

The use of alunitic kaolin in the production of ceramic membrane support

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Although Turkey's kaolin reserves are substantial, much of the reserves are of alunitic type and the largest deposit of this type is located in the Balıkesir-Sındırgı Region. Alunitic kaolin cannot be used in ceramic industry owing to its sulphur content. Since alunite is disseminated within kaolin, it is difficult to remove it from kaolin by using mineral processing methods. In this research, alunite existence within the kaolin was used as an advantage in the production of ceramic membrane support since it allows for the occurrence of desirable homogeneous porosity. For this purpose, 3 different alunitic kaolin samples were taken from the Balıkesir-Sındırgı Region and were comminuted. The materials obtained were shaped using dry pressing and slip casting methods to obtain ceramic membrane supports. The supports were sintered at 900 °C-1300 °C for 3 hours. The physical, mechanical and micro-structural properties of the sintered ceramic membrane supports were subsequently determined. The best porosity and strength results were obtained from SB1-1100 and PB1K-1100 coded supports which were made of K1 kaolin (having the highest alunite content).

Key words: Alunitic kaolin, Kaolin, Membrane support, Ceramic membrane.

Introduction

Ceramic membranes have been used successfully in many industrial processes for years to separate two phases owing to their high separating capacity, excellent thermal stability, high compressive strength, chemical stability and long operational life [1, 2, 3, 4]. In asymmetrical membranes, there is always a ceramic support enabling high strength and low resistance to fluid flow under a thin layer of separating surface. The permeability of ceramic membrane supports depends mainly on pore size and the distribution of open pores. Occurrence of pores, on the other hand, originates from the spaces between the grains and burning of organic matter within the raw materials and/or in the additives. Ceramic membrane supports are generally produced from materials such as alumina (Al_2O_3), cordierite ($2\text{MgO} \cdot 2\text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2$) and mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$). However, the cost of ceramic membrane supports produced from these materials is rather high since the cost of such starting materials and sintering temperature required is high. Therefore, it becomes important to produce alternative supports using cheaper starting materials [1, 3]. One of the prominent alternative raw materials is kaolin. Kaolin is sometimes used alone but generally used together with other materials such as dolomite, kieselsgur and alumina at various blending ratios to increase porosity.

There have been numerous researches on the ceramic membrane supports, especially on the use of kaolin to reduce the cost of ceramic membrane production. In such researches, kaolin was not only used alone [6, 9] but also used together with dolomite [1] and alumina [3, 4, 7]. Kaolin was also used together with materials such as sodium carbonate, calcium carbonate, boric acid and sodium metasilicate in order to produce economic ceramic membranes for micro-filtration applications [8]. After these researches, it was reported that ceramic membrane supports with high porosity were produced and the cost of production was reduced.

In this research, kaolin taken from Balıkesir-Sındırgı region was used to produce ceramic membrane support. The kaolin of the region has a SO_3 content of 4%-13,5% which originates from mineral alunite. The unbeneficiated kaolin of the region has a limited use in some cement and brick production and as a filling material [10]. However, alunitic kaolin of the region has no use at all in kaolin's most favourite area, the ceramic sector. Removal of gases and evaporation of alkali-sulphides when the alunitic kaolin is fired at elevated temperatures causes ceramic products to be more porous and fragile to flaw occurrence [11]. Unfortunately, it is not easy to remove alunite from kaolin by using conventional mineral processing techniques. Therefore, it was decided to convert the disadvantage of the alunite existence within the kaolin to an advantage in ceramic membrane support production by increasing the porosity of the body and thereby increasing the use of alunitic kaolin from the region.

