DEVELOPMENT OF NOVEL LOW THERMAL CONDUCTIVITY CONCRETE USING AEROGEL POWDER

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ABSTRACT

Concrete is one of the most commonly used construction material worldwide (Kosmatka, et al., 2008). The reason is that concrete is a relatively low cost material with good durability. It has high compressive strength and high fire resistance and also it is easy to be cast in any desire shape. On the other hand, the main drawbacks of concrete are related to its low tensile strength, high carbon dioxide emissions as a result of the use of Portland cement, and high thermal conductivity properties.

The proposed research project focuses on the development of a novel concrete with low thermal conductivity using of Aerogel powder in the mix code. Aerogel is a synthetic porous ultralight powder with very low density and very low thermal conductivity which is mainly used in buildings for external insulation.

In the current study, partial replacement of sand has been investigated using Aerogel powder. Characterisation of the new material using destructive and non-destructive methods has been done. Compressive, flexural strength and thermal conductivity measurements have been conducted and the results indicate that the proposed material can offer high enough strength together with low thermal conductivity. Around 40% reduction in thermal conductivity has been achieved with 16% replacement of sand with aerogel powder.

Keywords: Aerogel, concrete, thermal conductivity

1. Introduction

Worldwide there is an ever increasing pressure for countries, governments and companies to become greener and reduce carbon emissions in an attempt to help prevent climate change. This can be seen in renewable energy targets given to countries across Europe. For example in the Renewables Directive published in 2009, the UK was set the target that by the year 2020, 15% of its energy consumption would come from renewable sources (European Parliament & Council, 2009).

Concrete is the most widely used construction material and it is responsible for 5% of annual anthropogenic carbon dioxide (CO_2) production (Chemistry World, 2008). The major contributing factor to CO_2 emissions in the concrete industry is cement production, with around 1.1 tonnes of CO_2 produced per metric tonne of cement (Medgar, 2006). The majority of CO_2 is produced when Calcium Carbonates ($CaCO_3$) are heated at high temperatures in a kiln producing calcium oxides (CaO) and CO_2. This CO_2 has no further use and is subsequently released into the atmosphere.

One way for reducing CO_2 emissions during the production of concrete is to partially replace cement with waste materials such as PFA, silica fume and GGBS (Li and Tian 1997, Johari, et al 2011).

Another way of reducing the environmental impacts related to the use of concrete is by improving its durability and by enhancing the positive environmental aspects of structures. One of the most important factors for structures' energy efficiency is their ability to prevent heat loss.

In literature, there are studies on lightweight concrete, where part of aggregates was replaced by lightweight aggregates such as pumice and perlite which showed that lightweight concrete can have superior thermal insulation properties (Chandra and Berntsson 2002) but very low strength (Kan and Demirboga 2009, Chen and Liu 2007 and Saradhi et al. 2006).

In the present study, a novel concrete material has been investigated with partial replacement of cement with silica fume and GGBS, while sand is partially replaced by Aerogel powder. Aerogel is a nanoporour material with extremely low density and very low thermal conductivity (0.003-0.02

W/mk) (Haynes and Lide 2010). As a result, the new material has high compressive strength and low thermal conductivity.

2. Experimental procedure

2.1 Materials

The mix designs of the current study are presented in Table 1 and they are based in a previous study (Gao, et al (2014)). Five mixes with various aerogel contents have been examined, 4%, 8%, 16%, 24% and 40% replacement of sand by aerogel, alongside with a mix without aerogel powder (Table 1).

In all mixes silica sand with bulk density of 1600Kg/m^3 has been used and it has been partially replaced by aerogel powder (Aerogel UK ltd, with bulk density of about 110 kg/m^3). Aerogel that has been used in the present study, is a nano porous silica aerogel powder with high insulation performance (thermal conductivity between 0.018 and 0.020 W/Km at 25°C) and various applications. The powder is reusable, safe and environmentally friendly.

In all the examined mixes combination of Portland cement, Silica fume and GGBS has been used, since based on previous studies (Li and Tian 1997, Johari, et al 2011), as partial replacement of cement by silica fume and GGBS can considerably improve the mechanical properties of concrete. Using the information obtained from these studies it was decided that in the mix design 30% of the total weight of the ordinary Portland cement would be replaced with 10% silica fume and 20% GGBS.

All different mix designs are presented in Table 1.

