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Study the Physical Properties and Thermal Conductivity of Light Weight Refractories Bricks Produced by Adding porcelanite to Kaolinite

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ABSTRACT

This research was carried out to manufacture porous refractories bricks from locally raw materials (Porcelanite to Dwaikhla Kaolinite clays). The raw materials were tested by Chemical analysis and XRD to find their suitability to produce light weight ceramic refractories. Different percentage of kaolinite were added as binder to Porcelanite (raw materials). The specimens were pressed to dimensions (30×30) mm according to DIN51053 standards using semi-dry method at pressure of (24.5) MPa. After shaped process all specimens left to dry in air for (24hr) then dried at 110°C using electric oven and the specimens were fired at (1200, 1300 and 1400) °C. The fired specimens have been tested to determine their physical and thermal properties including bulk density, porosity, water absorption ,specific gravity and thermal conductivity. It also, has been observed from the results were within international standards, and local porcelanite and kaolinite could be used as source raw materials for manufacture light weight refractories.

Keywords: Light weigth refractories bricks, Dwaikhla clay (Kaolinite), porcelanite.

دراسة الخواص الفيزيائية والتوصيل الحراري لطابوق حراري مسامي منتج بإضافة البورسسلينايت الى الكاؤولينايت

الملخص

تم في هذا البحث صناعه طابوق حراري مسامي من مواد اوليه محلية (البورسلينايت الى أطيان دويخلة كاؤولينايت). المواد الأولية فحصت بواسطه التحليل الكيميائي وXRD لايجاد مدى صلاحيتها لإنتاج الحراريات السيراميكة الخفيفة الوزن. نسب مختلفة من الكاؤولينايت اضيفت كرابط الى (الماده الاوليه البورسلينايت). شكلت العينات الى الابعاد (30×30) ملم حسب المواصفة الالمانية (51053) DIN باستخدام طريقة الكبس شبه الجاف عند ضغط (24.5 MPa) بعد عمليه التشكيل تركت جميع النماذج لتجف في الهواء ل(24hr) بعدها جففت باستخدام مجفف كهربائي في درجه حراره 110مئويه وحرقت النماذج بدرجات (1200, 1300 and 1400) در جه مئويه. العينات المحروقة فحصت لحساب خواصها الفيزيائيه والحرارية تتضمن الكثافة الكتليه,

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المسامية الظاهريه, الامتصاصية, الوزن النوعي والتوصيلية الحرارية. لوحظ بان النتائج ضمن المواصفات العالمية للحراريات الخفيفة الوزن, كذلك امكانية استخدام المواد الأولية المحلية البورسلينايت والكاؤلينايت لصناعه حراريات سيرامكية خفيفة الوزن.

INTRODUCTION

Refractory materials may be define as materials that retain their physical and chemical identity when subjected to high operation temperatures. These materials are non-metallic compounds that can withstand high temperatures fluctuations between (1000 and 1500) °C [1,2], and have high resistance to fusion and withstanding high temperature both physicallyand chemically, and are also good thermal and electrical insulators used for metallurgical industry in the construction of all furnaces that used in the internal lining of furnaces for melting and heating before further processing, smelting in vessels for holding and transporting molten metals and slags, and in the flues or stacks through which hot gases are conducted [3].

Porcelanite is a light weight rock with density of 0.9-1.4 $\frac{gm}{cm^3}$ [4,5], and considered as important industrial sedimentary rocks that composed of at least 50% of opal-CT (opal-cristobalite and tridymite). Also it can be known by different names as Diatomite, diatomaceous earth, kieselguhr, cellite, filtac …etc.) [6].

The aim of this research was manufactured porous refractories bricks as thermal insulators for lining the furnaces by added locally raw materials (Porcelanite to Dwaikhla Kaolinite clays).

Experimental Procedure:

Raw Materials

In this study the raw materials were collected from Iraq Geological Survey.

