The Role of SiC and Different Binders on Mechanical Strength and Compaction of Silica Based Refractoriness Materials

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Abstract
Silica refractory bricks are used especially in the metallurgical industries, due to desirable properties such as particularly their high melting point and their rigidity and strength at high temperatures. In this research, different amount of SiC were added to Silica refractory containing different binders such as Borax, Boric acid, Calcium nitride, Sodium tri poly phosphate, Sodium hexametaphosphate (SHMP) and lime are added. Physical properties (density and porosity), mechanical properties (cold crush strength, CCS) and microstructure were studied. This study indicated that SiC improves the physical and mechanical properties. In general, increasing SiC with different binders improve the mechanical and compaction in the samples. Silica refractory sample containing 20%wt. SiC and 5% wt. borax as a binder had the best results of mechanical strength and compaction. In this sample, glassy phases formed fills the voids and increasing temperature between particles. In fact, glass phase formation increase compaction, density, and strength.

Keywords
Silica refractory, Binders, SiC, Compaction, Strength

1. Introduction

Refractory materials can be divided into several classes based on: chemical composition (acid, basic and special), method of implementation (shaped and unshaped), method of manufacture (fused and sintered), and porosity content (porous and dense). These materials are supposed to be resistant to heat and are exposed to different degrees of mechanical stress and strain, corrosion from liquids and gases, and mechanical abrasion at high temperature [1-8]. Different types of refractory materials can be synthesized according to the nature of the raw materials and the used process. The application fields of refractory are multiple and depend on the properties of each type. In fact, the performance of a refractory (good resistance to heat and thermal shock) is directly related to texture and richness of the mineral refractories, such as mullite, corundum, periclase, doloma, spinel and alumina [9, 10].

Silica refractory bricks possess excellent thermal shock resistance, particularly in certain temperature ranges. One of the outstanding characteristics of silica bricks is their resistance to corrosion by acid slag and iron oxide, but they are readily attacked by basic slag and fluorine [11,12].

Silica refractories are in the acidic refractories category. Silicon dioxide(white sand) was used as a raw material for production of this bricks. Good quartz should be gray. Reddish in color indicated the presence of finely distributed iron oxide. Darkto black discoloration is caused by manganese oxides or by contaminations.Understanding thecomposition ofimpuritiesinraw materials, and its

performance is very importantin controlling theproperties ofrefractories. Especiallythat,certain compoundsin theraw materialsmay beformed compounds with alowmelting pointand with drastic change in the viscosity of the liquid phase, strongly affect on behavior of refractories [13,14].
Another material that used for production of silica bricks is lime. A major function of the lime used in making silica refractories is affect the inversion of quartz to Tridymite. The phase diagram of silica-lime system shows why considerable quantities of lime may be used to bond the quartz in silica bricks without loss of refractoriness. The action of pure lime as a mineralizing agent in the tridymitisation of silica brick raw material at 1250 ˚C is due to the diffusion of calcium ions into the silica surface. The porosity in the refractory structure considerably influences the strength. According to the existing standards, the porosity of silica bricks varies between 20% and 24% [15].
In this study, different amount of SiC were added to silica refractories containing different binders such as borax, boric acid, calcium nitride, sodium tri poly phosphate, sodium hexametaphosphate (SHMP) and Lime to improve physical properties and mechanical properties.

2. Experimental Procedures

2.1 Materials

In this study, silica with different aggregation, as filler and base material was used. The chemical analysis of silica used inthisstudyare shownin Table 1.

Table1. The chemical analysis of silica used

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	SO_3	Na_2O	LOI
wt.%	95.65	1.41	1.24	0.474	0.217	0.200	0.092	0.38

Understanding the composition of impurities in raw materials, and its performance is very importantin controlling theproperties ofrefractories. Especiallythat,certain compoundsin theraw materialsmay beformed compounds with melting pointand with drastic change in the viscosity of the liquid phase, strongly affect on behavior ofrefractories.
Different binder such as Borax, Boric Acid, Calcium Nitride, Sodium tri poly phosphate (STPP), SHMPandlime are used.In this study, also used microsilica, nano silica and SiC with grain size about 100µm.
In order to overcome the inherent compressive limitations of powders it is possible increase their density by distributing the granule size. The key to the improvement of compaction is the proportion of granule size. In order to obtain the best mix ratio and distribute silica particles the Andreasen's formula was used.

$$q= (d/D)^{n}*100 \quad (1)$$

D: the largest granule size (mm), d: size of the existing granule (mm), n: shape factor (0.2-0.4)
q: percentage of granule sizes smaller than d
The mix ratio of silica granules is shown in Table 2 based on Andreasen's formula.