Table 1: Aerogel concrete mix design

Sample	**W/B**	**Water (kg/m^3)**	**Cement (kg/m^3)**	**Silica Fume (kg/m^3)**	**GGBS (kg/m^3)**	**Sand (kg/m^3)**	**Aerogel (kg/m^3)**	**Superplasticizer (kg/m^3)**
REF	0.35	205	409.5	58.5	117	1555	0	1.17
AC-4	0.35	205	409.5	58.5	117	1430	7.5	11.7
AC-8	0.35	205	409.5	58.5	117	1295.06	15	1.17
AC-16	0.35	205	409.5	58.5	117	1035.06	30	1.17
AC-24	0.35	205	409.5	58.5	117	900.12	37.5	1.17
AC-40	0.35	205	409.5	58.5	117	775.06	45	1.17

The densities of the materials used in the current study are shown in Table 2.

Table 2: Materials and their densities

Material	**Density (kg/m^3)**
Water	1000
Cement	3150
Silica fume	2200
GGBS	1900
Sand	1600
Aerogel	110

2.2 Experimental results

2.2.1 Density

The results obtained for the densities of the concrete samples at age of 28 days are shown in Figure 1. In general it can be observed that Aerogel concrete samples have less density than ordinary concrete ones.

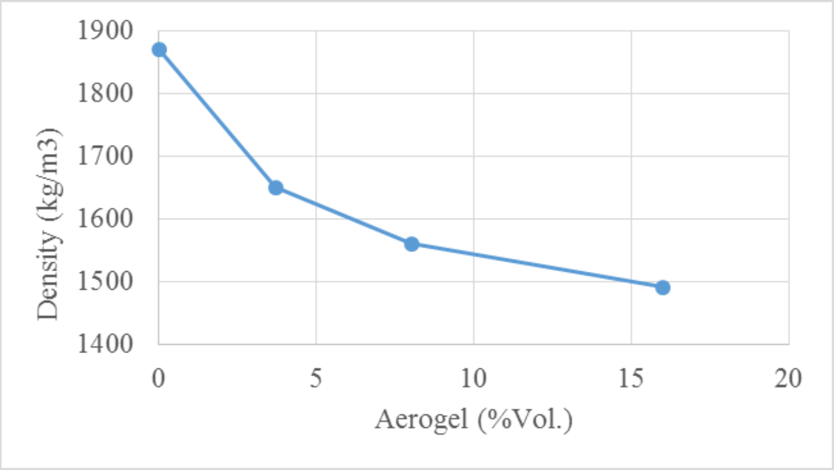


Figure 1. Effect of Aerogel content on density of concrete

From the results presented in Figure 1, it is obvious that as the Aerogel content is increased, the density of the concrete is reduced.

2.2.2 Compressive Strength

Compressive strength tests at the age of 28 days after casting was carried out in accordance with BS 1881-114:2015 Standards (Figure 2).

Figure 2. Compressive strength test

Total number of three specimens for each mix design was tested and the mean values for compressive strength for specimens with 0%, 8% and 16% aerogel content are shown in Figure 3.

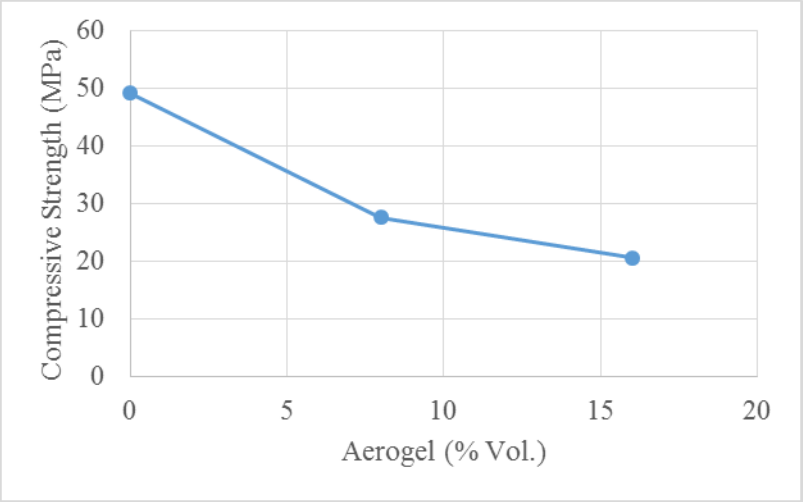


Figure 3. Effect of Aerogel content on compressive strength of concrete

Based on the results of Figure 3, as the aerogel content is increased the compressive strength values are considerably reduced. More specifically, when 16% aerogel was used, 60% reduction of the compressive strength was observed.

