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EFFECT OF RICE HUSK-DERIVED SiO_2-AEROGEL ON THE STRENGTH AND THERMAL INSULATING PROPERTY OF ORDINARY PORTLAND CEMENT

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ABSTRACT

Silica (SiO_2) aerogel is well known to have high porosity and light weight. In this study the effect of SiO_2 aerogel derived from local rice husks (RH-aerogel) on the strength and thermal conductivity of ordinary Portland cement (OPC) was investigated. The objective of the study was to produce a stronger building block with improved thermal insulating property. Increasing amounts of up to 7 % by weight of RH-aerogel were added to an OPC-water mixture as cement replacement. The mixture was well blended and casted into cubic blocks. The compressive strength and the thermal conductivity of the resultant blocks were determined at various intervals of hydration. Results of the study revealed that the addition of up to 7 wt% RH-aerogel to OPC did not significantly affect the compressive strength but reduced significantly the thermal conductivity by 50%. Comparison using rice husk ash in place of the RH-aerogel confirmed the superiority of the latter as a better cement replacement material since it has an added advantage of being thermally insulating, suitable for a hot country like Malaysia.

INTRODUCTION

Silica aerogels are unique porous materials often consisting of less than 10% silicon dioxide and more than 90% air. Due to their high porosity (up to 99%) and nanostructured nature, they have low density (<0.02 g/cm^3), low thermal conductivity (<0.02 W/m^{2}K), large surface area (≈ 1000 m^2/g) and transparency (>90% at 750 nm for 1 cm thickness)[i,ii,iii]. These properties make silica aerogels have many applications which have expanded into many fields such as acoustic super-insulators, filters for industrial pollutants, heterogeneous catalysis[iv] fillers for paints and catalyst supports[v].
Currently the method of preparing aerogels is sol-gel combined with supercritical drying using silicon alkoxides such as tetramethoxysilane (TMOS)[vi,vii] tetraethoxysilane (TEOS)[viii,ix] and polyethoxydisiloxane as precursors[x]. These chemicals are usually expensive making production on industrial scale is not economically viable. Cheap raw material or method of production is inevitably an important area of silica aerogel research. The use of cheaper inorganic precursors such as sodium silicate has been reported[xi].
Rice husk is a waste material whose ash is rich in silica could also be used as a cheap silica precursor to make silica aerogel. It has been reported that pozzolans or silica rich-materials, as cement replacements, could improve the overall strength of the cement composites[xii]. In this study we report on the effect of adding silica aerogel synthesised

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from local rice husks (RH-aerogel) on the strength and thermal conductivity of ordinary Portland cement for use as thermally insulating building material suitable for countries with hot climate.

EXPERIMENTAL

Synthesis of RH- aerogel.

The method used was a combination of conventional sol gel processing and that used by Venkateswara et al[6] followed by supercritical drying. The RH-aerogel synthesis and the corresponding composite are depicted schematically in Figure 1. Rice husk was first cleaned and dried before being burnt at 800ºC for approximately 2 hours or until the ash turned almost white. The ash was then dissolved in sodium hydroxide (1M) to obtain sodium silicate glass or aqua glass and neutralized with H_2SO_4 (1M) to form aquagel. The water in the aquagel was then replaced with alcohol to obtain alcogel followed by supercritical drying.

Preparation of RH- aerogel-cement composite

Cement mixture having OPC to water weight ratio of 3:1 was mixed thoroughly in and casted into cubic blocks having dimensions of 50 mm x 50 mm x 50 mm. These blocks were then used as control in the various analysis. For aerogel cement blocks similar procedure was followed except that 1-7 wt % of the cement weight was replaced with the RH-aerogel prepared in Sect. 2.1. For comparison purposes blocks containing rice husk ash (RH-ash) instead of the RH–aerogel were prepared in similar manner.

Characterisation

Compressive strength test of the cement composite was done using ELE compressive machine while Lee's disk method was applied for the thermal conductivity measurements.