Table2. The mix ratio of silica granules

Particles Size (μm)	841-1680	707-841	354-707	250-354	149-250	+149	Micro Silica	Nano Silica
Wt.%	18.7	4.09	14.4	6.27	10.6	35.9	5.37	5.4

In order to determine the effect of silicon carbide, 100 g of silicon with the aforementioned grading was mixed with 10 and 20 wt. % of SiC and then 5 wt% of the aforementioned binders was separately added to silicon. The mixture was mixed for three minutes. Table 3 shows the specifications of samples.

After adding the binders and mixing them with the main compound, 7 wt. % of moisture was added to the samples and they were mixed properly for 5 min.

After the mixing phase which resulted in a homogenous mix, the next step was to shape the samples. The most common way of shaping refractories is dry and semi-dry pressing. One of the most important objectives of pressing is to compact components to the possible extent by applying pressure.

Table3. Formulation of samples

Calcium Nitride wt.%	Borax wt.%	Boric Acid wt.%	SHMP wt.%	STPP wt.%	Lime wt.%	SiC wt.%	Silica wt.%	Sample code
-	-	-	-	-	5	10	100	A1
-	-	-	-	5	-	10	100	A2
-	-	-	5	-	-	10	100	A3
-	-	5	-	-	-	10	100	A4
-	5	-	-	-	-	10	100	A5
5	-	-	-	-	-	10	100	A6
-	-	-	-	-	5	20	100	A7
-	-	-	-	5	-	20	100	A8
-	-	-	5	-	-	20	100	A9
-	-	5	-	-	-	20	100	A10
-	5	-	-	-	-	20	100	A11
5	-	-	-	-	-	20	100	A12

In this step, the resulting mix wascast into a cylindrical mold and was shaped using a hydraulic press at a pressing pressure of 200 psi. Pressed samples were in the shape of bushes with external diameter of 50 mm, height of 15 mm, internal diameter of 30 mm and internal height of 10 mm. In the next step, the shaped samples were stored for 24 h in a dryer at a temperature of 60 degrees to be fully dried. Next, the samples were burnt in an electric furnace with a temperature increase rate of $5^{\circ}C/min$ at a temperature of 1350°C when the temperature reached 1350°C, samples were stored for two hours at this temperature.

2.2 Experimental Procedure

To assess and evaluate the porosity and density of refractory materials the Archimedes method was used.The diagonal pressure test is used as a means of measuring the strength of refractory materials. This test, which is known as the nucleus failure test or Brazilian test, is among the strength tests in

which failure is caused by application of tensile stress. The maximum tensile stress that uniformly affects a diameter under load is obtained as follows:

$$\sigma = 2F/\pi dl \quad (2)$$

σ: Effective stress, F: force, d: diameter (mm),l: height (mm)

3. Results

3.1 Density and porosity

Porosity percentage is one of the important characteristics of refractory samples and with an increase in density the physical properties of the samples improve at lower apparent porosity. Tables 4 and 5 show the porosity, water absorption percentage, and volume density of silica refractory samples that contained 10 wt. % to 20 wt. % of SiC and different binders. According to this Table, samples containing borax, SHMP, and boric acid showed the highest density and lowest porosity. These materials form a glass phase and improve the bonds between granules. Boric acid loses its moisture at a temperature of $170\,^{\circ}C$ and turns into HBO_2. At a temperature of $300\,^{\circ}C$, it loses water once again and breaks down to B_2O_3. Borax without crystallization water has relatively better properties compared to boric acid. The lack of crystallization water leads to a reduction in time and facilitates the refractory sintering process. At a temperature of $580\,^{\circ}C$, B_2O_3 in the refractory compound is melt and fills the spaces between silica particles. Hence, the porosity of the refractory material declines as its density grows. SHMP is inherently amorphous and its presence in the refractory compound leads to the formation of phosphate glass at the refractory level and binding of particles.

According to this table it can be concluded that by adding SiC to the refractory compound it is possible to enhance the physical properties of refractories. With an increase in the amount of the SiC added to the refractory compound, the physical properties of the refractory material improve drastically. Samples containing 20 wt% of SiC has a lower porosity and water absorption capacity than samples containing 10 wt% of SiC.