2.2.3 Flexural Strength

Flexural tensile strength was measured using three-point bending tests of beam specimens of size 100 x 100 x 500 mm. For every mix three flexural tests were conducted and the final flexural strength is the mean value of the three. Tests for flexural strength were carried out in accordance with the requirements of BS1881-124:2015. They were displacement control tests with a displacement rate of 0.25mm/min.

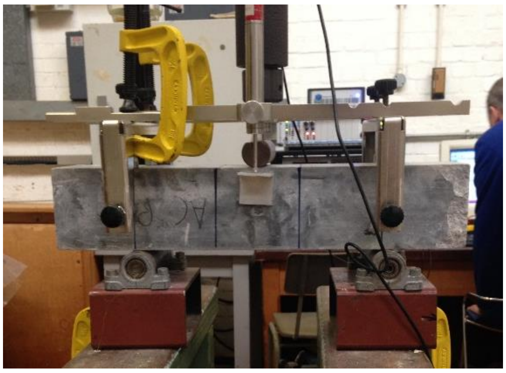


Figure 4. Flexural strength test

The results obtained for the flexural strength of each sample are shown in Figure 5.

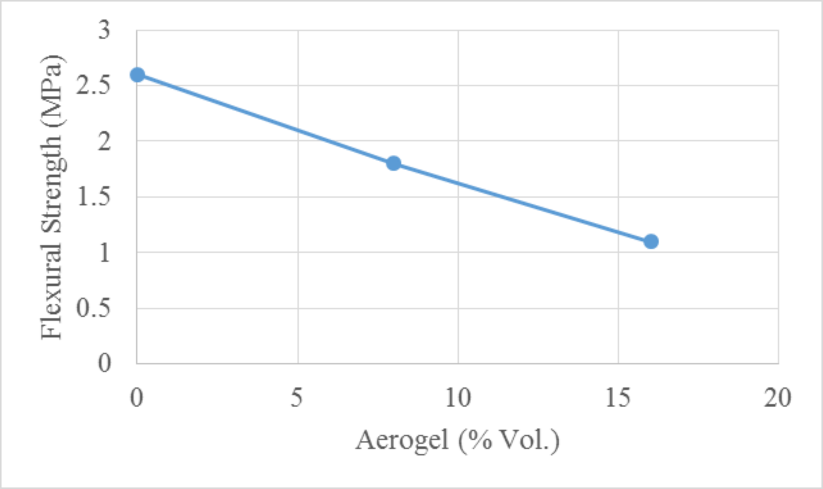
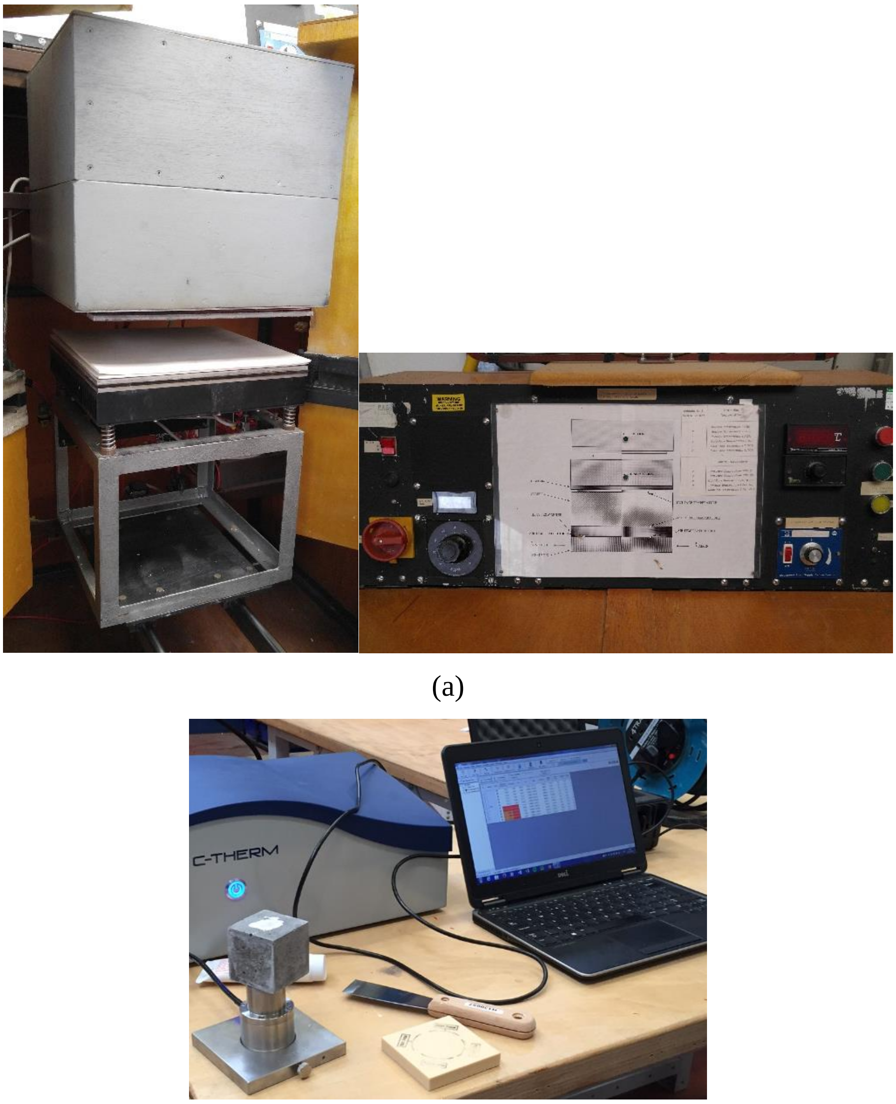


