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A view on organic binder effects on technical properties of ceramic Raschig rings

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Organic binders such as polyvinyl alcohol, carboxymethyl cellulose and Arabic gum are widely used to control the technological parameters required for green and sintered ceramic bodies. An industrial ceramic Raschig ring composed of kaolinite, illite, pyrophillite and quartz minerals was separately mixed with different content of above binders and formed by extrusion process in the shape of Raschig ring. The dried specimens were sintered at 1270°C and the physical-mechanical characteristics of sintered bodies were evaluated by measuring bulk density, total and closed porosities and compressive strength. In addition, the effect of binder type and amount on reliability of ceramic Raschig rings was evaluated by computing Weibull modulus. The obtained data exhibited optimum strength and reliability in presence 0,75 wt.% carboxymethyl cellulose.

Keywords: Raschig ring, binder, compressive strength, Weibull modulus

Influencia del aglomerante utilizado en el procesamiento de anillos Raschig cerámicos sobre las propiedades mecánicas

Los compuestos orgánicos tales como el alcohol polivinilico, la carboxilmetil celulosa y la goma Arábica son ampliamente utilizados para conseguir aglomerar los polvos cerámicos en verde. Se han preparado, por el método de extrusión, materiales cerámicos en forma de anillos Raschig a partir de minerales (caolina, illita, pirofilita y cuarzo) mezclados con diferentes contenidos de alguno de los aglomerantes mencionados. Los anillos, una vez secos, fueron sinterizados a 1270 ºC y caracterizados físicamente; se midieron la densidad, porosidad total y cerrada y las propiedades mecánicas. Asimismo se evaluó el efecto del tipo y cantidad de aglomerante empleado en el procesamiento de los anillos calculando el módulo de Weibull para los distintos anillos. Los datos obtenidos indican que la mayor resistencia mecánica se presenta cuando se ha utilizado 0,75% en peso de carboxilmetil celulosa como ligante.

Palabras calve: Anillos Raschig, aglomerantes, propiedades mecánicas, modulo de Weibull.

1. INTRODUCTION

Ceramic Raschig rings are very appealing for high performance application in chemical and oil industries due to their thermal and corrosion resistance in acidic environments (1). However, improvement and prediction of compressive strength for ceramic Raschig rings is important step in manufacturing this group of ceramics (2). As the stress concentrates at defect of ceramic body therefore, the homogeneity increment of ceramic microstructure improves the reliability of rings (3). The all most of ceramic bodies are brittle materials and stress is not relieved by local deformation near the crack tip as it happens in metals and polymeric materials. Therefore, it can be expected that cracks easily propagate and decrease the potential of applications (4,5). The compressive strength limiting defects often arise during manufacturing of ceramic Raschig rings and persist through the shaping process, so performance of the packed bed may be limited by this stage of process (6). For the ceramic bodies prepared by clay based materials, defects can be related to compaction of raw materials during shaping step. Extrusion is a widely used fabrication process for shaping of ceramics (7). In this method the paste of materials which are wetted to flow through the die by mostly water that may contains inorganic or organic additives such as binders, deflocculants and plasticizers were formed. The advantage of extrusion method is the production of rings with high reliability compared to other methods such as slip casting and pressing (2). A major disadvantage coming from extrusion is small internal defects remaining in structure of shaped body which can considerably limit the compressive strength of rings after the sintering (8).

The compressive strength of ceramic Raschig ring, σ, is related to the geometrical dimensions of rings method by following equation (9):

$$\sigma = \frac{KF}{L(D_o - D_i)} \qquad [1]$$

where F is the load for failure of rings, D_o, D_i and L are out diameter, inside diameter and width of ring respectively. K is the stress constant which is a function of D_i/D_o ratio and lies in the part of Frochts curve experimentally obtained to be equal 7 for extruded specimens in D_i/D_o ratio of 0.3-0.8

(9). Weibull analysis is widely used to determine reliability of materials. The Weibull modulus is closely related to defect statistic remaining in body structure. This method for reliability evaluation of ceramic Raschig rings relates strength to probability of failure using compressive strength distribution as follow (4,5):

$$P_n = 1 - \exp\left\{ - \int_v \left(\frac{\sigma - \sigma_w}{\sigma_0} \right)^m dV \right\} \qquad [2]$$

where P_n is the probability of failure, V is the sample volume, σ_w is the stress at which the probability of failure is zero, σ_0 is a characteristic strength and m is Weibull modulus. For brittle material such as ceramic and glass σ_w is often equal to zero which simplifies the equation to the two parameter model as:

$$\ln\left[- \ln\left(1 - P_n\right)\right] = m\ln(\sigma) + m\ln(\sigma_0) \qquad [3]$$

To apply this model, the compressive strengths a set of rings are ranked in order of ascending strength and the probability of failure of each sample is calculated using the following estimator. This equation was selected according the better fitting of experimental data reported by Salehi and Salem (10).

$$P_n = \frac{n}{1 + N} \qquad [4]$$

where n is the sample rank and N is the total number of tested samples. The slope of a plot with axes $\ln[(-\ln(1-P_n)]$ and $\ln(\sigma)$ gives the Weibull modulus and characteristic strength.