Table4. Porosity, water absorption andbulkdensityof silic are fractory samples Containing10 wt. % ofsilicon carbide

Water absorption (%)	Porosity (%)	Bulk Density (g/cm^3)	Binders
11.82	26.06	2.20	Lime
13.26	29.56	2.23	Sodium Tri Poly Phosphate
10.50	23.14	2.20	SHMP
11.76	23.65	2.10	Boric Acid
10.49	22.79	2.17	Borax
13.74	31.92	2.32	Calcium Nitride

Table5. Porosity, water absorption and bulk density of silica refractory samples containing 20 wt. % of silicon carbide

Water absorption (%)	Porosity (%)	Bulk Density (g/cm^3)	Binders
11.74	25.99	2.21	Lime
12.16	27.48	2.25	Sodium Tri Poly Phosphate
9.76	21.72	2.22	SHMP
10.71	22.75	2.12	Boric Acid
6.84	19.02	2.35	Borax
12.28	28.86	2.19	Calcium Nitride

3.2 Cold Crush Strength (CCS)

Cold crush strength is greatly influenced by the particles distribution function because distribution of particles affects the density and porosity of refractories. With proper distribution of fine and coarse particles and placement of fine particles between coarse particles, the raw density of the sample increases as its porosity declines. With the decrease in the porosity of the refractory structure and an increase in its density, the cold crush strength also grows.

The additives in the refractory compound improve the sintering of samples and the cohesion between refractory particles. As a result, the strength of refractories escalates. As the diagrams suggest, borax, boric acid and SHMP increase refractory strength. Sintering of silicon particles and sintering supplements such as borax, boric acid and SHMP at the time of baking the samples are factors that increase the strength of samples. Borax, boric acid and SHMP react with the silicon in the refractory compound during the baking process and form a glass phase. The resulting glass phase fills the spaces between particles and leads to the cohesion and cold compressive strength of samples.

The resulting diagrams suggest that by adding SiC to the refractory compound the cold crush strength of samples grows. Therefore, samples containing 20 wt% of SiCdemonstrates a better crush strength than samples containing 10 wt% of silicon carbide.

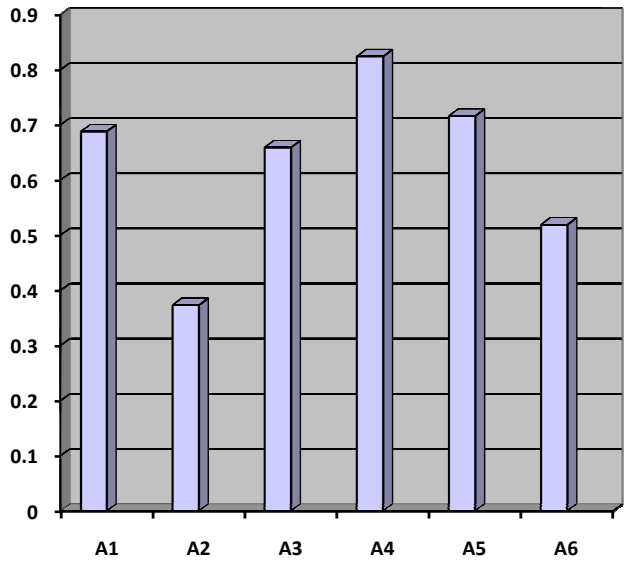

Figure3. Cold crushingstrength (MPa), ofsamples containing10 wt.%SiC with different binders

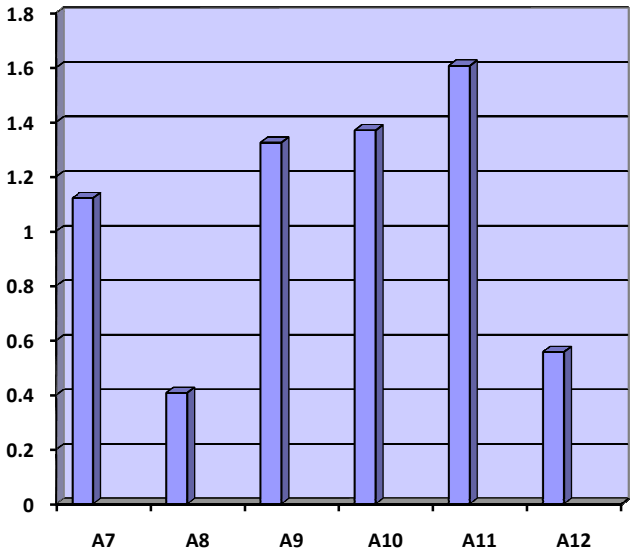

Figure4. Cold crushing strength (MPa), of samples containing20 wt. %SiC with different binders

3.4 Microstructure

The significance of microstructure studies for identification and analysis of refractory material properties results from their diversity of results. Results of microstructure studies give an overall image of the following properties of the structure: grading; type, extent and distribution of phases; porosity distribution; existence of defects such as cracks; and degree of homogeneity. These results can be used to predict the behavior of the refractory material.