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Materials and Method

Materials

The kaolins collected from the Balıkesir-Sındırgı Region of Turkey were grouped and coded according to SO_3 content as K1 (having the highest alunite content), K2 (having lower alunite content than K1) and K3 (with no alunite). Chemical analysis of the kaolins was made using an XRF instrument named Rigaku ZSX Primus II. Mineralogical analysis of the kaolin was made using an XRD instrument (Rigaku Miniflex ZD13113 series) using CuK α X-rays ($\lambda = 1,54056 \text{ \AA}$) in the range of $2\theta = 5-70^\circ$ at a rate of $2^\circ/\text{minute}$. Thermal behaviour of the kaolin was determined using a TG/DTA instrument called SII-Exstar 6300 in a dry air at a temperature range of $35^\circ\text{C}-1300^\circ\text{C}$, while micro-structures were investigated through a scanning electron microscope (SEM) called ZEISS-SUPRA 50 V model. Finally, specific surface area was determined using a BET instrument called Quantachrome NovaWin 2.

Production of ceramic membrane support

In order for the ceramic membrane supports produced to possess small pores and homogeneous porosity, 95% of the particle sizes of kaolin was attempted to reduce to $-20 \mu\text{m}$ after comminution. To reach this goal, preliminary grinding tests were carried out using ball and jet mills to determine which would produce the better result. The kaolins (K1, K2 and K3) were fed to the ceramic ball mill as 500 gr solid and to the jet mill as 200 gr solid at a solid/liquid ratio of 50%. The kaolins were comminuted in ball and jet mill for 60-360 minutes and 15-180 minutes, respectively. Hence, the optimum time period required for each mill to grind 95% of the kaolins to $-20 \mu\text{m}$ was determined. The kaolins comminuted for the optimum time period in each mill were then screened through a $20 \mu\text{m}$ sieve. They were then dried at 105°C for 24 hours and passed through a sieve of 1 mm to obtain granules which were finally used in the forming operation.

Forming was carried out by using dry pressing and slip casting methods. During the forming process by dry pressing, water only (no binder) and PVA-polyvinyl alcohol (0,024%-0,048%) were used. In dry pressing, the granules were pressed under a pressure of 90 kg/cm^2 to form ceramic membrane supports. In slip casting forming method, the suspensions with kaolin granules were prepared so as to find the optimum type and amount of electrolyte to be used. These operational parameters were then used to prepare mud with a solid/liquid ratio of 65%. This mud was poured into plaster casting moulds to drain water and form the supports. The ceramic membrane supports removed from the moulds were kept at room temperature for 2 days and then dried at 105°C for 1 day in a drier before sintering. The ceramic membrane supports formed by dry pressing and slip casting methods were sintered at

Table 1. The codes of the ceramic membrane supports.

Obtained from	Coded as
Supports comminuted by a ball mill and formed through slip casting	
K1 kaolin	SB1
K2 kaolin	SB2
K3 kaolin	SB3
Supports comminuted by a jet mill and formed through slip casting	
K1 kaolin	SJ1
K2 kaolin	SJ2
K3 kaolin	SJ3
Supports comminuted by a ball mill and formed through dry pressing	
K1 kaolin	PB1K
K2 kaolin	PB2K
K3 kaolin	PB3K
Supports comminuted by a jet mill and formed through dry pressing	
K1 kaolin	PJ1K
K2 kaolin	PJ2K
K3 kaolin	PJ3K

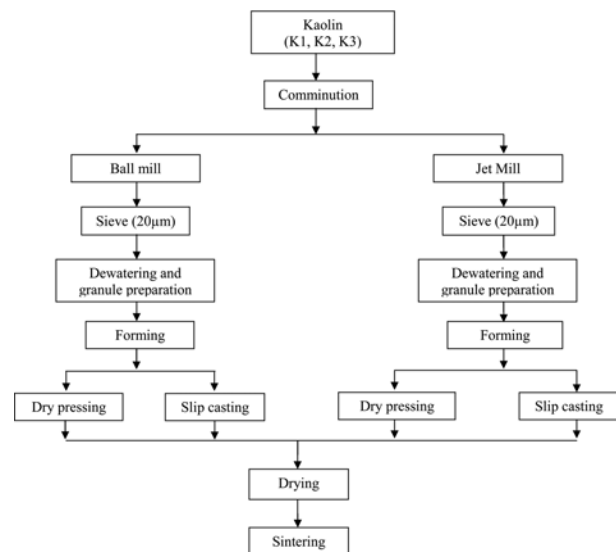


Fig. 1. Production stages of ceramic membrane supports.

