Effect of Additives on the Performance of the Fire-Clay Refractory Bricks

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Abstract

This work studied the effect of additive materials – ceramic powder, bentonite, and clay-on the performance of fire-clay refractory bricks. The results showed that as the percentage of ceramic powder, clay, or bentonite increased up to 1.5%, shrinkage of the bricks decreased and density of the bricks increased while porosity and water absorption decreased and compressive strength increased.

Introduction

Refractory materials make possible most of the scientific and technological inventions and developments we know today. The existence of virtually everything we see around us or use in everyday life in some way depends on refractory materials.

The development of heavy industries involving iron and steel, nonferrous commodities, cement, glass, boilers, ceramics, gas making, and myriad other enterprises would not exist without the development of refractories (El-Agamawi, 1974). Therefore, we can consider refractories as facilitating or enabling materials essential to the successful operation of any industry that uses high temperatures {Kingery et al (1960), Carniglia and Barna (1992), Lee and Moore (1998), Garbers-Craig (2008)}.

A broad range of applications can use numerous refractory compositions in a wide variety of shapes and forms. Two-thirds of all refractories used by industry involve preformed bricks and other fired shapes. The remainder takes the form of monolithic materials such as castables, plastics, and gunning or ramming mixes. These materials are placed directly in a furnace to form refractory lining upon firing (ASM International handbook committee, 1991).

Fire clay refractories represent the most important refractories from a turnover point of view. They see use in boiler furnaces, blast furnaces, gas retort settings, and lime kilns. In metallurgical furnaces they serve in the melting, reheating, and heat treatment of iron, steel, and nonferrous metals. Fire-clay hollow-ware goes into crucibles and furnace chambers. While inferior to silica and basic refractories in resistance to slag, dense and more aluminous bricks resist slag best.

Clay refractories shrink on firing, and they are less porous than silica refractories (porosity ranges 15–25%, with linear shrinkage at 1400ºC for 2 hours at less than 1%).

Hassan (2005) studied the effect of adding silicon carbide to Kankara clay and found that linear shrinkage and apparent porosity of the bricks made from the blend decreased with the amount of silicon carbide added. The cold crushing strength and thermal shock resistance of the bricks increased as the silicon carbide increased.

This paper studied the effect of adding ceramic powder, bentonite, or other clays to the performance of produced fire clay.

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Experimental work

Raw Materials

Main raw materials

This study used kaolin and ball clay from Sinai Company and grog delivered from special company**.** Table 1 gives the chemical composition of these materials.

Table 1

Chemical composition of refractory raw materials

Component	Kaolin	Ball clay	Grog
Al_2O_3	35	28	66
SiO_2	50	53.58	18.02
CaO	1.62	0.43	0.9
MgO	0.68	0.76	6.8
Na_2O	0.68	0.52	0.6
K_2O	0.1	0.43	0.25
Fe_2O_3	1.32	3.62	2.03
TiO_2	2.02	1.74	2.6
L.I	9.15	10.92	2.55

Additive materials

The additive materials are ceramic powder, bentonite and clay. The chemical composition of the additive materials used in this work is listed in table 2.

Table 2

Chemical composition of additive materials

Clay	Bentonite	Ceramic powder	Component
9.25	17.25	32.13	Al_2O_3
37.55	17.25	51.4	SiO_2
0.9	1.04	0.58	CaO
28	2.93	0.23	MgO
2.14	1.03	1.71	Na_2O
0.84	0.98	0.98	K_2O
2.78	7.77	2.35	Fe_2O_3
0.23	1.22	0.92	TiO_2
-	-	0.04	MnO

This study used about 46.36% ceramic powder with a size less than 0.833 mm, and about 33.56% of ceramic powder, with a size less than 0.75 mm; about 80% of bentonite is smaller than 0.75 mm. About 50% of the clay used was more than 0.75 mm, and about 50% was less than 0.75 mm.