The scanning electron microscopy micrographs samples containing 10 wt. % and 20 wt.% of silica carbide with 5 wt.% of SHMPis presented in the following.

As seen in these figures, the phosphate glass phase that formed by adding SHMP to the refractory compound provides a pervasive environment. Bubbles resulted from exposure of the compounds to hydrochloric acid are small. The relatively scattered porosity also reflects a reduction in strength and an increase in the corrosion of these samples. The cleavages result under the yield force from the glass phase.

The above figures indicate that the increased strength obtained by adding 20 wt. % of SiC to the refractory compound was higher than the results obtained by adding 10 wt.% of SiC.

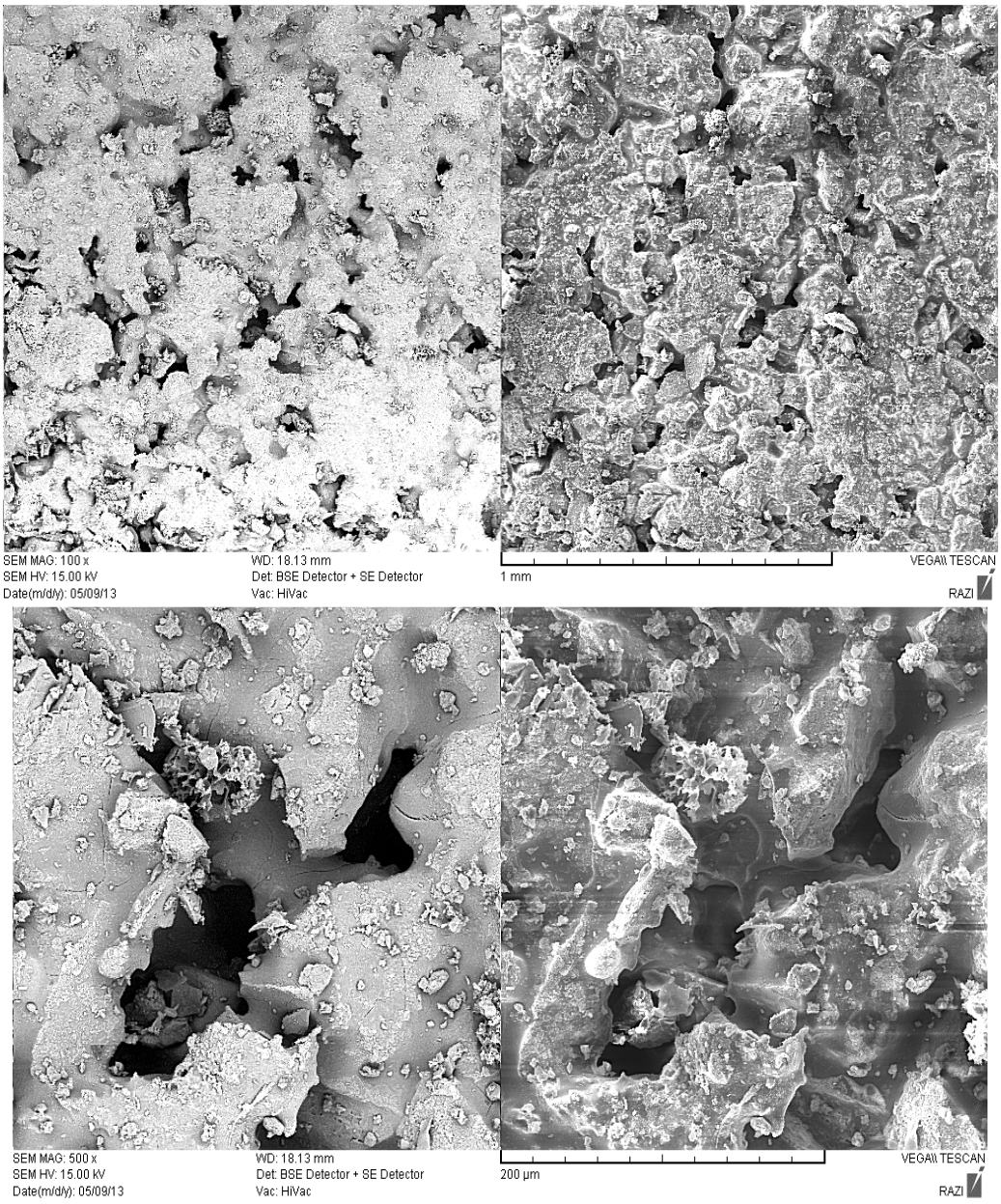

Figure5. SEM image ofa sample containing10 wt. %, SiC with 5 wt. %SHMP indifferent magnifications