The Chemical Analysis

Table (1) shows the chemical analysis of the raw materials which used in our development work. It has been indicated that the Dwaikhla kaolinite was suitable for manufacturing of refractory bricks. This test has been carried out by the researchers in Iraq Geological Survey.

The Mineralogical Investigation

Table (1). The chemical analysis of Kaolinite and Porcelanite.

The Ratio Percentage	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	MgO	CaO	TiO2	P2O5	Cl	SO3	L.O.I
Kaolinite Ratio %	48.5	34.21	1.33	0.4	0.2	0.23	0.13	1.4	0.01	0.08	0.07	13.44
Porcelanite	69.22	4.02	1.2	0.11	0.54	4.6	6.72	0.125	0.49	0.1	0.14	12.74

In addition to the chemical analysis, the burning characteristic of the raw materials depend upon the mineralogical composition which is usually determined by means of X-rays diffraction (XRD).The XRD charts of raw materials show in Figs.(2),(3) ,this test was carried out in the Iraq geological survey.

The Preparation of Specimens

For molding the specimens, the Kaolinite rocks were crushed, grinded and screened. The particle size of milled Kaolinite and Porcelanite was (425-300)µm, the specimens were mixed from Porcelanite, kaolinite in range P1 (90+10)%, P2 (70+30) %,and P3(50+50)% respectively and for each mix 10% of petiole was added. The green specimens shaped by the semi-dry method using a hydraulic press and a molding pressure of (24.5) MPa with addition of 12 wt.% of water. The specimens had a cylindrical shape (30 mm diameter and 30 mm high) according to DIN 51053 [7] .After molding and drying the specimens were fired at (1200,1300 and 1400)°C. The fired bricks were investigated to their important physical and thermal properties.

The Investigations

Apparent Porosity (P%), Water Absorption (W%), and Bulk Density (B).

The procedure involved first measuring the dry weight (D) in (g). The specimen was boiled in water for 5hr and allowed to cool in water for 24 hr. The saturated weight (W) in (g), and the suspended weight in water (S) in (g) are calculated according to ASTMC20-2000. The apparent porosity(P%) is expressed as the percentage of the volume of the open pores penetrated by the immersion liquid with respect to the total volume of the material. It can be calculated using formula [8].

$$P\% = \left(\frac{W-D}{V}\right)*100 \qquad \text{……. (1)}$$

Where

P%: apparent porosity, V: volume of pores in $(Cm^3) = W - S.$

Water absorption can be indicative of open pores due to the weight of moisture in pores compared to weight of sintered body and it depends on the properties of the raw materials, grain size, and the conditions of shaping process and firing temperatures [8], while water absorption is calculated as follows [9].

$$A\%=\left(\frac{W-D}{D}\right)*100 \qquad \text{……. (2)}$$

Where: A%: water absorption, W:saturated weight in (g), D:dry weight in (g) [9].
And the bulk density (B) can be defined as the ratio of mass of materials to its bulk volume. Where the volume involves the volume of solid components, pores and seal pores [10].
The bulk density of the components and the simplest method involves measuring dry weight divided by the exterior volume, including pores can be calculated as follows:

$$B=\left(\frac{D}{V}\right) \qquad \text{…. (3)}$$

Where

B: bulk density in $(\frac{g}{cm^3})$ [9].

True Specific Gravity (Sp.gr)

True specific gravity is also called absolute specific gravity, which is defined as the ratio of true density of a substance at a specific temperature of a solid to the true density of water determined at specific temperature [11].

The specific gravity is calculated from the following formula.

$$Sp.gr=\frac{(W-P)}{(W1-P)-(W2-P)} \quad \ldots(4)$$

Where:P: weight of the pycnometer in (g), W: weight of the pycnometer and specimen in (g), W1= weight of the pycnometer filled with water in (g), and W2= weight of the pycnometer, specimen and water in(g) [12]

Thermal Conductivity of the produced lightweight refractories.

Thermal Conductivity is a phenomenon by which heat is transferred from high temperature to low temperature region of a materials.

