TESCE, JULY 2000, PP. 67-79

Effect of polystyrene addition on the physical, mechanical and thermal properties of insulating fire bricks

By
H.B.Geneidy*, O.A.El Bary Ibrahim** and M.F.Abadir**

Abstract
The effect of the addition of polystyrene beds with four different particle size on the different properties of high temperature insulating fire bricks was investigated. Water absorption and porosity were found to increase with the increase in the polystyrene level as well as the size of its beads. The bulk density, the mechanical strength and the thermal conductivity generally decreased with an increase of these two factors. It was also found that the relation between strength and porosity did not depend on the size of the pores created by the addition of polystyrene. The same behaviour was also observed when correlating the thermal conductivity to porosity. The relation obtained did not depend on the pore size.

Key words: Insulating refractories – Polystyrene – Thermal conductivity – Strength

Introduction:

Insulating fire bricks (I.F.B.) are high porosity refractories of low thermal conductivity with subsequent high thermal insulating properties that make them suitable for minimizing heat losses in industrial furnaces. The necessary quality of insulation is obtained by adjusting the particle size of the solids, the pore size and the amount of porosity. A uniform distribution of pores ensures good insulating quality.

In Egypt, I.F.B. are made by mixing different types of clays with grog and foamed polystyrene beads (P.S.) in presence of water. This is followed by extrusion, drying the molded bricks and firing. The combustible matter burns and the products of combustion are expelled from the shaped refractory leaving a light product with the desired porous structure.

Previous work

According to E.S.S. (1), refractory insulating bricks can be classified into four groups following their maximum working temperature. This classification is shown in Table(1) together with their main properties.

The Egyptian Co for refractories, Helwan, Cairo

*** Chemical Engineering Department, Fac. Of Engineering, Cairo University*

Table (1): Classification of insulating refractories according to ESS

Max. Temp.°C	800	1000	1200	1450
Density kg/m^3	< 1100	<1100	< 1200	< 1400
Cold crushing strength M Pa	> 3	>3	>4	>5
Thermal cond. watt/m.K (recommended)	0.45 at 800°C	0.51 at 1000°C	0.55 at 1200°C	0.58 at 1400°C
% linear change on reheating	< 1% at 900°C	<1% at 1100°C	<1% at 1300°C	<1% at 1410°C

Several types of naturally occurring porous raw materials can be used to produce I.F.B. such as **diatomite** (2) , **vermiculite** (3) and **perlite** (4). However, most of the present world production is based on the addition of a combustible material to clays.

Clements (5) studied the effect of adding coke to clay and found that there was an optimum amount to be added below which the resulting body was too dense and above which there was loss of coherence. Another combustible material that was used by many authors is **saw dust**. Its addition to clay requires careful control of grain size besides its swelling tendency in contact with water (2). A successful application was elaborated by Gad et al (6) on blending with clay and vermiculite.

The addition of **polystyrene** to clay to produce I.F.B. is a relatively recent trend. This process has been studied by Sokov (7) who warned against rapid firing that would cause the brick to burst. He subsequently proposed a firing schedule which would yield sound bricks. This author, as well as others (e.g. Monshi et al, 8) have studied the mechanism of sintering in presence of a large number of pores and reported the corresponding sintering curves.

Experimental

Raw materials

- **Clays:** Two types of clays were used, originating from the **Abu Zneima** locality in Southern Sinai. These were the **Esseila** clay, a kaolin type and **Abu sbeira** clay, of the ball clay type. This latter had to be blended to impart some plasticity to the mix. X- ray diffraction showed that both types consisted essentially of kaolinite and quartz. The difference in their plasticity being mainly due to the presence of a relatively important level of organic impurities in the latter (9).
- **Grog:** This was added to decrease the drying shrinkage of the body and was prepared by crushing rejects of insulating fire bricks:

  The oxide analysis of the two types of clays and grog are given in Table (2) while their sieve analysis given in Table (3).

Table (2): Oxide analysis of raw materials

Oxides %	Al_2O_3	SiO_2	Fe_2O_3	CaO	MgO	L.O.I.
Abu Sbeira	24.03	65.86	1.28	0.62	0.50	7.80
Esseila	33.31	54.09	1.39	0.45	0.21	10.83
Grog	35.01	62.90	1.45	0.38	0.23	-

Table (3): Sieve analysis of raw materials

Mesh size	+8	+9	+16	+32	+65	-65
Particle size mm	2.362	1.981	0.991	0.495	>0.208	<0.208
Abu Sbeira	-	-	0.5	4.2	9.0	86.3
Esseila	-	-	0.7	7.8	23.5	68..0
Grog	6.7	6.7	21.5	20.0	12.8	32.7

- **Foamed polystyrene**: It has the formula $[C_6H_5\text{-}CH\text{-}CH_2\text{-}]_n$ and was imported from Bayer , GmbH . It was supplied in the form of spherical beads in four sizes having the characteristics shown in Table (4).

