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FACTORS AFFECTED THE PERFORMANCE OF FIRE CLAY REFRACTORY BRICKS

1. Introduction

Refractories are materials which remain unmelted at (1580ºC). They are chemically inert, strong enough to withstand the weight and wear of the melted material and slag resist to cracking and splitting under various temperatures and can be easily molded into bricks or other forms of construction materials [1].

The development of heavy industry and the necessary power production would have been impossible without development of refractories.

Fire clay refractories are the most important types from the point of view of turnover. They are used in boiler furnaces; blast furnaces, gas retort setting, lime kilns, metallurgical furnaces for melting, reheating and heating treatment of iron, steel or non ferrous metals.

They are inferior to silica and basic refractories in resistance to slag. Dense and more aluminous bricks resist slag the best.

Calcined clay or grog is added to the brick mix to reduce the firing shrinkage and to give greater stability in applications [8].

Much effort has been made to produce bricks with lower porosity for slag resistance by careful grog sizing, high pressure forming, and high firing [2].

If the grain size of the grog used in the body preparation is large, the resultant refractory goods are more porous, thus more resistant to sudden temperature changes. On the other hand if the grog used fine grained, the final fire clay material is less porous and thus more resistant to slag and chemical attack and characterizes by higher cold crushing strength.

This work aimed studies the factors affected the performance of the fire clay refractory bricks.

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2. Experimental work

2.1. Raw Materials

Kaolin and ball clay used in this experiment are delivered from Sinai Company, grog was delivered by special company. The chemical composition of these materials are shown in Table 1.

TABLE 1

The chemical composition of the refractory raw materials

Component	Kaolin	Ball clay	Grog
Al_2O_3	35.00	28.00	66.00
SiO_2	50.00	53.58	18.02
CaO	1.62	0.43	0.90
MgO	0.68	0.76	6.80
Na_2O	0.68	0.52	0.60
K_2O	0.10	0.43	0.25
Fe_2O_3	1.32	3.62	2.03
TiO_2	2.02	1.74	2.60
L.I	9.15	10.92	2.55

From this table it is clear that, kaolin contain 35% Al_2O_3 while ball clay and grog 28% contains 28%, 66% Al_2O_3 respectively. Also it is clear that ball clay contains more silica than kaolin and grog.

X-ray diffraction analyzes for raw materials are illustrated that kaolin consists mainly of kaolinite $Al_2Si_2O_5(OH)_4$, quartz (SiO_2) and anatase (TiO_2) so the ball clay. However, the grog mainly consists of multi $Al_{1.272}Si_{0.728}O^{4.864}$ and quartz SiO_2.

Differential thermal analyses (DTA) of the kaolin and ball clay show the thermal analysis of kaolin from which it is clear that it is endothermic at 517.7°C and exothermic at 986.4°C. The endothermic reaction is due to the removal of water crystallization of kaolin, while the exothermic reaction is due to the oxidation of FeS.

Differential thermal analyses (DTA) of the ball clay shows the thermal analysis of ball clay from which it is clear that there are endothermic reaction at 513.5°C, while exothermic ones at 957.8°C. The endothermic and exothermic reaction occur due to the same reasons explained before.

2.2. Preparation of raw materials

The grog was crushed in jaw crusher, while kaolin and ball clay were grinded in the roll grinder. Grog, kaolin and ball clay were mixed together according to the experiment program with the predetermined amount of water in the mixer.

The mixture of grog, kaolin and ball clay with water was then manually pressed in approximated brick shaper after which the manually pressed brick dried for one day before pressing in hydraulic press. Then, the bricks dried in air conditions for 5 days to eliminate the water before firing. The dried brick was then fired on the kiln according to the program schedule until the required temperature was obtained.

In thermal shock resistance, the specimens were heated in laboratory furnace till 1000°C and removed in hot state, then dropped into cold water. This treatment was repeated several times without spalling and this was the measure of their thermal shock resistance [4].

The apparent porosity is determined by the volume of liquid which was absorbed by the pores when the specimen is boiled in vacuum conditions, and when the material is saturated in water. The apparent porosity (PA) can be calculated from the formulae (1).

$$P_A = \left(\frac{d_2 - d_1}{V} \right) \times 100 \qquad (1)$$

Where: d_1 and d_2 is the weight of the absolutely dry specimen and the weight of the same specimen saturated in water [g], and V is the volume of the specimen [cm^3] [4].