The investigation of the thermal conductivity of produced lightweight refractories was carried out using (40×10) mm cylindrical specimens according to the standard specification of the instrument using Lee's disk type(Griffin & George Ltd), made(Germany). Lee's disk instrument consists of three copper plates (**A**-**C**) drilled to accept liquid-in-glass thermometers and a 6W and 0.2A electrical plate heater of the same diameter as the copper plates , the specimen was placed between copper plates **A** and **B**. The heater was sandwiched between plates **B** and **C** and, after tightening the clamp screw to hold all the discs together, the power to the heater was switched on. The whole assembly was placed in an enclosure to minimize the effects of draughts and a fourth thermometer was placed within the enclosure, fairly close to the apparatus, to measure the ambient temperature .The value for the thermal conductivity of the speimen is calculated,as follows:

$$e=\frac{VI}{a_A T_A + a_S (T_A+T_B/2) + a_B T_B + a_C T_C} \quad \ldots.(8)$$

$$K=(\frac{ed}{2\pi r^2 (T_B-T_A)}\left[a_S\left(\frac{T_A+T_B}{2}\right)+2a_A T_A\right] \quad \ldots(9)$$

Where

IV:Thermal energy passing through coil after reaching thermal equilibrium, e: Amount of energy passing through material disk at unit area for each second (W/m^2.second),a_A, a_B, a_C, a_S and a_H are the exposed surface areas of A, B, C, the specimen and heater, respectively.Areasa$_A$ and a_C include the flat ends of the disks. T_A, T_B and T_C are the temperatures of the disks A,B and C,d $_{A, B, C, S}$: Disk thickness,(m), r: Disk radius,(m), s: Specimen,*K*: Coefficient of thermal conductivity [13].

Discussion of Results:
Chemical Analysis:

The suitability of kaolinite for manufacture of refractory bricks depends primarily on its sintering and softening point. In this respect the chemical analysis is of great importance.Usually,refractory clays are classified by their alumina content. The TiO2 content in clay used for manufacture of refractory bricks normally ranges between 1 and 4%.The content of iron oxide (Fe_2O_3) which acts as a flux should not exceed 2.5%.The total content of alkalis and alkaline not exceed 6% [14], from the table (1) the chemical analysis of the kaolinite (the clay) which is used in this research ,it has been indicated that suitability of kaolinite clay for refractory manufacturing..

Mineralogical Analysis

The results of XRD for raw materials kaolinite and porcelanite which is considered as important industrial sedimentary rocks that composed of at least 50% of Opal CT(Opal structure mix of cristobalite and tridymite) [6], as shown in fig. (2) and (3) that kaolinite sample contains kaolinite and quartz. Whereas Opal CT is the main phase of porcelanite with little portion of tridymite, also cristobalite presence was noticed. A medium presence portion of dolomite phase can be obtained.

Apparent porosity (P%), Water absorption(W%),Bulk Density (B), and Specific Gravity (Sp.gr).

It can be seen from table (2)that the apparent porosity us ranged between (39.315-62.311)%. The relationships between apparent porosity and firing temperatures are shown decreasing in the apparent porosity with increasing in fired temperatures and the P1specimens have the highest value of apparent porosities due to highest weight percentage of porcelanite in mixture ratio of this specimen as shown in fig.(4), which is showed high porosity up to about 50% of the total rock volume in its natural formation [15].