Table (4): Characteristics of polystyrene beads

Mean diameter mm	Range mm	Density kg/m³
1.84	±0.03	153
2.45	±0.04	70
3.125	±0.05	56
4.21	±0.06	41

It is clear that larger sizes have lower densities presumably because of the inclusion of larger pores .

Preparation of bricks

The ingredients were mixed in the following ratio: Abu Sbeira clay 28% , Esseila clay 56% and grog 16%. This ratio was so adjusted to yield a final alumina percentage of 30% necessary to withstand a working temperature of 1300°C. Polystyrene beads were added in different weight ratios ranging from 1% to 10% (7). Mixing was performed in a double blade kneader with 20% water. The paste was then hand molded in wooden frames so that the final fired bodies would have the following dimensions: 230x115x65 mm for bricks and 200x105x22 mm for tiles. These were left to dry in open air until their moisture content decreased to 3-5%.

The dry bricks were then fired in a muffle furnace according to a prefixed schedule: A constant rate of 4°C/min. up to 200°C , then at a rate of 1°C/min. up to 350°C at which they were soaked for 150 min. to allow for all P.S. to oxidize and the volatile products to evolve. This step was followed by heating at a rate of 2°C/min from 450 to 600°C to allow for the dehydroxllation of clays. Above this temperature , no further evolution of gases is expected and the temperature was raised at a rate of 10°C/min. until 1300°C where the bricks were left to soak for 5 hours.

Measurements of physical properties

- **Water absorption , bulk density and porosity:** These properties are closely related and were determined by ASTM C20-87 using the hot test piece boiling water method. In such types of products all the porosity is of the open type so that the bulk density is equal to the apparent density.
- **Cold crushing strength and modulus of rupture:** These were determined using ASTM C93-84. The rate of application of load was taken as recommended by ISO 8895. The samples used for crushing strength had a cross section of 114x114 mm while those tested for MOR had the dimensions: 200x22x22 mm.
- **Thermal conductivity:** This was determined following the Japanese standard JIS R2618 that uses a steady state modification of the hot wire method.

Results and Discussion

Water absorption , porosity and bulk density

The effect of the of PS added on the water absorption is given in Fig.(1). As expected , water absorption increases with the fraction of PS added as well as the size of the granules.
Also , as can be seen from Fig.(2) , the porosity increases in the same way. On the other hand Fig.(3) gives the variation of bulk density with the fraction of PS added as well as its particle size. Here , the bulk density is seen to decrease with an increase in the amount of PS added as well as its particle size.

Mechanical properties

Fig.(4) shows the effect of adding PS on the modulus of rupture (MOR) of the tiles. An increase in the amount of PS added or its particle size is accompanied by a decrease in the MOR. A similar trend is followed by the compressive strength as can be seen from Fig.(5). It was found , however , that it was possible to correlate the compressive strength to porosity for all particle sizes investigated. In that case , such correlation was independent from the size of PS added. Fig.(6) shows the relation between the logarithm of compressive strength vs porosity.

The relation takes the form:

$$\sigma = 296 * e^{-8.09p}.$$

This is the form suggested by Ryskewitsch to correlate strength to porosity (10)
On the other hand, it was possible to correlate the compressive strength to the MOR. Such correlation is shown in Fig.(7). It takes the form:

$$\sigma = 1.89*(MOR)^{0.915}$$

Thermal conductivity

In Fig.(8) is shown the dependence of thermal conductivity at 500°C of IFB on the fraction of PS added. As can be seen from that figure, we may state that generally speaking, the values of thermal conductivity were lower for higher contents of PS and for larger sizes. This is expected since increasing both the amount and the diameter of the added beads enhance the formation of pores. It should be noted, however, that in the case of coarse PS (4.21 mm), there has been an increase in the values of thermal conductivity as the fraction of PS increased above 0.02. The reason for this behaviour is that when enough large pores are formed, they may connect together forming larger pores with a subsequent increase in heat transfer due to convection (11). A similar behaviour was noted when the thermal conductivity was measured at other temperatures. Fig(9) shows the relation between the thermal conductivity and the fraction of PS at 800°C. It is clear that the general pattern observed in Fig.(8) is the same. On the other hand, Fig.(10) shows that the increase in temperature favors a higher conductivity. It was possible to correlate the values of thermal conductivity to temperature and fraction of PS added (X). For the finest fraction (size = 1.84 mm), the correlation was linear with a determination coefficient of 0.925. This relation is: $K = 0.514 + 8.43x10^{-5}T - 2.13X$

Similar relations were also obtained for other sizes.

Finally, following Kingery et al. (11), it was possible to correlate the thermal conductivity to porosity in an equation having the form: $K = A.(1 - p)$ at different temperatures. Only two such correlation are shown in Fig.(11). The regression equations could be integrated in one single equation relating the thermal conductivity to both temperature (°C) and porosity over the range of temperatures investigated for all sizes of PS added. This equation takes the form:

$$K = (0.0003.T + 0.81).(1 - p)$$

We conclude that thermal conductivity is only affected by the amount of pores present but not their size.