The water absorption (W) of a refractory is the ratio between weight of the absorbed water and weight of the specimen [4] and equals to

$$W = \left(\frac{d_2 - d_1}{d_1} \right) \times 100 \qquad (2)$$

Apparent density is equal to the ratio between weight of specimen d1 and its volume V.

3. Results and discussions

3.1. Effect of grog percentage on the properties of the produced brick

In this work the size of grog is – 3 + 2.5 mm, the percentage of kaolin to ball clay ratio is fixed to 1:1 and the percentage of added water = 12%. The brick pressure conditions are fixed at 55.37 MPa with firing temperature = 1200°C, while the percentage of grog was changed. The density of the brick, percentage of porosity and water absorption were measured too and the results are illustrated on the Figures 1–3.

Figure 1 shows the relationship between the percentage of grog and bulk density of the brick. It is clear that as the percentage of grog increased the bulk density of the brick also increased. This may occur due to decreasing of the porosity of brick causing increasing the percentage of grog (Fig. 2). This may be due to the evaporation of water from kaolin and ball clay and lack of water evaporation from grog.

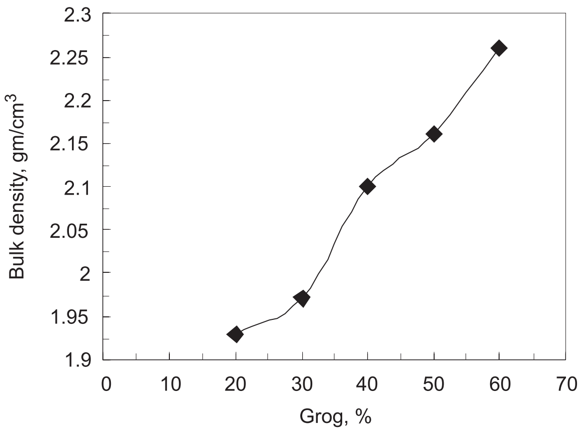

Fig. 1. Effect of grog % on the bulk density of the produced brick

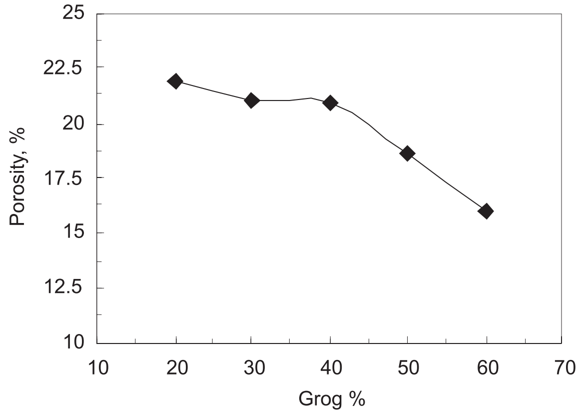

Fig. 2. Effect of grog % on the porosity of brick

Figure 3 illustrates the relationship between the percentage of grog and the percentage of water absorption. It is clear that as the amount of grog increased the water absorption decreased. This may be attributed to the decrease of porosity.

Effect of the grog percentage on the volume shrinkage of the produced bricks after drying for 5 days and firing is illustrated on Figure 4. It is clear that as the percentage of grog increased both, volume shrinkage of dry bricks and fired bricks are decreasing. This may be caused by the fact that the grog did not shrink.

Figure 5 illustrated the effect of the grog percentage on the compressive strength and thermal shocks of the produced bricks from which it is clear that both crushing strength and thermal shocks increased as the percentage of grog increased. This may be result of the decreasing of the porosity of the bricks (Fig. 2).

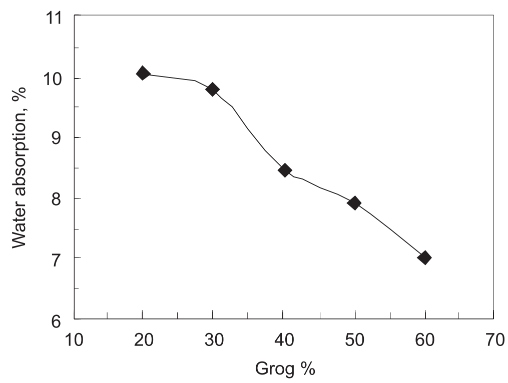

Fig. 3. Effect of grog % on water absorption

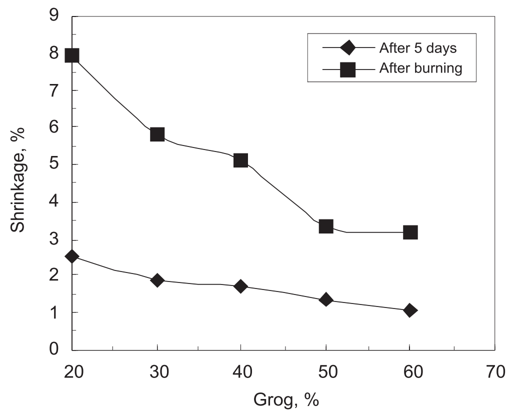

Fig. 4. Effect of grog on the shrinkage of the produced bricks after drying for 5 days and after burning