Whereas the apparent porosity of insulation refractories must not be less than 45% according to ISO 5016-1986 standard, and it can be noticed from the results that the P1,P2, and P3 code specimens are recommended within the requirements of this specification except the ratios of P3 code specimens at (1300 and 1400)°C[16]. From table (2) it is seen that the decreasing of water absorption with raising in fired temperature, this decreasing in values are related to the decreasing in porosity with increasing in fired temperatures [17], and also, it can be indicated that the values of bulk density are ranged between (0.995-1.287)$\frac{g}{cm^3}$, that the results of bulk density of all fired specimens are increased with increasing in firing temperatures due to the decreasing of porosity [18], as shown in fig.(5). It can be found from the results of bulk density all the values are within the BS, 1902 part B 1976 [19], that recommended the bulk density of light weight refractories must not be more than(1.2) $\frac{g}{cm^3}$ except the results of P3 (1.287) $\frac{g}{cm^3}$, which fired at 1300°C . The results of specific gravity are decreased with increasing fired temperatures for all mixed ratio this due to increasing in the reaction rate between mixture contents, specially the flux oxide which leads to produce refractories with low specific gravity and the impurities present affect the refractory specific gravity. The impurities that extent within the material structure of kaolin reacts to form the large amount of fusible materials, which have small specific gravity, and the specific gravity decreases with raising of firing temperatures. This reduction in specific gravity values refers to the presence of the impurities and (fluxes materials k2O,Na2O, CaO and MgO) with lower specific gravity, which react to form low specific gravity [20].

Thermal Conductivity

The thermal conductivity of the fired produced specimens are variation from (0.148-0.286) to (0.364-0.391)$\frac{w}{m°k}$ at (1200-1400) °C respectively. This variation due to the varied of porcelanite percentage in the mixed ratio of the specimens which characterized by porous structure whereas these (pores) filled by air and act insulators caused reduction in coefficient of heat transfer because the conductivity.

The reasons standing behind this increase in thermal conductivity are the increase of the density and the corresponding reduction in apparent porosity as the temperature was increased as shown in fig (6). This phenomenon resulted from increase in sintering process and the crystal growth due to crystallization [21].

Thermal conductivty increasing with increasing in firing temperature and decreasing with increasing in apparent porosities presented in specimens as shown in figs.(7, and 8). From table (2) that shows the results of thermal conductivity are of light weight and the values of bulk density range between (0.995-1.169) $\frac{g}{cm^3}$, to (1.116-1.287)$\frac{g}{cm^3}$at (1200-1400) °C respectively which according to the BS, 1902 part B 1976 [19], that recommended the bulk density to be not more than (1.2)$\frac{g}{cm^3}$.

CONCLUSIONS

1-The chemical analysis indicated that the Dwaikhla clay and porcelanite are suitable for manufacture light weight refractory bricks.

2-Optimuim conditions obtained using a mix of a Porcelanite+kaolinite in the ratio of (90+10) % respectively with 10% petiole of all mixtures and added water 12% this is shown in the P1 code specimens which are shown the lowest value of thermal conductivity fit with the recommended (1.008-1.728) $\frac{w}{m.°k}$ according to Chester.

3-Optimuim firing temperature was 1400°C.

4- It is found from the results that the thermal conductivity of light weight ceramic refractories are insulation materials have values of bulk density are fit with international standards.