Table I: The chemical analysis of used kaolin

L.O.I	Na_2O	K_2O	MgO	CaO	TiO_2	Fe_2O_3	Al_2O_3	SiO_2
6.0	0.20	4.50	0.15	0.50	0.25	0.35	28±1	58±1

Table II: The geometrical dimensions of dry specimens

composition	binder (wt.%)	length (cm)	internal diameter (cm)	external diameter (cm)
STD	-	2.50±0.03	1.48±0.01	2.48±0.01
STD+PVA	0.25	2.50±0.03	1.48±0.01	2.48±0.01
	0.50	2.48±0.03	1.49±0.01	2.47±0.01
	0.75	2.52±0.03	1.49±0.01	2.47±0.01
	1.00	2.48±0.03	1.49±0.01	2.46±0.01
STD+CMC	0.25	2.52±0.04	1.48±0.01	2.49±0.01
	0.50	2.47±0.03	1.48±0.01	2.48±0.01
	0.75	2.48±0.04	1.50±0.01	2.47±0.01
	1.00	2.49±0.02	1.49±0.01	2.47±0.01
STD+AG	0.25	2.48±0.03	1.49±0.01	2.46±0.01
	0.75	2.51±0.02	1.48±0.01	2.44±0.01
	1.25	2.51±0.04	1.49±0.01	2.44±0.01
	1.75	2.51±0.05	1.48±0.01	2.42±0.01
	2.25	2.51±0.06	1.48±0.01	2.42±0.01

The objective of this study was to examine the influence polyvinyl alcohol, PVA, carboxymethyl cellulose, CMC, and Arabic gum, AG, on physical-mechanical properties of dried and sintered ceramic Raschig ring fabricated by extrusion process. In order to better understand the role of binder type and content on reliability of rings, the Weibull statistic theory were applied and results were compared with scanning electron microscopy tests.

2. EXPERIMENTAL PROCEDURE

Different series of specimens were prepared by extruding of industrial kaolin with different type and amount of binders. Dried density, porosity and compressive strength were measured. The influence of binder on characteristics of sintered specimens such as shrinkage, water absorption, bulk density, total and closed porosity, compressive strength and Weibull modulus were evaluated.

Industrial kaolin with mean particle size of 2.6 μm, specific surface area of 3.6 m^2/g and true density of 2.30 g/cm^3 was used in this investigation. The chemical analysis and XRD pattern of raw material are presented in Table I and Figure 1 respectively. The pastes were separately prepared using different content of PVA, CMC and AG as binders. The mentioned binders with different content firstly were dissolved in distilled water and then were added the kaolin powder. The content of moisture in prepared pastes was considered 30 wt% per unit of dried powder. Based on the earlier studies carried out by Salehi and Salem (6) the obtained pastes which contain different binder percentage per unit of dry kaolin were left for 48 hour to achieve the homogenous moisture. The pastes were continuously de-aired using a laboratory pug mill and extruded using an extruder, prototype. The extrusion rate was set at 8 mm/min and shaped specimens were cut as Raschig rings with the same dimensions in length and outer diameter after drying in 100°C. The drying process was performed in laboratory oven to remove the moisture of specimens.

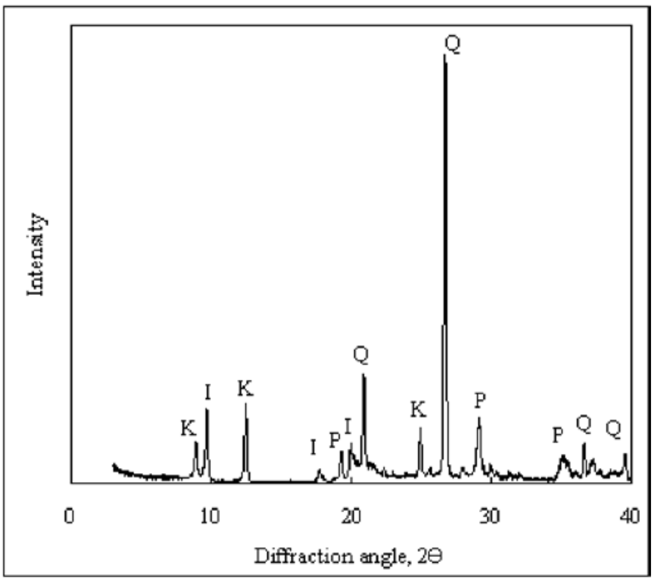

Figure 1: The XRD pattern of kaolin used in experiments
I: illite, K: kaolinite, P: pyrophillite and Q: quartz

The geometrical dimensions of rings were presented in Table II Dried density was measured using weight and geometrical dimension of rings and total porosity of them were determined from the following equation:

$$\text{total porosity} = 1 - \frac{\text{bulk density}}{\text{true density}} \quad [5]$$

In order to study the effect of binder on compressive strength of final product, the dried rings were sintered in an electrical high temperature furnace (Model EX. 1500-6L, Iran) using the firing schedule described in Table III.

