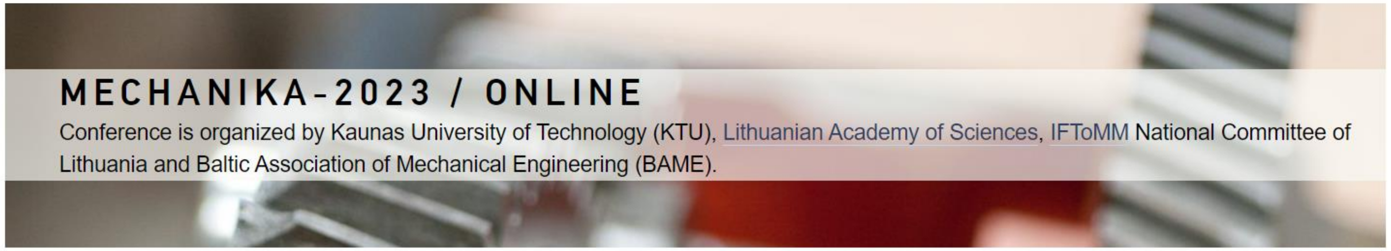

Effect of Different Curing Conditions and Aerogel Addition on Thermal Properties of Cement Based Mortars

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Scopes

1. **Introduction**
2. **Materials and Methods**
3. **Thermal conductivity test results**

   Pore contents of mixtures
4. **Conclusion**

Introduction

Today, energy consumption has become an important problem with the increasing population. In many countries, one third of total energy consumption and 30% of greenhouse gas emissions are caused by buildings [1, 2]. For this reason, it has become necessary to use energy-saving building materials in order to reduce energy consumption in buildings [3]. At the same time, the cement industry consumes a lot of energy during cement production and causes carbon dioxide emissions.

Introduction

5-7% of total global CO_2 emissions are due to cement production only and 900 kg of CO_2 is released into the atmosphere as a result of one ton of cement production [4]. From this point of view, the use of industrial waste products instead of a certain amount of cement in concrete production offers a sustainable solution. Thus, the need for cement production is reduced by using waste-based products in cement-based mixtures, so environmental pollution and production costs can be reduced.

Introduction

Fly ash is an industrial by-product obtained from the combustion of coal or other fossil raw materials in thermal power plants. Storage and reuse of fly ash into the atmosphere is discussed due to the negative effects on human health and the environment [5]. Considering the increasing storage costs, there are many advantages of reusing waste fly ash [5, 6]. In addition, fly ash can be used as a thermal insulator due to its low thermal conductivity [7].

Introduction

Considering that 70% of the energy consumption in buildings is due to heating, it is a priority to reduce the energy losses that may occur by improving the thermal insulation performance of the buildings [3, 8]. At this point, the combination of waste-based materials and additives that increase the pore content in the cement matrix offers a sustainable solution [8, 9].

Introduction

In this respect, silica aerogels have the potential to improve the insulation performance of cement-based mixtures with their low thermal conductivity, low density and high void properties [10]. Silica aerogels have the lowest thermal conductivity among all insulation materials with a thermal conductivity coefficient of 0.014 W/mK [11]. Most of the studies using aerogel to improve the thermal insulation performance of cement-based mixtures contain a high proportion of aerogel by volume [12, 13]. However, the high production cost of aerogel limits the use of aerogel in cement-based mixtures [14].

Introduction

A limited number of studies have been conducted on the thermal insulation performance of cement-based mixtures in which silica aerogels are used at low rates as cement additives [15, 16].

This study presents an experimental study on the pore and thermal properties of cementitious mortars produced by using low silica aerogel as cement additives and waste fly ash instead of a certain amount of cement. The relationship between thermal and porosity properties of the produced mortar samples under different curing conditions was investigated.

Materials and Methods

CEM I 42.5 R type Portland cement and Standard Rilem sand were used in the production of cement based mortars. The cement used in the mixtures are produced in accordance with the TS EN 197-1 standard [17]. Fly ash used in all of the experimental studies was classified as Class F fly ash according to ASTM C-618 standard [18]. Lithium carbonate (Li_2CO_3) with a unit volume weight of 0.85 - 0.90 g/cm3 was used as activator in experimental studies. Lithium carbonate (Li_2CO_3) was added to the mortar mixes at a constant rate of 0.07%.

