from 0.62 to 1.89 GPa.

Keywords: *Eco-ceramic, porosity, flexural strength, flexural modulus*

1. Introduction

Membrane technology advances significantly in various areas of chemical and biochemical processing, especially ceramic membranes for their high thermal stability and handling of corrosive feedstock. Present and ongoing research in membrane technology aims to use low-cost raw materials to minimize the cost of ceramic membranes [1,2].

Nowadays fundamental research regarding fabrication of ceramic membranes is focused towards different type of precursors like sawdust and their impact on porous texture and mechanical strength of the inorganic matrix [3]. In addition to this, the feature of such research is to find such a raw material which not only can provide thermally and mechanically stable membrane but also can offer low manufacturing cost.

The environmentally conscious ceramics i.e., eco-ceramics have some benefits over traditional ceramics like low energy consumption during the entire manufacturing process of composites, availability of wide variety of microstructures. The use of sawdust provides a low-cost starting material that has the capabilities of presenting agreeable porous structures that are normally produced by traditional ceramic processing techniques.

Porosity, an important characteristics of ceramic membranes, act as crack initiation sites and has an influence on mechanical strength. Ceramic membranes can be porous or dense, depends on the particle size of raw materials, as well as drying and sintering.Ceramic products undergo thermal and mechanical stress during sintering. Both flexural strength and flexural modulus are the key physical parameters of ceramic material as they are brittle in nature.

The flexural strength is the material's ability to resist deformation under load and depends on crack initiators or flaws present initially inside the ceramics and the amount of raw materials present in the specimen.But these crack initiators are not identical in nature and can provide rupture of membranes at different loading forces [4]. A relationshipbetween themechanical strengthand Young’s modulus of

ceramic specimens is also well known [5].On the other hand, flexural modulus is an intensive property which does not depend on the size or the amount of material in the specimen and the presence of cracks.
Hypothetically, linearity between the flexural strength and flexural modulus is valid when flexural modulus is measured separately, not simultaneously with mechanicalstrength.
The objective of this paper is to verify the effect of porosity on the flexural strength and flexural modulus for the fabricated eco-ceramic membrane and a linear relationship between flexural strength and flexural modulus.

2. Materials and methods

The chemicals used in this study are kaolin (LobaChemiePvt. Ltd., Mumbai, India, >99.5%), sawdust (taken from local sawmill), and feldspar (National Chemicals, Gujarat, India) for the fabrication of eco-ceramic membrane support served for different functional aspects. Kaolin is used to provide low plasticity and high refractory properties to the membrane support. Sawdust is used as a pore former and releases CO2 gas when heated. The released carbon dioxide gas emits via some uneven paths which makes the membrane porous and contributes to the membrane porosity. Feldspar employs to offer a glassy matrix in the early stage of the firing process, bonded the other raw materials of the system together. Sodium metasilicate (M/s Lobachemie, India) and boric acid (M/s Merck Specialities Pvt. Ltd., India) have been used as binder.Sodium metasilicate enhance the mechanical strength by making silicate bonds among all the raw materials. Boric acid acts as a colloidal agent and forms metallic metaborates during sintering process, also maintains homogeneity in the membrane structure by increasing dispersion properties of the inorganic precursors.
The tubular support membrane is prepared by thorough mixing and grinding of dry inorganic raw materials (kaolin, saw dust, feldspar and binders) of two different compositions using mixer machine and ceramic mortar. Four membranes have been prepared by applying two different forming pressures (7.84 and 11.76 MPa) namely M1 to M4, listed in Table 1. All the mixtures placed separately into a cylindrical mould (50 mm diameter, 50mm height and thickness of 10 mm) made by mild steel. The raw materials are pressed into the mould using hydraulic press (Velan Engineering, Tamilnadu, India) by uniaxial dry compaction. Then the mixture is kept under distributed pressure for 1 min to prevent the propagation deformation and kept homogeneity in the raw material mixture. The irregular shape and sizes of sawdust particles is separated using Gyratory shaker. The fabricated membrane is removed cautiously from the mould and subjected to two heat treatment steps. Firstly, the membrane is dried at room temperature for 24 h. After that, it is dried at 100°C for 12 h in a muffle furnace followed by heating at 250°C for 24 h. Secondly, the membrane is heated from 250°C to the desired temperature at a heating rate of 2°C/min. Then the membrane is kept into the furnace for 5 h for sintering at 850°C. Then the membrane is cooled by an atmospheric cooling process implemented by switching off the muffle furnace which is earlier maintained at a desired sintering temperature. The membranes achieved a hard, rigid and porous texture after sintering.
Characterization techniques include volumetric porosity determination technique and three-point bend test (ASTM D790) to determine the porosity and the modulus of rupture (flexural strength and flexural modulus).The volumetric porosity of all the membranes is calculated by gravimetric analysis of water, based on the entrapment of water in the pores of the membrane walls. Initially, the dry sintered membranes are measured, then the membranes are dipped into deionized water for 24 hours. The soaked membranes then dried by tissue paper and weighed.The volumetric porosity is calculated using equation number 1, given below.

