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PRODUCTION OF INSULATING REFRACTORY BRICKS USING RICE STRAW

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ABSTRACT

Fire clay insulating bricks were produced using different percentages of rice straw as a porosity generator. Firing was performed at temperatures reaching 1300°C for a soaking time of one to three hours. The sintering parameters, the cold crushing strength, the modulus of rupture and the thermal conductivity (at temperatures from 400 °C to 800 °C) were determined as a function of the percentage rice straw added and the firing temperature. It was found that the level of addition of rice straw necessary to get a reasonable porosity resulted in low mechanical properties. Hence, in addition to rice straw, 1% polystyrene (PS) was mixed with the raw materials to get the required porosity together with mechanical properties within the standard limits. It was concluded that a brick prepared using 25% rice straw and 1% polystyrene fired at 1300 °C for one hour abided by the standards required for insulating bricks to be used at a maximum service temperature of 1100 °C.

Key Words: Rice straw – Light weight – Refractory

1. INTRODUCTION:

Light weight insulating bricks are a major component in furnaces. Fire clay insulating bricks amount to an appreciable fraction of the world production of insulating refractories. The ASTM classifies fire clay insulating refractory bricks according to their bulk density and the temperature at which the brick shows a percentage linear change on reheating equaling 2% (Table 1) [1]. These bricks can be produced either by using naturally occurring porous materials, such as diatomite, perlite, vermiculite, or by adding a combustible material, such as coal, anthracene, saw dust [2,3,4]. They are formed by either extrusion or pressing, although in this latter case, there is a maximum molding pressure above which the bulk density decreases [5]. Drying is performed in the conventional way and firing is usually effected at temperatures higher than 1200 °C [6].

Among the combustible materials that are present in huge amounts in Egypt is rice straw. The annual production of rice in Egypt in 2002 was estimated to be over 6 million tons. Government policy prior to 2000 was to buy this rice straw from the farmers and use it for the manufacture of plywood. The decreased demand on this particular item, coupled with the rapidly increasing production of rice resulted in the accumulation of huge amounts of straw that were left to the farmers to deal with. The easiest solution they found was to burn this straw, which caused a serious pollution problem extending over thousands of square kilometers.

In the present paper, it is tried to incorporate rice straw as a combustible material in the production of light weight insulating fire clay refractories of type 23 (in accordance to the Egyptian Standards 71-1973) which have a maximum service temperature of 1200 °C. Their standard properties are shown in Table 2.

2. EXPERIMENTAL TECHNIQUES AND RAW MATERIALS

Raw Materials:

The clay used in this study was a ball clay obtained from Aswan, in upper Egypt. Its chemical analysis is shown in Table 3. X-ray diffraction showed it to consist mainly of kaolinite and quartz. This was ground to pass 100 mesh screen (0.147 mm). Its thermal analysis was effected in a thermal analyzer (Shimadzu type TGA-50). At a heating rate of 10 °C/min. The result is shown in Fig.1 and reveals that chemical water is eliminated in the range of 550 – 750° C.

Grog was prepared by firing the above-mentioned clay to 900 °C and ground to pass the same mesh size as clay.

Rice straw was brought from Minufeya Governorate in the Nile Delta. It was brought as ground. Screen analysis showed that 90% pass 60 mesh screen (0.246 mm). Its chemical analysis is shown in Table 4.

Procedure:

Thermal analysis was performed on the rice straw in the aforementioned thermal analyzer at a heating rate of 10 °C/min. The result is also shown in Fig.1 and reveals that there is a major weight loss ending at 360 °C and a slight loss ending at 650 °C. Thermal analysis of both clay and rice straw was important in order to determine the range of temperature over which they decompose so as to select a suitable firing schedule that would not affect the bricks [7].

Foamed polystyrene beads were obtained from the local market. It was found to have an average diameter of 1.84mm and a specific gravity of 0.153.

Kneading was performed in a two-arms kneader using 15% grog and 25 to 35% water and different percentages of rice straw ranging from 0 to 30% (based on the weight of clay + grog). Two sizes of moulds were used: 230mm x 115mm x 65mm, to be used for physical and mechanical tests and 200 mm x 105 mm x 22 mm to be used for the determination of thermal conductivity. Hand molding was performed in each case. The specimens were first air-dried overnight then allowed to dry at 90 °C for two hours. The moisture content, as determined after drying did not exceed 0.08%. Firing was then effected using a suitable heating schedule taking into consideration the range of temperature over which the straw decomposes (350 - 550°C) as well as the range of decomposition of kaolinite (550-750 °C). This is shown in Table 5. The soaking time was varied from one to three hours and two firing temperatures were used 1200 and 1300°C. The following tests were performed on the fired samples: bulk density, apparent porosity and water absorption [ASTM C20-87], cold crushing strength [ASTM C93-84]. Thermal conductivity was measured using the hot wire method after calibration of the apparatus using a brick of known thermal conductivity at each temperature [JIS R 2168, 1992]. Values of thermal conductivity were measured at temperatures ranging from 400 °C to 800 °C. The percent linear change on reheat was measured according to [ASTM C210-85].

