Production of High Alumina Fire Brick from Iraqi Clay

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Abstract

The importance of refractory materials in various industries such as lining of kilns, furnaces and the need for exploitation of raw materials which are available in Iraqi industries. So this work deal with the exploitation of Iraqi kaolin from Dewechla deposits, as a raw material in the manufacturing of high alumina fire brick.

High alumina fire brick specimens (alumina content about 70%) were prepared by semi-dry pressing, then drying and burned at different temperatures 1200,1300, 1400,1500C° for 2hr soaking time and 100C°/hr firing rate. Investigations of these specimens show that, the increasing alumina content will increase the strength, the porosity of the fire products, while the hardness, apparent density, water absorption and permanent linear change will decrease. These properties affected by the firing temperature, where the formations of the mullite phase play a governed role in the behavior and properties of the final products. In addition, the results reveal that the fire brick products appear to withstand thermal shock resistance; it can be used as thermal insulator in various industries. The thermal conductivity and density behavior of products containing alumina > 70% are vary as a function of porosity. Thus, the insulating property of the end product can be improved through the porosity and its distribution.

Keywords: Alumina, Fire brick, mullite, Dewechla-clay, Kaolinite.

أنتاج طابوق ناري عالي الألومينا من أطيان عراقية

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الخلاصة

نظرا لاهمية الحراريات في الصناعات المختلفة (تبطين المواقد والافران) والحاجة الماسة الى استغلال الموارد الاولية التي يتمتع بها العراق، فأن هدا البحث يهدف الى استغلال الكاؤلين العراقي المستخرج من منطقة دويخلة غرب العراق كمادة اولية لتصنيع الطابوق الحراري عالي الالومينا. لقد تم تحضير النماذج باستخدام طريقة الكبس شبه الجاف ،وبعد التجفيف اجريت عملية الحرق(التلبيد) عند درجات حرق مختلفة (1200،1300،1400،1500) °م وبزمن انضاج قدره ساعتان وبمعدل 100م°/ساعة،بعدها اجريت عمليات الفحص والاختبار لمعرفة الخواص الفيزياوية والميكانيكية فضلا عن الحرارية للنماذج المحروقة ،حيث أظهرت النتائج ان رفع نسبة الألومينا في أطيان الكاوؤلين يؤدي الى زيادة الانضغاطية ومسامية وموصلية المنتج يقابلها نقصان في صلادة وكثافة وامتصاصية الماء فضلا عن تأثر جميع هذه الخواص بدرجات الحرق وذلك لتكون طور المولايت الذي يلعب دورا مهما في تحسين خواص المنتج الحراري فالنتائج أظهرت ايضا تحسنا في مقاومة المنتج للصدمة الحرارية،كذلك أظهرت النتائج ان كل من الموصلية الحرارية والكثافة تعتمدان بشكل ملحوظ على المسامية للمنتج الحراري النهائي .

Introduction

Refractory kaolin clay is becoming important as a structural ceramic for high temperature applications. It is produced primarily by two methods: plastic molding and semi-dry pressing beside other conventional methods. Both processing methods rely on additives to promote densification; usually alumina is added as improver to the thermo-physical and thermo-mechanical properties of the product. The possibility of improving the thermo-physical properties of refractory clay through addition of Al_2O_3 to the Dewechla-clay is of more practical significance. Refractory clay used for making fire-clay products undergoes a number of transformations during firing, resulting in a product made up of a highly refractory crystalline mullite ($3AL_2O_3$- $2SiO_2$) and a vitreous siliceous matrix (glass) of high viscosity . As the mullite phase in the product is increased, there is an increase in phase composition causing an improvement of the physical, mechanical and thermal properties of the final product where the mechanism of mullite formation depends upon the method of combining the alumina-silica containing reactants [1].