$$\varepsilon_v = \left(W_2 - W_1\right) \big/ \rho_{H_2O}.V \qquad (1)$$

Where, W_2, W_1, ρ_{H_2O} and V are the weights of the wet and dry membrane samples, the density of the deionized water and the volume of the fabricated membrane, respectively.

Table 1. Properties of the fabricated eco-ceramic tubular membrane

Combinations	Applied pressure in MPa	Kaolin in %	Sawdust in %	Feldspar in %	SM in %	BA in %
M1	7.84	50	10	30	5	5
M2	7.84	50	10	25	10	10
M3	11.76	50	10	30	5	5
M4	11.76	50	10	20	10	10

A measurement of flexural strength and flexural modulus has been done on ASTM standard equation. This test can affect the structure of the tested material and create microcracks in ceramic materials as ceramics are brittle in nature. For that reason, a flexion of the sample is often used for ceramic materials, called three-point-bending testis performed to measure the strength of the prepared specimen using a Universal Tensile Test Machine (Deepak polyplastPvt. Ltd., India) maintaining 60 mm support span at room temperature at a stroke rate of 0.5 mm/min. Rectangular bar-shaped specimens are prepared by maintaining thickness/length ratio 1:16 for determining the flexural strength at room temperature. The flexural strength and flexural modulus for rectangular shape specimen is generated by the instrument automatically using equation number 2 and 3, mentioned earlier.

$$\sigma_{UF} = 3P_{\max}.L/2bh^2 \quad (2)$$

$$E_F = mL^3/4bh^3 \quad (3)$$

Where, σ_{UF} and E_F is the flexural strength and flexural modulus of the ceramic material, $P_{\max}$ is the maximum load at failure, L is the specimen length between the two support points, b is the specimen width, h is the specimen thickness, m the initial slope of the load–deflection curve.

3. Results and discussions

3.1. Effect of pressure and binder on Porosity

The volumetric porosity of M1 to M4 sintered at 850°Cis listed in Fig.1. In this study, the porosity of the membranes isdependent on two major factors: (i) effect of forming pressure; and (ii) amount of binder.Fig.1 shows the influence of forming pressure and amount of binder on the porosity of M1, M2, M3 and M4 membranes. Porosityis reducing abruptly with increasing binder content as well as forming pressure, is due to more and more contact of particles with each other at higher temperature.But, the difference in porosity is not so much higher though the variation in forming pressure is high.

