Study The Bulk Density, Open Porosity and Coefficient of Thermal Conductivity of Refractory Mortar Contains Kaolin-Metakolin-Fire Brick Powder-SiC

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الخلاصة

يتضمن هذا البحث استخدام مادة خام اقتصادية متوفرة في العراق وهي الكاؤولين(kaolin)، والتي تتوفر في الصحراء الغربية من العراق، حيث ان تشخيص تأثير بعض الإضافات على خواص الكاؤولين يفتح الافاق للاستفادة منه في التطبيقات الصناعية المستقبلية للبلد. تم تحضير عينات من (90٪) (70٪كاؤولين + 30٪ ميتاكاؤولين) مع استخدام نوعين من الإضافات وهي مسحوق كاربيد السليكون (SiC) والنوع الثاني من الإضافات هو مسحوق الطابوق الناري(FBP) والذي تم تحضيره من مخلفات البطانة الحرارية للأفران الحرارية. حرقت العينات بدرجات حرارة (1100)، (1200)، (1300)، (1400) و(1500) م^{0}. عدة خواص تم دراستها خلال هذا البحث مثل الكثافة الحجمية والمسامية المفتوحة ومعامل التوصيل الحراري، حيث وجد إن زيادة درجة حرارة التلبيد تزيد من الكثافة الحجمية ومعامل التوصيل الحراري وتتناقص المسامية المفتوحة. وجد ان الإضافة (10٪) من مسحوق كاربيد السليكون تزيد من معامل التوصيل الحراري والمسامية المفتوحة وتقلل من الكثافة الحجمية. اما العينات المحتوية على5%SiC+5%HBP تكون ذات خواصها المدروسة بحالة متوسطة بين (10٪) مسحوق كاربيد السليكون و(10٪) مسحوق الطابوق الناري. في حين العينات المحتوية على (10٪) مسحوق الطابوق الناري لها اقل مسامية مفتوحة ومعامل توصيل حراري وكان لها أكبر كثافة حجمية.

الكلمات المفتاحية

كاؤولين عراقي، مسحوق طابوق ناري، كاربيد السليكون، مسامية مفتوحة، كثافة حجمية، معامل التوصيل الحراري.

Abstract

This study includes the use of economic raw material available in Iraq, which is available in the Western Desert of Iraq, where the knowledge of the effect of some additives on the properties of the Iraqi kaolin allows for use in the future industrial applications for the country. The samples were prepared from (90%,70%Kaolin+30% meta kaolin) with two types of additives, the first type is the powder of silicon carbide(SiC) and the second type of additives is the fire brick powder(FBP) which was prepared from the wastes of the furnace linings. The samples were fired at the temperature of (1100), (1200), (1300), (1400) and (1500) C^o and several properties were studied such as bulk density, open porosity and coefficient of thermal conductivity. The addition of (10%) silicon increases the thermal conductivity and open porosity coefficient and reduces the bulk density, while the addition of (5%SiC + 5%FBP) have an intermediate property between (10%) Silicon powder and (10%) FBP. While samples contain (10%) FBP have lower open porosity and coefficient of thermal conductivity with larger bulk density.

Keywords

Iraqi kaolin, fire brick powder, SiC, bulk density, open porosity, coefficient of thermal conductivity.