Figs. 1-3 show the X-ray diffraction pattern of ceramic powder, bentonite, and clay. Ceramic powder consists mainly of mullite ($Al_{4.52}Si_{1.48}O_{9.74}$), corundum ($Al_2O_3$), cordierite ($Mg_2Al_4Si_5O_{18}$), and magnesium aluminum oxide ($MgAl_2O_4$) (Fig. 1). The bentonite mainly consists of kaolin, montmorilanite, and quartz (SiO_2) (Fig. 2), while the clay consists mainly of montmorilanite, quartz (SiO_2), calcite ($CaCO_3$), and gypsum ($CaSO_4\cdot\cdot 2H_2O$).

Preparation of raw materials

We used a jaw crusher on the grog and prepared the kaolin and ball clay by roll grinding. The grog, kaolin, and ball clay with the additive materials were mixed together according to the experiment's program with a predetermined amount of water in the mixer.

We then manually pressed the mixture with the water into approximate brick shapes, after which we dried the bricks for one day before pressing them with a hydraulic press. We then air dried the bricks for five days to eliminate moisture before firing. After five days we kiln-fired the dried bricks at the required temperature.

For thermal-shock resistance, we heated the specimens to 1000°C, removed them in their heated state, and dropped them into cold water. The number of times they withstand stand this treatment without spelling signifies a measure of their thermal-shock resistance (Kenneth 1972).

The volume of liquid absorbed by the pores when the specimen is boiled in a vacuum and the material is saturated with water determines the apparent porosity. We can calculate the apparent porosity (P_A) by

$$P_A = [(d_2 - d_1) / V] \times 100$$

where d_1 and d_2 represent the weight of the absolutely dry specimen and the weight of the same specimen saturated with water in grams, respectively, and V signifies the volume of the specimen cm^3 (Kenneth 1972).

The water absorption (W) of a refractory is the ratio between the weight of the absorbed water to the weight of the specimen (Kenneth 1972) and equals

$$W = [(d_2 - d_1) / d_1] \times 100 \%$$

Apparent density equals the ratio between the weight of specimen d_1 and its volume V.

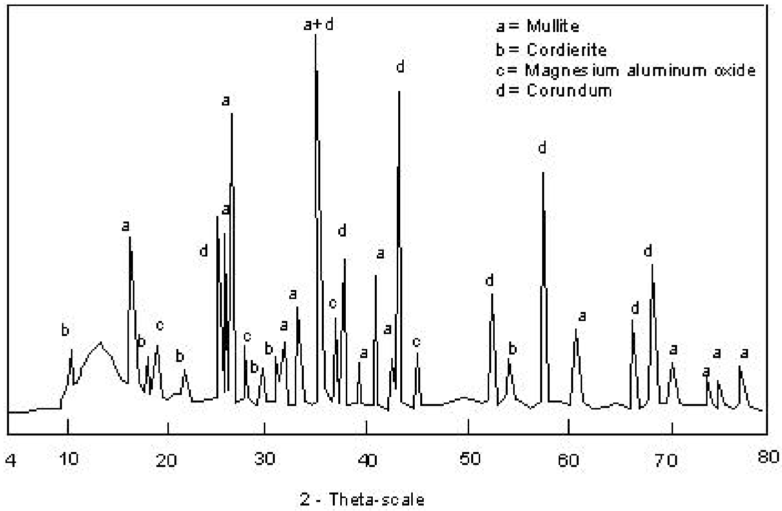

Fig. 1. X-ray diffraction of ceramic powder.

