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STUDY THE EFFECT OF USING LOCAL MATERIALS AS REFRACTORY BONDING MORTAR IN IRAQI

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ABSTRACT

In this research, Iraqi bauxite was used as raw material, after preparation the producing a grog. The mix proportion was applied, (96:4), (93:7) and (90:10) as (bauxite grog: kaolin binding), and the sodium silicate solution as adhesive material 5% by weight of the mix.The burning temperatures for specimens' producing were 1450°C. The physical investigation was carried such as (bulk density, specific gravity, apparent of porosity and water absorption). While the mechanical tests (compressive, bonding) strength, durability investigations such as (thermal shrinkage, reheating expansion and thermal shock). It was found the third group recorded the highest compression and bonding strength and thermal shock resistance and the best physical properties after burning at 1450 °C, with mix proportion (90: 10).

KEYWORD: refractory mortar, local materials, thermal shrinkage, bonding strength, compressive strength.

دراسة تأثير استخدام المواد المحلية كمونة رابطة حرارية

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الخلاصة

في هذا البحث تم استخدام اطيان البوكسايت العراقي كمادة اولية بعد تحضيرها لانتاج الركام الحراري (كروك). تم تطبيق ثلاث نسب (96: 4), (93: 7) و (90: 10) (ركام البوكسايت الحراري: المادة الرابطة الكاؤولين) وكذلك محلول سليكات الصوديوم كمادة لاصقة بنسبة 5% من وزن العينة لكل خلطة . كانت درجة حرارة حرق العينات تصل الى (1450) درجة مئوية .

تم اجراءالتحريات الفيزيائية مثل (الكثافة الظاهرية , الوزن النوعي, المسامية الظاهرية, و امتصاص الماء) . بينما الفحوصات الميكانيكية التي اجريت على العينات هي (مقاومة الانضغاط , مقاومة الربط) وكذلك فحوصات الديمومة مثل (الانكماش الحراري, التمدد بعد اعادة الحرق والصدمة الحرارية) حيث سجلت الخلطة الثالثة (10:90) اعلى مقاومة للانضغاط والربط والصدمة الحرارية وافضل خواص فيزيائية بعد الحرق بدرجة 1450 ^{o}م.

1. INTRODUCTION

Refractories are ceramic materials used in processes where service conditions are severe, such as high temperatures, aggressive liquids or gasses, or mechanical stress. These processes are found in the metal, cement, ceramic, and glass industries (Simon et al., 2003). The local production of refractory binding materials has become necessary because of its increasing needs. It will also reduce the cost and quantity of imported refractory materials from the other country (Agbajelola, 2011). Therefore the Refractory are facilitating or enabling materials, and are essential to the successful for the operation any industry need high temperatures in operation (Al-Tememy, 2014).

The refractory masses or unshaped refractory materials that made from a mixture consists the refractory that based on component and binder. These materials are used in particular as building compositions for the construction, repair, and maintenance of the internal linings of vessels for steel production and as mortar for example units for the smelting or treatment of molten steel (Petriz and Luftenegger, 2012).The refractory mortars that generally preferred are consisting of at least one high temperature (calcined) refractory aggregate and at least one raw (naturally occurring) refractory powder like the various commercially available clays which may serve as a binder for the aggregate. The additional refractory aggregates and /or the additional refractory powders may be used in various combinations. Special binder materials also may be present where the clay used does not provide sufficient cohesiveness (Sullins, 1988).

The advantages of refractory mortars were:

A. The undesirable effects of steam escaping from mortared joints when “burning in” are reduced considerably.

B. Drying and firing shrinkage is very low due to high solids content and a small amount of water required for mixing.

C. The present mortar does not over fire or bloat at high temperatures.

D. Minimum silicates reduce brick penetration so that the mortar. Do not alter brick properties (Begley and Patrick, 1969).

E. Mortars are sometimes thinned with water and used as coatings for the face of the refractory walls in order to seal the joints further or to protect the wall from destructive elements in the furnace (Kadhum and Jaffer, 2013).

Moreover, the refractories are consisted on ceramic materials due to their usage in industrial processes of metal, cement, ceramic and glass that included severe service conditions like high temperatures, aggressive liquids or gasses, or mechanical stress (Simon et al., 2003).