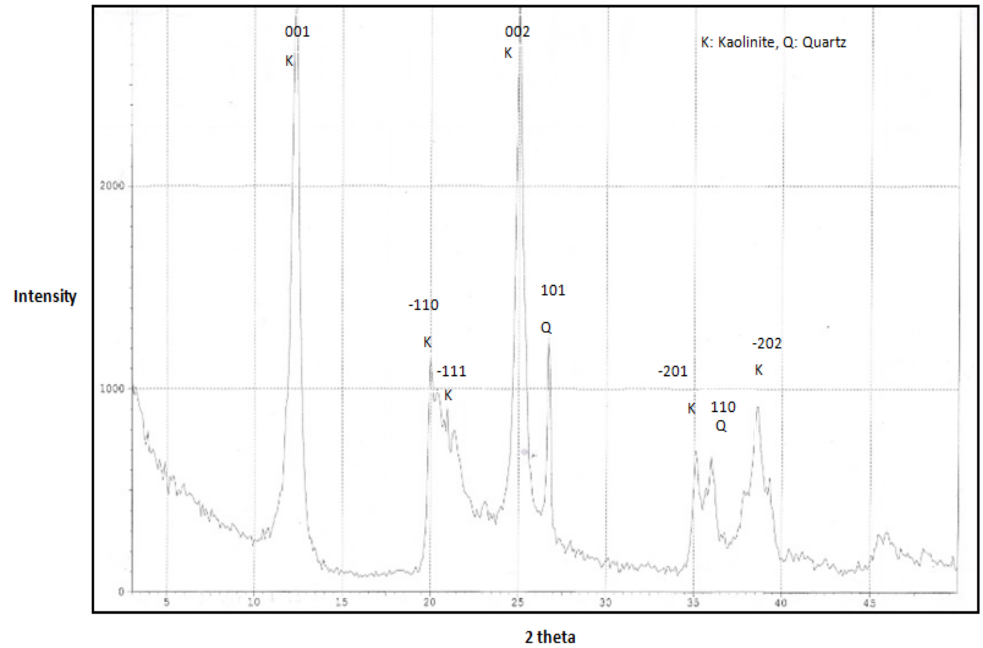

Figure (2). XRD of kaolinite raw material.

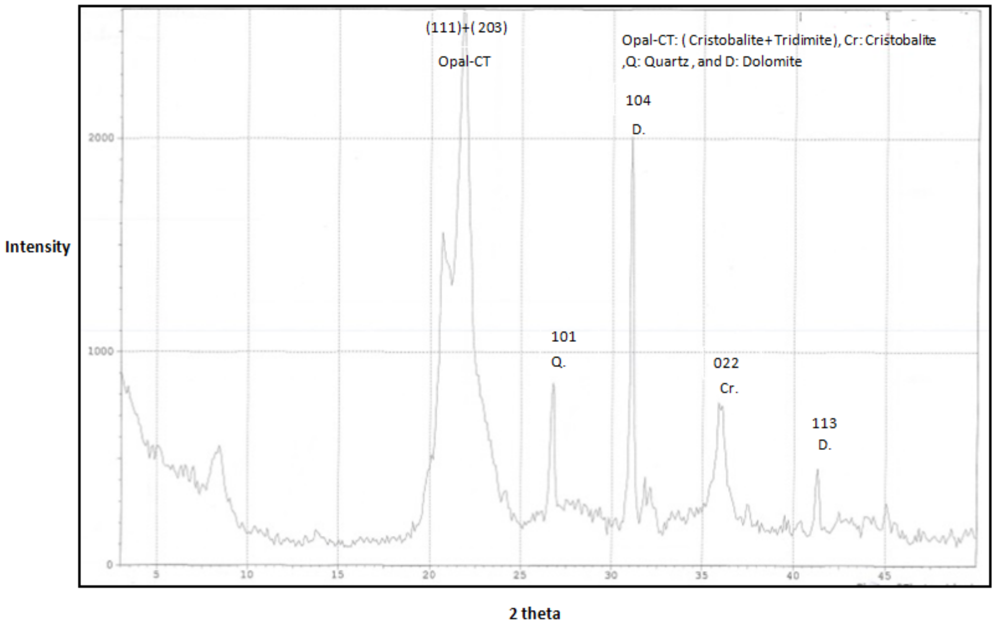

Figure (3). XRD of porcelanite raw material.