3. Results and Discussion

3.1 Effect of Addition of Rice Straw on the Properties of Samples fired at 1200 °C

3.1.1. Bulk density

Fig. 2 shows the effect of the addition of rice straw on the bulk density of samples fired at 1200 °C for one hour. Its value decreases from 1470 kg/m^3 for samples containing 10% rice straw to 1100 kg/m^3 for samples containing 30% rice straw. These values of density are much higher than those reported in Table 2 for type 23 insulating bricks. Therefore, it was thought convenient to add a small amount of foam PS to the mixture. When 1% PS was added, and firing performed under the same conditions, it was possible to reach a bulk density of 780 kg/m^3 for samples containing 25% straw (Fig.2).

3.1.2 Water absorption

As expected, the addition of rice straw with or without 1% PS increases the level of water absorption above 90% (Fig.3).

3.1.3 Apparent porosity

Fig 4 shows the effect of adding rice straw on the porosity of samples fired for one hour at 1200°C. It is clear that such additions increases the porosity, this increase being enhanced by the addition of 1% PS.

3.1.4. Compressive strength

As stated by ES71-1973, insulating fire bricks of type 23 should have a compressive strength exceeding 1.5 MPa. AS seen from fig 5, the addition of 255 rice straw and 15 PS, although yielding bricks satisfying the bulk density criteria, gives a strength lower than the recommended value for samples fired at 1200°C for one hour. Fig.6 shows that when the soaking time was increased

to two, then three hours, the value of compressive strength stabilized at about 1.25 MPa, which is still lower than the standard requirement.

3.1.5. Modulus of rupture (MOR):

Samples containing 25% rice straw and 1% PS and fired, even for three hours, at 1200°C gave MOR values barely exceeding the standard value of 1 MPa (see Table 2). (Fig.5,6).

3.2 Effect of Addition of Rice Straw on the Properties of Samples Fired at 1300 °C

3.2.1. Bulk density

When firing was effected for one hour at 1300 °C, the values of bulk density increased, due to sintering, over the corresponding values at 1200 °C. Fig.2 shows, however, that as the percent of rice straw was increased, the two values came very close together, so that at 25% rice straw addition the bulk densities at 1200 °C and 1300 °C were 780 and 800 kg/m^3 respectively. At 30% level of addition, the two values were almost identical at 700kg/m^3.

3.2.2. Water absorption

As we can see in Fig.3, water absorption was reduced in samples fired at 1300 °C compared to those fired at 1200 °C. This fact is expected because firing at higher temperatures tends to close the pores and consequently, the water absorption is decreased.

3.2.3. Porosity

Here the same effect is observed as seen in Fig.4. At 1300 °C, the pores are on average lower by approximately 10% than the corresponding values of the samples fired at 1200 °C.

3.2.4. Compressive strength and modulus of rupture

The effect of varying the firing temperature on the strength on the fire samples is shown in Fig.7. As it can be seen, firing for one hour at 1300 °C of samples containing 25% rice straw and 1% PS gave values of compressive strength and MOR above the standard values of 1.5 MPa and 1 MPa .

The relation between the compressive strength and porosity has been found to follow a semi-logarithmic relation [8]. This is shown in Fig.8.

3.3 Thermal Properties of Samples Fired for 1 hour at 1300 °C

Samples containing 25% rice straw and 1% PS fired for one hour at 1300 °C were tested for thermal conductivity at temperatures of about 400 °C, 500 °C, 600 °C and 800 °C as previously stated. The values of thermal conductivity obtained are shown in Table 6. These were used to correlate the thermal conductivity K to temperature in °C as follows:

$$K = 3x10^{-7}T^2 - 0.0002\,T + 0.26 \text{ W/m}^\circ\text{C}$$

The values of thermal conductivity measured at different temperatures were compatible with the requirements of insulating bricks type 23.

Also, the percent linear change on reheating was measured by firing the bricks produced to 1300 °C for two hours. The average value obtained was 1.145% which is less than the recommended value of 1.2% (see Table 2).

4. CONCLUSION

Insulating fire bricks were prepared by mixing different percentages of rice straw with clay and adding 1% foamed polystyrene. It was found that bricks samples consisting of 74% clay, 25% rice straw and 1% PS, fired at 1300 °C for one hour gave physical, mechanical and thermal properties compatible with insulating fire bricks type 23, according to the Egyptian Standards 71-1973. Table 7 shows the comparison between the obtained results and the standard requirements.

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Table 1 : ASTM classification of insulating fire bricks (C155-88)

Group identification	Temp. at which the % reheat change does not exceed 2% , °C	Maximum Bulk Density , kg/m^3
Group 16	845	540
Group 20	1065	640
Group 23	1230	770
Group 26	1400	860
Group 28	1510	960
Group 30	1620	1090
Group 32	1730	1520
Group 33	1790	1520

Table 2 : Properties of group 23 insulating fire bricks (ES 71, 1973)

Property	Type 23 fire insulating brick
Minimum % Alumina	20%
Maximum Bulk density , kg/m^3	800
Compressive strength , MPa	1.5 – 2.0
MOR , MPa	1.0 – 1.2
Maximum % change on reheating	1.2%
Max. Thermal conductivity at 400 °C, W/m. °C	0.22
Max. Thermal conductivity at 600 °C, W/m. °C	0.25
Max. Thermal conductivity at 800 °C. W/m. °C	0.30

Table 3 : Chemical analysis of clay used

Component	Percent
SiO_2	52.03
Al_2O_3	28.72
Fe_2O_3	2.57
CaO	1.02
Na_2O	0.272
K_2O	0.38
L.O.I.	12.22