1.Introduction

Refractory are materials, mostly non-metallic minerals that have enormous heat capacities and can withstand high temperatures, refractory materials are used in various fields and different aspects of the scientific life process and industrial plants such as lining furnaces, reactors and others [1]. Therefore, according to the working conditions and application of these materials, refractories must possess certain characteristics that enable them to have a long life, they must have a good thermal shock, corrosion resistance and have a specific value for thermal conductivity and thermal expansion coefficient [2]. Many types of refractories are often used in various basic metal industries such as in the process of making steel [3]. The requirements for refractories vary according to industrial application e.g., the properties of refractories used in the aluminum metal industry may be different from those used in the steel industry [4]. The clay minerals are considered to be important industrial raw materials which used in many industrial and scientific applications, such as ceramics, paper industry, petroleum industry, catalysts, etc. [5]. The field of application of the clays is closely related to its general characteristics. Therefore, studying and diagnosing the nature of industrial clays helps in determining the best exploitation, thus providing greater opportunities to benefit from the various modern applications [6]. Many studies have dealt with different and varied aspects of clay properties. Al-Nasrawy *et al*. [7] investigated the effect of different percentage addition of α-SiC powder on the physical and mechanical properties of Iraqi kaolin, where they made sample consist of SiC with additions from different percentages of Iraqi kaolin, they found that the physical and mechanical properties of the samples fired at (1400) ^{o}C changed with the addition of added kaolin. Iyasara *et al.* [8] examined the possibility of improving the physical properties of dense refractory bricks (reducing shrinkage, pores and increased corrosion resistance) of the local clay with grog addition, where they found that the increase in the percentage of grog resulted in decreased shrinkage and density, through their findings they concluded that the use of (% 30) grog led to get optimal apparent porosity of (% 20.22) and cold crushing strength of (61.77) MPa. Amkpa *et al*. [9] found that the firing temperature (1200) ^{O}C was better for mechanical, chemical and physical properties, the optimum values for porosity was (24.52%), the compressive strength was (15.37) MPa and bulk density was (1.8) g/cm^3. Also Bwayo and Obwoya[10] studied the effect of particle size of a mixture of ball clay, kaolin, and sawdust on thermal conductivity and diffusivity of ceramic bricks through preparing samples fired at (950) ^{O}C, they found that coefficient of thermal conductivity decreased with increased particle size of kaolin and ball clay. The objective of the present study is to characterize the effect of SiC and FBP on the open porosity, bulk density and coefficient of thermal conductivity of refractory mortar prepared from Iraqi kaolin.

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2.Experimental Part

2.1. Raw materials

The raw materials used in this research are Iraqi kaolin, powder of silicon carbide(SiC) and fire brick powder (FBP). FBP was obtained from the grinding of waste lining furnace. Iraqi kaolin was laboratory milled into powder of particle size of (4.299) µm and particle size distribution given in Fig. (1). The particle size measurement were done by using Bettersize (2000) laser particle size analyzer. Metakaolin powder(MK) was fabricated by heating Iraqi kaolin at (800) C° for an hour. Metakaolin powder was identified from disappearance of the kaolinte peaks in XRD pattern. Metakaolin has particle size of (7.067) µm and the particle size distribution is shown in Fig. (2). Silicon carbide is the first type of additives which has a particle size of (69.81) µm and particle size distribution is shown in Fig. (3). While firebrick powder (FBP) is the second type of additives. It has a particle size of (97.08) µm and particle size distribution is shown in Fig.(4).

2.2. Sample preparation

The best conditions were chosen in terms of the percentage of water added (solid/ water =1.5) and the binding material sodium silicate (4) g. The ratio of metakaolin added to kaolin was (30%), in other words, the main mixture consists of (70% Kaolin+30%) meta kaolin. So that the samples after drying had no cracks and have the largest values of bulk density and compressive strength.

Table (1) shows the weight ratios of prepared mixtures. The ingredients were mixed with an electrical mixer where the amount of binding material was (4) g of sodium silicate, the water quantity was (100) g and the total solid powder was (150) g. The powders are then weighed and mixed with water (but manually mixed for (5) minutes before that), then powders were added to water gradually and continue mixing for (2) hours. After finishing the mixing process, the mixture put in lubricated wooden molds, leave for a week and be removed from the molds, then placed in the oven and gradually rise to (110) ° C and remain for (24) hours. Samples were fired by an electric furnace at (1100), (1200), (1300), (1400), and (1500) °C with a sintering rate of (3) C° / min with a soaking time of one hour.

Table (1): The sample compositing of different additives and firing temperature.

Matrix(70%kaolin+30%metakaolin) wt%	SiC wt%	FBP wt%	Firing temperature ^{O}C
90	١٠	0	1100
			1200
			1300
			1400
			1500

90	5	5	1100
			1200
			1300
			1400
			1500
90	0	10	1100
			1200
			1300
			1400
			1500

2.3. Physical Measurement

2.3.1 bulk density

It is calculated by using the Equation [11]:

$$BD = W_1/(V_1-V_2),$$

where BD: bulk density, g/cm^3

W_1: Dried weight, g;

V_1: Soaked weight, cm^3;

V_2: Suspended weight, cm^3.