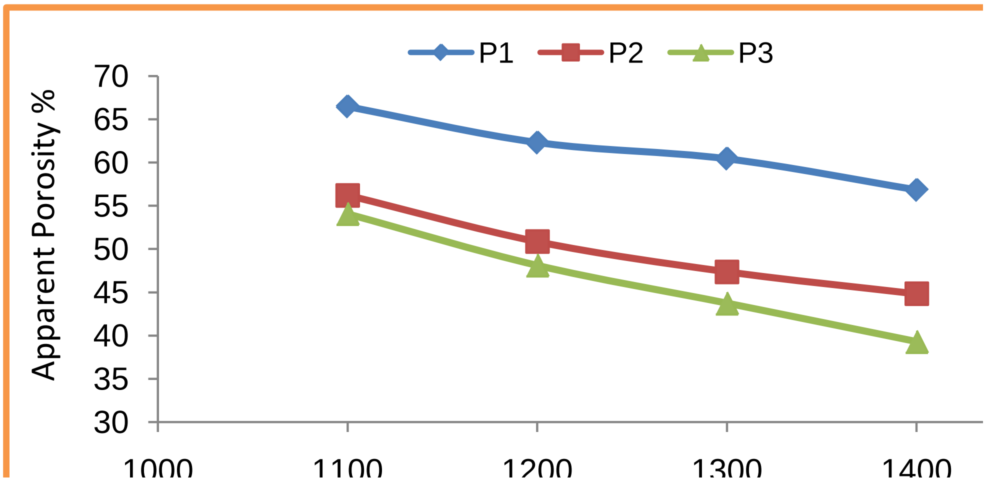

Figure (4). Relationship between Apparent porosity% and firing temperature.

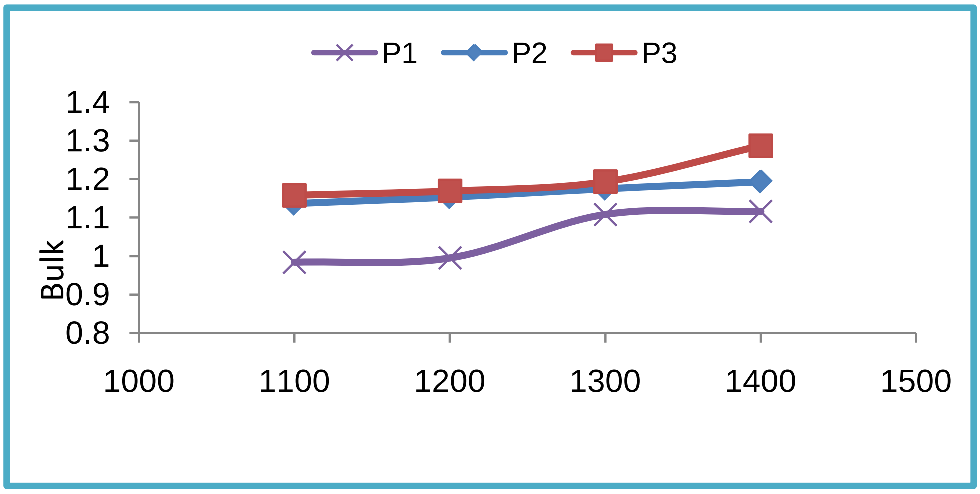

Figure (5). Relationship between bulk density and firing temperature.

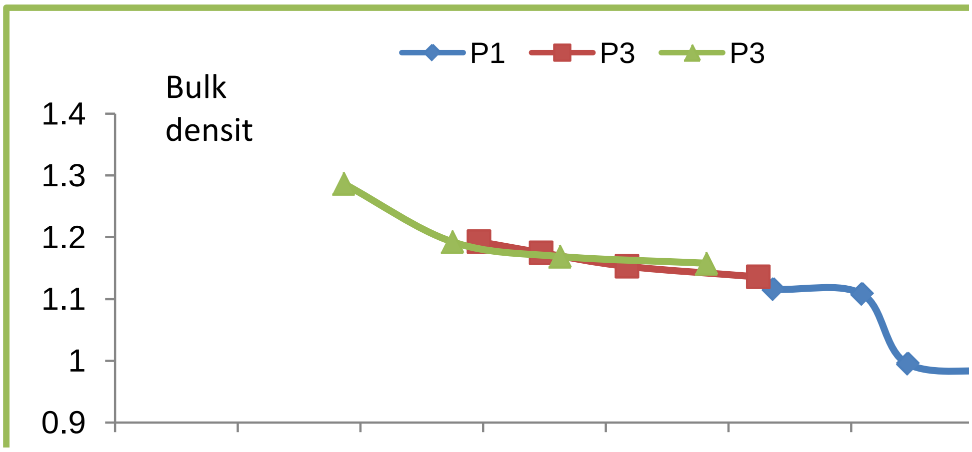

Figure (6). Relationship between apparent porosity and bulk den sity.