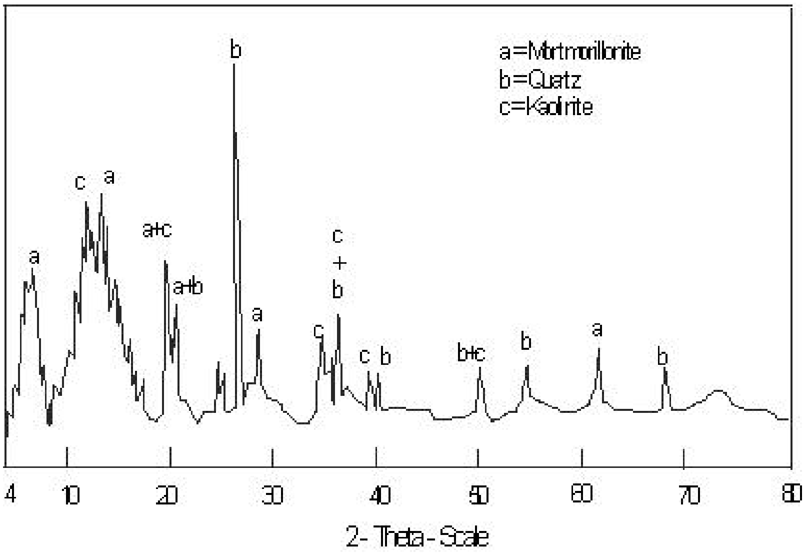

Fig. 2. X-ray diffraction of bentonite.

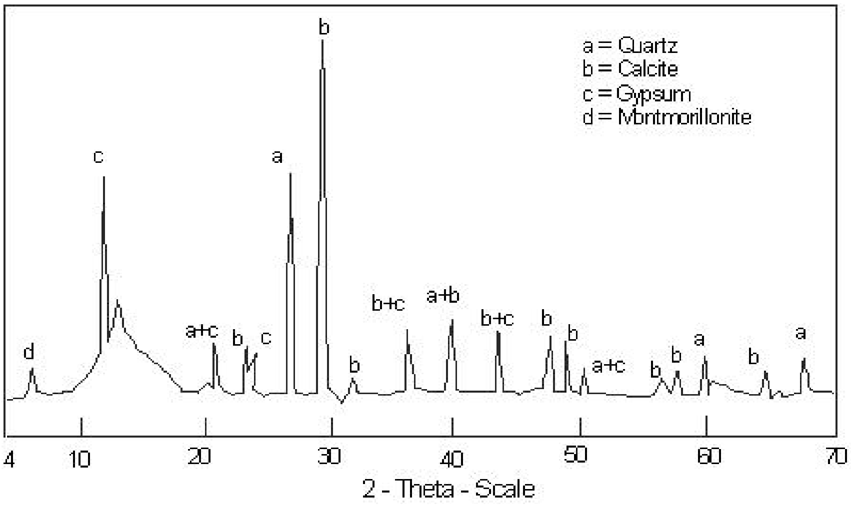

Fig. 3. X-ray diffraction pattern of clay

Results and discussion

Effect of added ceramic powder

In this work, the size of the grog is -3+2.5mm, the percentage of kaolin to ball clay ratio is fixed at 1:1; the percentage of water added is 12%; the pressed is fixed at 55.37 MPa with a firing temperature at 1200°C; the percentage of grog is 50% {Elngar.M.A.G. et al(2009)}; and the amount of added ceramic powder varied.

Fig. 4 shows the relationship between the percentages of ceramic powder added and bulk density and porosity of the brick. This demonstrates that as the percentage of ceramic powder increased, the bulk density of the brick increased, and the porosity decreased. This may occur because the ceramic powder melted more and subsequently closed more pores.

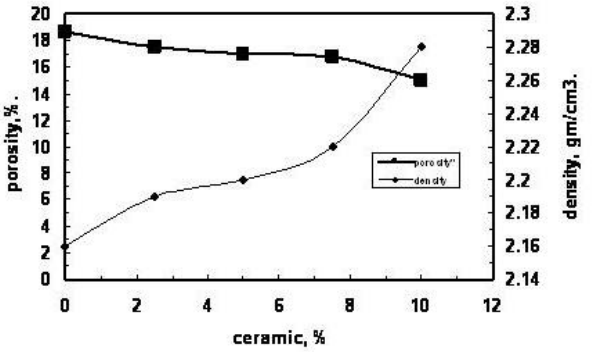

Fig. 4. Effect of the percentage of ceramic powder on the bulk density of produced bricks.

Fig. 5 illustrates the relationship between the percentage of ceramic powder and the percentage of water absorption and reveals that as the amount of ceramic powder increased, the water absorption decreased. We may attribute this to the decrease of porosity.