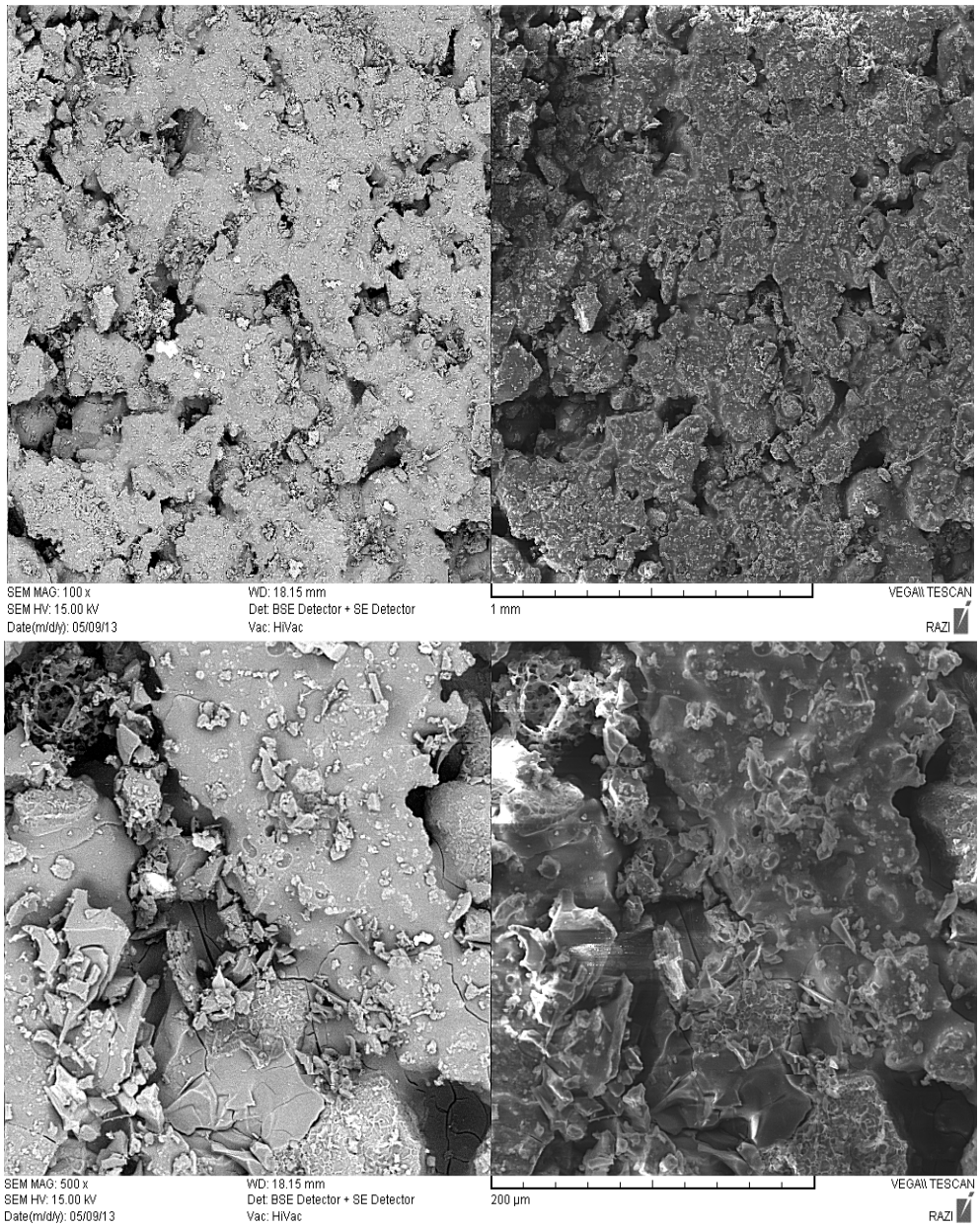

Fig.6. SEM micrographs of a sample containing 20 wt. %, silicon carbide With 5 wt.% SHMP in different magnifications

4. Conclusion

1- According to above results, increasing SiC with different binders improve the mechanical and compaction.

2- With an increase in the amount of the SiC added to the refractory, the properties of the compound improve considerably. On the other hand, use of binders such as borax, boric acid and SHMP also helps improve refractory properties.

3- In fact, these materials react with the silicon in the compound at the time of baking the refractory and by forming a glass phase result in improved particle cohesion, increased density, reduced porosity, increased cold compressive strength.

5. References

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