900°C , 1000°C , 1100°C , 1200°C and 1300°C with a temperature increment of $2,5^\circ\text{C}/\text{minute}$ for 3 hours. Some physical and mechanical properties of the sintered ceramic membrane supports such as shrinkage, strength, bulk density, water absorption and porosity were determined. Bulk density, water absorption and porosity were determined using an Archimedes Scale. Pore volume and pore diameters of the supports having the best porosity and strength values were determined by using a BET instrument called Quantachrome NovaWin2. Micro-structure of the membrane supports was investigated through a scanning electron microscope (SEM) called Leo 1430 VP. The supports formed were

coded as given in Table 1 and the production stages of ceramic membrane supports are summarized in Figure 1.

Results and Discussion

Results for the determination of kaolin properties

Chemical analysis

Chemical composition of the kaolins is given in Table 2. As seen from Table 2, there are noticeable differences between the kaolins tested in terms of SiO_2 , K_2O and SO_3 contents. In the K1 kaolin, SiO_2 is the minimum, and K_2O and SO_3 contents are the maximum. In the K3 kaolin, SiO_2 is the maximum, and K_2O and SO_3 contents are the minimum. Fe_2O_3 content which is regarded as a major impurity for kaolin is the maximum in the K3 kaolin, lower in the K2 kaolin and the minimum in K1 kaolin. Varying Fe_2O_3 contents caused colour differences in the kaolins; such as K3 kaolin was reddish pink, K2 kaolin was pink and K1 kaolin was very light pink in colour. There was not a noticeable difference in terms of Al_2O_3 , TiO_2 , CaO , MgO and Na_2O contents between the kaolins. The loss of ignition (L.O.I.) increased as the SO_3 content of the kaolins increased. Therefore, loss of ignition was the maximum in the K1 kaolin, lower in the K2 kaolin and the minimum in the K3 kaolin.

Table 2. Chemical composition of the kaolins.

Comp. (%)	K1 Kaolin	K2 Kaolin	K3 Kaolin
SiO_2	38,29	55,24	63,11
Al_2O_3	24,88	25,58	25,43
TiO_2	0,21	0,38	0,26
Fe_2O_3	0,37	1,08	1,25
CaO	0,10	0,11	0,10
MgO	0,04	0,04	0,04
K_2O	2,81	1,08	0,27
Na_2O	0,16	0,16	0,22
SO_3	13,15	4,05	1,16
L.O.I.	19,62	11,88	7,85

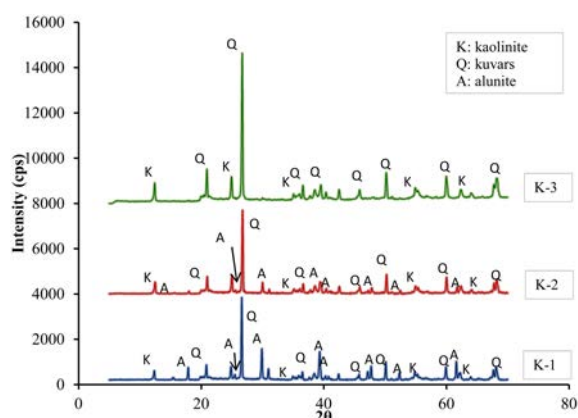


Fig. 2. XRD patterns of the kaolins.

Table 3. Rational mineralogical analysis of the kaolins (K1, K2, K3).