Conclusion

The effect of adding PS beads with different particle size on the different properties of IFB was investigated. It was found that an increase in the percentage of PS added and in the size of the beads gave bricks having higher water absorption , higher porosity but lower bulk density. The relation between both compressive strength and modulus of rupture of the bricks and porosity did not depend on the particle size of the PS added. Also , the thermal conductivity of the bricks decreased with an increase in the percent PS added and its size. However , the relation between thermal conductivity and porosity was only dependent on temperature and not on the size of the pores formed.

References

(1)Egyptian Standard Specifications: " Insulating refractory materials ", 1973-71

(2)Chesters J.H. " Refractories , production and properties ", Iron and steel Ins. London (1973) , pp402-412 and 428-430.

(3)Nandi D.N., " handbook of refractories " Tata-Mc Graw-Hill pub. India , 1987 , pp.60-62

(4)Clements J.F. , Trans.Brit.Cer.Soc. , Aug.1966 , pp468-471

(5)Albert J. , proceedings of the 7th conference on the silicate industry , Budapest , 1965 , pp.608-611

(6)Gad G. and Gharib N. , Jour. Chem. UAR , V9 , N°2 , 1965 , pp243-255

(7)Sokov V.N. , Refractories ,V6 , 5-6 , 1995 , pp144-148

(8)Monshi A. and Chahouki M. , 3rd EuroCeram Conf., 1993 , V3 , pp271-276

(9)Geneidi H.B. and Abadir M.F., Trans of the 1st Int. Conf. on clays , Cairo , Sept.1994

(10)Ryskewitsch D. , Jour. Am. Ceram. Soc. , V36 , 1953 , pp65-69

(11)Kingery W.D. , Bowen H.K. and UhlmannD.R. , " Introduction to ceramics " , 2nd Ed. J.Wiley &sons , N.Y. , 1976 , pp636-640

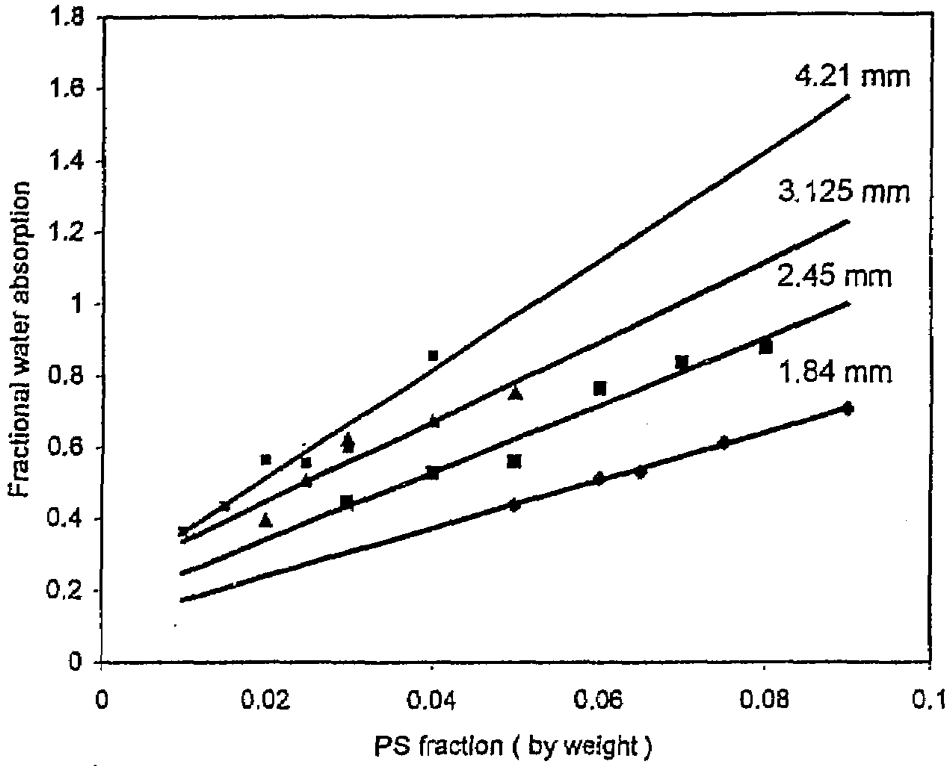

Fig.(1): Fractional water absorption vs fraction of PS added (by weight)