Table 4 : Chemical analysis of rice straw used

Component	Percent
Humidity	9.02
Protein	3.20
Ether	0.37
Ash	17.8
Soluble carbohydrates	39.4
Cellulose	30.4

Table 5 : Firing schedule of samples

Temp. °C	100	150	200	225	250	300	350	450	550	650	1200
Soaking time min	10	10	20	20	20	20	150	60	60	60	$\geq$60

Table 6 : Thermal conductivity at different temperatures

Temp.°C	415	503	575	670	790
K W/m.°C	0.224	0.231	0.235	0.250	0.290

Table 7 : Compliance of brick properties with ES 71,1973

Property	Standard , type 23	Brick samples
Minimum % Alumina	20%	28.75%
Maximum Bulk density , kg/m^3	800	790
Compressive strength , MPa	1.5 – 2.0	1.55
MOR , MPa	1.0 – 1.2	1.4
Maximum % change on reheating	1.2%	1.145
Max. Therm. Conductivity at 400 °C, W/m. °C	0.23	0.228*
Max. Therm. Conductivity at 600 °C, W/m. °C	0.25	0.248*
Max. Therm. Conductivity at 800 °C. W/m. °C	0.30	0.292*

* Values at the mentioned temperatures are calculated from the regression equation, since the values shown in Table 6, being the experimental figures, were measured at slightly different temperatures.

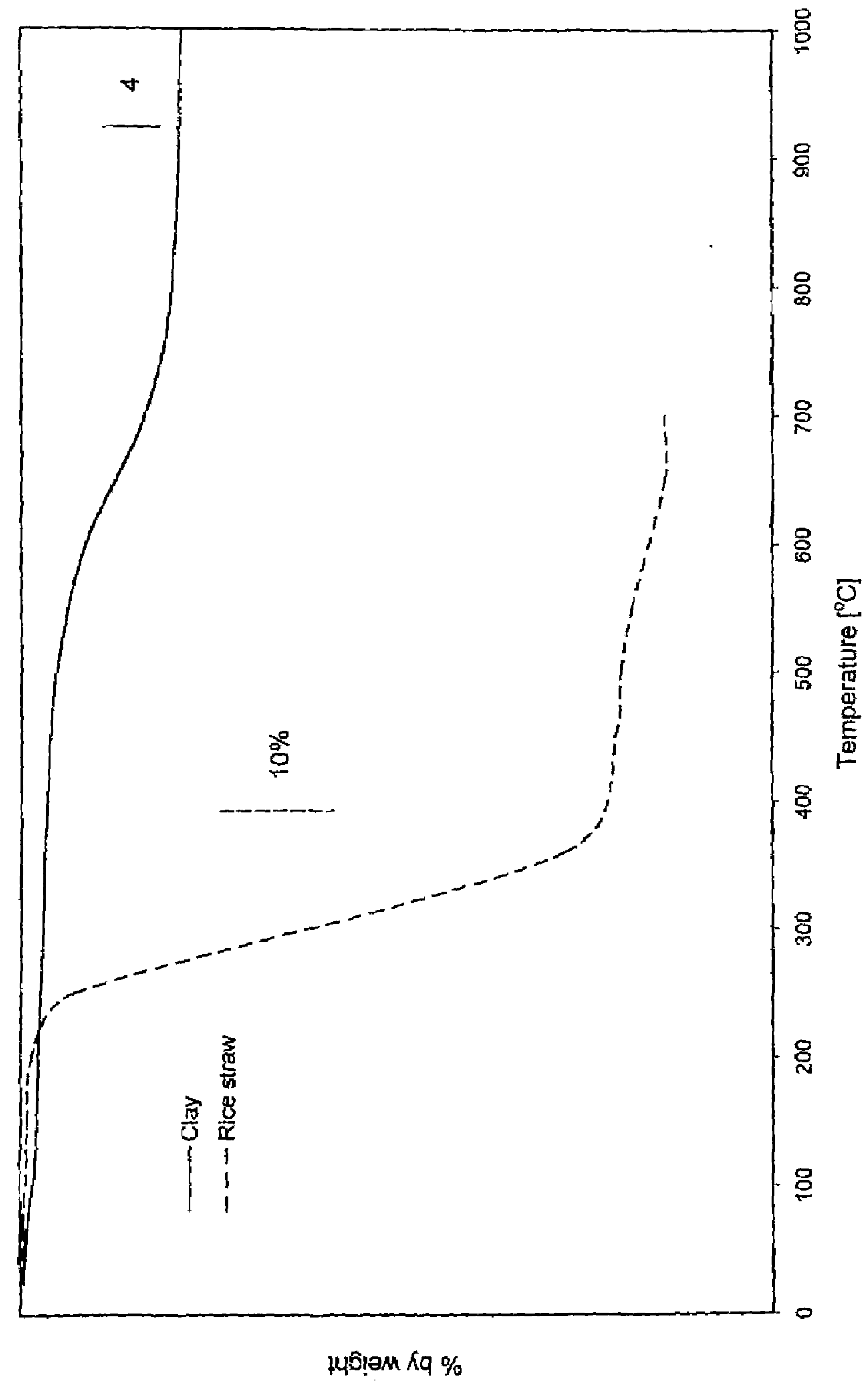

Fig 1 : TG trace of the clay and the rice straw used at a heating rate of 10°C/min