2. EXPERIMENTAL PROGRAMS

2.1. Materials

2.1.1. Raw material:

The Bauxite clay as a raw material of grog has been used. It was provided from AL-Anbar City \ Bauxite Quarries region by the State Company for Mining Industries, in Iraq; and chemical analysis. They were carried out in Building Research Directorate:

The Ore Bauxite was rock exposed to jagging, grinding, which is consisted alumina, silica, and little amount of Gibbsite. Table 1 as illustrated the main oxides ratio.

2.1.2. Binding material:

The Kaolin clays it was used as binding material clay (white kaolin) a granular product produced by crushing and grinding, usually of alumina-silica composition (Harbison, 2005).Chemical analysis as illustrated in Table 1.

Table 1. Chemical analysis of raw materials.

Raw materials	Al_2O_3%	SiO_2%	MgO%	CaO%	Fe_2O_3%	L.O.I %	SO_3%
Bauxite	57.69	22.22	1.32	1.15	1.29	14.73	1.60
Bauxite Specific limits*	50 (min.)	40 (Max.)	----	-----	1.3 (Max.)	----	-----
White-Kaolin	42.90	47.95	Nil	0.76	0.32	13.06	Nil
White-Kaolin Specific limits*	32 (min.)	50 (Max.)	----	-----	1.4 (Max.)	-----	-----

*According to ref. Iraqi Chemical Standard.

2.1.3. Adhesive material:

The sodium silicate (Na_2SiO_3) solution was used in this work as an adhesive material. It is locally named as water glass which has been production in Iraq.

The Sodium silicate dissolving it in water considered a helpful to mix it easily with components during mixture preparation. The density of sodium silicate dissolved in water ranged between (2.4-1.2) gm⁄cm3 Refractory materials. The Sodium silicate in solution form used throughout this work has a density of (1.5 gm. /cm^3).

Water glass (Na_2SiO_3) is a useful adhesive of solids because:

a) It is responsible for hardening the mixtures.
b) It Using sodium silicate solution in forming samples
c) It helps to significantly reduce porosity for the product, therefore, it is used with most ceramic products.
d) Sodium silicate is inexpensive and abundantly available, which makes it use popular in many refractory applications Refractory materials.

2.2. Preparation processes

At the first, the raw materials are crushing and sieving. The purpose of the jagging and grinding process is to increase the surface area of the particles, and that will tend to increase the adhesive among grains and increase its ability to reaction with each other or with the binding materials during firing and leading to improve the physical and mechanical properties Refractory materials.

After that the ore bauxite clay formation as a rectangle shape by a plastic method and drying at room temperature for (24 hrs.) to loss the formation water, and drying in dryer oven at (110°C) for (24 hrs.). The form bauxite clay was burning in a special kiln at (1400°C) for (2 hrs.) in the laboratories of Materials Engineering Department in University of Technology. Then, used in the mixtures after jagging and grinder by disc mail in Central Baghdad Laboratory. The purpose of burnt clay was to reduce shrinkages cracks and deformations throw green stage, and finally, sieving by using sieve no. 200 (75µm) according to (ASTM – C 64, 1972) to make the grog.

And mixing water and (5%) by weight of sodium silicate solution as an adhesive material with bauxite grog and kaolin as a binding material by electrical mixer Science Journal, 9, pp. 10 (2001) as illustrated in Table 2.

After that casting cubic specimen (20*20*20) mm, the thermal treatment in room conditions for (24 hrs.) and oven at (110°C) for (24 hrs.); finally, burning specimens (1450°C) for (2 hrs.). The burning was carried out in Laboratory of materials engineering college in ceramic Department in the University of Babylon. Table 3 show the detail of burning.

Table 2. Details of mix proportion.

Mix No.	Mix symbol	Description (grog: binding material)	Mix proportion (grog: binding material)
1	B: K	Bauxite: Kaolin	96:4
2	B: K	Bauxite: Kaolin	93:7
3	B: K	Bauxite: Kaolin	90:10

Table 3. Details of burning treatment temperature.