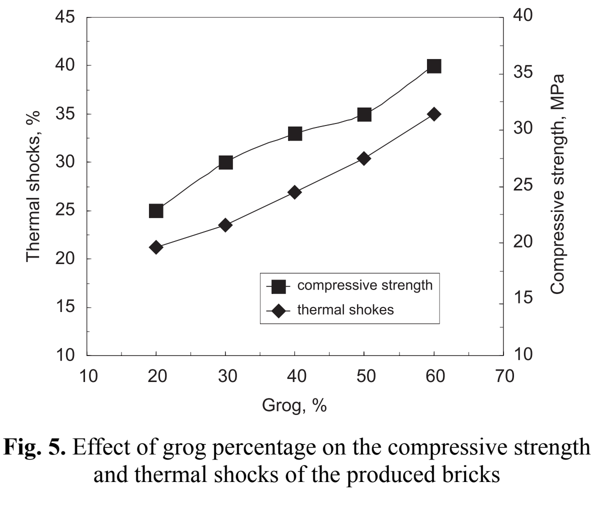

Fig. 5. Effect of grog percentage on the compressive strength and thermal shocks of the produced bricks

3.2. Effect of the grog percentage on the chemical composition of the produced bricks

Table 2 illustrates the relation between amount of grog and the chemical composition of the bricks. From this table it is clear that as the amount of grog increased the percentage of alumina increased and reached the value of 54.63% at 60% of grog used. The percentage of silica decreased to 34.08% at 60% of used grog. This is due to the fact that grog contains high amount of alumina and low of silica.

TABLE 2
The effect of the percentage of grog on the chemical composition of the produced bricks

% Grog	Al_2O_3	SiO_2	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2
20	41.53	49.78	1.088	2.04	0.66	0.29	2.624	2.214
30	44.81	45.86	1.067	2.65	0.655	0.288	2.556	2.271
40	48.08	41.95	1.046	3.27	0.65	0.284	2.488	2.328
50	51.36	37.98	1.025	3.89	0.645	0.28	2.42	2.385
60	54.63	34.08	1.004	4.51	0.64	0.276	2.352	2.442

3.3. Effect of the water percentage added on the properties of the produced brick

In this work, the size of grog was – 3 + 2.5 mm, the percentage ratio of kaolin to ball clay was fixed as 1:1 and the percentage amount of grog was 50%. The pressure conditions for the bricks were fixed as 55.37 MPa, temperature of firing = 1200°C while the percentage of added water were various. Figure 6 shows the relationship between the percentage of added water and bulk density of the brick. It is clear that as the percentage of water increased the bulk density of the brick decreased. This may be due to the evaporation of water and subsequently the porosity of the brick increased as is shown on Figure 7.