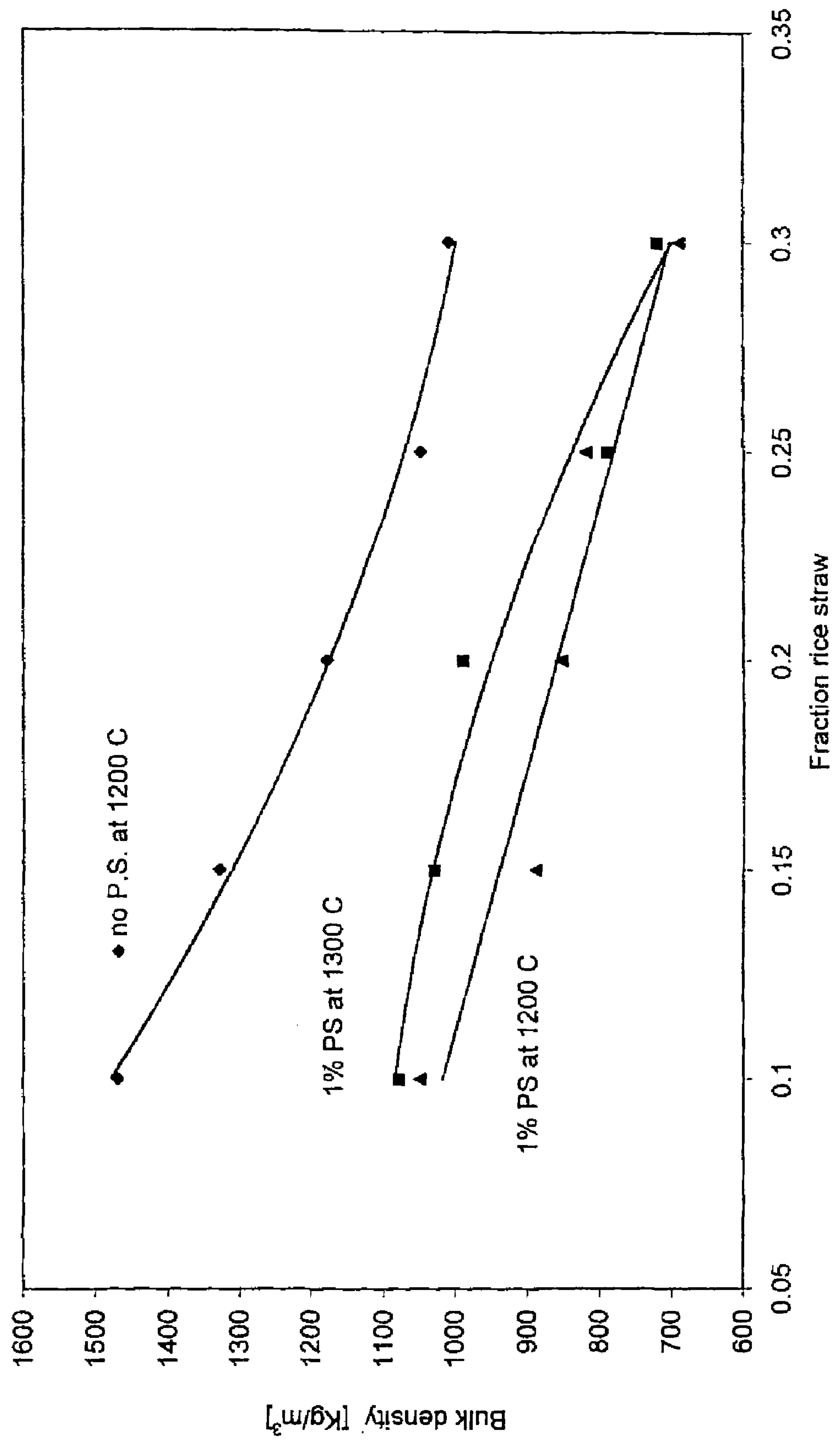

Fig.2 Effect of the addition of rice straw and firing temperature on the bulk density