Al-Taie et al [2], have studied extensively the role of additives in the semi-dry pressing of kaolin clay. Densification is initiated by interaction between alumina and kaolin in the presence of the liquid phase. They found that the increasing of alumina content of the clay product increases the amount of glassy phase. This change in phase composition causes an improvement of the physical, mechanical and thermal properties of the fire product. Also they found that, higher alumina content was responsible for more mullite and less glassy matrix in the fired product.

Chester [3] used fire-clay having mechanical composition similar to that of Dewechla clay and achieved a value of 1490C$^{\circ}$ for the subsidence temperature of the produced brick. Kumazawa, Ohata et al.[4] and Kumazawa, Kanzaki et al.[5],show that in the absence of grain boundary glassy phase, polycrystalline fire clay product retains > 90% of its room-temperature strength to 1500ºC with excellent thermal shock resistance and low thermal conductivity.

This paper describes the characterization of kaolin-Al_2O_3 powder with heating and sintering behavior, where the firing behavior is mainly affected by minor components supplying fluxing (iron, alkali and alkaline-earth) oxides [6]. The experimental results show that the physical, mechanical and thermal properties of refractory product could be improved by increasing the weight percentage of alumina in the Dewechla clay.

Experimental Procedure:

(1) Specimen preparation

Iraqi kaolinite clay with samples composition shown in table.1 were examined which are representative of the raw material used currently by the Iraqi fire brick industry were examined. In the laboratory, kaolinite clay samples were dry grounded, then mixed with 35wt% of alumina in order to raise its alumina content to about 70 wt%. Kaolin-alumina specimens were compacted by using semi-dry pressing method (hydraulic press under 300kg/cm^2 and water content 6-9%). The specimens had a cylindrical shape (30mm diameter and 30mm height) for testing the physical, mechanical and thermal shock resistance properties at different firing temperatures 1200, 1300, 1400, 1500 °C for soaking time 2hr with firing rate 100°C/hr. Iraqi kaolin clay with the composition shown in Table 1 was chosen for the study.

Table.1: Chemical composition and loss on ignition of Iraqi kaolin, wt%

SiO_2	46.88
Al_2O_3	34.99
Fe_2O_3	00.85
Na_2O	00.69
K_2O	00.68
TiO_2	02.88
LOI	12.94

(2)Physical and mechanical properties

The firied specimens were characterized by measuring each for firing shrinkage according to ASTM C-326[7], apparent porosity, apparent density and water absorption according to B.S1902 [8]. Also, compressive strength was measured according to ASTM standard [9].

(3)Thermal properties

One of the biggest challenges of the refractory materials during metallurgical applications, are the thermal conductivity and thermal shock resistance properties. In the present work, thermal conductivity was measured by Lees disc method with specimens dimensions 50mm diameter and10mm thickness, while thermal shock resistance was measured according to DIN1608 [10] by placing the specimens in a furnace heated to 900C° for15 min. duration. Rapid quenching was accomplished by dipping in cold water with checking for cracks or other possible visible changes in the structure and counting the number of cycles without major damages for specimens sintered at 1200,1300,1400 and1500 °C.

(4)Hardness test

Hardness test was carried out using Brnell hardness test. Brnell hardness test uses a diamond indenter of square pyramid shape which applies to the surface of the specimen for (10-15) sec 500 gm load after refining with 1000 grid grinding fire clay paper in order to reduce the machining scratches and decrease the influence of surface defects on hardness behavior.

Results and Discussion

From table.2, it can be seen the following;
The apparent density of the kaolin clay specimens increases with increase of firing temperature due to chemical reaction which tends to produce material with low melting point leading to increase of liquid which

filling the internal pores, eventually increasing the apparent density [11].

Also, it can be seen that there is a reduction in percentage apparent porosity with increasing firing temperatures due to the appearance of liquid phase as a result of phase transformation. This liquid phase fills the pores and expels the air bubble resulting in considerable reduction of pore size. All these results are directly reflected in percentage of water absorption.

Compressive strength and hardness (mechanical properties) of the kaolin clay specimens increase with firing temperatures as a result of all reasons which are mentioned before and these properties are affected strongly by the porosity reduction and its distribution in the final product.