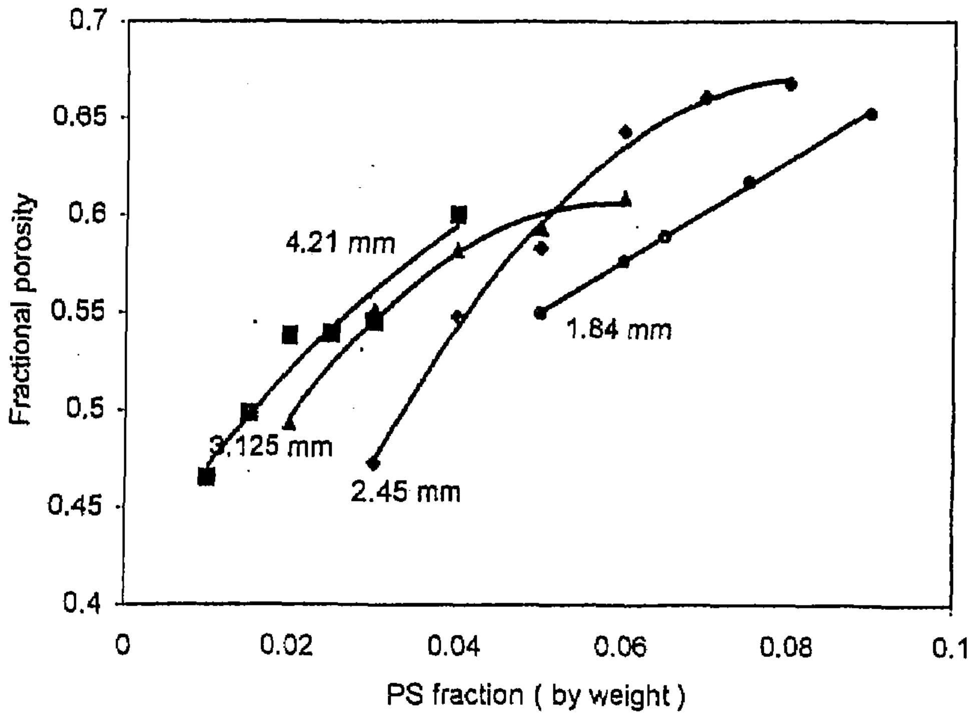

Fig.(2): Fractional porosity vs fraction of PS added (by weight)

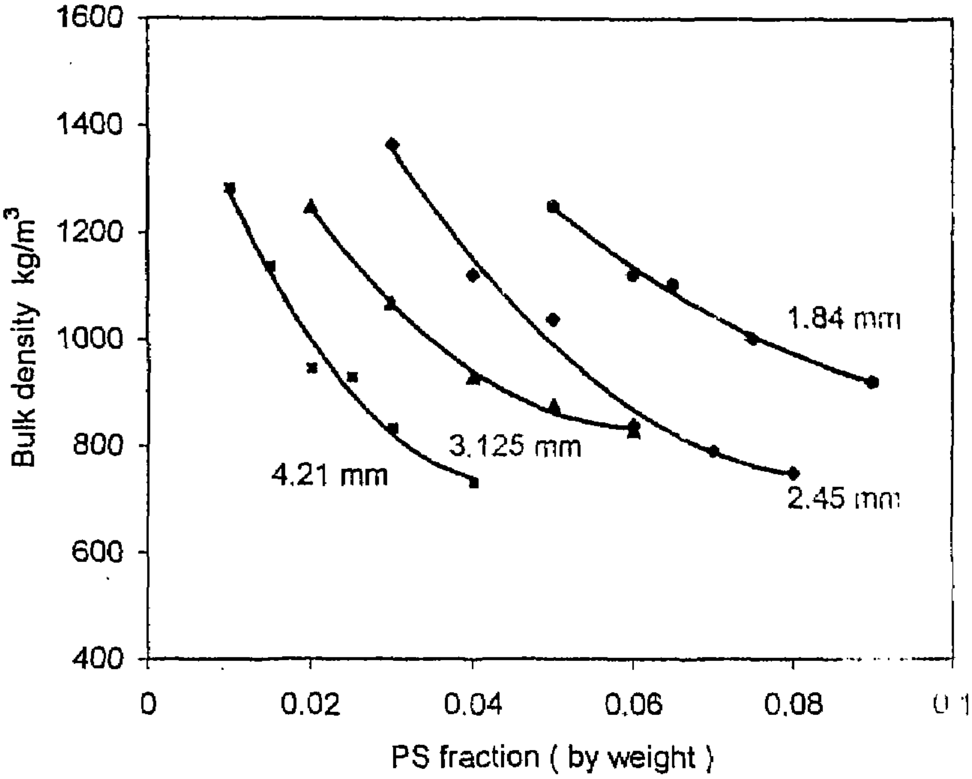

Fig.(3): Bulk density vs fraction of PS added (by weight)