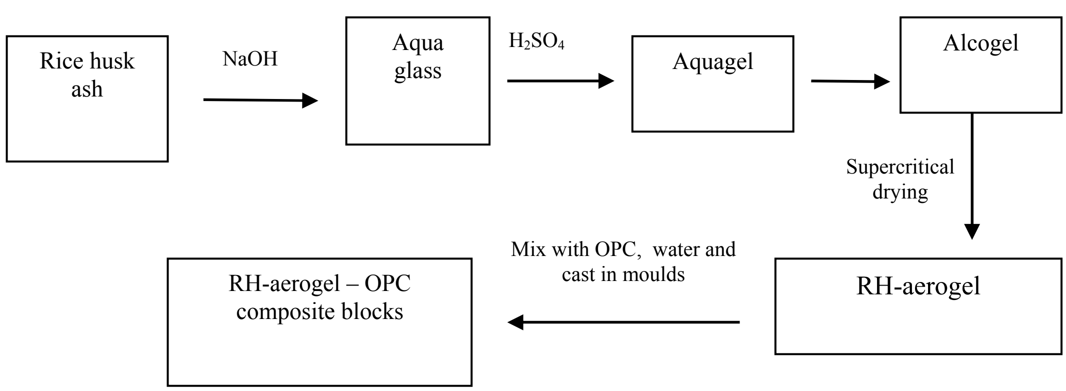

Figure 1: Schematic flow diagram of synthesising silica aerogel from rice husks and the cement composite

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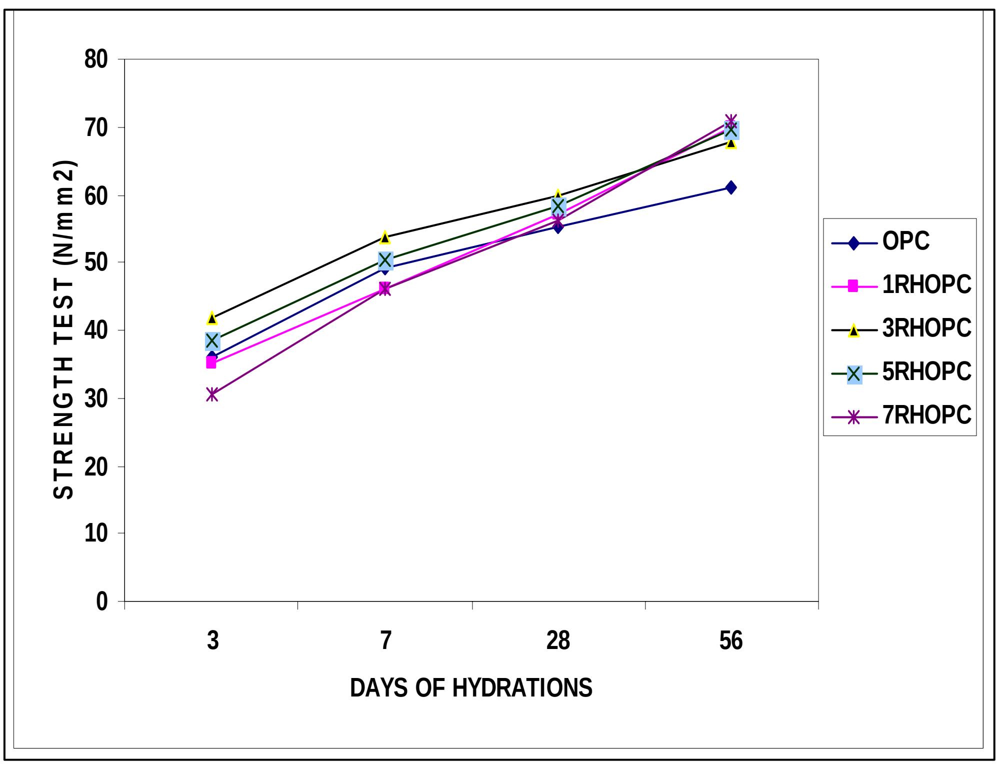
RESULTS AND DISCUSSION

Rice husk-derived silica aerogel

The RH-aerogel obtained after supercritical drying was white in colour and fluffy. It was however opaque and not transparent as in the case of using TMOS or TEOS as the precursors[6]. The reason why the aerogel derived from rice husk was opaque and not transparent is, however, unclear but possibly due structural changes during processing. Table 1 lists some of the properties of the RH-aerogel of this study.