Thermal conductivity decreases with firing temperature as a result of the phonon role in thermal conductivity mechanism which match with harmonic theory of crystals and pores distribution, while the results confirmed that thermal shock resistance improved with the increase of firing temperatures

As the forming process which was used in the present study was a semi-dry pressing method, there is no significant variation in linear and volumetric shrinkage (see table .3).

Tables. 4a, and 4b show that the addition of alumina to kaolin clay improves thermal shock resistance of the final product as the probability of appearance the 1^{st} crack is shifted to the next cycles. This is due to the crystallizing the glassy phase at temperature 1400-1500°C to form cristobolite [12].

Figures 1-7 confirm that the addition of alumina to the fire clay leads to an increase in apparent porosity, compressive strength (about50-150%), thermal conductivity and thermal shock resistance, while other properties such as apparent density, water absorption, hardness (about33%);will decrease .This is due to that the addition of alumina to Dewechla clay to bind the excess silica(SiO_2) released during transformation of the clay mineral kaolinite may increase the amount of mullite in the product and reduce the amount of glassy matrix [13-14].

The behavior of density-porosity relationship is the same in cases, kaolin and kaolin+35% Al_2O_3 fired clay products, but the difference can be explained by the decrease of density about 20% as a result of increasing the alumina content. Also, porosity increased with decreasing density (see Figures 8-9). So, higher density will reduce the porosity of the final product, i.e; there is an inverse relationship between density and porosity for both cases of fire end products. While thermal conductivity, which is affected by porosity increases with increasing porosity, increase about 75% with increasing alumina content in the fire products, as expected the high alumina products are poorly sintered which results in a porous product mainly of alumino-silicate phases. So, thermal conductivity was found proportional with porous product. (See Figures 10-11).

Table.2: Physical, mechanical and thermal properties of fire clay (Kaolin+Al_2O_3).

property	1200 °C	1300 °C	1400 °C	1500 °C
Apparent density gm/cm^3	1.85	1.90	2.10	2.14
Apparent porosity gm/cm^3	15.5	9.6	3.85	0.94
Water absorb.%	2.14	2.10	1.67	0.84
Compressive strength kg/cm^2	156	181	213	251
Brnell hardness kg/mm^2	11	11.6	12.2	13.1
Thermal conductivity w/mk	3.8	3.5	2.99	2.85
Thermal shock resistance cycle)	9	10	13	14

Table.3: Show the linear and volumetric shrinkage for kaolin and kaolin-alumina product.

Sample		Firing Temperatures °C			
		1200 °C	1300 °C	1400 °C	1500°C
Kaolin	L	0.140	0.142	0.142	0.143
	V	0.182	0.194	0.223	0.255
Kaolin +Al_2o_3	L	0.132	0.133	0.134	0.134
	V	0.165	0.174	0.180	0.190

L: Linear shrinkage, V: Volumetric shrinkage

Table.4.a: Thermal shock resistance of refractory kaolin clay.

	1200 °C	1300 °C	1400 °C	1500 °C
No. of cycle,1st crack was noted	3	3	2	2
No. of Cracks	5	5	3	2
No. of cycles	9	10	13	14

Table.4.b: Thermal shock resistance of kaolin-alumina product.

	1200 °C	1300 °C	1400 °C	1500 °C
No. of cycle,1st crack was noted	4	4	4	3
No. of cracks	6	6	5	4
No. of cycles	10	11	14	15