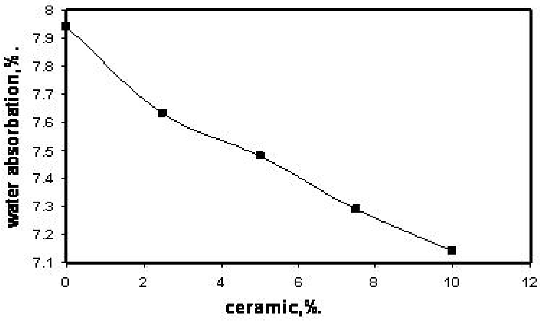

Fig. 5. Effect of ceramic powder percentage on the water absorption of produced bricks.

Fig. 6 shows the effect of the ceramic powder percentage on the volume shrinkage of the produced bricks after 5 days drying and firing. We can clearly see that as the percentage of ceramic powder increased, volume shrinkage of both dry bricks and fired bricks increased. We can attribute the increased shrinkage during firing to the melting of components of the ceramic powder before other constituents of the bricks.

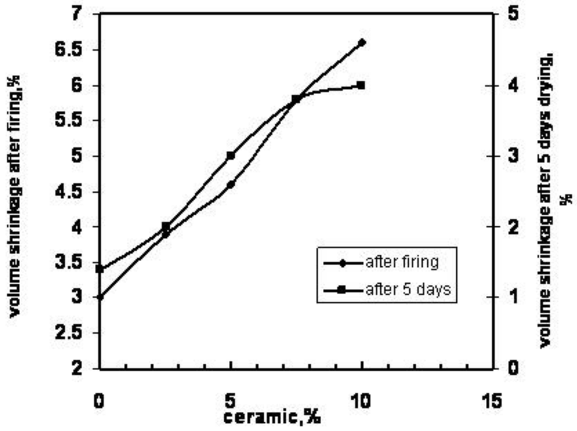

Fig. 6. Effect of ceramic powder percentage on volume shrinkage of produced bricks.

Fig. 7 reveals that both crushing strength and thermal shocks increased as the percentage of ceramic powder increased. This may occur because of the decreased porosity of the bricks and because the strength is directly proportional to the shrinkage that takes place during the firing of these refractories (Wynnyckyj and Fahidy (1974)).

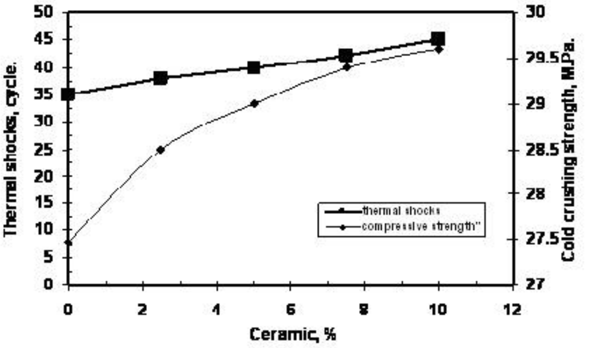

Fig. 7. Effect of ceramic powder percentage on cold compressive strength and thermal shocks of produced bricks.

Table 3 demonstrates the relationship between the amount of ceramic powder and the chemical composition of the bricks and shows that as the amount of ceramic powder with percentages of

Al_2O_3, CaO, MgO, TiO_2, and SiO_2 decreased, the Na_2O, K_2O, and Fe_2O_3 slightly increased. This occurs because the ceramic powder contained less Al_2O_3, CaO, MgO, TiO_2, and SiO_2 and more Na_2O, K_2O, and Fe_2O_3 (Table 2) than the raw materials (Table 1).

Table 3
Effect of percentage of ceramic powder on the chemical composition of produced bricks

% ceramic powder	Al_2O_3	SiO_2	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2
0	51.36	37.98	1.025	3.89	0.645	0.28	2.42	2.385
2.5	50.12	37.07	1.025	3.80	0.675	0.30	2.42	2.351
5.0	48.93	36.20	1.016	3.70	0.704	0.32	2.43	2.319
7.5	47.80	35.37	1.007	3.62	0.731	0.34	2.432	2.289
10.0	46.69	34.58	0.999	3.54	0.758	0.35	2.44	2.26

Properties of brick produced by replacement of ceramic powder in place of of kaolin and ball clay

In this work, ceramic powder completely replaced the kaolin and ball clay while the amount of grog was fixed and equal to 50%; the amount of water was 12%, and the firing temperature was 1200°C. Table 4 shows these results.