The geometrical dimensions of sintered ring were reported in Table IV. The following parameters were selected to evaluate the properties of ceramic Raschig rings according standard methods shrinkage, water absorption, bulk and true densities and total and open porosity (11,12). The total porosity of sintered body was calculated using equation 5 and the difference of total and open porosities shows the value of closed porosity. XRD test (Model D5000 Siemens, Germany) was carried out on sintered sample to identify the minerals formed in ceramic body.

To determine compressive strength of ring, at least twenty sintered specimens were diametrically compressed between the two plates with cross head speed of 1 mm/min and the strength was calculated using equation 1. The Weibull modulus was evaluated using the least-square method by a two-parameter model. The morphology of the defects and pores were observed after sintering runs by scanning electron microscopy (Model Eol-4401, England). The SEM tests were performed on cross section of specimens.

Thermogravimetric analyses (Model Perkin Elmer SII, England) were performed on powder containing different content of binders. The samples were heated from room temperature to 750 °C at heating rate of 5°C/min. Fourier transform infrared spectrometry, FTIR, (Model Unicam Mattson 1000, Philips) were obtained to determine chemical groups of binders.

TABLE III: THE SINTERING PROGRAM OF FURNACE

heating rate (°C/min)	temperature range (°C)	time (min)
5	25-600	115
0	600	60
10	600-1270	67
0	1270	120

TABLE IV: GEOMETRICAL DIMENSIONS OF SINTERED RINGS

composition	binder (wt.%)	length (cm)	internal diameter (cm)	external diameter (cm)
STD	-	2.20±0.03	1.28±0.01	2.13±0.01
STD+PVA	0.25	2.20±0.03	1.29±0.00	2.13±0.02
	0.50	2.18±0.02	1.29±0.00	2.13±0.02
	0.75	2.23±0.02	1.28±0.01	2.11±0.01
	1.00	2.18±0.03	1.29±0.00	2.11±0.02
STD+CMC	0.25	2.25±0.03	1.29±0.01	2.12±0.01
	0.50	2.16±0.02	1.28±0.01	2.12±0.01
	0.75	2.21±0.03	1.30±0.00	2.12±0.01
	1.00	2.19±0.03	1.28±0.00	2.11±0.01
STD+AG	0.25	2.19±0.03	1.29±0.01	2.12±0.01
	0.75	2.23±0.02	1.29±0.01	2.11±0.02
	1.25	2.22±0.04	1.28±0.01	2.11±0.02
	1.75	2.21±0.04	1.28±0.01	2.09±0.01
	2.25	2.22±0.02	1.28±0.01	2.09±0.01

3. RESULTS AND DISCUSSION

In order to obtain complementary evidence for the chemical bands of binders, FTIR spectra were recorded in the region of 500-4000 cm^{-1}. Figure 2 shows that FTIR spectroscopy is very sensitive to -O- appeared in wave number of 1070 cm^{-1} in all of binders. There is a group transmittance peaks between 1430-1450 cm^{-1}, which is due to bands of $-CH_2$ groups and the bands at 1700 cm^{-1} corresponds to -C-O that is observed in PVA. The transmittance peaks related to C-H and C-CO-OH groups were also appeared in FTIR pattern of PVA in wave numbers of 2250 and 3400 cm^{-1}, respectively. The vibrations of C=O and -CO-ONa groups can be observed both in CMC and AG patterns in wave number of 1650 and 3450 cm^{-1} respectively.

Figure 3 depicts the TG curves for three binders used in composition of ceramic Raschig rings at heating rate of 5°C/min. The thermogravimetric curves show two weight loss of 1 and 4 wt.% which correspond to burning of binders and dehydroxylation of the kaolinitic-illitic clay.

The physico-mechanical properties of dried bodies containing different type and amount of binders were reported in Table V. The composition without binder, denoted by STD, shows the lowest bulk density and highest volume of porosity compared to the rings prepared by addition of binders. The total porosity should be less to effective control of compressive strength of dried body. The bodies which appear significantly changes in bulk density were selected for further studies of compressive strength test in each run. From the data of Table V, it is obviously seen that the STD specimen prepared without binder shows the lowest dry strength of 28 kPa. It is also clearly observed that the addition of PVA in ceramic body composition shows maximum strength compared to the