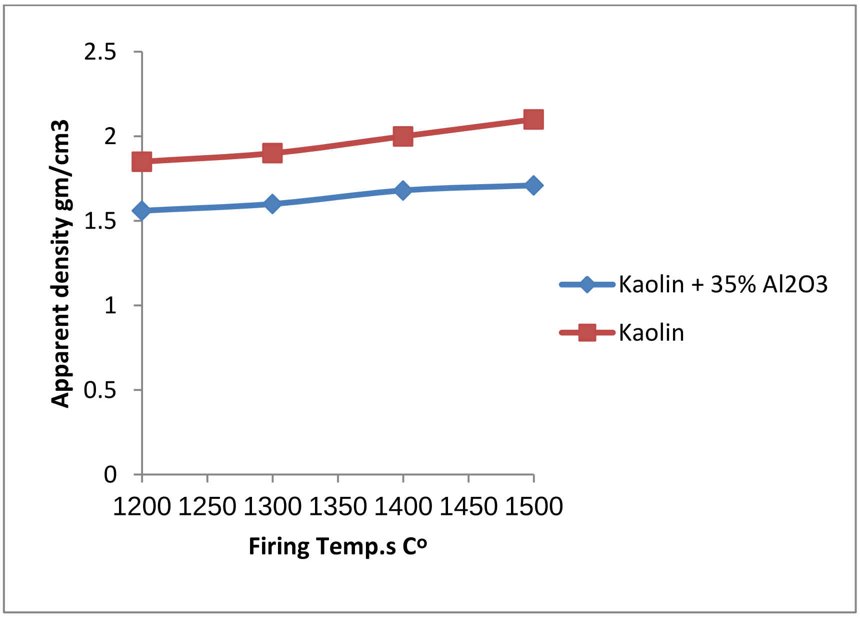

Fig.1: Effect of Alumina content and firing temperatures on the apparent density of the fire product.

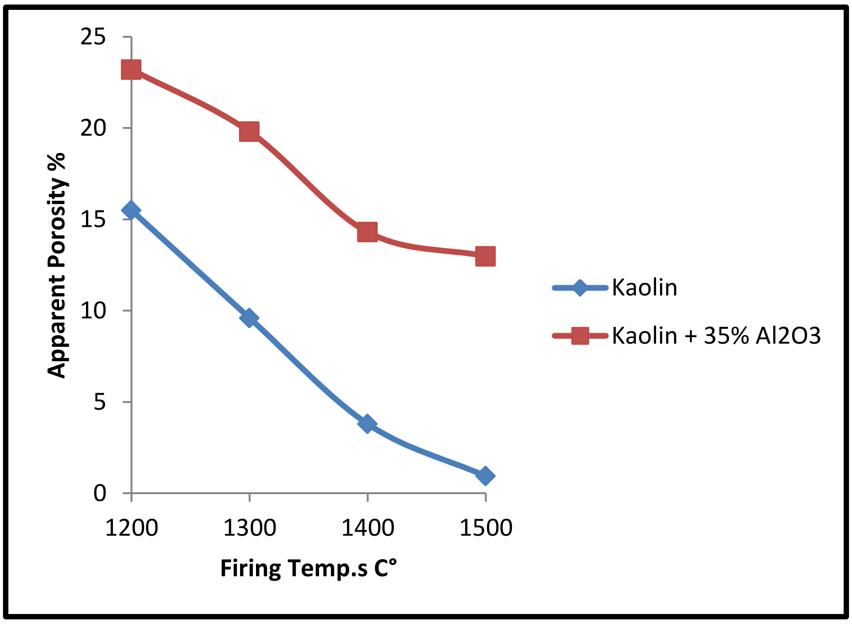

Fig. 2: Effect of Alumina and firing temperatures on the apparent porosity of the fire product.