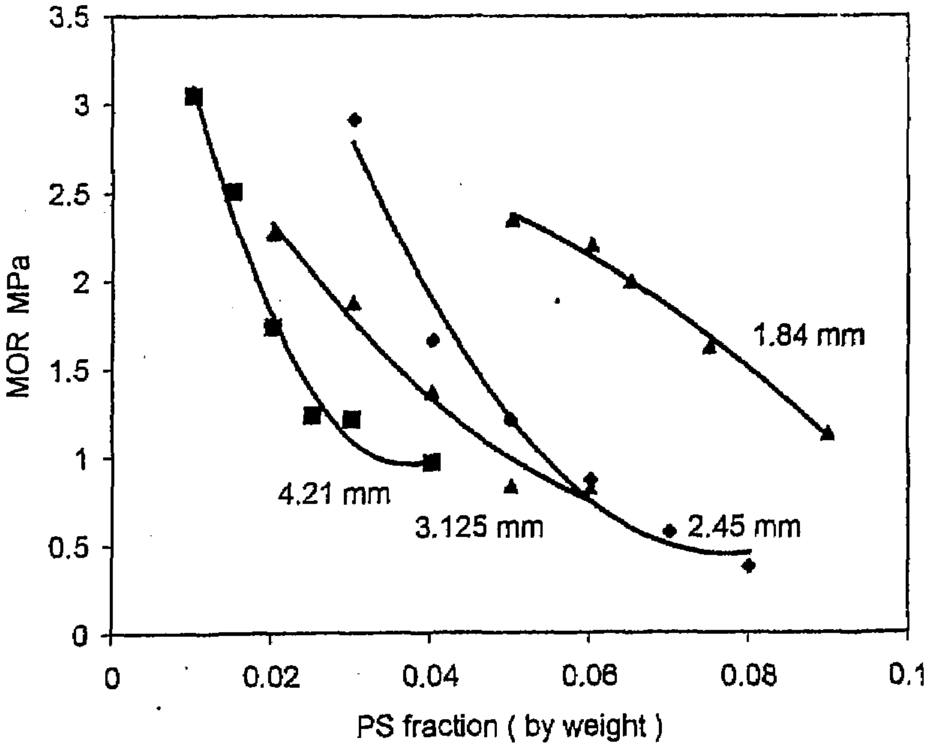

Fig (4): MOR vs fraction of PS added (by weight)

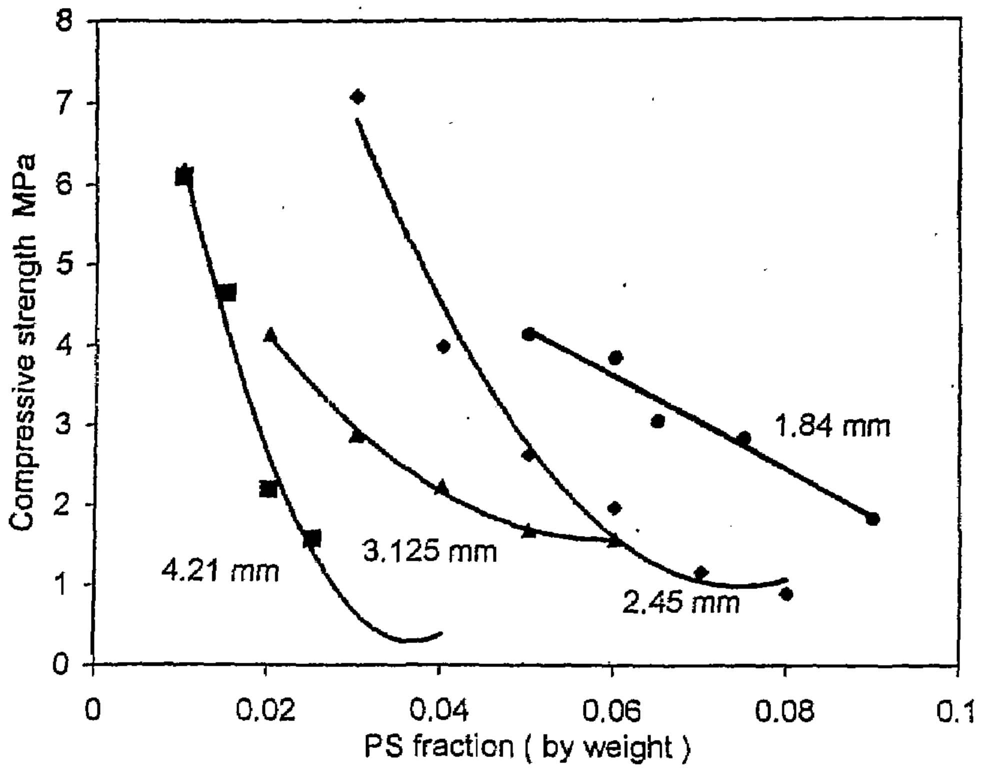

Fig.(5): Compressive strength vs fraction of PS added (by weight)