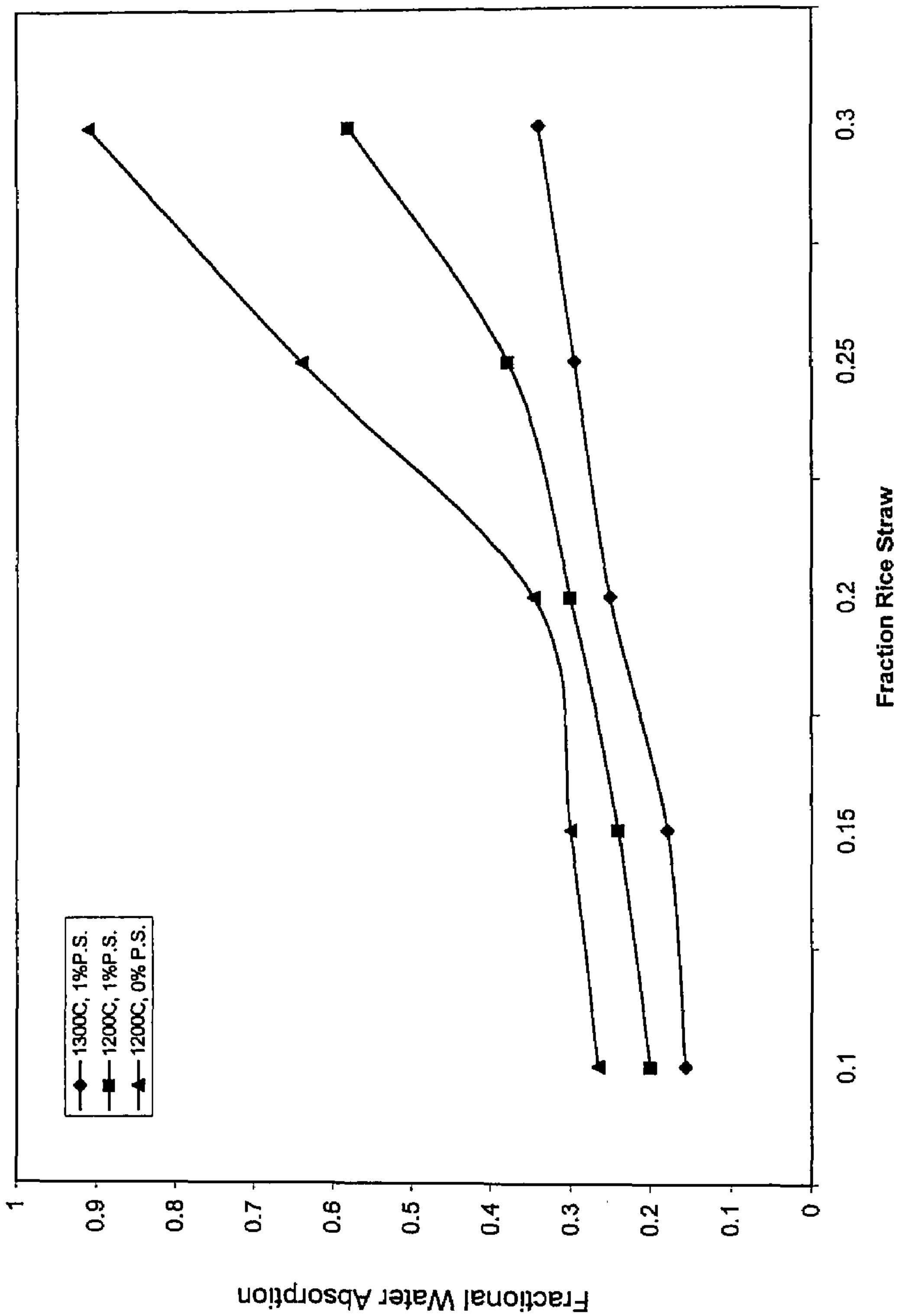

Fig.3 Effect of the Addition of Rice Straw on the Fractional Water Absorption of Samples Fired at 1200°C & 1300°C