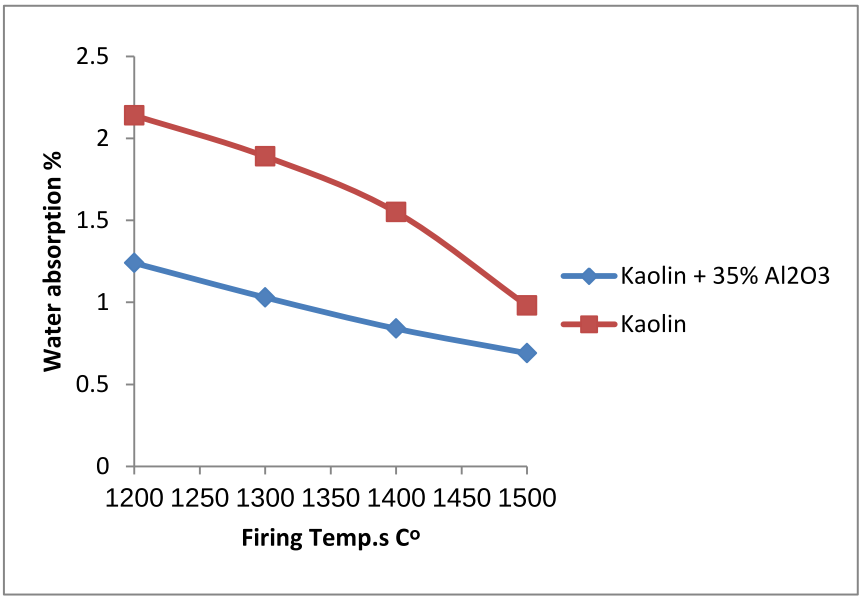

Fig.3: Effect of Alumina and firing temperatures on the water absorption of the fire product.

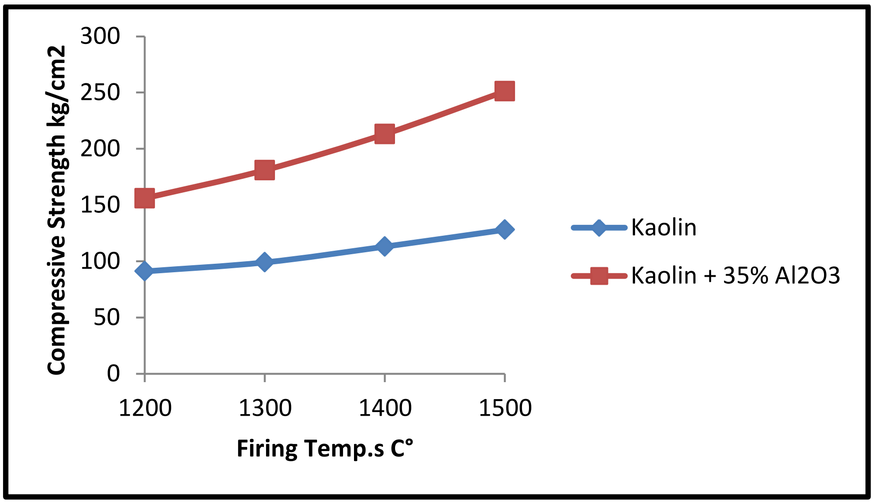

Fig.4: Effect of Alumina and firing temperatures on the Compressive Strength of the fire product.

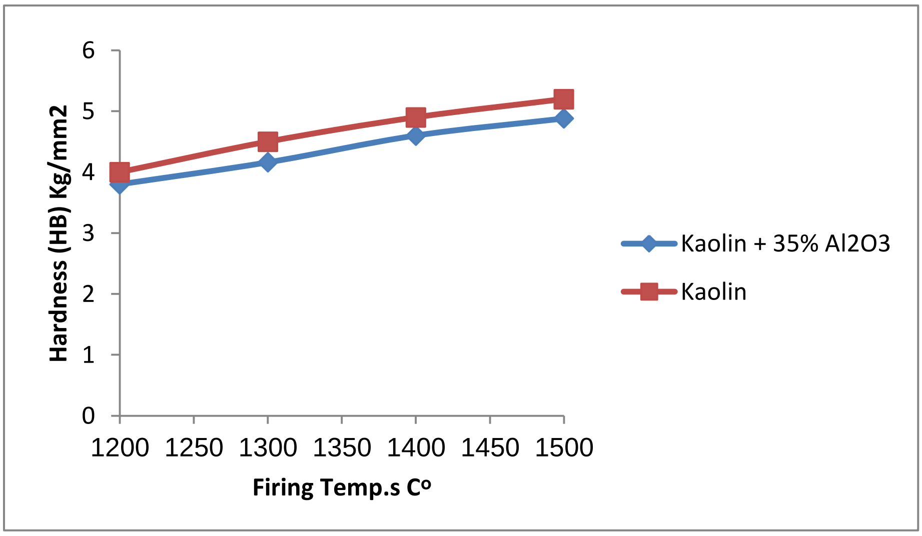

Fig.5: Effect of Alumina and firing temperatures on the Hardness of the fire product.