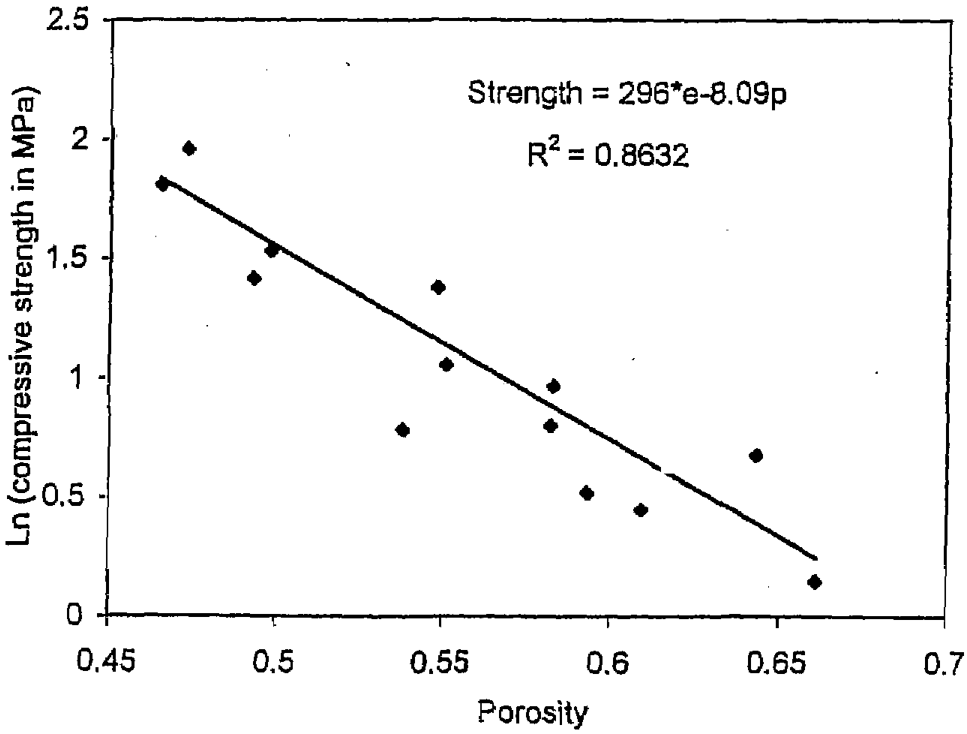

Fig.(6) Linearized relation between porosity and compresive strength

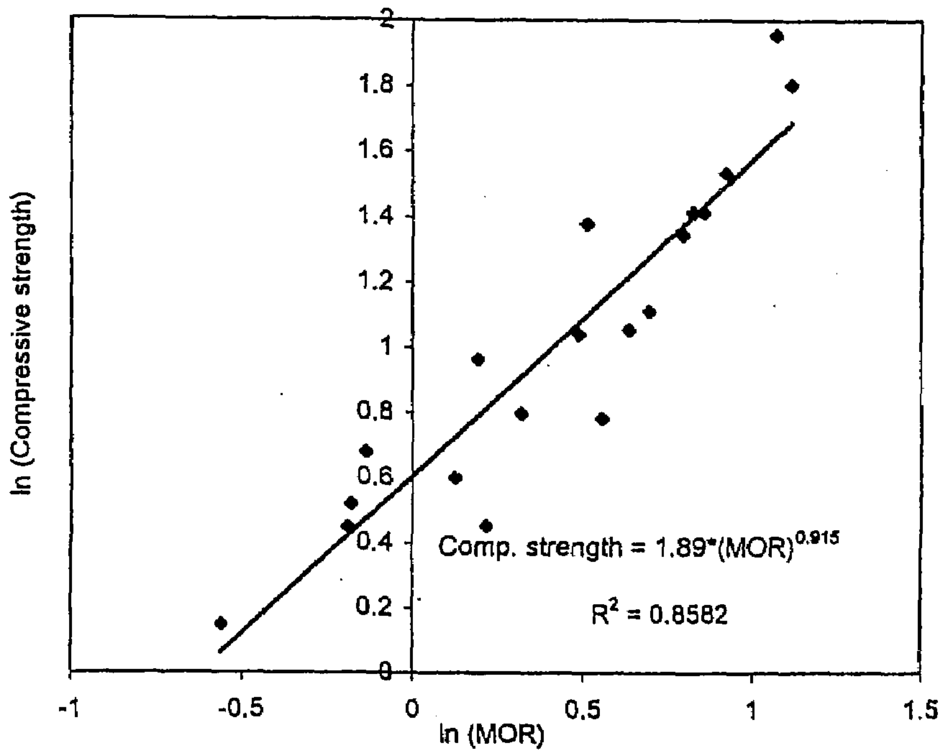

Fig.(7): ln (compressive strength) vs ln(MOR)