Burning Temperature (°C)	
Raw materials	Thermal bearing
1400	1450

3. RESULT AND DISCUSSION

3.1. Compressive strength

This test was measured according to ASTM C64 – 72 (1972) and using a digital compressive machine of ELE international company with loading rate (1.5000 KN/min).

The compressive strength of the refractory mortar was evaluated for all mixes before and after burning at 1450ºC specimens. The results illustrated in Table 4 while Fig. 1 explained the results.

From the Table 4 shows the results of the cold crushing strength the mix three gave a minimum strength of (1.82MPa); which is within an acceptable range (1.3MPa) suggested for refractory. However, ASTM recommended (1.3MPa) as the minimum value for refractory materials (ASTM C64, 1972). This shows that bauxite grog can comfortably withstand impacts at low temperatures (Chukwudi and Eng., 2008).

And it was noticed before burning has the highest compressive strength for mix one and two, but the opposites occurred in the case of mix one. But, the hot compressive strength was showed the opposites behavior than cold compressive strength. The highest compressive strength after burning specimens achieved in mix three.

At the same time, the cold compressive strength of specimens before burning was decreased whenever the kaolin (binding material) content increased. While the hot compressive strength of specimens after burning at 1450°C was increase whenever the kaolin (binding material) content increased; (The temperature of a structure incorporating the present mortar is raised during use; the hydraulic bond begins to fail at intermediate temperatures and a ceramic bond a form which maintains the desired strength above (1600°C) (Saife and Dawoed 2002).

Table 4. Cold and hot compressive strength of mortar specimens.

Mix No.	Mix proportion (grog: binding)	Cold compressive strength (MPa) at room temperature	Hot compressive Strength (MPa)
1	96:4	2.38	81.30
2	93:7	2.05	86.25
3	90:10	1.82	94.10

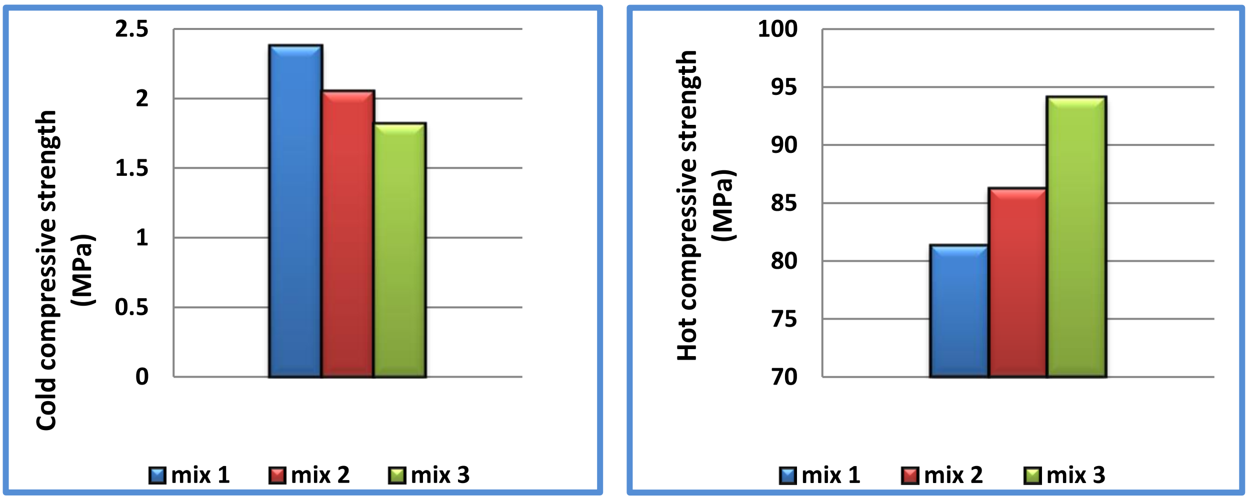


Fig. 1. Cold and hot compressive strength of refractory mortars.

3.2. Bond strength test

Bond strength test was measured by using flexural/tensile testing machine of ELE international company. The preparation of the specimens, included of cutting the fire brick into prism dimension by electrical hacksaw for concrete sawing, then bonding the two parts by refractory mortar products according to (ASTM C 198, 2002). Remained specimens into room temperature for (24 hrs.), drying in oven dryer at (110 ºC) into (24 hrs.) the specimens were tested before burning and after burning.