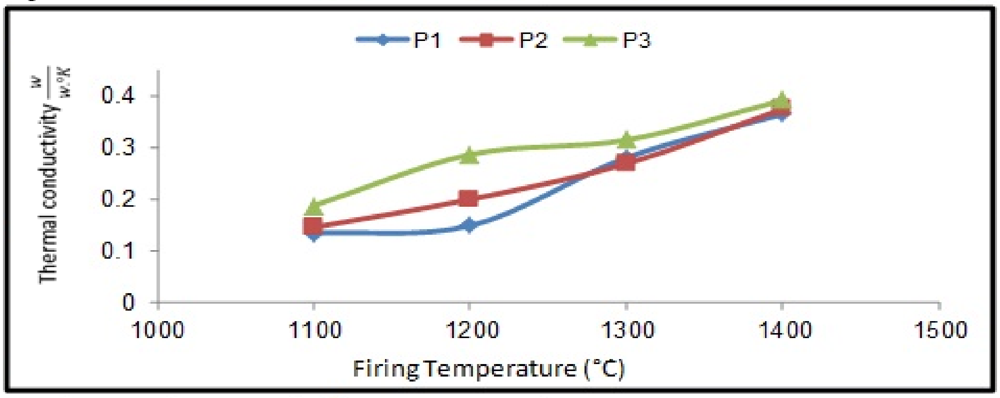

Figure (7). Relationship between thermal conductivity and firing temperature.

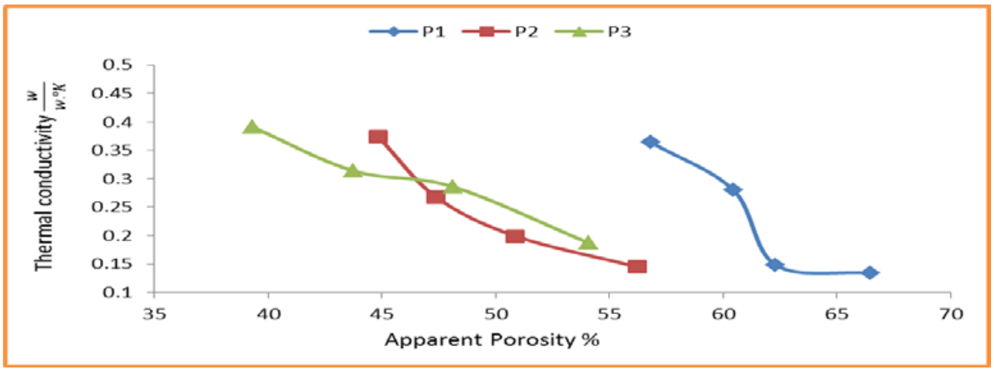

Figure (8). Relationship between thermal conductivity and apparent porosity.

Table (2). Mixes of specimens and codes, where P: porcelanite, K: kaolinite, O: petiole of palm for fired specimens fired at 1100-1400 °C.

Speci-mens code	**The firing temperature**	***Apparent porosity %***	***Water absorption***	**Bulk density $\frac{g}{cm^3}$**	**Specific gravity**	***thermal conductivity $\frac{W}{m.K}$***
(P1) 90%P+10%K+10%O	1100°C	66.469	39.927	0.984	2.573	0.134
	1200°C	62.311	36.952	0.995	2.561	0.148
	1300°C	60.453	32.974	1.108	2.455	0.280
	1400°C	56.834	30.422	1.116	2.439	0.364
(P2) 70%P+30%K+10%O	1100°C	56.220	36.883	1.136	2.588	0.145
	1200°C	50.871	33.564	1.153	2.486	0.199
	1300°C	47.373	31.951	1.175	2.467	0.268
	1400°C	44.836	28.033	1.193	2.453	0.374
(P3) 50%P+50%K+10%O	1100°C	54.093	34.756	1.158	2.718	0.187
	1200°C	48.124	32.677	1.169	2.695	0.286
	1300°C	43.744	27.422	1.193	2.684	0.314
	1400°C	39.315	24.825	1.287	2.676	0.391

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