(%)	K1	K2	K3
kaolinite	34,40	54,93	61,56
quartz	26,38	29,70	34,48
alunite	37,71	10,49	2,50

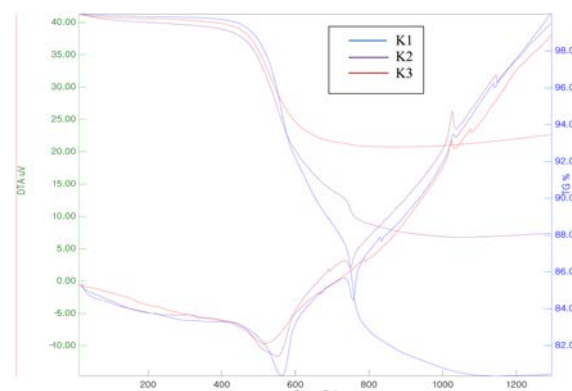


Fig. 3. TG/DTA curves for the kaolins.

Mineralogy

The result of XRD analysis for the kaolins is given in Figure 2. Semi-quantitative rational mineralogical analysis based on the mineralogical composition and chemical analysis is given in Table 3. From Figure 2, it is seen that all 3 kaolin samples have mineral kaolinite. Kaolin samples also have a considerable amount of quartz. As seen from the XRD patterns, the intensity of the alunite peak is maximum in the K1 kaolin and lower in the K2 kaolin whereas there is no alunite peak observed in the K3 kaolin. This result is in good correlation with the chemical analysis given in Table 2 and the rational analysis given in Table 3. The results of the investigation were also in good correlation with the literature reviewed [11, 12, 13, 14].

Thermal properties

The results of TG/DTA analysis of kaolin samples are given in Figure 3. As seen from Figure 3, endothermic reactions occurred owing to the removal of crystal water from kaolin samples of K1, K2 and K3 at 566 °C, 553 °C and 528 °C, respectively. This result is in good correlation with the findings of Chen and Tuan's [9] on different kaolins. There is a secondary peak at 756 °C as seen from the K1 curve. A similar but smaller peak can be seen at 749 °C for the K2 kaolin. These peaks were caused by the removal of sulphur from the alunite body and the results are also in good correlation with the findings of Genc [15], Kakali [16], Ozdemir and Cetisli [17]. No similar peak occurred for the K3 kaolin since there is no mineral alunite in its composition. The other peaks of the kaolin samples are all exothermic. The first exothermic peak originated from the occurrence of the primary

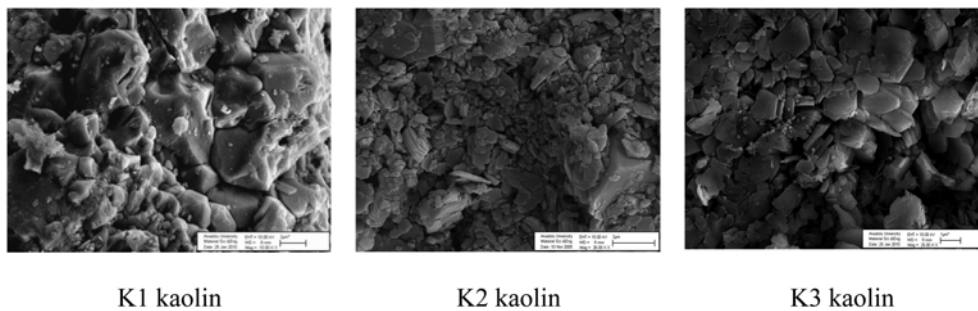


Fig. 4. SEM pictures of kaolins.

mullite phase and these occurred in the temperature range of 1024-1028 °C. The secondary exothermic peaks owing to the occurrences of secondary mullite phases were seen at temperatures of 1138 °C, 1145 °C and 1077 °C for the K1, K2 and K3 kaolin, respectively. The secondary exothermic peak for kaolin with no alunite occurred at a relatively lower temperature.