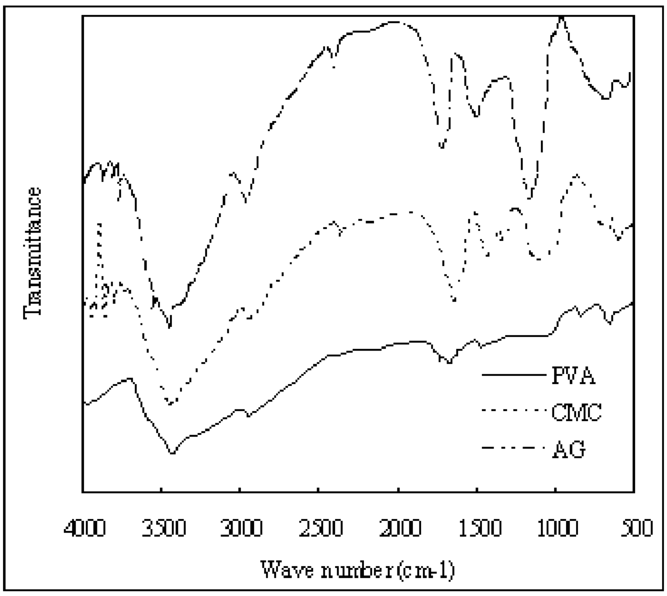

Figure 2: FTIR patterns recorded on PVA, CMC and AG

other cases. Among the various content of PVA used in this investigation the presence 1 wt% PVA in body composition shows maximum improvement in dry compressive strength. The strengths of 383 kPa for body prepared with 1 wt% PAV and 28 KPa for STD indicate the increase of 13 times approximately. CMC and AG also improve the strength of rings but the specimens show only an increase of 5 and 4 times in presence at 1 wt% CMC and 2.25 wt.% AG respectively. Compared to STD strength, this increment in dry compressive strength was obtained in presence 0.5 wt% PVA. Maximum strength has been observed in specimens that prepared with PVA indicating significantly improvement over STD composition. Among all specimens prepared with binders used in this work, AG shows lowest degree of improvement in strength. This variation in strength indicates coherence between kaolin and PVA when the results compares to those for CMC and AG.

The ceramic Raschig rings were fired in 1270 °C and the physical properties of bodies containing different type of binders were measured and the results were reported in Table VI.

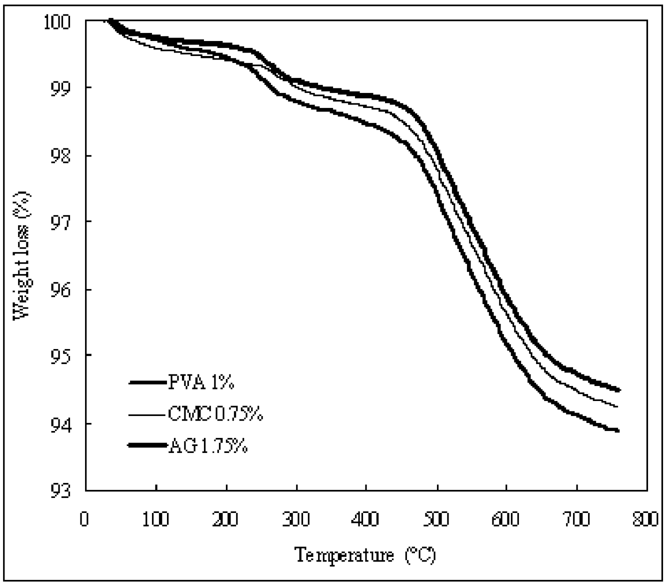

Figure 3: TG curves of bodies containing different content of PVA, CMC and AG

Table V: Physico-mechanical properties of dry bodies containing different type and amount of binders

composition	binder (wt.%)	bulk density (g/cm³)	total porosity (%)	dry strength (kPa)
STD	-	1.56±0.01	32.0±0.4	28±1
STD+PVA	0.25	1.58±0.02	31.5±0.8	-
	0.50	1.58±0.01	31.2±0.4	132±4
	0.75	1.60±0.01	30.5±0.4	-
	1.00	1.64±0.01	28.7±0.4	383±4
STD+CMC	0.25	1.57±0.02	31.9±0.8	-
	0.50	1.57±0.01	31.8±0.4	84±1
	0.75	1.63±0.02	29.2±0.8	116±3
	1.00	1.61±0.01	30.3±0.4	163±4
STD+AG	0.25	1.62±0.01	29.5±0.4	-
	0.75	1.63±0.01	29.0±0.4	-
	1.25	1.64±0.01	28.9±0.4	-
	1.75	1.69±0.01	26.5±0.4	139±5
	2.25	1.69±0.01	26.5±0.4	146±4

Table VI: Physical properties of sintered bodies containing different type of binders

composition	binder (wt.%)	shrinkage (%)	water absorption (%)	bulk density (g/cm³)	total porosity (%)	closed porosity (%)
STD	-	15.0±0.2	0.26±0.00	2.36±0.01	6.6±0.4	5.8±0.2
STD+PVA	0.25	14.9±0.2	0.68±0.01	2.37±0.01	6.1±0.4	4.4±0.2
	0.50	15.1±0.2	0.62±0.00	2.38±0.01	6.0±0.4	4.4±0.2
	0.75	15.5±0.3	0.58±0.03	2.38±0.02	5.7±0.8	4.4±0.2
	1.00	15.8±0.3	0.43±0.03	2.43±0.02	3.8±0.8	3.3±0.1
STD+CMC	0.25	15.0±0.1	0.31±0.00	2.37±0.01	6.5±0.4	5.7±0.1
	0.50	15.1±0.1	0.31±0.00	2.37±0.01	6.4±0.4	5.6±0.1
	0.75	15.3±0.1	0.15±0.00	2.38±0.00	6.1±0.2	5.9±0.0
	1.00	15.3±0.1	0.26±0.01	2.37±0.01	6.5±0.4	5.9±0.2
STD+AG	0.25	15.2±0.2	0.47±0.02	2.37±0.01	6.4±0.4	5.4±0.2
	0.75	15.3±0.1	0.47±0.01	2.37±0.00	6.2±0.2	5.3±0.2
	1.25	15.4±0.2	0.36±0.02	2.38±0.00	5.9±0.2	5.2±0.1
	1.75	16.2±0.2	0.29±0.01	2.41±0.01	4.7±0.4	4.1±0.1
	2.25	16.3±0.0	0.23±0.01	2.40±0.01	5.1±0.4	4.5±0.2