Table 1: Physical properties of rice husk derived aerogel composite compared with control and other pozzolans.

	RH-Aerogel	OPC	RH-ash
Apparent Density (g/cm^3)	0.03	2.0	-
Surface area (m^2/g)	600	0.4	40
Porosity	506	-	-
Particle diameter (µm)	0.1	13	20
Pore diameter (µm)	0.02	-	-



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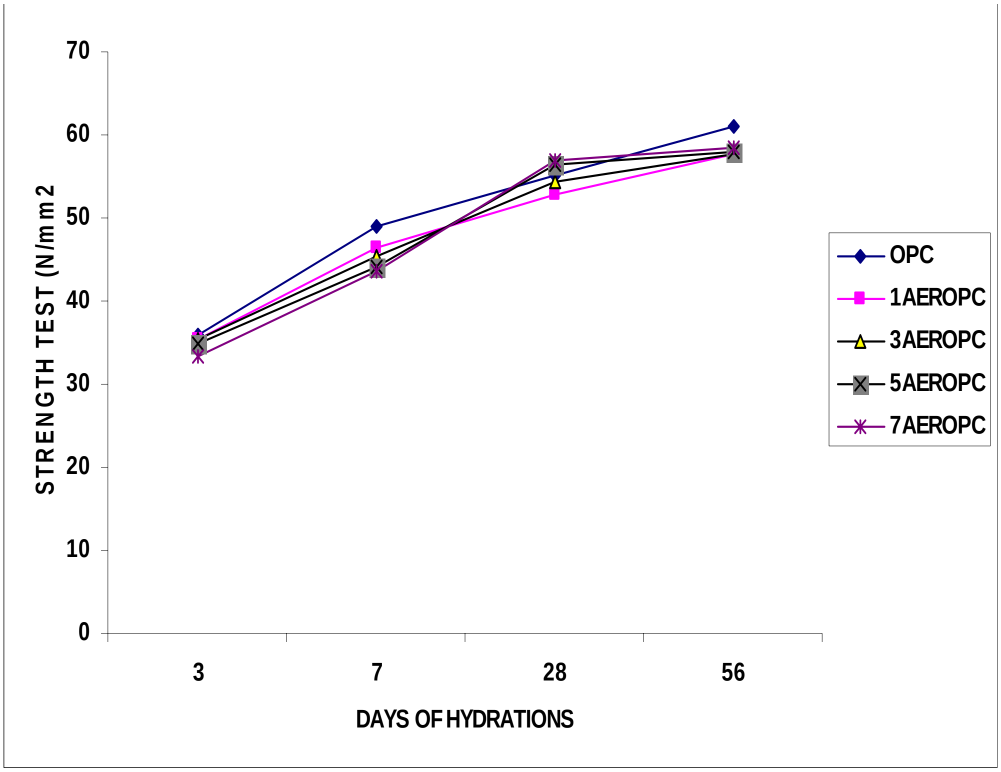

(b)

Figure 2: The effect of increasing the amounts of pozzolans on compressive strength of OPC against days of hydration. a: 1-7wt% of RH-ash; b: 1-7 wt% of RH-aerogel.

Characterisation of cement- composite blocks

Compressive Strength

Figure 2a and 2b show the compressive strengths of samples with RH-aerogel and RH-ash respectively as cement replacements. It is obvious that the strength of the cement composite increased with increase in the amount of pozzolans added and increase in days of hydration. Addition of 3-7 wt% of RH-ash was found to increase the compressive strength by about 20% from 60 N/m^2 (OPC) to about 70 N/m^2 (RH-ash-OPC composite) after 56 days of hydration. Similar increase was, however, not observed in the case of RH-aerogel. The increase in the compressive strength values for 3-7 wt% addition of RH-aerogel was insignificant since the values were very close to those obtained for OPC.

OPC consists of tri- and di-calcium silicates as the major composition (70 wt%). When in contact with water, cement reacts with it (hydration process) to give a porous rigid gel. The hydration products are mainly calcium hydroxide and calcium silicate hydrate.