Micro-structure

SEM pictures of kaolins are seen in Figure 4. When SEM pictures from Figure 4 are examined, the mineralogical structure of the kaolins is found to be very similar to each other. In these pictures, mineral kaolinite was seen to possess forms which are typical for kaolinite morphology in general; they were seen as book bunches or fan shaped and irregularly scattered. Moreover, rhombusal alunite minerals were noticeable in the K1 and K2 kaolin. It was indicated that mineral kaolinite may look like coarse pseudo-hexagonal crystals or have forms such as book bunches or be worm shaped [18, 19]. Ekinci *et al.* [20] who geologically studied the kaolin of the region, reported similar results.

Specific surface area

The specific surface areas of the K1, K2 and K3 kaolins were determined as 4,256 m²/gr, 7,189 m²/gr and 9,541 m²/gr, respectively. These results indicate that the specific surface area of the kaolin samples increases as the amount of mineral kaolinite increases or the amount of alunite decreases (Table 3). This can be explained by the fact that the specific surface area of kaolinite is much higher than that of alunite [21, 22]. The difference in the hardness values of kaolinite and alunite also played an important role for the difference in specific surface area. As it is known, Mohs hardness grade for kaolinite is 2-2,5 while it is 3,5-4 for alunite [23, 24, 17]. Therefore, the K3 kaolin was relatively comminuted further during milling operation which increased the ratio of fine particles and, therefore, the specific surface area for the K3 kaolin.

Results of ceramic membrane support production

Forming results

Since after the preliminary milling tests, optimum

time periods were chosen as 360 minutes for the ball mill and 60 minutes for the jet mill, the comminution of the kaolin samples was carried out using these optimum time periods and the materials comminuted to produce ceramic membrane supports were stockpiled. The forming processes were carried out on these stockpiled materials. The best result was obtained when PVA was used as a binder at 0,048% for the kaolins formed by dry pressing after being comminuted by ball and jet mill. Therefore, all the kaolins comminuted were formed by dry pressing under the pressure of 90 kg/cm² using PVA (0,048%) as a binder before sintering. When 0,024% PVA or no binder (water only) was used, flaw occurrence within the supports was noticed together with a layering problem after pressing.

In slip casting, electrolytes in various types and amounts were tested in order to prepare casting mud with suitable flow characteristics for the kaolins comminuted in the ball and jet mills for optimum time periods. Optimum flow characteristics were obtained when 0,12% sodium silicate + 0,20% darwan, 0,12% sodium silicate + 0,42% darwan and 0,42% sodium silicate were used for the kaolins of K1, K2 and K3 (comminuted in ball mill), respectively. Hence, the kaolins were converted into casting mud at 65% solid/liquid ratio using optimum types and amount of electrolyte. Casting mud was then poured into plaster moulds to form the supports. The formed supports were taken out of the moulds and kept at room temperatures for 2 days before being dried at 105°C for 1 day. The supports were finally ready for sintering processes. The kaolins comminuted by the jet mill were not formed by the slip casting method owing to the agglomeration problems faced during electrolyte application.

Sintering results

Supports comminuted by ball mill and formed by dry pressing

Desired mechanical strength was not obtained from the supports comminuted by a ball mill, formed by dry pressing and sintered at 900 °C. A porous structure was not obtained when sintering was made at 1300 °C (excessive sintering). Therefore, physical tests were conducted on the supports sintered at 1000 °C, 1100 °C

Table 4. Properties of the supports comminuted in ball mill and formed by dry pressing.

	Temp. (°C)	PB1K (13,15% SO ₃)	PB2K (4,05% SO ₃)	PB3K (1,16% SO ₃)
Total shrinkage (%)	1000	2,74	1,74	1,10
	1100	5,16	3,14	1,59
	1200	11,55	7,02	3,24
Strength (MPa)	1000	5,14	2,61	1,81
	1100	9,50	8,63	3,45
	1200	36,81	32,09	18,96
Water Absorption (%)	1000	31,33	29,64	28,37
	1100	29,27	26,24	28,24
	1200	13,78	19,16	25,76
Porosity (%)	1000	45,67	44,44	43,22
	1100	44,38	41,53	43,09
	1200	26,46	33,81	40,89
Bulk density (gr/cm ³)	1000	1,48	1,50	1,53
	1100	1,52	1,58	1,52
	1200	1,92	1,76	1,59

and 1200 °C; the results are given in Table 4.