The shrinkage of bodies containing different content of PVA continuously increases reached a maximum value in presence 1 wt% PVA. It is obvious that the change in shrinkage values is negligible when the ceramic body contains low content of PVA, less than 0.75 wt %. Among the various content of CMC used in this work shrinkage approximately remains constant near to 15.2 %. The variation in shrinkage of bodies contain different amount of AG is similar to bodies prepared by PVA. Shrinkage remains constant when the amount of AG used in preparation of body was less than 1.25%. Therefore, the composition prepared by 1.75 and 2.25 wt% AG show high value of shrinkage indicating an increment of 1%.

Using the amount of water absorption reported in Table VI, the increase in binder amount is mostly accompanied with decrease in water absorption in three groups of compositions. This decrease in water absorption occurs as a result of compaction of body during extrusion process. Regardless the some exceptions, the water absorption less than 0.5% satisfied the standard range for production of ceramic packing. Table VI presents the value of bulk density for kaolin/binder compositions sintered at 1270°C. Similarly, the bulk density of bodies containing 1% PVA and 1.75% AG were higher than that for body prepared by 0.75% CMC. These results follow the fact that the mentioned compositions were compacted relatively better compared to compositions prepared with CMC.

The total and closed porosities of ceramic Raschig rings should be compared in order to discuss the densification, because the number of pores and porosity significantly affect the compressive strength of sintered bodies. Table VI reports the values of total and closed porosity of rings prepared with different type of binders. The value of total and closed porosity of body containing 1% PVA considerably are low in comparison to the other kaolin/binder compositions, even the presence 2.25% AG in body composition could not decrease the porosity.

For the better understanding the effect of binder type and content on reliability of ceramic Raschig rings, Weibull statistic method was used. According to ASTMC-1239 standard (13) method the confidence bounds can be constructed for estimated Weibull characteristic strength. The 90% confidence bound on characteristic strength is obtained from the 5 and 95 percentile distributions. The probability of failure as function of compressive strength were shown corresponding to binder type and content in Figure 5. The strength of ceramic Raschig rings prepared with different binder content show good agreement with linear correlation coefficient of 0.95 to 0.98 with Weibull model and good adjustment can be observed between the experimental data and Weibull distribution obtained by Equation 2. The lower and upper values of strength and Weibull modulus obtained for kaolin/binder system are presented in Table VII

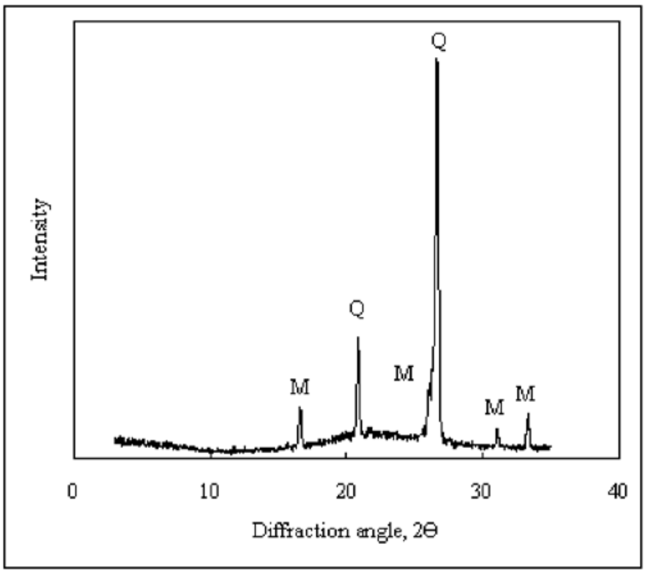

Figure 4: The XRD pattern of fired specimens in 1270°C, M: mullite, Q: quartz

The confidence bounds of strength vary proportionally with their total porosities with exception in body containing 0.75% CMC. The strength of this body was remarkably improved by using 0.75% CMC in body composition. The strength reached a maximum value and then decreased with a corresponding increase in CMC content. On the other hand, the strength of bodies prepared with 1.75% AG is considerably high which is near to maximum strength of body prepared with 0.75% CMC. The strength of rings separately prepared with 1% PVA and CMC, are quite equal to average value of 32 MPa. The strength of bodies prepared by 0.5% PVA and CMC tend to behave similar to STD composition with value of 21