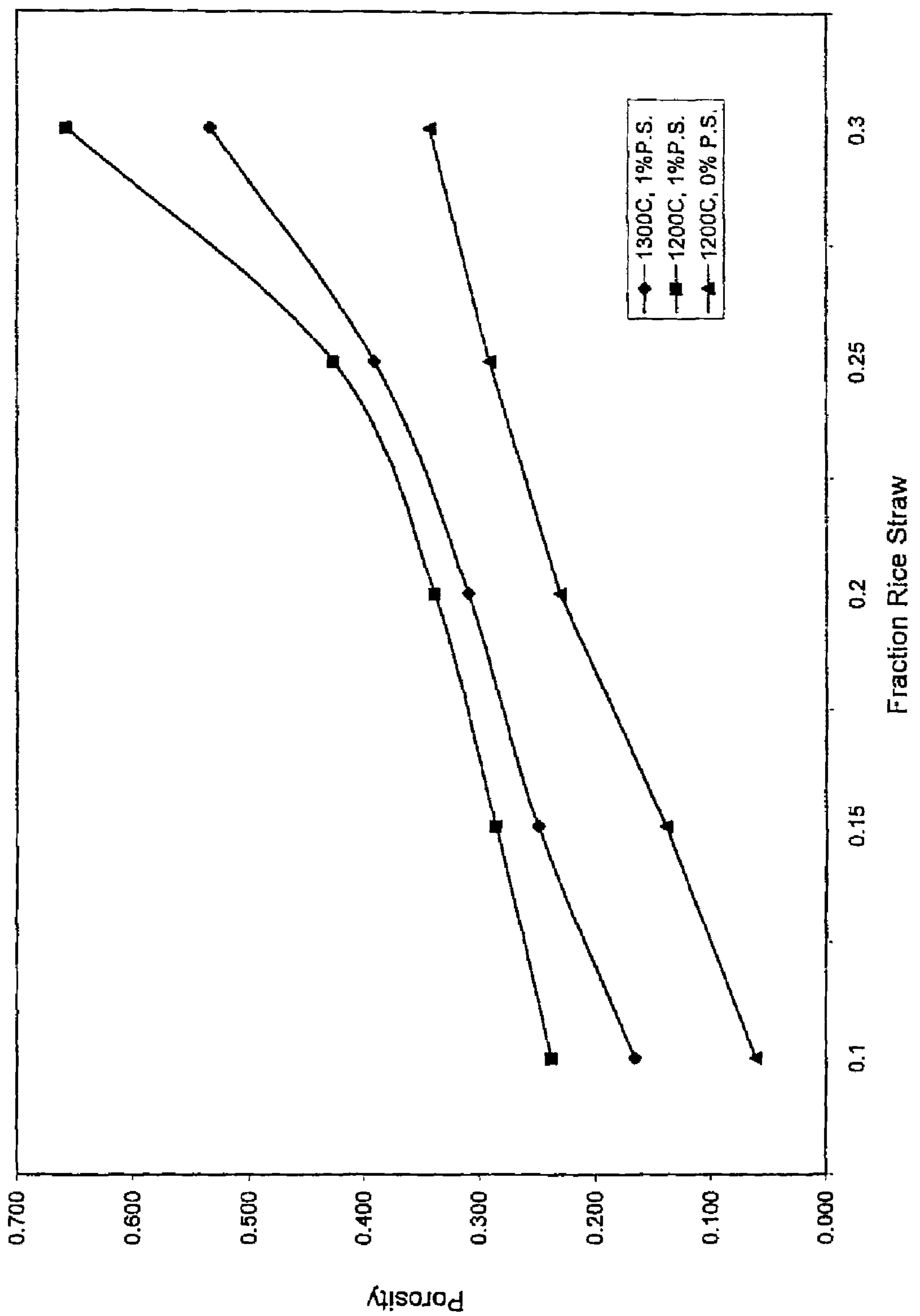

Fig.4 Effect of the Addition of Rice Straw on the Porosity of Samples Fired at 1200°C & 1300°C

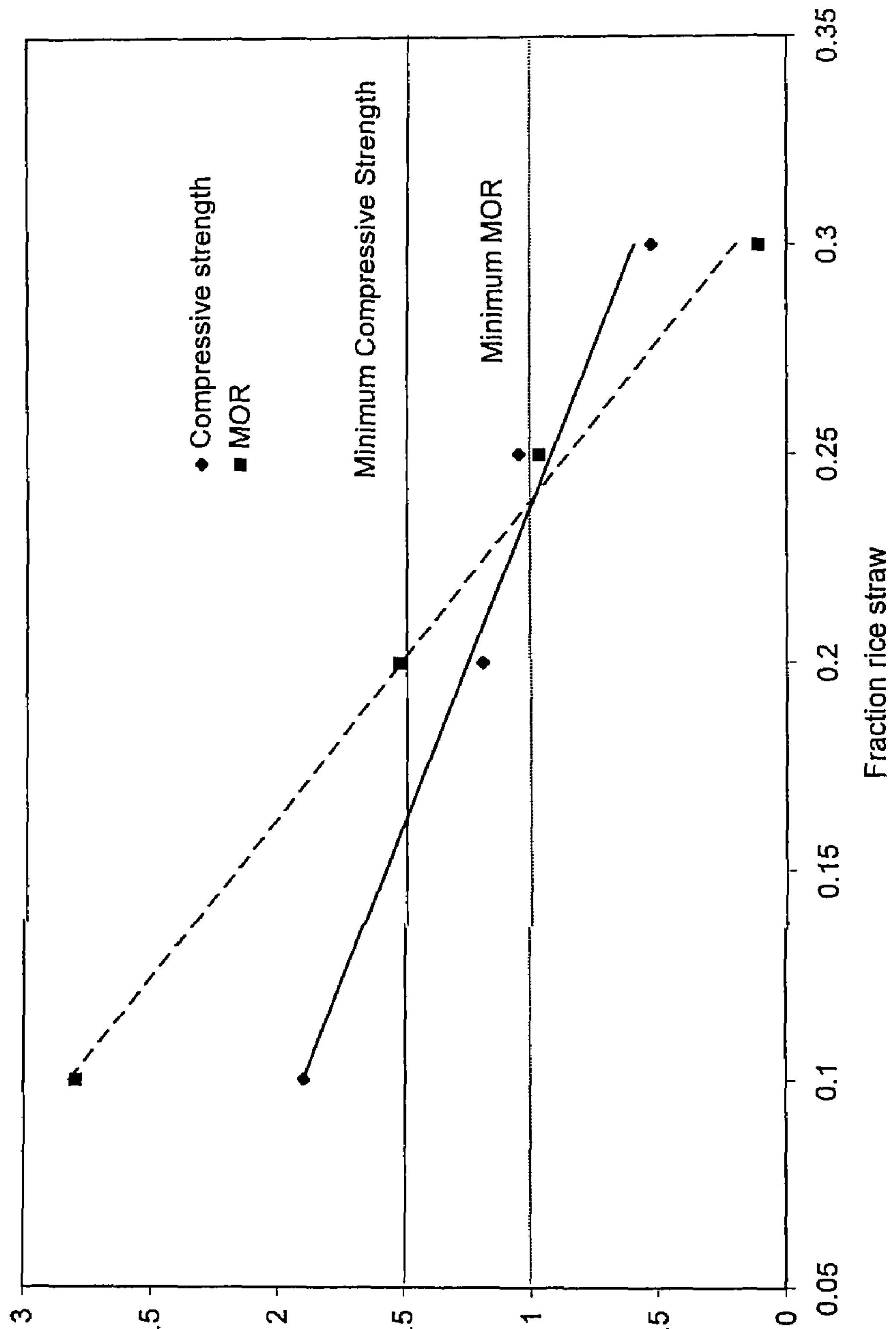

Fig.5 Effect of the addition of rice straw and 1% P.S.on the strength of samples fired at 1200°C