Figure 5. Effect of Aerogel content on flexural strength of concrete

The results of Figure 5 indicate an almost linear reduction of the flexural strength with the increment of aerogel content which reaches up to 60% reduction for 16% aerogel content

2.2.4 Thermal Conductivity

Thermal conductivity measurements of aerogel concrete samples were conducted at 28 days after casting using two different methods. For the first method, an equipment which has been designed in the School of Computing, Engineering and Mathematics in University of Brighton has been used and it is based on traditional guarded hot plate method. For the second method, Thermal Conductivity (TCi) has been used, which is based on a modified transient plane source method.



(a)

(b)

Figure 4. Thermal conductivity analysers a) guarded hot plate method and b) TCi Analyser

In the following Figure 6, thermal conductivity values for the examined mixes are presented. Both methods were used and the values of hot-cold plate system were appropriately calibrated using the results of TCi.

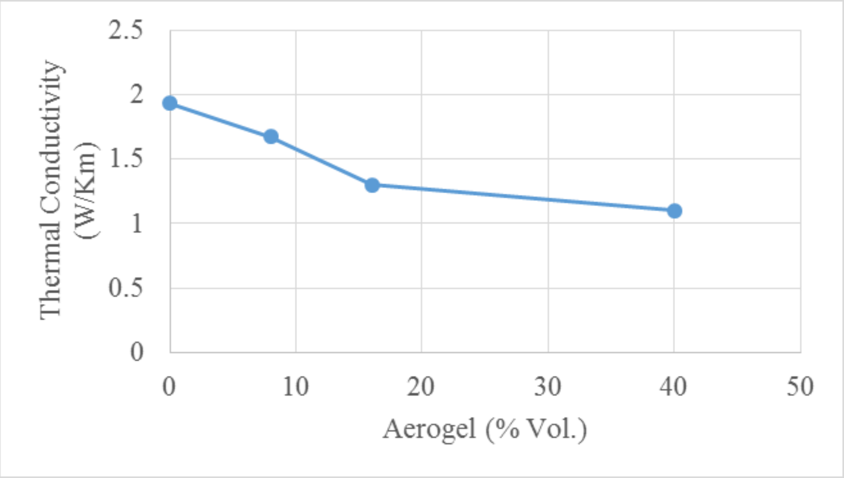


Figure 6. Effect of Aerogel content on thermal conductivity

It can be seen that thermal conductivity is reduced with the increase in aerogel content. For volumetric replacement of sand by aerogel between 16 to 40%, thermal conductivity is reduced by 33 to 43% comparing its value with thermal conductivity of 0% aerogel mix.

On the base of strength, tests showed that 16% replacement of sand by aerogel, gives a compressive strength of 20MPa and flexural strength of 1.1 MPa (Figures 3, 5).