TABLE VII: MECHANICAL PROPERTIES OF SINTERED BODIES CONTAINING DIFFERENT TYPE AND AMOUNT OF BINDERS

composition	binder (wt.%)	characteristic strength (MPa)	Weibull modulus		compressive strength (MPa)		R[a]
			lower bound	upper bound	lower bound	upper bound	
STD	-	25.8	2.4	4.4	23.1	29.0	0.95
STD+PVA	0.50	23.3	8.2	15.8	22.3	24.1	0.97
	1.00	33.7	5.4	10.5	31.8	35.7	0.95
STD+CMC	0.50	25.5	4.8	8.5	24.0	27.1	0.97
	0.75	44.3	4.3	7.7	41.2	47.0	0.96
	1.00	35.6	5.6	10.7	33.7	37.5	0.98
STD+AG	0.75	30.2	4.1	7.8	28.1	32.5	0.95
	1.75	39.6	3.9	7.1	36.7	42.7	0.96

[a]*R: Linear regrassion cofficint*

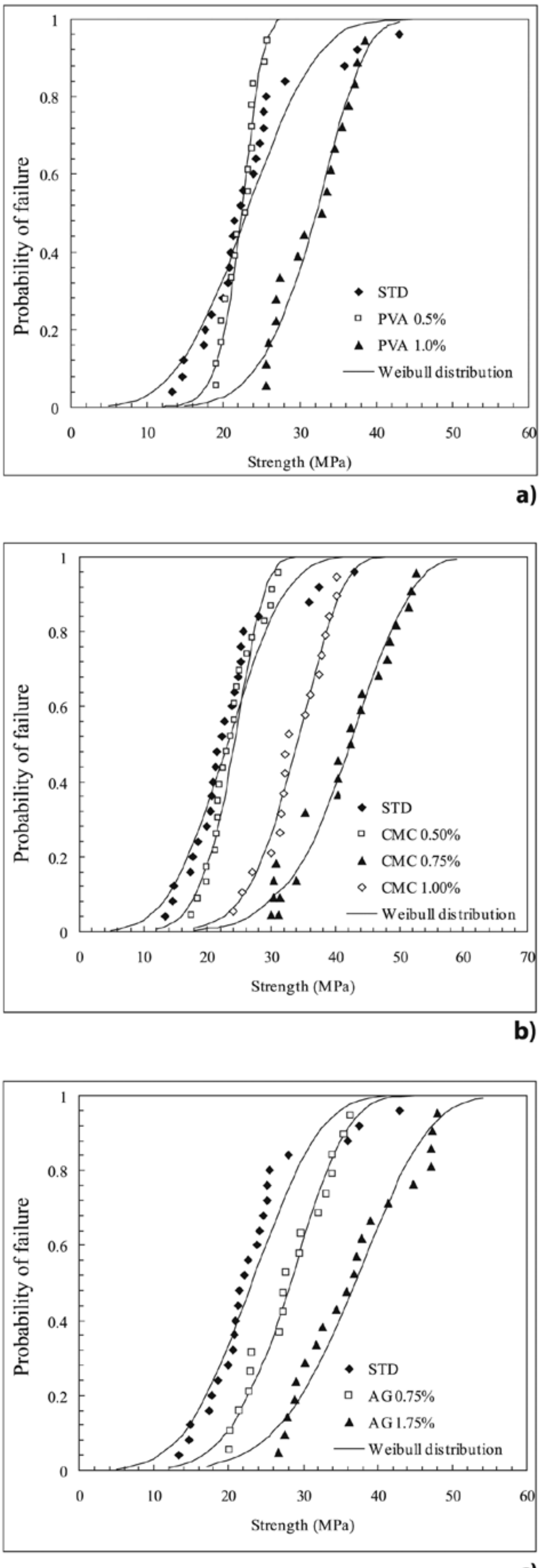

Figure 5: The probability of failure as function of compressive strength Raschig rings prepared with different type and content of binders, (a) PVA, (b) CMC and (c) AG