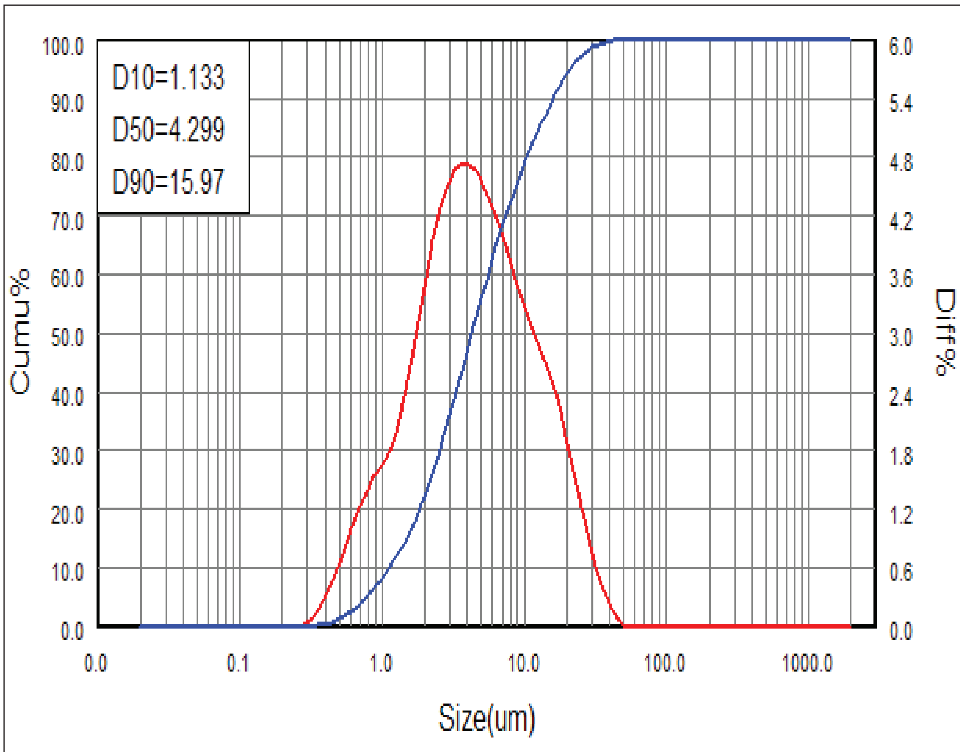
2.3.2 Apparent porosity

It is calculated from Equation [11]:

$$AP= (W-D)/(W-S)*100,$$

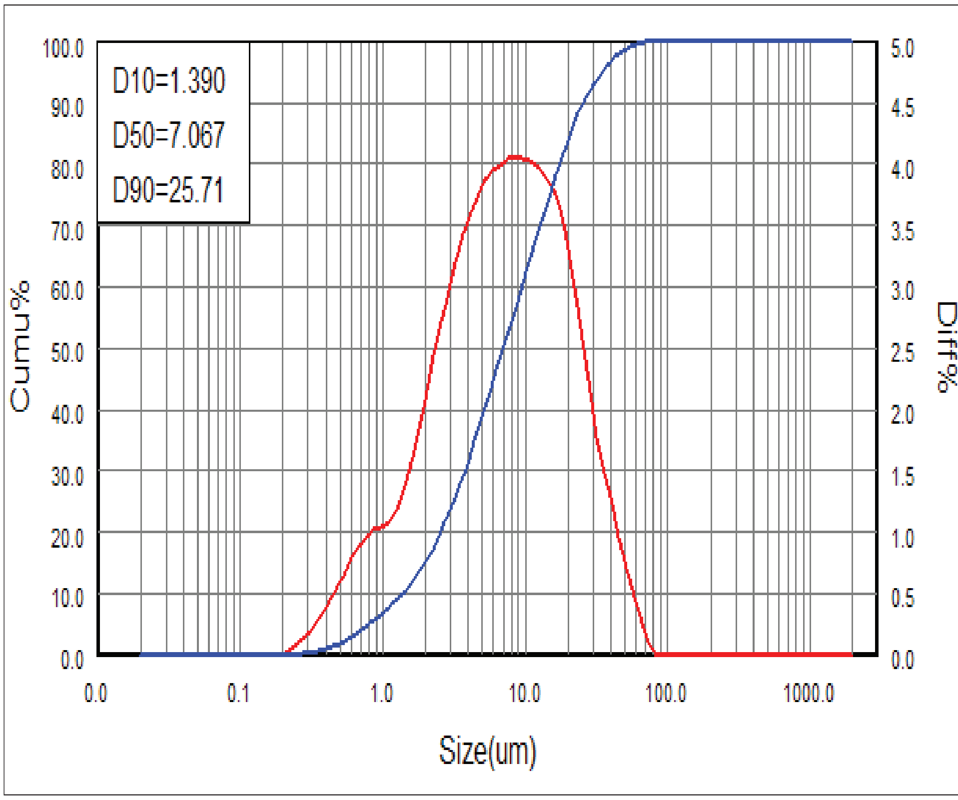
where *AP*: Apparent porosity, %; *W:* Suspended weight, g; D*:* Dry weight, g;

S: Soaked weight, g.