2.2.5 Ultrasonic Purse Velocity test – Non-destructive method

Quality of the new Aerogel concrete was also evaluated using the Ultrasonic Pulse Velocity (UPV) method. This is a non-destructive method which is based on measurements of the velocity of ultrasonic pulse through the concrete. Tests were carried out on 100mm cubic specimens according to British Standards (BS EN 12504-4: 2004) (Figure 7).

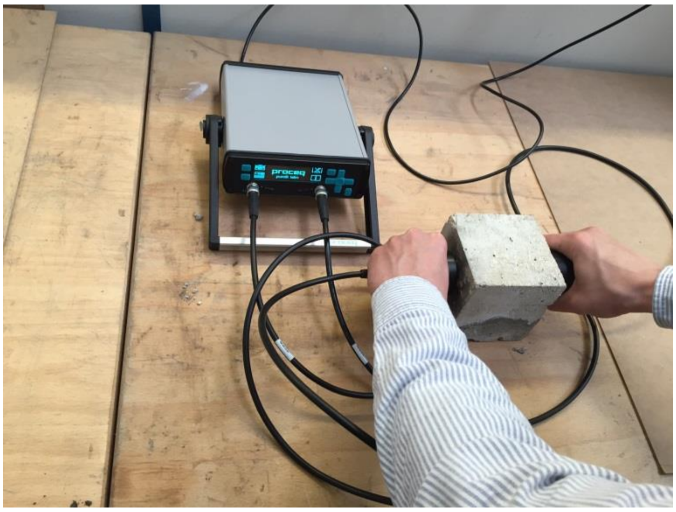
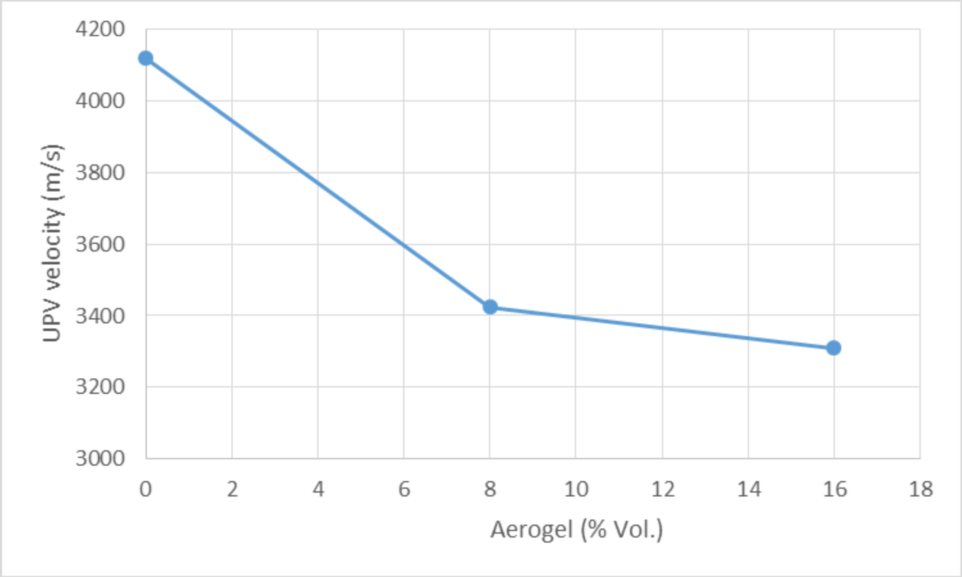


Figure 7. UPV tests on cubes

Pulse velocity values are related to the compressive strength of specimens with various aerogel contents and the results are presented in figure 8.



(a)

Figure 8. Relationship between UPV velocity compressive strength

From Figure 8 it is obvious that, as expected, pulse velocity is increased as aerogel content is reduced.

3. Conclusions

A novel concrete using aerogel as partial replacement of the sand in the mix design has been developed. A 16% volumetric replacement of sand with aerogel, showed a density of 1500 kg/m^3, compressive strength of 20 MPa and thermal conductivity of 1.3 W/km which is 40% reduction of the thermal conductivity of the respective mix without aerogel. At the same time an attempt of characterising the compressive strength of this new material using non-destructive techniques such as UPV, showed that there is a logarithmic relationship between the velocity of UPV wave and the compressive strength of the sample, while for the flexural strength this relationship is more difficult to describe. It should be mentioned that further research is needed in order to better understand the effect of aerogel in cementitious concrete.

4. References

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