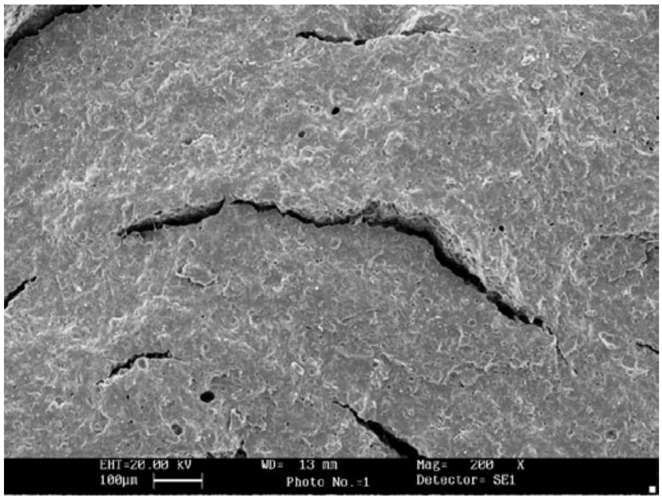

Figure 6: The morphology of defects in STD composition

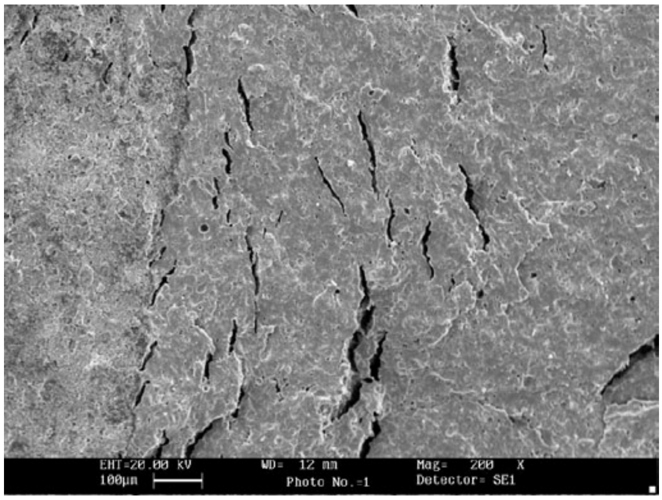

Figure 7: The morphology of defects in body prepared by 0.75% CMC

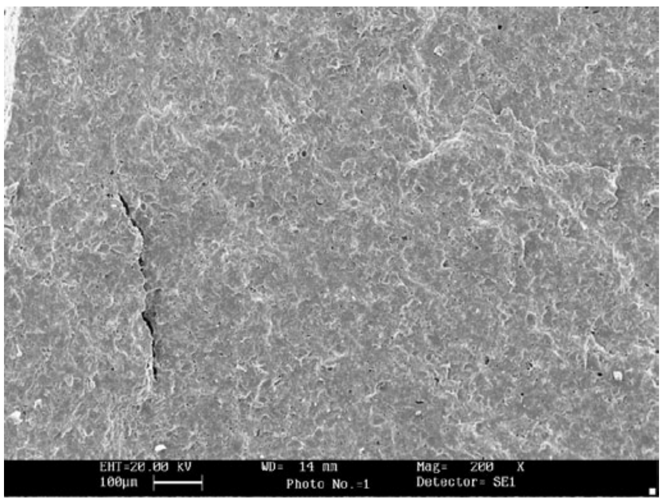

Figure 8: The morphology of defects in body prepared by 1.0% PVA

MPa that shows the presence 0.5% of above binders did not affect the strength of body.

The porosity dependency of strength for bodies containing 0.75% CMC does not different significantly from the STD body. Especially, the total porosity of body prepared with 0.75% CMC was round of 6.0% which is the same for STD composition. Generally, pores should be eliminated because the strength of ceramics exponentially decreases with increasing of porosity. It is interesting to note that the body containing 0.75% CMC shows a high strength despite its large porosity.

It has been reported that the strength of clay based ceramics are affected by the mineralogical phase produced during the sintering process. Consequently, the formed phase such as mullite and residual crystals such as quartz influence the strength of ceramic Raschig rings which is found in XRD pattern of fired specimens in 1270°C as shown in Figure 4.

It is clearly seen from the data of Table VII that the use of binder in composition of ceramic Raschig rings improves the Weibull modulus as result, the reliability of failure. The values of Weibull modulus are in agreement with scattering found for strength data. Despite, increment of binder content, the Weibull modulus shows a general decrease particularly for specimens containing PVA. This trend can be attributed to defects and pore size distribution in ceramic body. The defects population plays significant role in mechanical strength and reliability of rings. They can contribute also to increase the data scattering. Therefore, the reliability of rings decreases as function of defect distribution. As discussed before, since the composition of clay and heat treatment was kept constant in this investigation, the results concerning the specimen strengths can be attributed to structure texture of rings. The rings prepared by 0.5 wt% PVA shows considerably increase

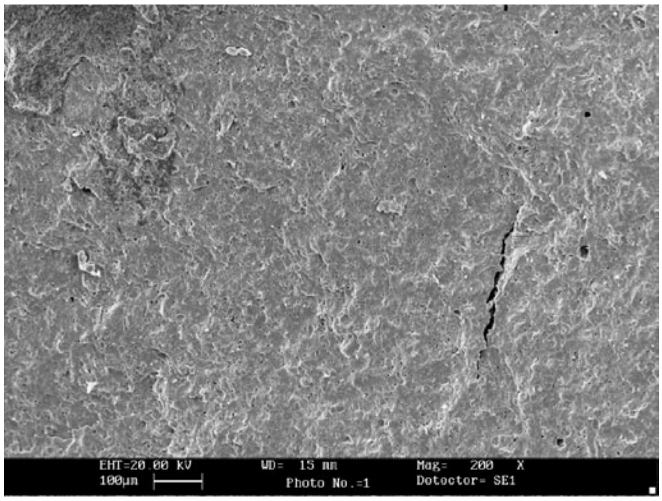

Figure 9: The morphology of defects in body prepared by 1.75% AG

in reliability compared to STD composition. The presence 0.5 wt% PVA in initial composition causes homogenous distributions of defects on structure of rings. The total porosity of specimens also, is not approximately affected in presence of 0.5 wt% PVA.