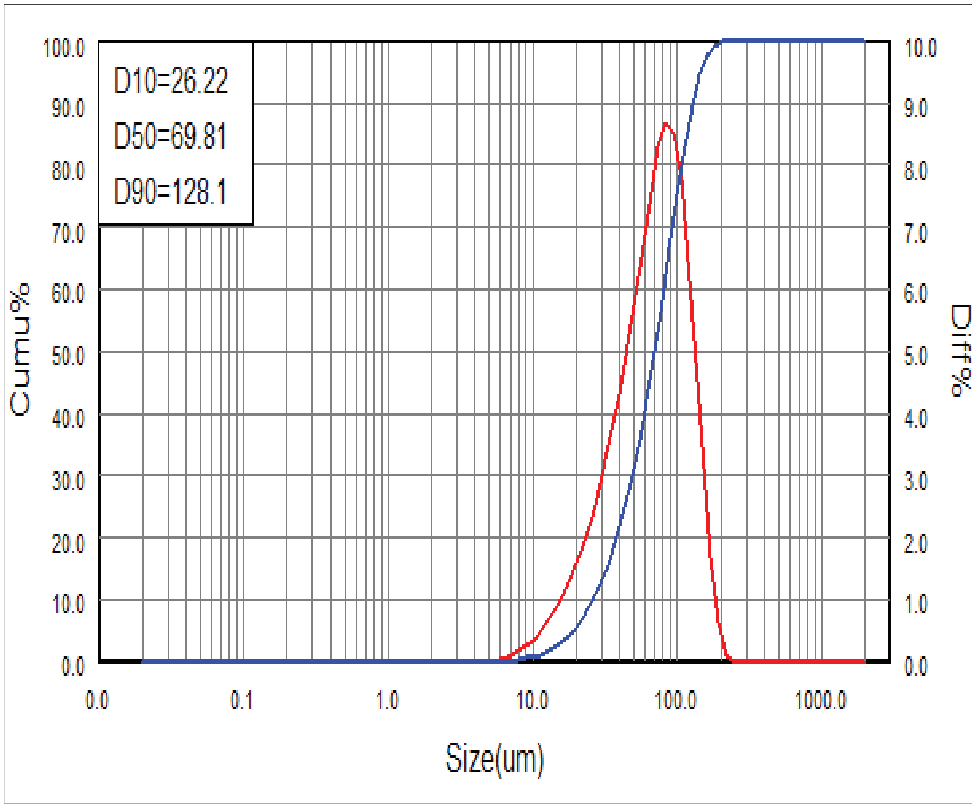
Diam um	Percent
0.100	0.00
0.200	0.00
0.500	1.24
1.000	8.19
2.000	22.01
5.000	55.89
10.000	78.75
20.000	94.13
45.000	99.94
75.000	100.00

Fig. (1): particle size distribution of Iraqi kaolin.



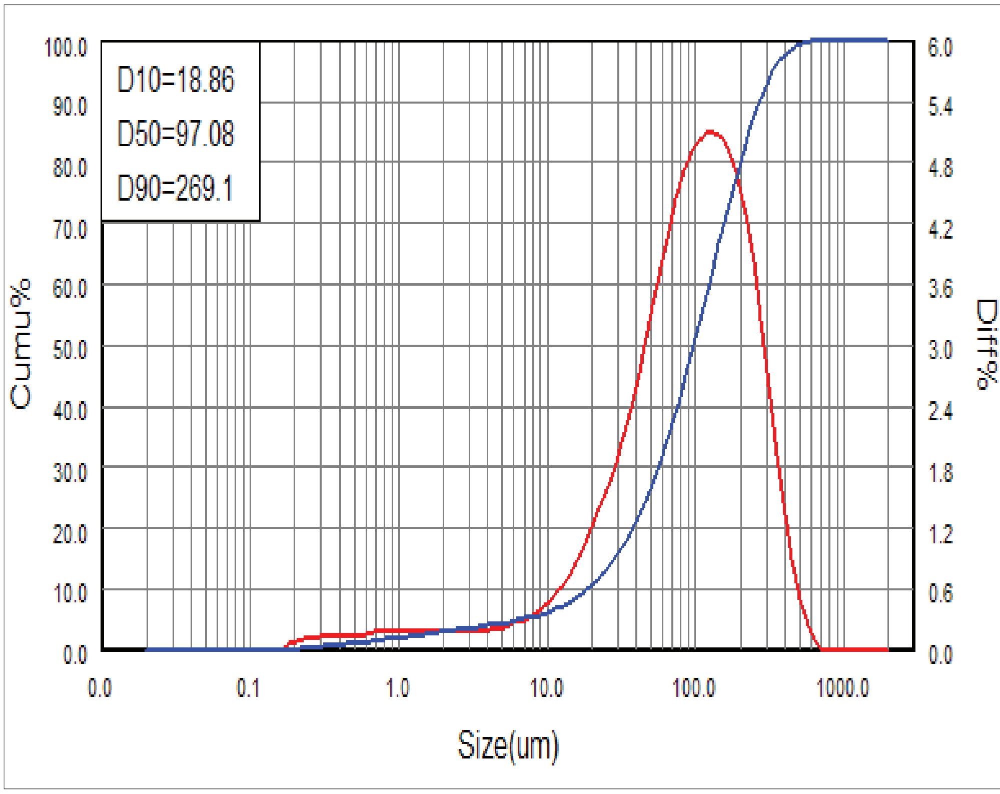
Diam um	Percent
0.200	0.01
0.500	1.78
1.000	6.85
2.000	15.06
5.000	38.63
10.000	61.69
20.000	83.83
45.000	97.78
75.000	99.95
100.000	100.00