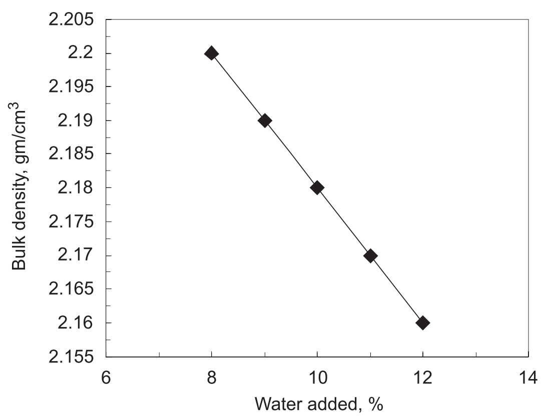

Fig. 6. Effect of added water on the density of the produced bricks

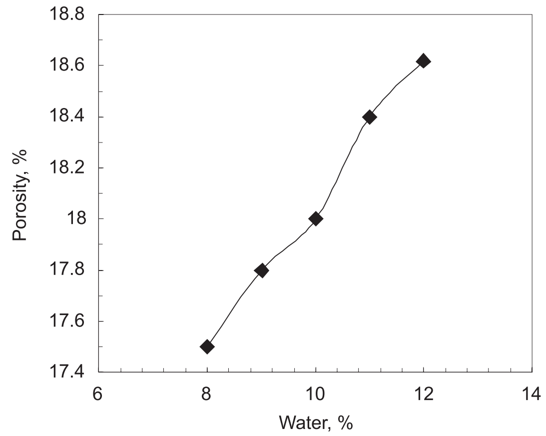

Fig. 7. Effect of added water on the porosity of the produced bricks

Figure 8 illustrates the relationship between the percentage of added water and the percentage of water absorption. It is clear that as the amount of water added increased the water absorption also increased. This may be caused by the increase of the porosity.

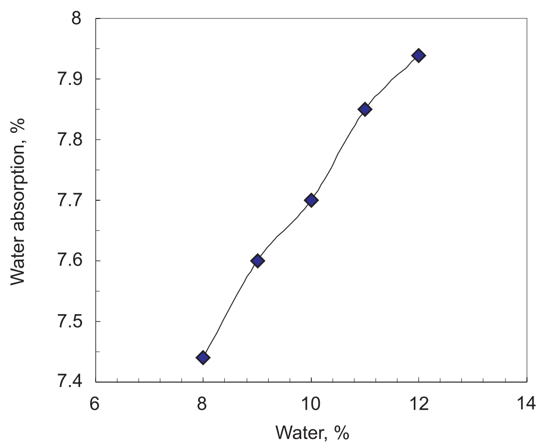

Fig. 8. Effect of water percentage on the absorption of produced bricks

Effect of added water percentage on the volume shrinkage of the produced bricks after drying for 5 days and after firing is illustrated on Figure 9. It is obvious that as the water added to the raw mix. increased the volume shrinkage of bricks, after drying for 5 days and after firing, increased. This may be due to the evaporation of water from the bricks.

Effect of water added percentage on the compressive strength and thermal shocks of produced bricks is illustrated on Figure 10, from which it is clear that the thermal shocks and compressive strength decreased as the amount of water added to the raw mix increased. This is due to the increase of porosity as shown on Figure 7.also the micropore voids vary with the moisture content of the briquette and the removal of water causes a general contraction of the structure such as the volume of voids decreases in proportion to the amount of water removal [3].

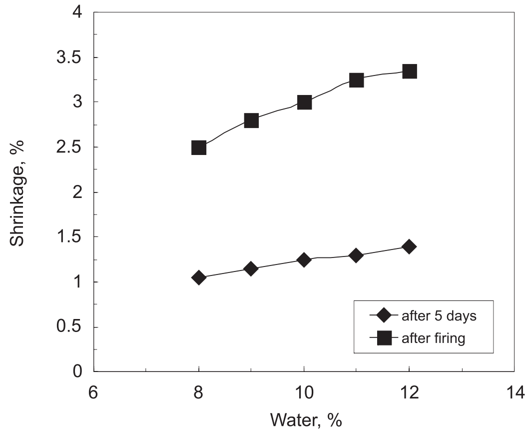

Fig. 9. Effect of added water percentage on the shrinkage of produced bricks after 5 days and after firing

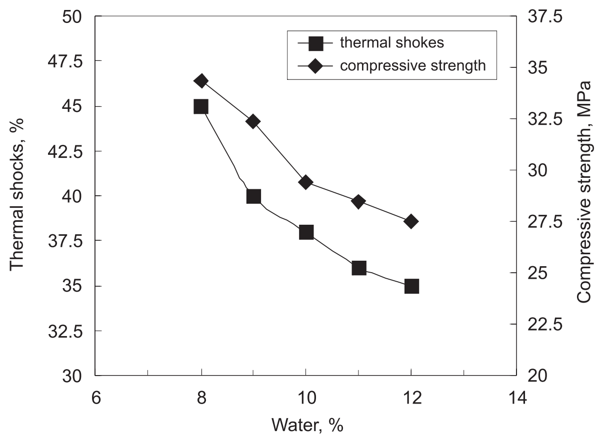

Fig. 10. Effect of added water on the compressive strength and thermal shocks of the produced bricks

3.4. Effect of the grog size on the properties of the produced brick

In this work the size of grog were changed while the grog percentage is fixed at 50%. The percentage of kaolin to ball clay ratio is fixed 1:1 and the percentage of added water =

12%. The pressure conditions were fixed 55.37 MPa and temperature of firing = 1200°C while the grog size were changed.