The results of bonding strength before and after burning at 1450ºC were illustrated in Table 5, while Fig. 2 and Plate 1 showed the bond specimen in three point load test.

The results of the cold bonding strength before burning showed that the mix three gives the lower strength of (0.85 MPa). From the other hands, the mixes were showed a decrement in cold bonding strength with the increment of kaolin (binding material) contain from (1.25MPa) to (0.85MPa). Those aren't within an acceptable value (1.3MPa) as the minimum bonding strength for refractory materials ASTM recommended (ASTM C64, 1972). This shows that mixes can't comfortably withstand impacts at low temperatures (Chukwudi and Eng. (2008).

However, the bonding strength values of the specimens (hot) after burning are higher than the specimens (cold) before burning, but the Table 5 shows the mix three give a (4.32 MPa). While the mixes one and two were failed in the burning kiln no strength (NS).

From the other hands, the highest cold bonding strength was achieved by mix one, while the highest hot bonding strength was obtained by mixes three.

Table 5. Cold and hot bonding strength of mortar.

Mix No.	Mix proportion (grog: binding)	Cold bonding strength(MPa)	Hot bonding strength (MPa)
1	96:4	1.25	NS
2	93:7	0.88	NS
3	90:10	0.85	4.32

Plate 1. Flexural/ tensile testing machine of ELE.

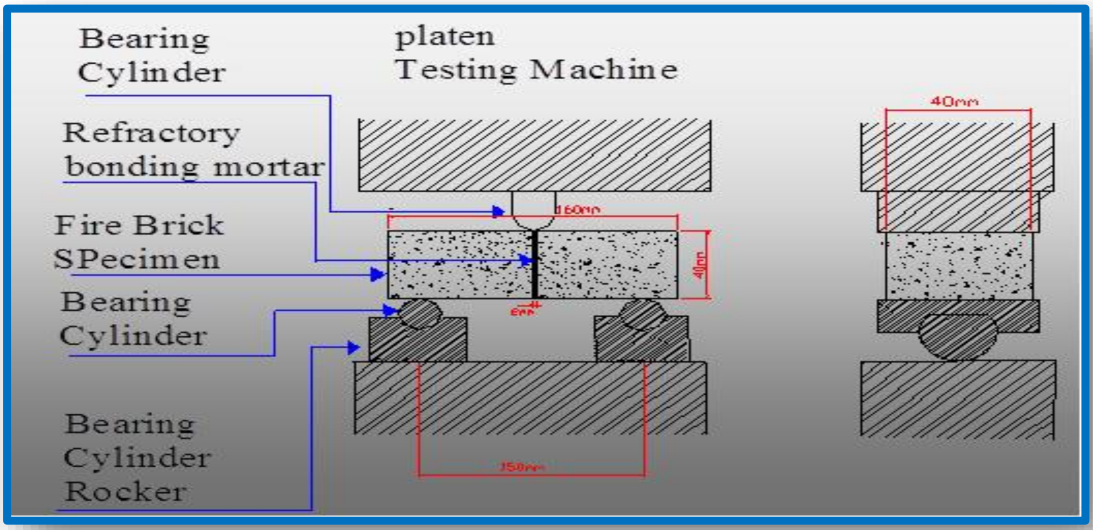


Fig. 2. Three-point load on fire brick by flexural/ tensile testing machine.

3.3. Thermal shrinkage

The Thermal shrinkage test was measured before and after burning the specimens as shown in Table 6 by using the (electronic digital caliper) tool. The thermal shrinkage was measured according to (ASTM C 179, 2004).

The linear thermal shrinkage of the refractory mortar was evaluated for all mixes before and after burning the specimens at 1450°C. So, the results were illustrated in Table 7 to range from (10% to 15%).

It was noticed gave the highest value of the linear thermal shrinkage for mix three and two, which fell outside the recommended range. While the linear thermal shrinkage for mix one was within the recommended range. Chester, (1973), recommended linear shrinkage range of (7%-10%) for refractory clays.