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These products are deposited on the surface and form a dense layer which encapsulates the cement grains and strengthen the cement concrete. As the hydration proceeds, the thickness of the layer and the strength increase. The reaction that occurs during hydration/strengthening of the cement is shown below.

Calcium silicate + Water → Calcium silicate hydrate + Calcium hydroxide + heat

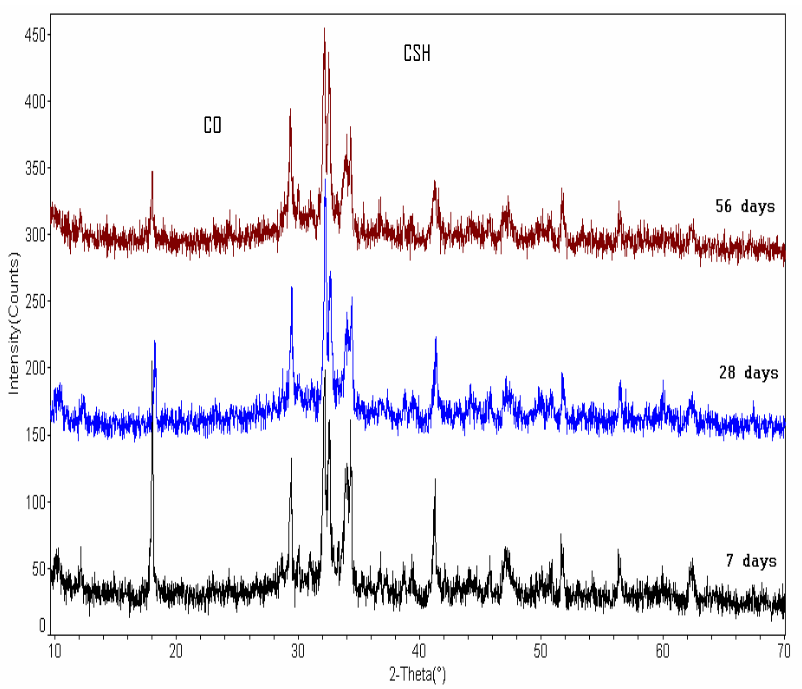
$2Ca_2SiO_4 + 5H_2O \rightarrow 3CaO\cdot 2SiO_2\cdot 4H_2O + Ca(OH)_2 + 58.6\ kJ$ ------------------Eqn.1

In the presence of pozzolan:

$Ca(OH)_2 + SiO_2 \rightarrow CaO.SiO_2.H_2O$ ---Eqn.2

Table 2: Properties of OPC and 7wt% pozzolans-cement composites

Property	OPC	RH-OPC	RH-aero-OPC	Aerogel (TEOS)
Apparent density (g/cm^3)	2.01	1.94	1.84	0.03
BET surface area (m^2/g)	0.42	0.21	0.11	606
Particle diameter (μm)	13	7	25	5
Thermal Conductivity (W/mK)	0.54	0.43	0.22	0.10



(a)

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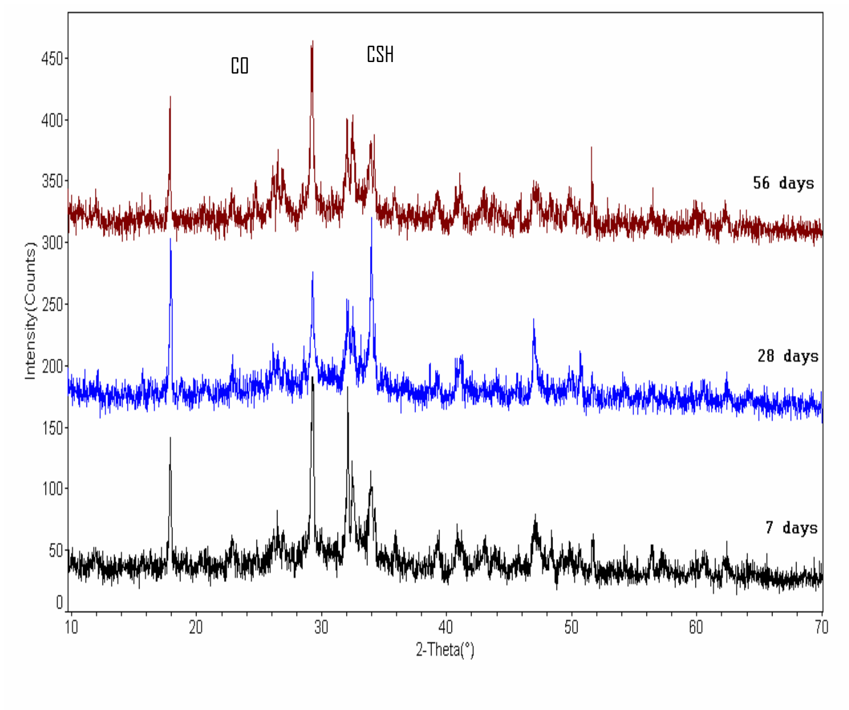