Table 4
Comparison between properties of produced bricks using ceramic powder in place of a mixture of ball clay and kaolin

Percentage of ceramic powder in the mixture, %	100	zero
Compressive strength, MPa	32.8	27.47
Thermal shocks, cycle	48	35
Volume shrinkage after 5 days,%	4.4	1.39
Volume shrinkage after firing,%	6.8	3.0
Water absorption, %.	7	7.94
Bulk density, g/cm^3.	2.35	2.16
Porosity, %.	14.6	18.62

Table 4 demonstrates the superiority of the bricks produced using ceramic powder over that produced using a mixture of ball clay and kaolin. This occurs due to the ceramic powder's ability to melt easier.

Fig. 8 shows an X-ray analysis of the bricks prepared from 50% grog and 50% ceramic powder, with 12% water, and fired at 1200°C. This figure reveals the main constituent of the bricks: mullite Al ($Al_{1.27}.2Si_{0.728}O_{4.864}$), quartz ($SiO_2$), corurndum ($Al_2O_3$), Cristobalite ($SiO_2$), and Albite ($NaAlSi_3O_8$). These phases formed for the following reasons. The kaolinite crystals remain intact until they reach 450°C, and they break down into an amorphous mass. At this point the water is expelled with absorption of heat and loss of weight. Meta-kaolin ($Al_2O_3.2SiO_2$) forms at 980°C. A sharp escalation of heat causes sudden crystallization of the amorphous mass into mullite, although gamma (Al_2O_3) has been found as a transitory phase. As temperature increased, the mullite crystals grow, and the glassy phase pulls the particles together, causing shrinkage. Around 1200°C, cristobalite crystallizes from siliceous glass.

$Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$ -------450°C---------$Al_2O_3{\cdot}2SiO_2$ -------980°C (Agamawi 1977)

Comparing Figs. 8 and 9, we can see that the phase of Albite $NaAlSi_3O_8$ occurs more in the case of ceramic powder than in the case of kaolin and ball clay because ceramic powder containing feldspar was used as fluxing material, while the corundum Al_2O_3 in the case of ceramic powder occurs less than in the case of kaolin and ball clay, and the other components remain nearly the same.

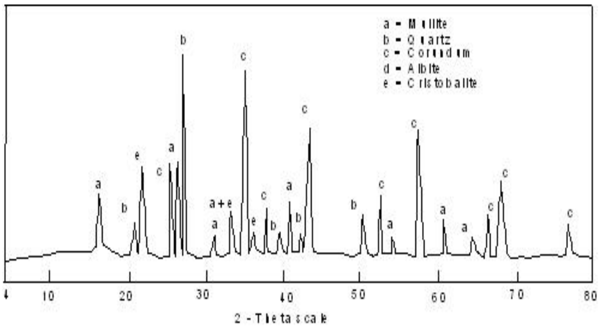

Fig. 8. X-ray of the produced bricks using ceramic powder instead of a mixture of ball clay and kaolin.

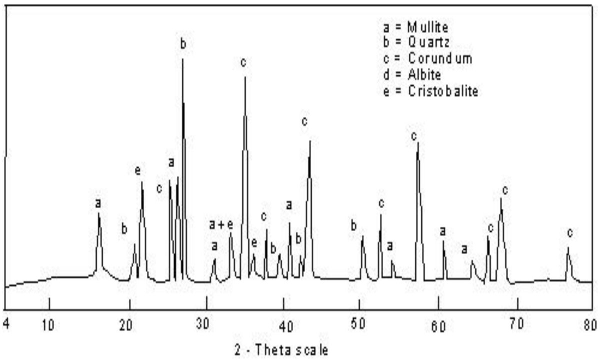

Fig. 9. X-ray of the produced bricks using a mixture of ball clay and kaolin.