Fig. (2): particle size distribution of Iraqi metakaolin.



Diam um	Percent
1.000	0.00
2.000	0.00
5.000	0.00
10.000	0.68
20.000	5.58
45.000	26.33
75.000	54.84
100.000	75.45
200.000	99.74
300.000	100.00

Fig. (3): particle size distribution of SiC powder.



Diam um	Percent
20.000	10.56
45.000	23.87
75.000	39.78
100.000	51.25
200.000	80.03
300.000	92.83
400.000	97.66
500.000	99.35
600.000	99.88
700.000	100.00

Fig. (4): particle size distribution of fire brick powder(FBP)

2.3.3. Coefficient of thermal conductivity

The coefficient of thermal conductivity is measured by using a YBF-3 thermal coefficient meter, which depends on the steady state method The time required to measure the sample is two hours. The sample is placed between the two copper disks, after which the apparatus is programmed at (100)°C. After reaching the steady state, the voltage values V_1 and V_2 are taken. The irradiation rate of the lower copper disk, at the adjacent to V_2, was then calculated directly and the following equation is used:

$$\lambda=(mch_B) / (\pi R_B^2 (V_1-V_2)) \quad ((2h_p+R_p)/((2R_p+2h_p)) \Delta T/\Delta t_{T=T_2} \quad W.m^{-1}.C^{-1},$$

where:

V_1: the value of voltage of the upper copper disk,

V_2: the value of voltage of the upper lower disk,

m: the mass of the radiating disk, i.e. the lower copper plate,

c: the specific heat capacity of the copper plate ($3.805*10^2$ jkg°C^{-1})

h_B: the thickness of the sample,

R_B: radius of the sample,

h_p: the thickness of the radiating disk,

R_p: radius of radiating disk,

$\Delta T/\Delta t_{T=T_2}$: The radiating rate of the lower copper disk at temperature adjacent to T_2.

3. Result and discussion

Fig. (5) shows the behavior of samples prepared from 70%))90%(kaolin +30%

metakaolin) with the additives. It is found that the bulk density increases with the increase of firing temperature until (1400) C°. This general behavior is due to the increase in the percentage of the liquid phase which forms the glass phase after the firing process [12]. While the density drops at (1500) C°. This is mainly a result of the expansion of gases (bloating) enclosed in the matrix due to the presence of Fe_2O_3 in the kaolin powder which changes into Fe_3O_4 and generates O_2 at elevated temperature [13,14].

As shown in Fig. (5) the bulk density values are greater in the case of (% 10) FBP. On the other hand, the addition of (5%) FBP+(5%) SiC caused increasing the values of bulk density compared with the addition of (10%) SiC alone. However, silicon carbide possesses the advantage of inhibiting sintering rate of the refractory material [15]. Silicon carbide is a crystalline material, the colour of which is determined by the level of impurities. Pure silicon carbide is colour less and transparent, the green to black colour of the industrial SiC results from impurities mostly iron [16,17]. Therefore, it is expected that samples prepared with addition of (10%) SiC will cause an increase in bloating during sintering leading to decreasing the values of bulk density.