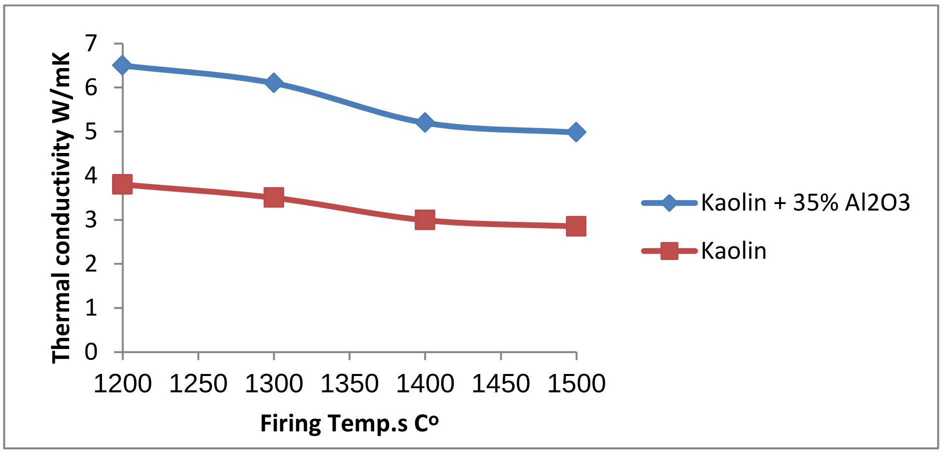

Fig.6: Effect of Alumina and firing temperatures on the thermal conductivity of the fire product

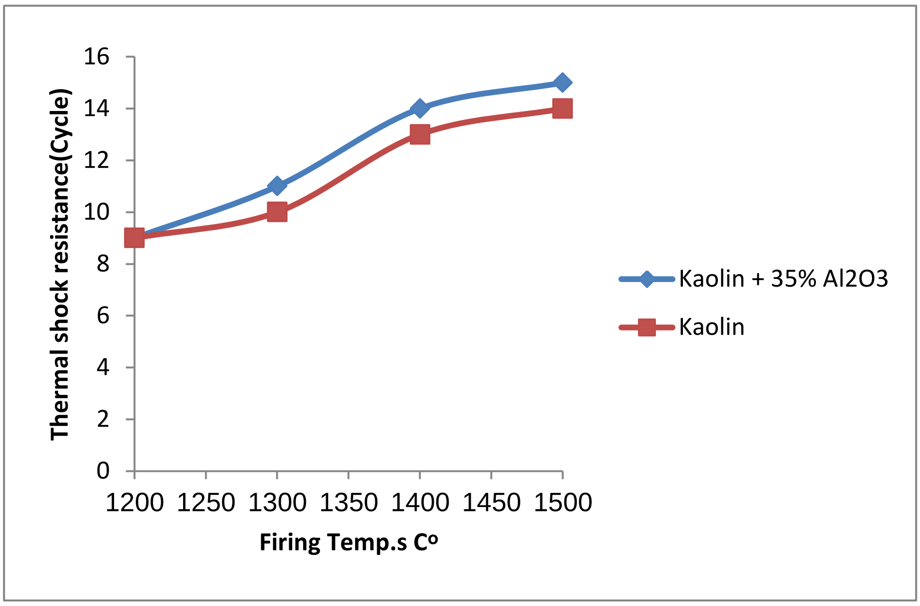

Fig.7: Effect of Alumina and firing temperatures on the Thermal shock resistance of the fire product.