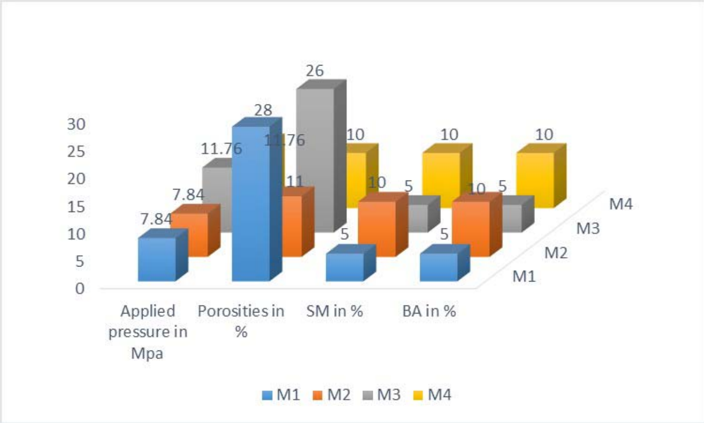
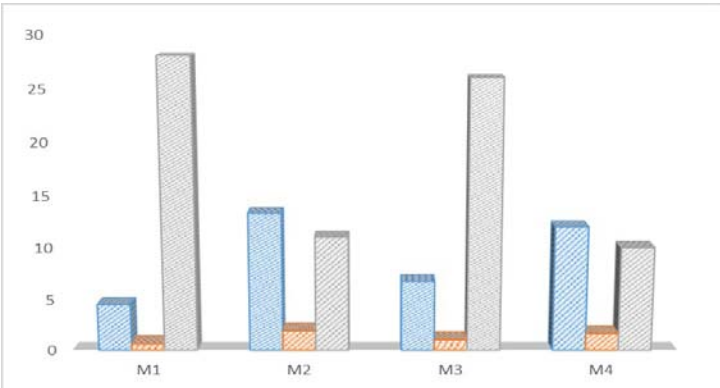


Fig. 1. Influence of forming pressure and binder content on porosity of the fabricated membrane

3.2. Effect of porosity on modulus of rupture (MOR)



	M1	M2	M3	M4
Flexural strength in Mpa	4.46	13.29	6.72	11.99
flexural modulus in Gpa	0.62	1.89	1.01	1.61
Porosities in %	28	11	26	10

Fig. 2. Dependence of modulus of rupture (MOR) on the porosity of the fabricated membrane

Fig. 2 shows a linear relationship between flexural strength and flexural modulus versus porosity during three-point bend test at room temperature. During sintering, the particles starts to form necks with each other. With increasing sintering temperature, the initially formed necks become broader, the shrinkage becomes larger and causes an abrupt decrease in porosity.Less porous texture inhibits crack propagation, results a higher flexural strength and flexural modulus. In Fig. 2, the result of M2 and M4 strongly approves this theory and establishes that flexural strengthof a ceramic membrane is inversely proportional to the porosity of that particular ceramic.A typical relationship between the deflection and loading force of the fabricated eco-ceramic sample in the three-point-bending test is depicted in Table 2.It is observed from the table that percentage deflection is 5% for M2, M3 and M4 whereas it is only 2% for M1. This is due to the presence of less amount of binders present in M1. Though M3 contains same amount of binders as in M1, it is showing 5% deflection as it is fabricated at higher pressure.

Table 2. Dependence of deflection on loading forces

Combinations	Loading Force 1 in N	Deflection in mm	Loading Force 1 in N	Deflection in mm	Percentage of deflection
M1	5.5	0	7.73	0.02	2
M2	9.31	0	16.69	0.05	5
M3	6.11	0	10.06	0.05	5
M4	5.52	0	11.82	0.05	5

4. Conclusion

A verification of theoretical linearity between flexural strength and flexural modulus versus porosity is performed with fabricated eco-ceramic membrane made of cheap raw materials (kaolin, sawdust, feldspar, sodium silicate and boric acid) at 850°C.The conducted experiments clearly summarizes that

(a) with increase in forming pressure and high binder content, porosity decreases
(b) both flexural strength and flexural modulus increase linearly with decrease in porosity

5. References

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