Fig. (6) and three shows the variation of open porosity with the addition of FBP and / or SiC. Open porosity is found to be less when (10%) FBP is added, while open porosity is greater in case of (10%) silicon carbide. Hamisi *et a.l*[18] expressed the densification in term of open porosity where they found that the decrease in open porosity for Pugu kaolin is due to densification that has taken place. Therefore, sintering is less in samples containing (% 10) SiC as evidenced by high values of open porosity.

Fig. (7) shows the behavior of the coefficient of thermal conductivity of samples of prepared from (90%) (70%)K + 30% MK) with different additives of B.P and / or SiC with increased firing temperature. It is clear that the values of the coefficient of thermal conductivity are greater for samples containing (10%) SiC, while decreasing with decreasing SiC. While samples containing (10%) FBP have the lowest values for conductivity. It is important to say that porosity is an important cause of decreased thermal conductivity where thermal conductivity decreases in refractory materials as its porosity increases with the pores acting as non-heat conducting media [19].

Although the samples containing (10%) SiC have higher open porosity than the other samples but they have a larger values of thermal conductivity. This is because the thermal conductivity of SiC is (270) W / mK°[20]. In other words, the high value of SiC conductivity has a greater effect than the effect of increased open porosity. For example it was found that samples prepared from a mixture of SiC and alumina, at sintering temperature of (1500) C°, have a higher thermal conductivity than samples of prepared from alumina alone [21].

4.conclusion

From study the behavior of samples prepared from (90%) (70%kaolin +30% metakaolin) with additives with firing (1100), (1200), (1300), (1400) and (1500) C° some conclusion are found. It was found that, for all samples, the bulk density increases with increasing of firing temperature up to (1400) C° then the density drops at (1500) C°**.** The open porosity decreases with increasing firing temperature up to (1500) C°. The bulk density increases with increasing of FBP while the open porosity decreases with increasing of FBP. Finally, the values of the coefficient of thermal conductivity are greater for samples containing (10%) SiC.

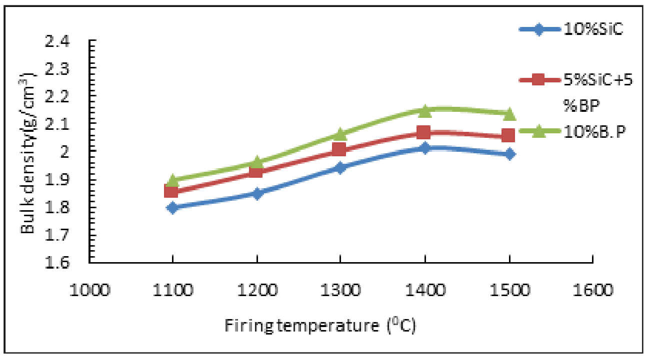


Fig.(5): variation of bulk density with firing temperature with different additives.

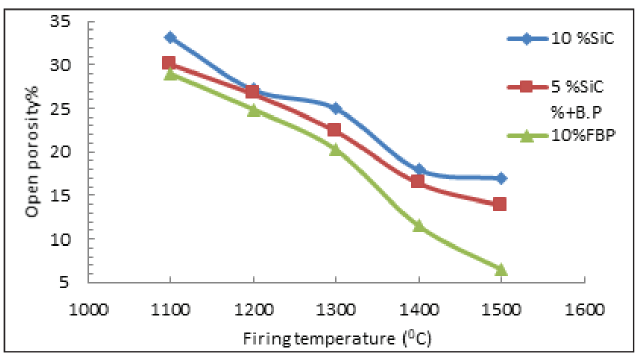


Fig (6): variation of open porosity with firing temperature with different additives.

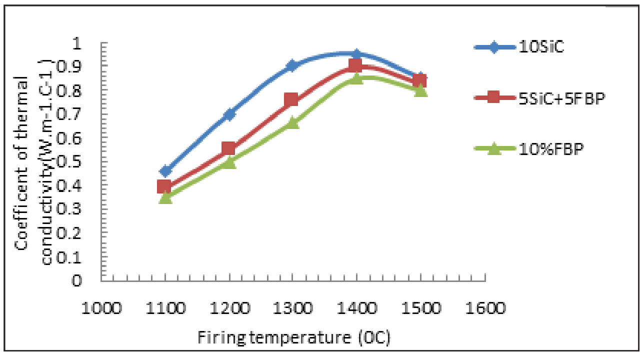


Fig (7): variation of coefficient of thermal conductivity with firing temperature with different additives.

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