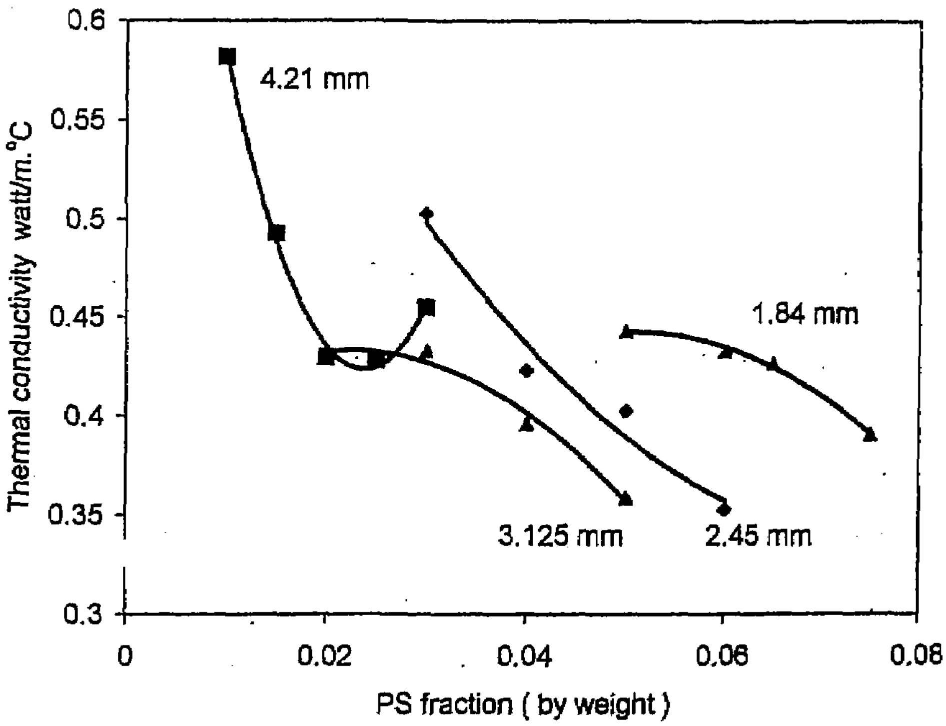

Fig.(8): Thermal conductivity at 500 ° C vs fraction of PS added (by weight)

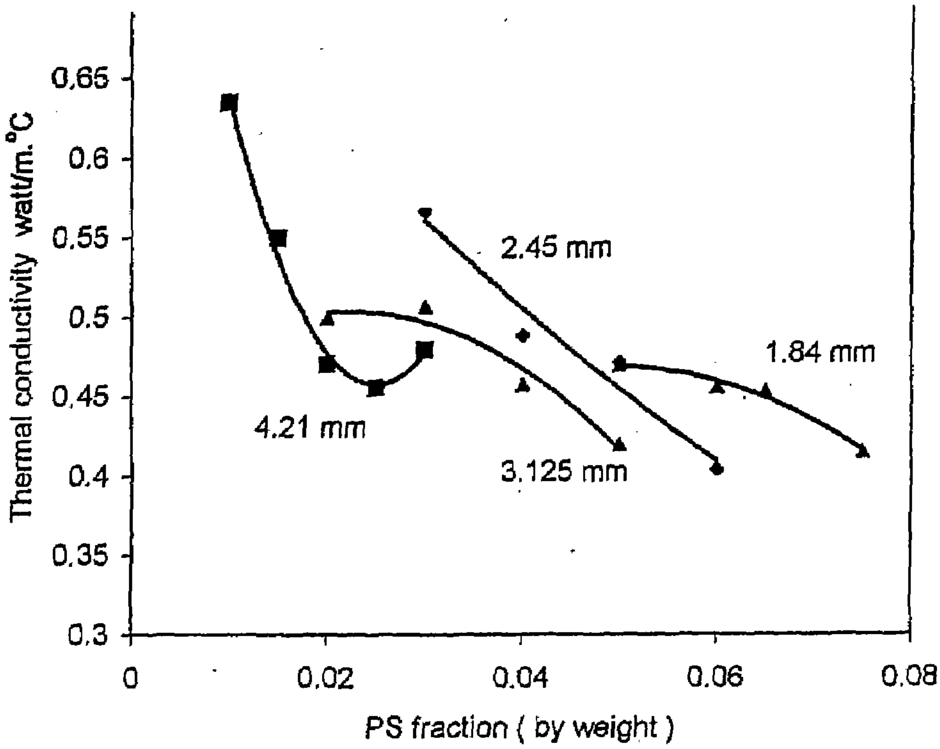

Fig.(9): Thermal conductivity at 800°C vs fraction of PS added (by weight)