When shrinkage values are considered (Table 4), it is seen that shrinkage of the PB1K support is higher than those of PB2K and PB3K at all sintering temperatures applied. This result was thought to be caused by the sulphur content of alunite within the K1 kaolin (having the highest amount of alunite). This result was also supported by the highest loss of ignition (L.O.I.) value of the K1 kaolin (Table 2 and Figure 3).

When strength values are considered, the strength of the PB1K support is higher than those of PB2K and PB3K. This was caused by the higher potassium oxide content of the K1 kaolin (Table 2). As given in the literature, potassium oxide increases mechanical strength of ceramic bodies by forming a glassy phase during firing which enables the grains to bond to each other [25]. As seen from Table 4, strength values of the supports sintered at 1200 °C were quite high which was caused by the high sintering temperature applied [26, 12].

When porosity and water absorption values are considered, the porosity and water absorption values of the PB1K support are seen to be higher than those of the other supports sintered at 1000 °C and 1100 °C since the K1 kaolin has higher alunite content. In fact, the removal of sulphur within the alunite creates pores which in turn increase porosity and water absorption values of the support. However, the porosity and water absorption values of the PB1K support become lower than those of PB2K and PB3K as the sintering took place at 1200 °C. This interesting result was caused by the fact that the spaces or pores occurred by the removal of sulphur were closed as the sintering initiated and glassy phase was occurred because of the higher potassium oxide within the K1 kaolin. During

Table 5. Properties of the supports comminuted in ball mill and formed by slip casting.

	Temp. (°C)	SB1 (13,15%SO ₃)	SB2 (4,05%SO ₃)	SB3 (1,16% SO ₃)
Total shrinkage (%)	1100	6,14	4,59	4,29
	1150	9,21	6,88	4,51
	1200	14,77	8,48	5,49
Strength (MPa)	1100	8,71	3,67	2,65
	1150	23,06	18,22	11,08
	1200	35,29	23,05	11,59
Water Absorption (%)	1100	36,16	33,03	30,85
	1150	23,22	27,42	29,35
	1200	18,74	23,59	27,20
Porosity (%)	1100	49,75	47,13	44,96
	1150	38,53	42,43	41,18
	1200	33,83	38,44	41,02
Bulk density (gr/cm ³)	1100	1,38	1,43	1,46
	1150	1,66	1,55	1,50
	1200	1,81	1,63	1,54

sintering, particles get closely compacted owing to the atomic diffusion of contacting particles which resulted in a decrease in the body porosity. As is well known, after ideal sintering porosity completely disappears and the body becomes more compact [27, 28].

As seen from Table 4, the bulk density of the PB1K support at 1000 °C and 1100 °C is lower than those of PB2K and PB3K, since the porosity of the PB1K support at the same temperatures is higher than those of the others. However, the bulk density of the PB1K support at 1200 °C is the highest of all which is explained by the fact that pores of PB1K are closed down after sintering resulting in a more compact body. When the parameters in Table 4 were considered, the highest porosity supports having 8 MPa strength value were chosen as the best performing supports. As is indicated by the literature, any products to be used as ceramic membrane supports should have a mechanical strength of 3-8 MPa and a porosity of 40-50% [1, 2, 3, 4, 8, 9, 29, 30]. Accordingly; PB1K and PB2K sintered at 1100°C and PB3K sintered at 1200 °C were chosen as the best performing ceramic membrane supports after the tests.