Effect of addition of bentonite

This study used -3+2.5mm grog. The percentage of kaolin to ball clay ratio was fixed at 1:1, and the percentage of water added was 12%. The pressed brick pressed was fixed at 55.37 MPa with a firing temperature of 1200°C. The percentage of grog was 50%, while the amount of bentonite added varied.

We can see that as the percentage of bentonite increased to 1.5%, the bulk density of the brick increased. The bulk density of the brick then decreased as the amount of bentonite increased more than 1.5% (Fig. 10). The increase of bulk density with the addition of 1.5% bentonite may result from the decrease of porosity of the brick, and it may be that bentonite at this value makes more contact with the particles of the raw material (Fig. 10).

Fig. 11 shows that as the amount of added bentonite increased to 1.5%, the water absorption decreased. We can attribute this to the decrease of porosity. The water absorption then increased slightly as the amount of bentonite added increased this as the porosity of the brick increased.

Fig. 12 shows the effect of the percentage of bentonite added on the volume shrinkage of the produced bricks after 5 days drying and subsequent firing. This shows that as the percentage of added bentonite increased to 1.5%, volume shrinkage of both the dry bricks and firing increased and shrinkage of the bricks decreased.

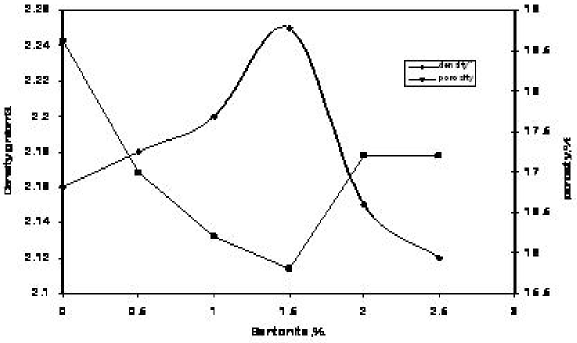

Fig. 10. Effect of bentonite percentage on the bulk density of the produced bricks.

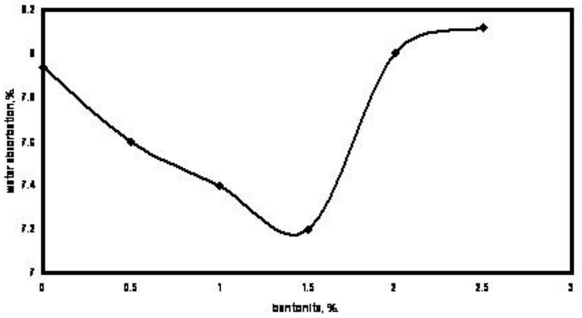

Fig. 11. Effect of bentonite percentage on water absorption of the produced bricks.

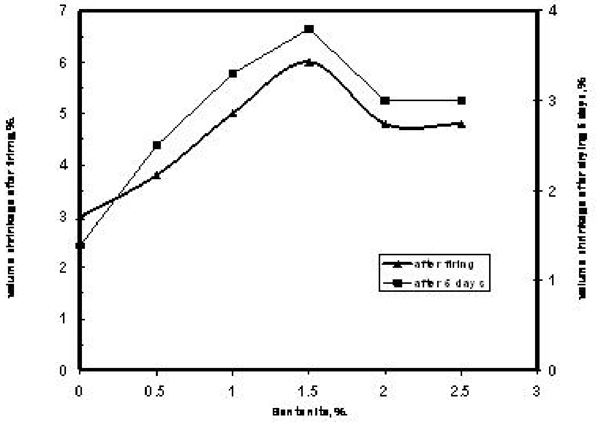

Fig. 12. Effect of bentonite percentage on volume shrinkage of the produced bricks.