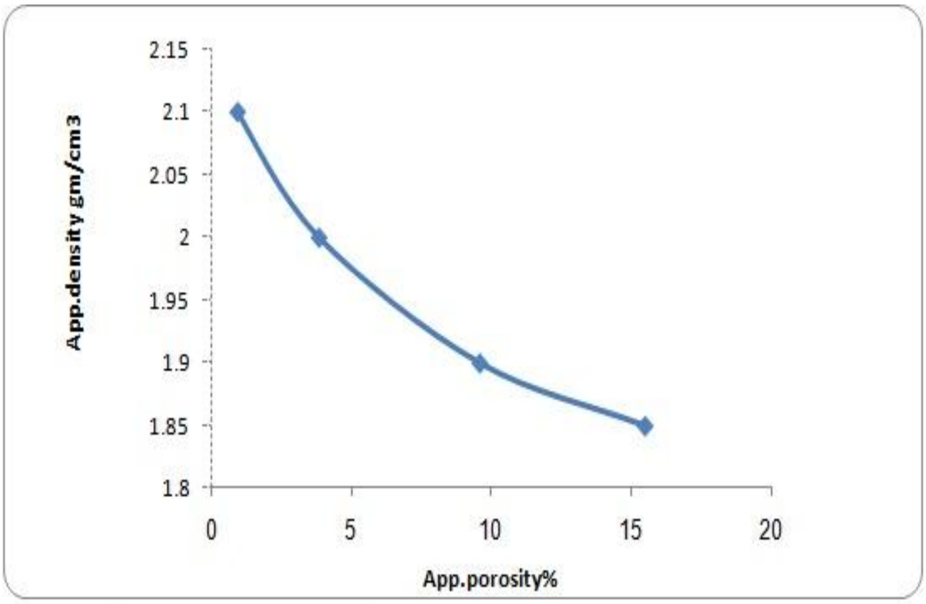

Fig.8: Apparent density-Apparent porosity relationship of kaolin clay.

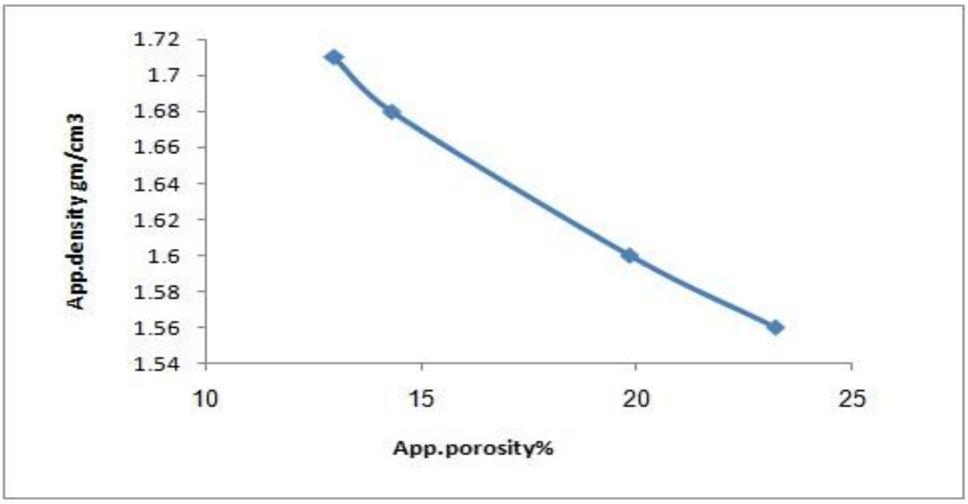

Fig.9: Apparent density-Apparent porosity relationship of kaolin+35% Al_2O_3product.