The SEM photograph of fracture surface shows the presence of large defects in STD composition heterogeneously distributed in cross section of ring as shown in Figure 6. The presence of defects homogeneously distributed in structure of ring prepared by 0.75 wt% CMC is the main reason for improving reliability of rings as shown Figure 7. In particular, the decrease in dimension of defects in body prepared by 0.75% CMC can be considered a responsible for the compressive strength and Weibull modulus of rings compared

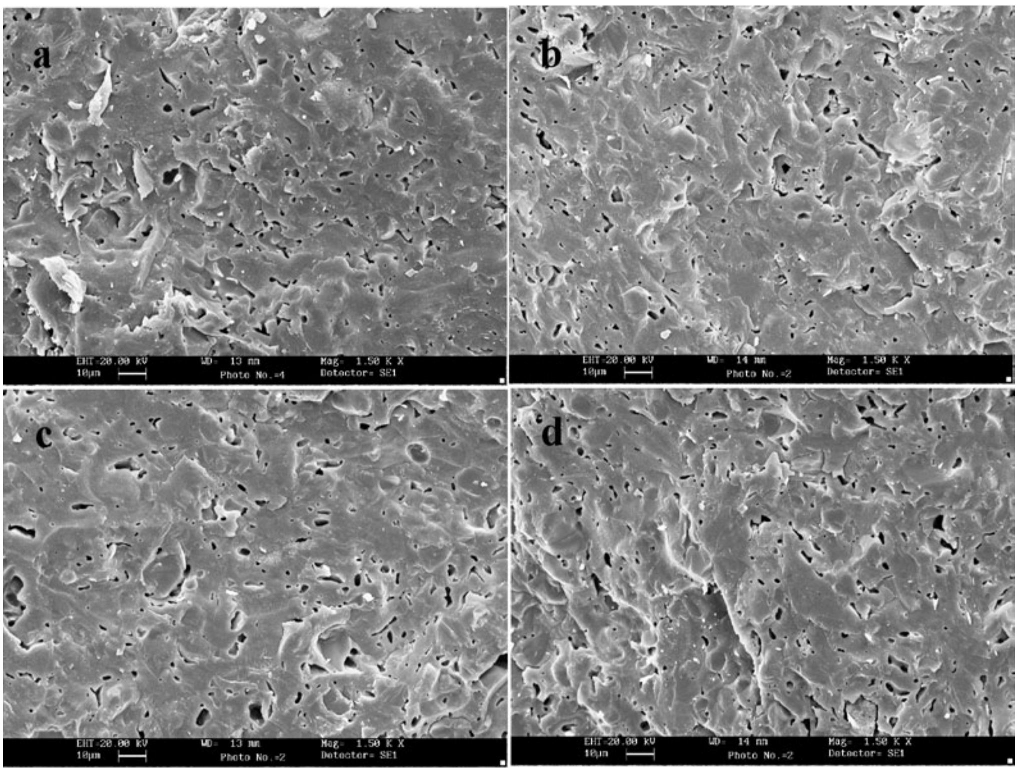

Figure 10: The SEM photographs of fracture surface of specimens prepared by (a) with out binder, STD, (b) 1.0% PVA, (c) 0.75% CMC and (d) 1.75% AG

to STD structure. The increment in Weibull modulus of body prepared by AG is the less than that for the rings prepared by PVA and CMC. The results can be attributed to a low homogenously distribution of defects and their dimensions on fracture surface of rings (Figure 8). The inefficient coherence between the clay and AG may be not able to remove the defects of specimens during extrusion as presented in Figure 9. The fracture surface of rings prepared with 1.75wt% AG shows rather large defects compared to specimens prepared with 0.75 wt% CMC.

The morphology of pores in ceramic Raschig rings prepared by different type of binders was compared in Figure 10. The substantial difference was not observed in distributions of closed pores in microstructure of rings. Therefore, from point of view, the defect dimensions and their distribution can be considered to be the main responsible for mechanical behavior. Also, the product containing 0.75 wt% CMC is suggested as optimum binder content for extrusion process of ceramic Raschig rings.

4. CONCLUSIONS

Physico-mechanical properties of dried and sintered ceramic Raschig rings were studied in presence different type and content of binders. Compressive strength and Weibull modulus were measured to evaluate the effect of binder on reliability of rings. The following conclusions were drawn from this investigation:

1. The addition of 0.5wt.% polyvinyl alcohol improves the mechanical reliability of sintered ceramic Raschig rings due to homogeneous distribution of defects. The increase in binder content yields the defects with elongated dimensions that decrease the Weibull modulus as well as reliability of rings.

2. Carboxymethyl cellulose and Arabic gum did not influence the Weibull modulus of compressive strength compared to polyvinyl alcohol. However, the difference in defect dimensions are affected by carboxymethyl cellulose therefore, the compressive strength is improved in presence of 0.75 wt.% of this binder.

3. The sintered specimens with high value of strength were fabricated by addition of 1.75 wt.% Arabic gum but the Weibull modulus were 5.2, which is relatively lower than that for specimens prepared with polyvinyl alcohol and carboxymethyl cellulose.

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