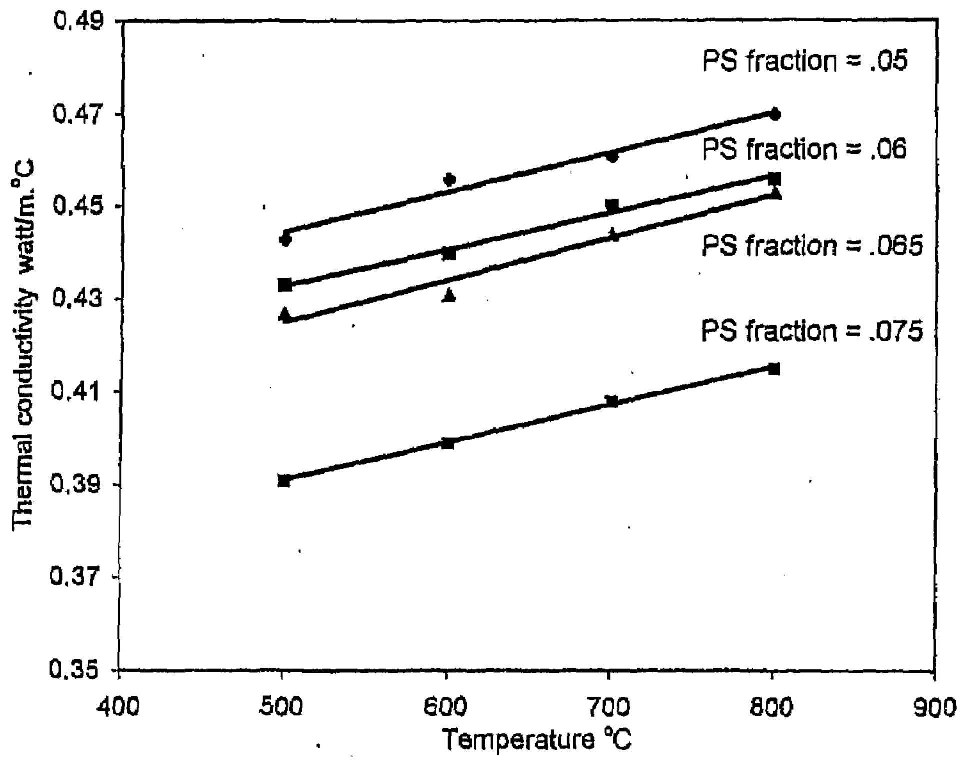

Fig.(10): Effect of temperature on the thermal conductivity of IFB containing PS of size = 1.84 mm

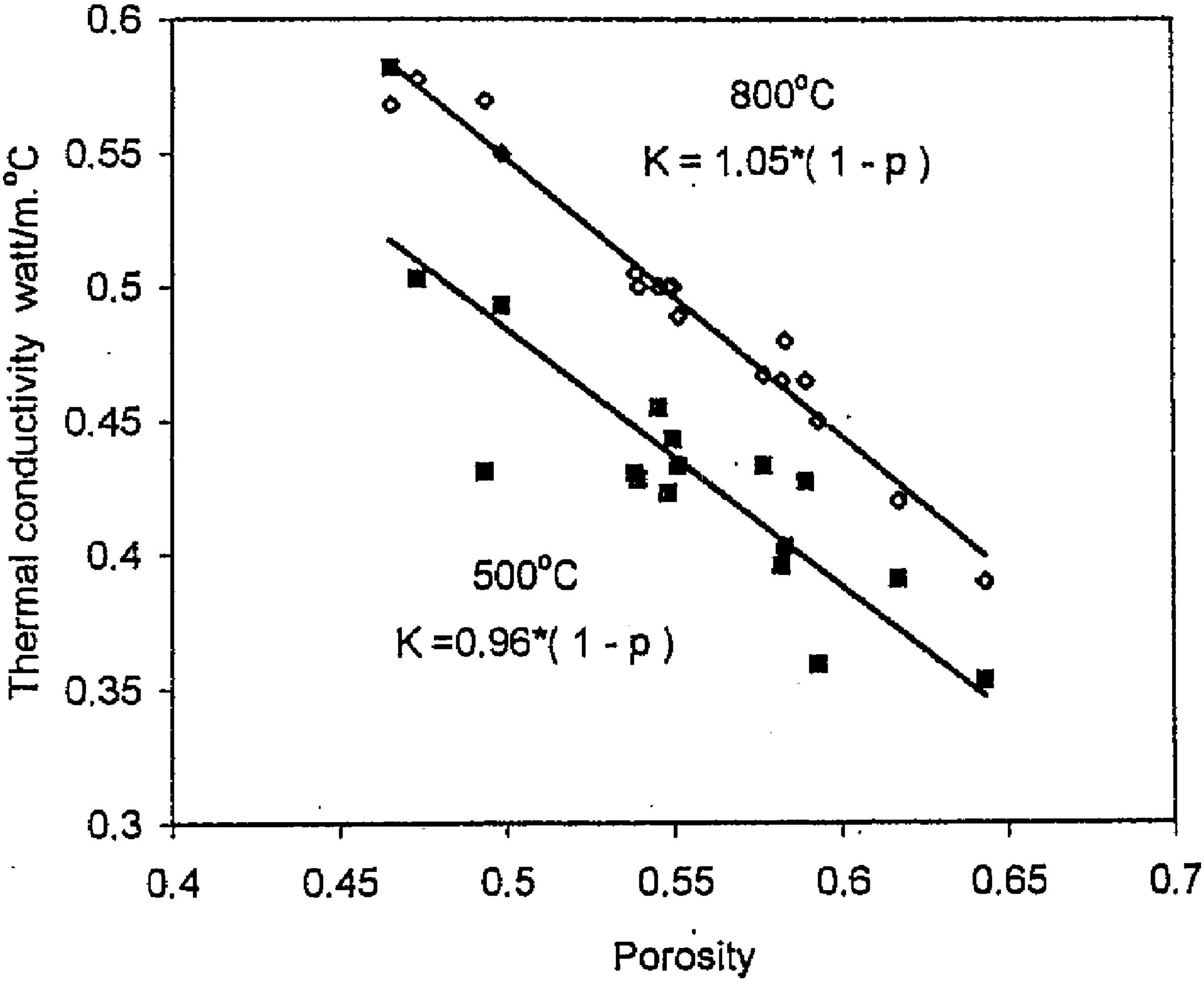

Fig.(11): Effect of porosity on thermal conductivity