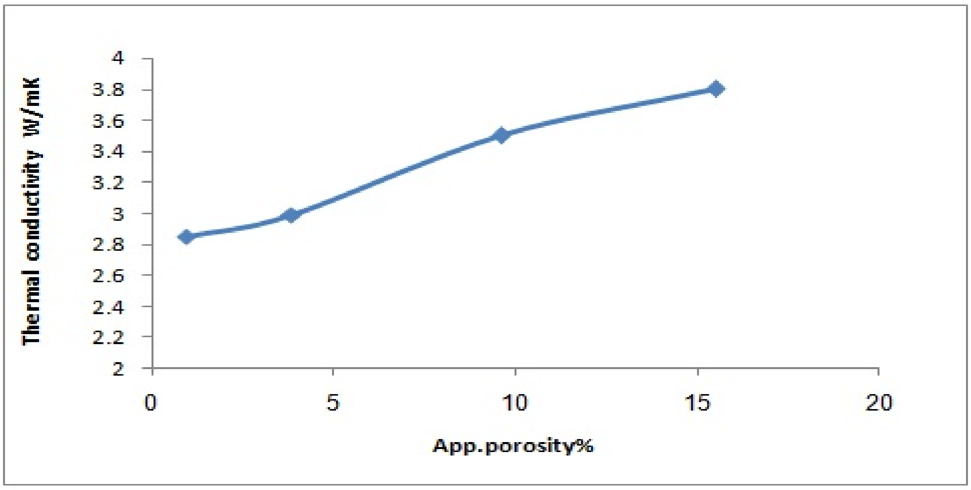

Fig.10: Thermal conductivity-porosity relationship of kaolin clay.

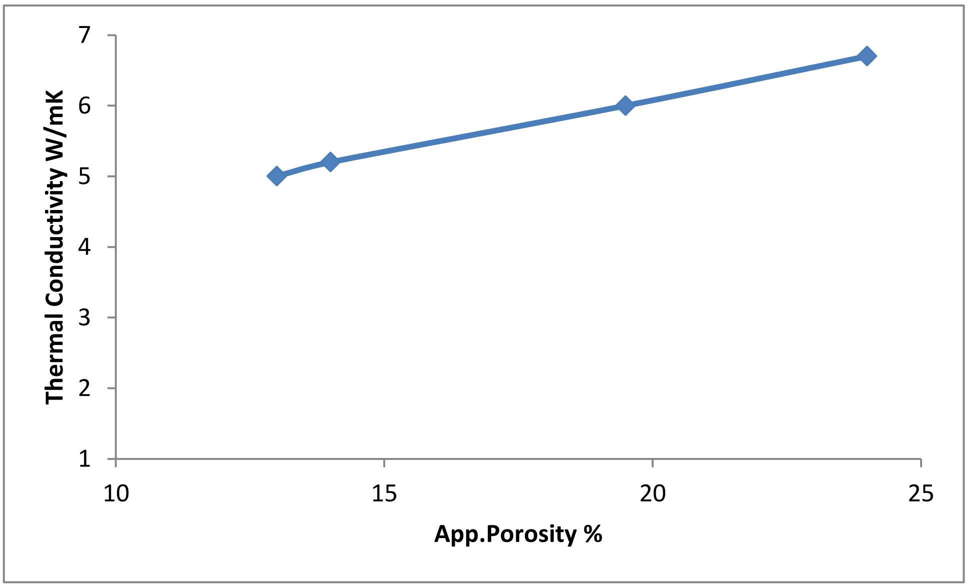

Fig.11: Thermal conductivity-porosity relationship of kaolin+35%Al_2O3 product.

Conclusions

1. The kaolinitic clay from the Dewechla deposits is suitable for the manufacture of refractory bricks which meet the requirements for medium heat duty materials. After addition of Al_2O_3, final refractory products meet the requirements for high heat duty materials.

2. The method recommended for molding of the refractory products is the semi-dry pressing method with water content 6-9%. Suitable compaction was achieved by moulding at a pressure 300 kg/cm^2, the firing temperature was 1500 $^{\circ}$C.

3. Al_2O_3 amounts in the range of 35% we added to fire clay are sufficient to improve the physical, mechanical and thermal properties of the final products.

4. There is a clear correlation between density and porosity, thermal conductivity and porosity of the fire products having this specific composition. Higher porosity causes a decrease in the temperature of deformation of fire clay products.

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