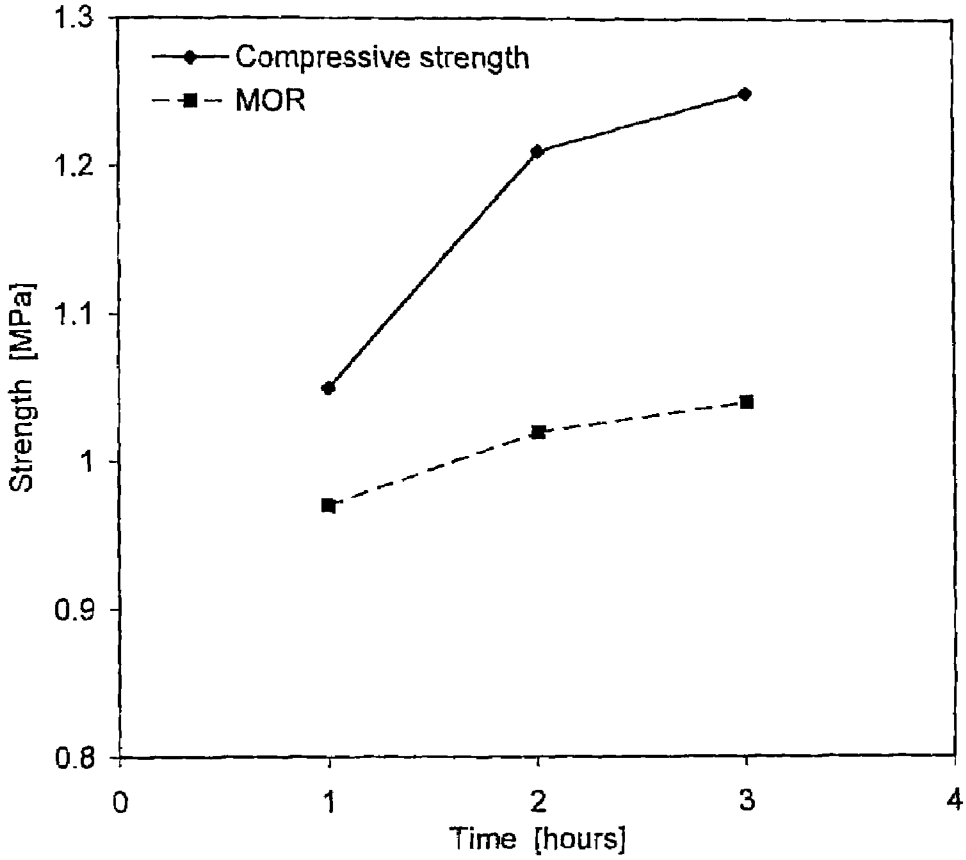

Fig 6 : Effect of soaking time at 1200°C , on the strength of samples containing 25% straw and 1% PS