Supports comminuted in ball mill and formed by slip casting

Desired mechanical strength was not obtained from the supports comminuted by a ball mill, formed by slip casting and sintered at 900 °C and 1000 °C. A porous structure was not obtained when sintering was made at 1300 °C (excessive sintering). Therefore, physical tests were conducted on the supports sintered at 1100 °C, 1150 °C and 1200 °C and the results are given in Table 5. When Table 5 is examined, it is noticed that the physical properties of the supports formed by slip

Table 6. Properties of the supports comminuted in jet mill and formed by dry pressing.

	Temp. (°C)	PJ1K (13,15% SO ₃)	PJ2K (4,05% SO ₃)	PJ3K (1,16% SO ₃)
Total shrinkage (%)	1000	3,04	1,94	1,28
	1100	8,12	4,36	2,14
	1200	16,33	9,31	3,61
Strength (MPa)	1000	5,20	3,72	2,17
	1100	23,53	12,42	7,08
	1200	38,89	36,43	27,02
Water Absorption (%)	1000	30,79	24,72	27,56
	1100	27,33	25,18	25,39
	1200	9,14	15,11	23,18
Porosity (%)	1000	44,75	40,58	42,84
	1100	42,96	40,99	41,19
	1200	19,72	28,81	38,34
Bulk density (gr/cm ³)	1000	1,39	1,64	1,55
	1100	1,62	1,63	1,57
	1200	2,16	1,91	1,65

casting were similar those of the supports formed by dry pressing (Table 4). According to the parameters given in Table 5, the best performing supports were chosen as SB1 sintered at 1100 °C, and SB2 and SB3 sintered at 1150 °C.

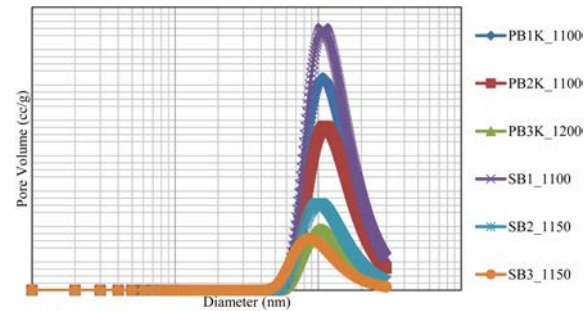
When Table 4 and Table 5 are compared (forming methods), the strength and bulk density values of the supports formed by slip casting and sintered at 1100 °C and 1200 °C are lower than those of the supports formed by dry pressing and sintered at the same temperatures. On the other hand, total shrinkage, water absorption and porosity values of the supports formed by slip casting are higher than those of the supports formed by dry pressing at the same sintering temperatures. This result is caused by the fact that pressing creates more compact (stiff) packaging for the grains.

Supports comminuted in jet mill and formed by dry pressing

Physical properties of the supports comminuted in the jet mill and formed by dry pressing are given in Table 6. From Table 6, it is noticed that the physical properties of the supports were similar to those of the supports comminuted in the ball mill and formed by dry pressing (Table 4). According to the parameters in Table 6, the best performing supports were chosen as PJ1K sintered at 1100 °C, and PJ2K sintered at 1100 °C. When Table 4 and Table 6 are compared (comminution methods), the strength values of the supports formed by dry pressing and comminuted in the jet mill are higher but the porosity values are lower. Therefore, it can be said that it is better to use a ball mill for comminution if dry pressing is used as a forming method, considering the crucial properties such as porosity and strength of the supports.

Table 7. Properties of the best performing supports.

Code of the support	Sintering temp. (°C)	Strength (MPa)	Porosity (%)
PB1K	1100	9,50	44,38
PB2K	1100	8,63	41,53
PB3K	1200	18,96	40,89
SB1	1100	8,71	49,75
SB2	1150	18,22	42,43
SB3	1150	11,08	41,18

**Fig. 5.** Pore volume and pore diameter relationships of the supports.

Supports comminuted in jet mill and formed by slip casting

In slip casting, some agglomeration problems were faced during the preparation of casting mud with the kaolins comminuted in the jet mill. Although different types and amounts of electrolyte were tested, a suitable casting mud was not made possible. Therefore, the kaolins comminuted in the jet mill were not formed by the slip casting method.