Figure 11 shows the relationship between the size of grog and bulk density of the brick. It is clear that as the size of grog decreased the bulk density of the brick increased. This may be due to the porosity of the brick decreased as the grog size decreased as shown in Figure 12.

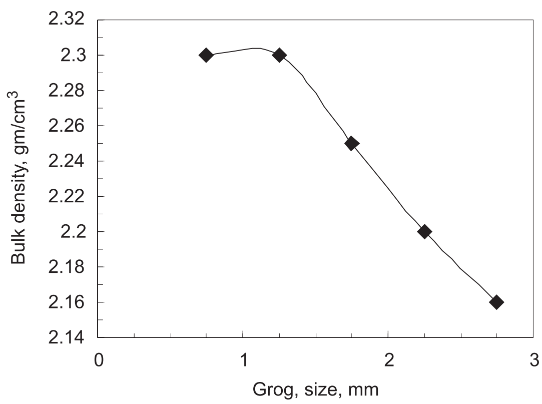

Fig. 11. Effect of grog size on the bulk density of the produced bricks

Figure 12 shows that as the size of grog decreased the porosity of the brick decreased too. This may be due to the higher contact of fine particles.

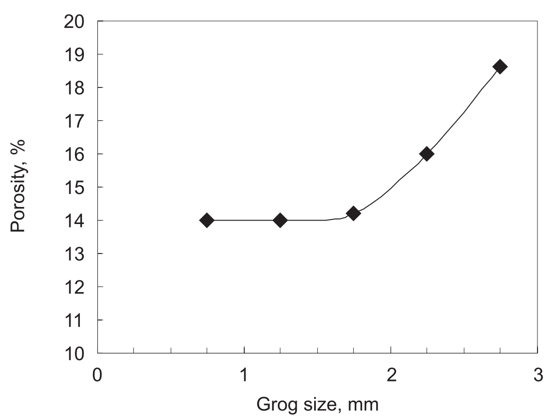

Fig. 12. Effect of grog size on the porosity of the produced bricks

Figure 13 illustrates the relationship between grog size and the percentage of water absorption. It is clear that as the size of grog increased the water absorption increased too. This may be attributed to the increase of porosity as the size of grog increased.

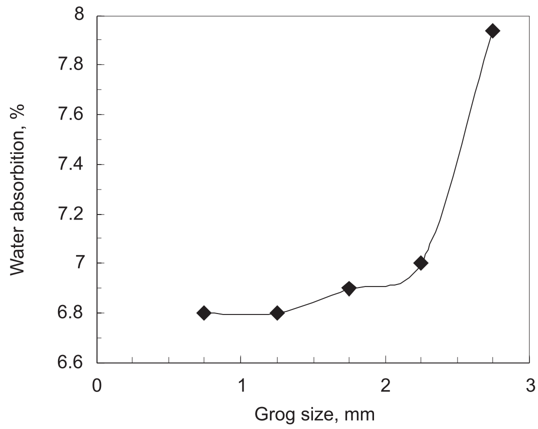

Fig. 13. Effect of grog size on the water absorption of the produced bricks

Effect of the grog size on the volume shrinkage of the produced bricks after drying for 5 days and after firing is illustrated on Figure 14. It is clear that as the grog size increased both volume shrinkage of dried bricks and fired bricks are increased slightly. The lower volume shrinkage at small size of grog particles may be due to the higher contact between the grog particles.

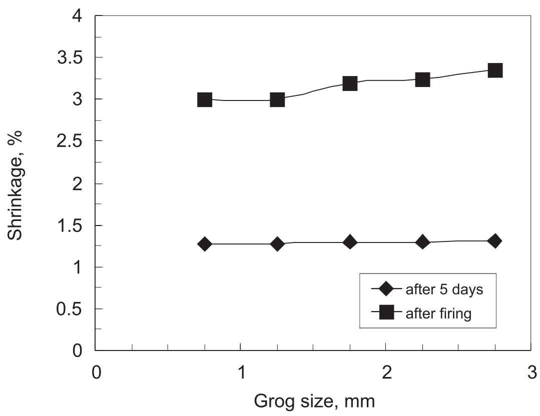

Fig. 14. Effect of grog size on the shrinkage of the produced bricks after drying for 5 days and after firing

Figure 15 shows the effect of the grog particles size on the compressive strength and thermal shocks of the produced bricks. It is clear that as the grog size increased the compressive strength and thermal shocks decreased. This may be due to the porosity of the bricks.