Fig. 13 demonstrates the effect of the additional percentage of bentonite on the compressive strength and thermal chokes of the produced bricks. This makes it clear that both crushing strength and thermal shocks increased as the percentage of bentonite increased up to 1.5% then slightly decreased as the amount increased. The increase of both crushing strength and thermal shocks when the amount of bentonite increased to 1.5% may occur because of the decreased porosity of the bricks (Fig.10). Also, the strength is directly proportionate with the shrinkage that takes place during the firing of these refractories {Wynnyckyj and Fahidy (1974)}. Possibly, the bentonite increased the coagulation between the particles and improved the specific area of the mix {Mayer (1980)}, which subsequently resulted in an increase in the refractory strength {Ahmed (1996)}. Further, we can attribute the slight decrease of both crushing strength and thermal shocks when the bentonite increased more than 1.5% to the change of the structure of the brick.

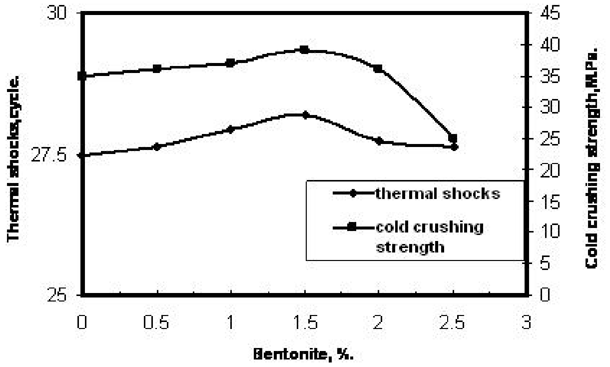

Fig. 13. Effect of bentonite percentage on cold compressive strength and thermal shocks of the produced bricks.

Table 5 illustrates the relationship between the amount of bentonite added and the chemical composition of the bricks, and it shows that as the amount of bentonite increased the percentage of all chemical components slightly decreased.

Table 5

Effect of percentage of added bentonite on the chemical composition of the produced bricks

% bentonit	Al_2O_3	SiO_2	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2
0	51.36	37.98	1.025	3.89	0.645	0.28	2.42	2.385
0.5	51.11	37.79	1.020	3.87	0.642	0.279	2.41	2.373
1.0	50.85	37.61	1.015	3.85	0.639	0.277	2.40	2.362
1.5	50.61	37.42	1.010	3.83	0.636	0.276	2.39	2.350
2.0	50.36	37.24	1.005	3.81	0.633	0.275	2.38	2.339
2.5	50.12	37.06	1.001	3.80	0.629	0.274	2.37	2.327

In this work, as mentioned earlier, the grog measured -3+2.5mm; the percentage of kaolin to ball clay ratio was fixed at 1:1; the water added was 12%; the pressed is fixed at 55.37 MPa with firing temperature at 1200°C; and the percentage of grog is 50%, while the amount of added clay varied.

Fig. 14 shows the relationship between the percentages of the added and the bulk density of the brick. We clearly see that as the percentage of clay increased, the bulk density slightly increased. The increase in bulk density may relate to the porosity of the brick decreasing as the amount of added increased (Fig. 14). On the other hand, it may relate to the added clay leading compacting between the raw materials.

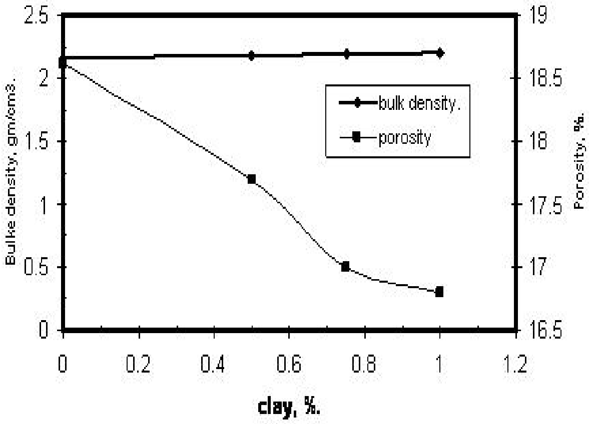

Fig14. Effect of clay percentage on the bulk density of the produced bricks.

Fig. 15 gives the relationship between the percentage of clay added and the percentage of water absorption. We can see that as the amount of added increased, the water absorption decreased; this we can attribute to the decrease of porosity.