Pore distribution and micro-structure

The best performing supports produced by the kaolins comminuted in ball and jet mills and formed by dry pressing and slip casting are given in Table 7. The results of BET surface area and pore distribution analysis of the selected (best performing) supports are given in Figure 5. As seen from Figure 5, the volume and the distribution of the pores for the supports are homogeneous and the average pore diameter is about 100 nm. The porosity of the PB1K support having the highest alunite content is higher than those of PB2K and PB3K which were all comminuted in the ball mill and formed by dry pressing. This was explained by the fact that removal of sulphur at this temperature within the K1 kaolin, used to produce PB1K support, increased the porosity and PB1K was sintered at a lower temperature than PB3K.

Among the supports comminuted in the ball mill and formed by slip casting, SB1 has the highest porosity compared to those of SB2 and SB3 owing to its high alunite content. This was again explained by the higher alunite content of the K1 kaolin used in the production of the SB1 support and the lower sintering temperature applied to this support. As seen from Figure 5, the

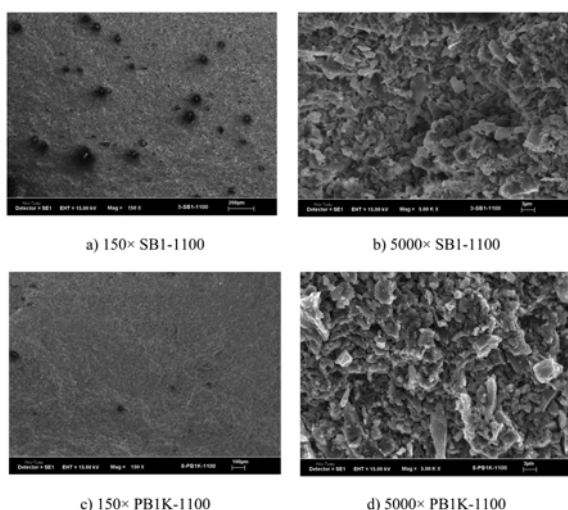


Fig. 6. SEM pictures of the highest porosity ceramic membrane supports.

PB1K-1100 and SB1-1100 supports have the highest porosity which were obtained by the comminution of the K1 kaolin in the ball mill and formed by dry pressing and slip casting, respectively. When these two supports were compared, it is seen that the SB1-1100 coded support formed by slip casting is more porous. This result was explained by the fact that the spaces between the grains of this support are larger which allows sulphur gases to escape more easily creating a porous structure. SEM pictures of the highest porosity supports are given in Figure 6. From Figure 6, removal of sulphur gases from the body and consequently why the porosity of the SB1-1100 is higher than that of PB1-1100 is easily seen.

Conclusions

The following conclusions were derived from the research carried out to investigate possible use of the Balıkesir-Sındırgı kaolin in ceramic membrane support production:

- The highest porosity was obtained from the supports produced by the comminution of K1 kaolin in a ball mill (having the highest alunite content) and formed by dry pressing and slip casting methods; namely SB1-1100 and PB1K-1100.
- The second highest porosity was obtained from the supports produced by the comminution of K2 kaolin in a ball mill (having lower alunite content than K1) and formed by dry pressing and slip casting methods; namely PB2K-1100 and SB2-1150.
- The lowest porosity was obtained from the supports produced by the comminution of K3 kaolin in a ball mill (having no alunite content) and formed by dry pressing and slip casting methods; namely PB3K-1200 and SB3-1150.

- The amount and the distribution of the pores for the supports produced were found to be very homogeneous and the average pore diameter was about 100 nm.
- It was found that as the alunite content of the ceramic membrane supports increased so does the value of the porosity of the supports.

Consequently, it was proven that alunitic kaolin, which is not currently used in ceramic industry, could be used in the production of ceramic membrane supports using their high alunite content as an advantage to increase the desired porosity in such supports.

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