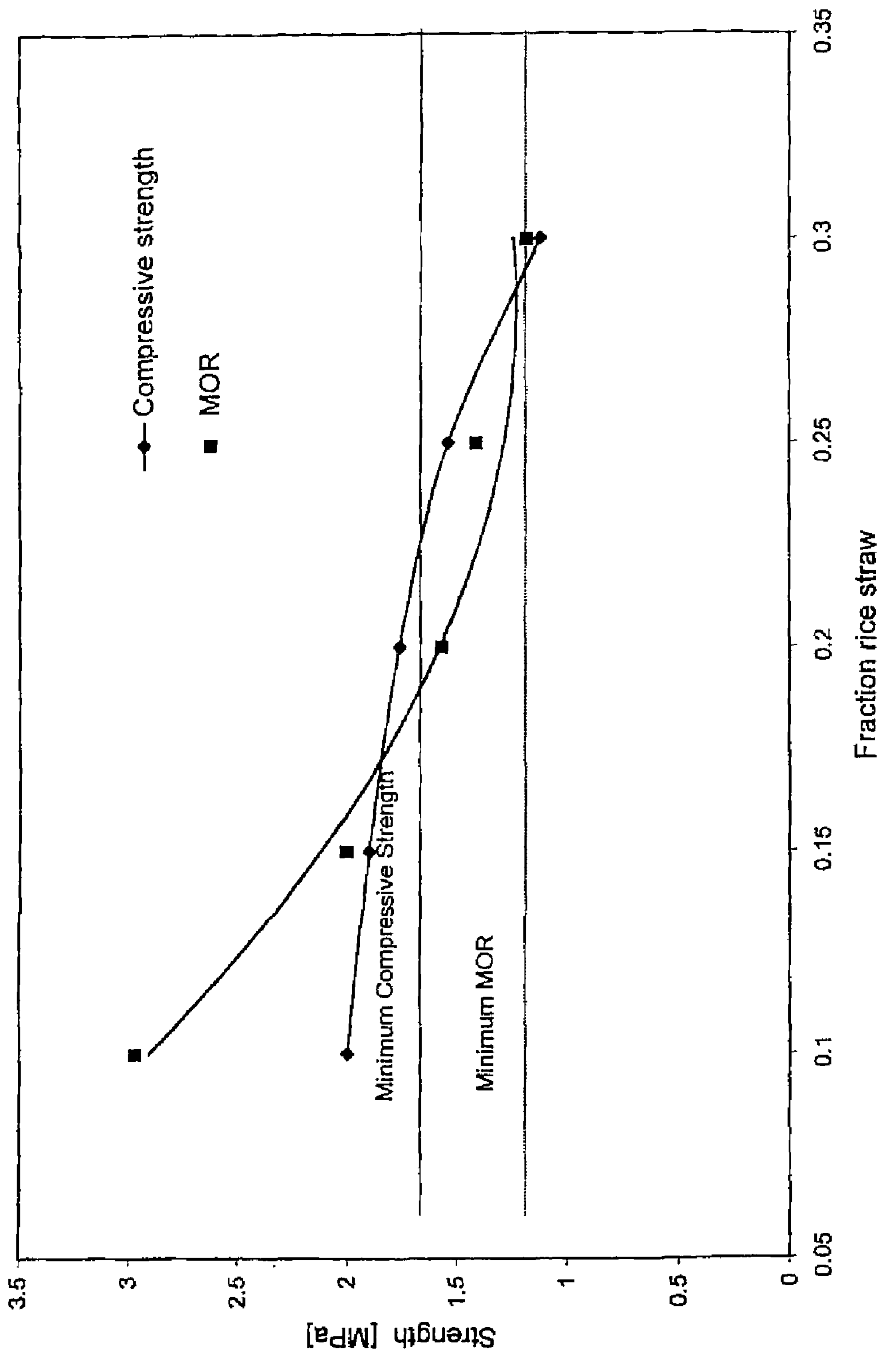

Fig.7 Effect of the addition of rice straw on the strength of samples fired for 1 hour at 1300°C

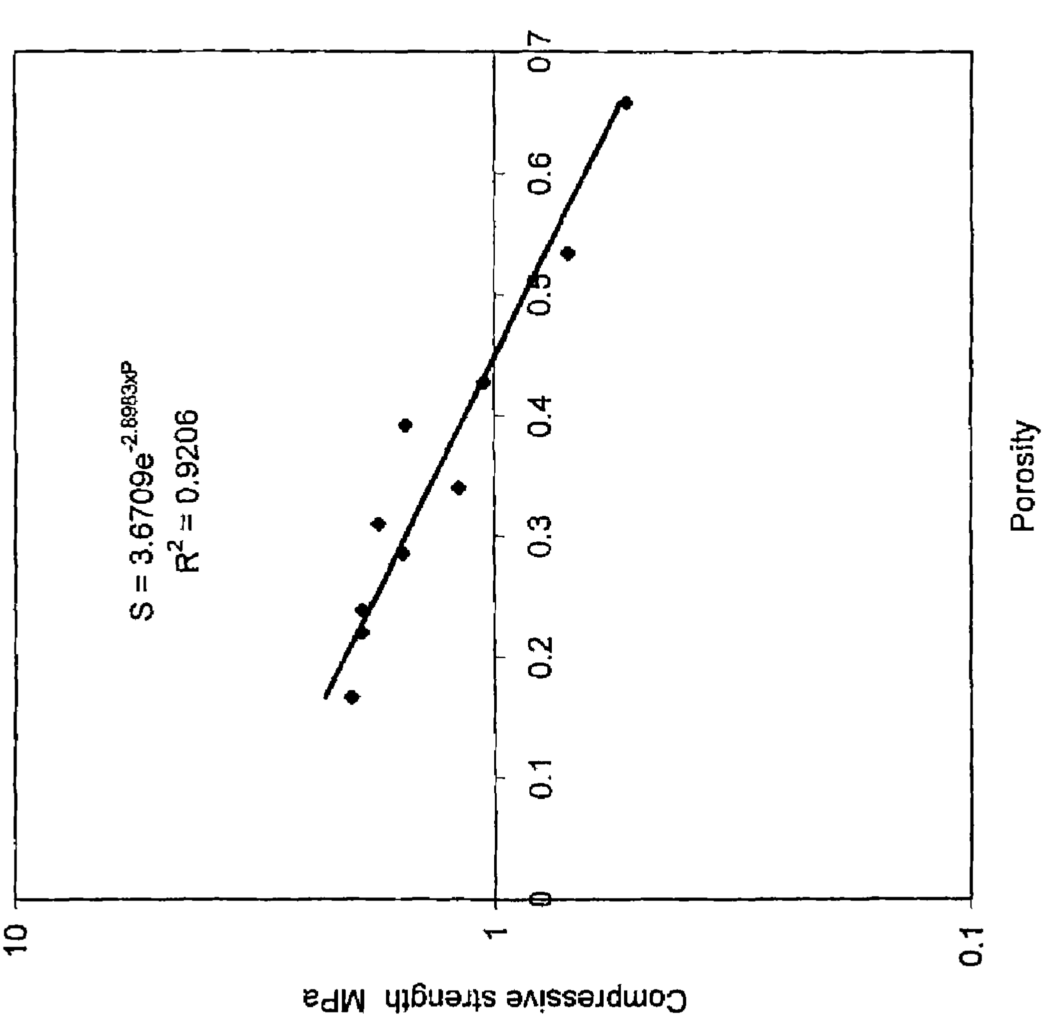

Fig.8 Semi-logarithmic reation between porosity and compressive strength