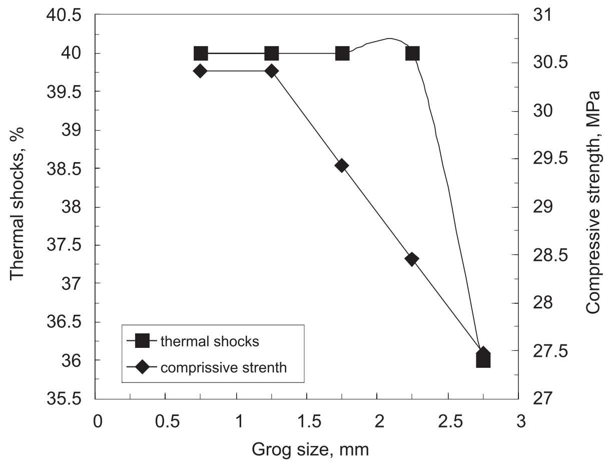

Fig. 15. Effect of grog size on the compressive strength and thermal shocks of the produced bricks

3.5. Effect of the pressure load on the properties of the produced brick

In this work, the size of grog particles is – 3 + 2.5 mm, the percentage of grog = 50%, kaolin to ball clay ratio is fixed 1:1 and the percentage of water added = 12% and temperature of firing = 1200°C while the pressure load varies from 31.59 to 55.37 MPa.

Table 3 shows the compressive strength, thermal shocks, shrinkage of bricks after drying for 5 days, shrinkage after firing, water absorption, bulk density and porosity of the produced bricks at different pressure load.

TABLE 3

Effect of pressure load on the properties of the produced brick

Pressure load, MPa	31.59	39.54	55.37
Compressive strength, MPa	16.4	24.5	27.47
Thermal shocks, %	30	32	35
Volume shrinkage after 5 days	1.4	1.3	1.28
Volume shrinkage after firing	3.3	3.1	3
Water absorption, %	10	8.8	7.94
Bulk density, gm/cm^3	1.97	2.0	2.16
Porosity, %	22	19.6	18.62

From Table 3, it is clear that as the pressure load increased the compressive strength, bulk density and thermal shocks also increased. While the shrinkage of bricks after drying for 5 days, shrinkage after firing, water absorption, and porosity of the produced bricks were decreasing when the load pressure increased. This is due to the increase of briquette compaction and subsequently the van der Waals forces increased [5, 6]. Also, this may be due to the increase of briquetting pressure leads to progressive crushing of the macropores [3]

3.6. Effect of firing temperature on the mechanical properties of the produced brick

In this work the size of grog particles is – 3 + 2.5 mm, the percentage of grog particles = 50%, kaolin to ball clay ratio is fixed as 1:1 and the percentage of added water = 12%. The pressure load was fixed and equal to 55.37 MPa, while temperature of firing varies from 1200 to 1300°C.

Table 4 shows the compressive strength, thermal shocks, shrinkage after firing, water absorption, bulk density and porosity of the produced bricks at different firing temperature. It is clear that as the temperature of firing increased the compressive strength, bulk density and thermal shocks increased too. While the shrinkage after firing, water absorption, and porosity of the produced bricks were decreased as the temperature of firing increased. The increase of firing temperature influences on better bonds between the particles [7].

TABLE 4
Effect of firing temperature on the mechanical properties of the produced brick

Firing temperature, °C	1200	1250	1300
Compressive strength, MPa	27.47	28.0	29.2
Thermal shocks, %	35	38	38
Volume shrinkage after firing	3	2.9	2.9
Water absorption, %	7.98	7.7	7.7
Bulk density, gm/cm^3	2.16	2.2	2.2
Porosity, %	18.62	17.0	16.9

4. Conclusions

There are many factors affected on the performance of the fire clay refractory bricks such as size of grog particles, percentage of added water to the raw material, percentage of grog, temperature of firing and load pressure. In this work the following results are obtained:

1) As the percentage of grog increased the shrinkage of bricks decreased, density of bricks increased and the porosity and water absorption increased.
2) As the added water to the raw material increased the porosity of the bricks increased, water absorption increased and the crushing strength and density decreased.

3) As the size of grog increased the crushing strength of the produced bricks decreased.
4) Both pressure load and temperature of firing have the same effect on the performance of fire clay bricks.

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