3.4. Reheating expansion

The reheating expansion test was consisted of measuring the dimensions of specimens after burning and after re-burning at (1400°C) as shown in Table 6. The reheating expansion was measured according to (ASTM C 179, 2004).

The results for specimens were illustrated in Table 7. It was noticed that re-burning the specimens at 1400 °C was led to expand the specimens for all mixes. Moreover, the specimens were given same values of expansion for mixes one and three that containing low and high content of kaolin (binding material). that's due to the phase of Mullite is considered as a binding phase in most of the refractory brick and it has a high resistance to melting and minimum thermal expansion as well as low thermal conductivity (Al-Amer and Al-Kadhemy, 2015).

Table 6. Details of thermal shrinkage and reheating test conditions.

Temperature grog burning (°C)	Temperature before specimens burning (°C)	Temperature specimens burning (°C)	Temperature after re-burning of specimens (°C)
1400	110	1450	1400

Table 7. Linear thermal shrinkage and reheating expansion.

Mix No.	Mix proportion (grog: binding)	Linear Thermal shrinkage%	Reheating expansion % at 1400^{o}C
1	96:4	10.0	5.6
2	93:7	10.5	5.3
3	90:10	15.0	5.6

3.5. Physical properties

For physical measurement, water displacement method has been used according to (ASTM C20, 2010). This method consists of using three weights for the specimens dry, saturated and suspended in water calculated after boiling the specimens in water for (2 hours) and emersion it for (12 hrs.) before calculating the weights mansion previous. These weights were used in the equations to calculate the physical properties which are the bulk density, specific gravity, the percentage of apparent porosity, and water absorption.

The results of physical properties were illustrated in Table 8 for mortars burning at 1450^{o}C.

A. Bulk density

It was noticed that bulk density of refractory mortars was increased whenever the kaolin (binding material) content increased for all mixes and that is due to bulk density of kaolin (binding material) range from (2.6 to 2.63) suggested for refractory clays by (Chester (1973) (Chukwudi and Eng., 2008) as shown in Table 8 and Fig. 3 (a).

From the illustrated results, it was observed the mixes were showed a high bulk density for all mixes except mix one where the opposites occurred.

For many refractories materials, the general indication provides from bulk density of the product quality; the refractory with higher bulk density (low porosity) it is considered that will be better in the quality. When the bulk density increase the volume stability increases, the capacity of heat, as well as the abrasion and slag penetration resistance Introduction to refractory and insulating materials. (24/3/2017).

B. Apparent porosity

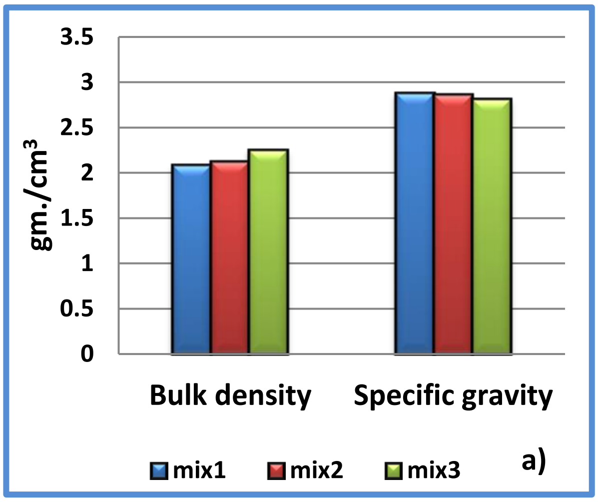
The results were showed that percentage of apparent porosity of bauxite mixes were high apparent porosity. Moreover, the porosity of mixes was low whenever the Kaolin (binding material) content increased (result from bulk density was increased) as shown in Table 8.

The samples of mixes for three mixes gave apparent porosity values between (20.03% - 27.78%) which are within the acceptable range (10-30%) suggested for refractory clays by Chester (1973) Chukwudi, B., Eng., M. (2008). The high porosity materials tend to be highly insulating as a result of the high volume of air they trap because air is a very poor thermal conductor. As a result, the materials have a low porosity are used in the hotter zones generally, while the materials have a more porous are usually used for the thermal backup

(Abdul-Hamead, 2011), as shown in Fig. 3 (a) and (b).