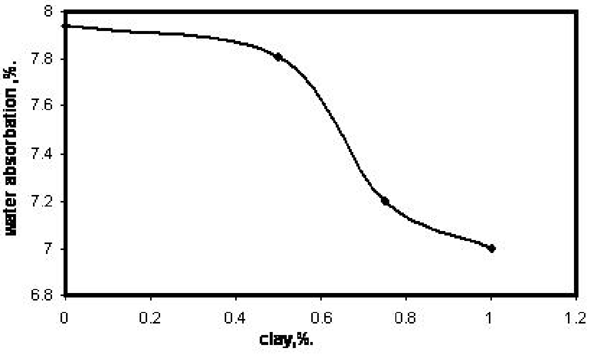

Fig. 15. Effect of percentage of clay on water absorption of produced bricks.

Fig. 16 reveals the effect of the percentage of clay added to the volume shrinkage of the produced bricks after drying for five days and subsequent firing. We can clearly see that as the percentage of added clay increased, the volume of shrinkage of the dry and fired bricks increased slightly. This may occur because the shrinkage of the clay is approximately similar to that of the kaolin and ball clay.

Fig. 16 illustrates the effect of the percentage of the added clay on the compressive strength and thermal chokes of the produced bricks. This reveals that both crushing strength and thermal shocks increased slightly as the percentage of clay increased.

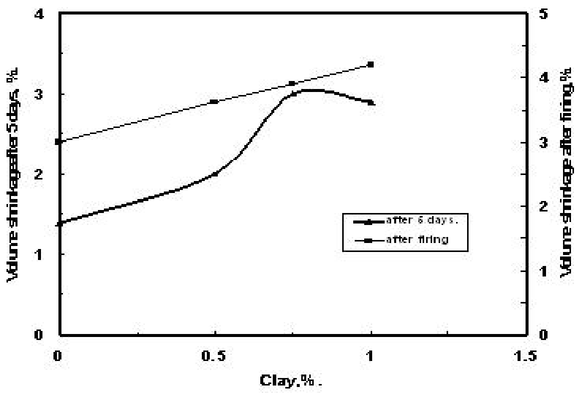

Fig. 16. Effect of clay percentage on volume shrinkage of the produced bricks.

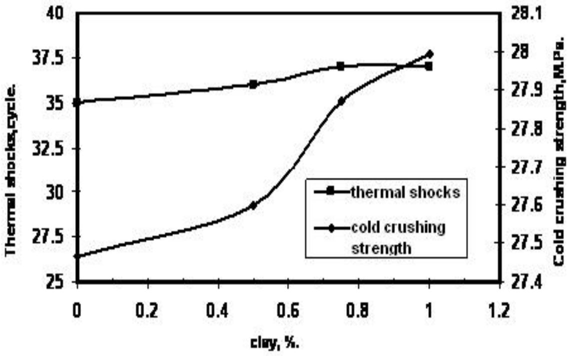

Fig. 17. Effect of clay percentage on cold compressive strength and thermal shock of the produced bricks.

Table 6 shows the relationship between the amount of clay and the chemical composition of the bricks, and it also shows that as the amount of clay increased, the percentage of all components of the bricks decreased slightly.

Table 6

Effect of the percentage of added clay on the chemical composition of the produced bricks

% Clay	Al_2O_3	SiO_2	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2
0	51.36	37.98	1.025	3.89	0.645	0.28	2.42	2.385
0.50	51.11	37.79	1.019	3.87	0.642	0.279	2.41	2.373
0.75	50.98	37.70	1.017	3.86	0.640	0.278	2.40	2.367
1 .00	50.85	37.61	1.015	3.85	0.638	0.277	2.396	2.361

Conclusion

1. Addition of ceramic powder up to 10% in this study's investigation range improved the property of the fire bricks.
2. Addition of bentonite up to 1.5% improved the properties of fire clay.
3. Addition of clay within this study's investigation range improved the physical properties of the fire bricks.

The chemical analysis of the produced bricks changed according to the chemical analysis of the additive materials.

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