(b)

Figure 3: XRD of a: RH-ash and b: RH-aerogel–OPC composites with varying days of hydration showing the development in tricalcium silicate hydrate (CSH) and calcium hydroxide (CO).

According to equation 1, the strength of the final cement composite is dependent on the formation of tricalcium silicate hydrate ($CaO.SiO_2.H_2O$) which in turn depends upon the silica availability in the matrix. The more tricalcium silicate hydrate forms, the higher shall be the strength of the final cement. It must be noted that lime or calcium hydroxide ($Ca(OH)_2$ is also produced in the above reaction. Lime in the presence of water can react with silica to produce calcium silicate hydrate as shown by equation. 2. Hence, the increase in strength observed when RH-ash was used as cement replacement (Figure.2a). It was anticipated at the beginning that RH-aerogel would give a similar effect considering that it has equally high silica content (~99%). The only difference between them was in the porosity. The RH-aerogel was a lot more porous than RH-ash. The high porosity was contributed by the supercritical drying. In spite of having extremely high porosity and high surface areas which theoretically should favour a more efficient production of tricalcium silicate hydrates, the RH-aerogel was not reactive resulting in the almost similar strength values. A possible explanation could be the RH-aerogel had turned hydrophobic and therefore was inert to react with $Ca(OH)_2$. The hydrophobicity could possibly be a result of some structural modification taking place during processing. Hydrophobic silica aerogels has in fact been reported[xiii].

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Figure 3 shows XRD profiles of OPC composites using the different pozzolans to monitor the development of tricalcium silicate hydrate with respect to days of hydration of the cement. As can be seen the intensity of $Ca(OH)_2$ peak (CO) decreases as the days of hydration progresses showing that the $Ca(OH)_2$ produced had reacted with the silica in the RH-ash. No obvious decrease was observed in the case of RH-aerogel.

Thermal conductivity

Table 2 shows comparison on the thermal conductivity of the various cement composites with 7% of pozzolans as cement replacement after 56 days of hydration. A marked drop in thermal conductivity was detected after 56 days of hydration of 7 wt% RH-aerogel-OPC composite. The thermal conductivity dropped to as much as 50% as compared to OPC. The insulating effect of aerogel was profound as only a small amount (7 wt%) of the RH-aerogel was used to give such a significant drop. Table 3 summarises the properties and thermal conductivity of cement composites with different pozzolans after 56 days of hydration.

CONCLUSIONS

Rice husk derived aerogel in spite of having good properties such as porosity and light weight did not significantly improve the compressive strength of ordinary Portland cement after 56 days of hydration unlike when rice husk ash was used. The unexpected effect was assumed to be due to some structural arrangement which could have occurred during the supercritical drying process rendering the RH-aerogel hydrophobic and hence not reactive. On the contrary, however, the addition of only a small amount of up to 7 wt% of RH-aerogel as cement replacement resulted in dramatic drop of the thermal conductivity. This means that the cement composite blocks could also act as thermal insulators hence are very useful for the construction industry. In a hot country like Malaysia, the use of such cement blocks could help prevent external heat from seeping into houses and buildings during the day.

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