Table 8. Physical properties of mortar specimens after burning at 1450°C.

Mix No.	Mix proportion (grog: binding)	Bulk density (gm./cm^3)	Specific gravity (gm./cm^3)	% apparent porosity	% Water absorption
1	96:4	2.08	2.88	27.78	13.33
2	93:7	2.12	2.86	26.17	12.37
3	90:10	2.25	2.81	20.03	8.93



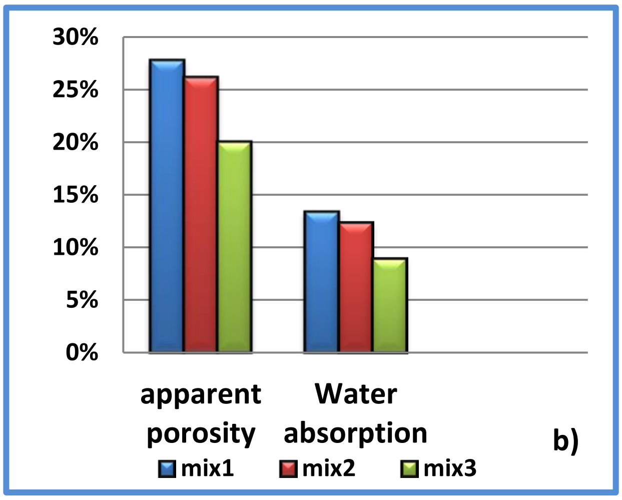


Fig. 3. a) Bulk density and specific gravity of refractory mortars,

b) Apparent porosity and water absorption.

3.6. Thermal shock resistance

In this test, the specimens were heating in an oven at (600°C) for (1 hr.) Then suddenly put off from oven and directly applied the specimens into the ice-water to observation the cracks occurrence (Saife, 2002). Two cycles were applied on the specimens; it was testing in Department of Applied Sciences at The University of Technology. After shocking specimens in ice water, it was measured compressive strength to know how to lowering in strength after shock.

Table 9 shows the compressive strength of specimens for mix one and three before and after applying thermal shock.

From the previous observation of compressive strength, mix three that high content kaolin (binding material) gave higher compressive strength than mix one that low content kaolin (binding material) mixes. But, after applying to the thermal shock, it was observed that the opposite's behavior of compressive strength before thermal shock occurred after thermal shock. Moreover, whenever the kaolin (binding material) content increased the compressive strength increased for mixes before and after applying to the thermal shock.

From the other hands, the values of the reduction in compressive strength after the thermal shock the opposites occurred for mixes containing a high content of kaolin (binding material). Also, the reduction values decreased whenever the kaolin (binding material) content increased. It was directed influence by percentage of apparent porosity for specimens.

Table 9. Thermal shock of mortar specimens.

Mix No.	Mix proportion (grog: binding)	Cycles No.	Compressive strength		% Reduction in strength
			Before shock	After shock	
1	96:4	2	81.3	52.3	35.7
3	90:10	2	94.1	74.4	20.9

4. CONCLUSIONS

At the end of this study about Iraqi refractory mortar some conclusions are reached:

1. The bulk density was increased whenever the plastic clay increased for burnt refractory mortars at 1450^{o}C by about (1.8% - 5.7%) for three mixes.
2. The apparent porosity was decreased with the increment of kaolin (binding material) content.
3. Cold compressive strength for refractory mortar mixes was decreased with kaolin (binding material) content increased.
4. The hot compressive strength after burning at 1450^{o}C was increased with the increment of plastic clay ratio in mixes.
5. The cold bonding strength of refractory mortar for firebrick specimens was decreased when the plastic clay increased.
6. The hot bonding strength of burning refractory mortar specimen's showed failing during the burnt process for groups one and two but only group three gives a hot bonding strength to (4.32 MPa).
7. The reduction percentage of compressive strength was decreased with a decrement of porosity after two cycles of a thermal shock for refractory mortar for group one and three.
8. Thermal expanded of refractory mortars that burning was increased with the increment of kaolin (binding material) content for group two and three, while group one was no thermal expanded.
9. The refractory mortars were showed an increment in thermal shrinkage since the kaolin (binding material) content increased which contained.

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