Materials and Methods

Mortar production was carried out in 40 mm x 40 mm x 160 mm molds. The total of cement components used is 450 g. The ratio of water/binder material in the mixtures was chosen as 0.50. The total amount of binder material is the sum of the amount of cement and fly ash used. The aerogel used in the production of the mortar samples was added to the total amount of binder material.

Materials and Methods

The mixture amounts for mortar production are given in Table 1.

Table 1. Mixture proportions of cement based mortars

Mixture No	Cement content (%)	Fly ash content (%)	Aerogel content (%)	Cement (g)	FA (g)	Aerogel (g)	W/B	Water (ml)	Sand (g)
M1	0	40	0	270	180	-	0.50	225	1350
M2	60	40	0.25	270	180	1.13	0.50	225	1350
M3	60	40	0.50	270	180	2.25	0.50	225	1350

Materials and Methods

The prepared samples were kept at room temperature (20+2° C) for one day and then taken into three different curing environments. These are water curing, wetting-drying cycle and $MgSO_4$ solution. Three samples were produced from each mixture for all curing environments. For curing in water, the samples were kept in a curing pool at 20 ± 2° C for 112 days.

Materials and Methods

The samples, which were subjected to the wetting-drying cycle, were kept in a curing pool at 20 ± 2° C for one week and then kept at room temperature for the next week. Mortar samples cured in $MgSO_4$ solution were kept in a solution containing 13% $MgSO_4$ for one week and then kept in an oven at 105° C for the second week. For the wetting-drying and $MgSO_4$ curing environments, two consecutive weeks were considered as one cycle and the samples were cured for 8 cycles (16 weeks).

Testing

Thermal conductivity and mercury intrusion porosimetry (MIP) tests were applied on the samples that completed the curing processes in water, under the effect of wetting-drying and $MgSO_4$. With the thermal conductivity test, the thermal conductivity coefficient λ (W/mK) of the sample is measured. Coefficient measurements were made with a TCi, C-Therm brand device.

Testing

Thermal conductivity tests were carried out in accordance with ASTM D7984-16 standard [19]. In order to be able to measure, the shortest dimension of the sample should be 3 cm and smooth. The test was carried out at five different points of the sample and the thermal conductivity coefficient was determined by taking the average of these five measurements.

Testing

After performing thermal conductivity tests on the samples, MIP tests were carried out. With this test, the pore properties of the mortar samples can be determined. MIP test is applied using Micromeritics brand device. The device can measure the gap diameters of 3nm - 360μm in the sample and works in the pressure range of 0.33 - 413.6 MPa.

Finding and Arguments

Thermal Conductivity Test Results

The thermal conductivity test results of cement-based mortars containing 40% fly ash, which complete the curing processes in water, under the effect of wetting-drying and $MgSO_4$ are presented in Figure 1. According to this; for samples cured in water, when 0.25% aerogel is added to the mixtures, the thermal conductivity coefficient decreased by approximately 35%.

Finding and Arguments

Thermal Conductivity Test Results

If the aerogel additive was increased to 0.50%, the thermal conductivity coefficient gave very close results with the sample containing 0.25% aerogel. Among the mortar samples that completed the curing process under the wetting-drying effect, when the aerogel additive was 0.25%, the thermal conductivity decreased by 14.7% and when the aerogel content was increased to 0.50%, the thermal conductivity coefficient decreased by approximately 22% compared to the M1 sample without aerogel.

Finding and Arguments

Thermal Conductivity Test Results

For the samples cured in $MgSO_4$ solution, when the aerogel additive was added to the mixtures at the rate of 0.25%, the thermal conductivity coefficient decreased by 19.3 %, and when the aerogel additive was increased to 0.50%, the thermal conductivity coefficient gave very close results with the M1 sample without aerogel.

Finding and Arguments

Thermal Conductivity Test Results

The lowest thermal conductivity coefficient among all curing groups was obtained as 1.27 W/mK from the M2 sample with 0.25% aerogel content, which completed the curing process in $MgSO_4$ solution. The maximum decrease in thermal conductivity with the addition of aerogel was observed in the M3 sample with 0.50% aerogel content, which completed the curing process in water.

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Finding and Arguments

Thermal Conductivity Test Results

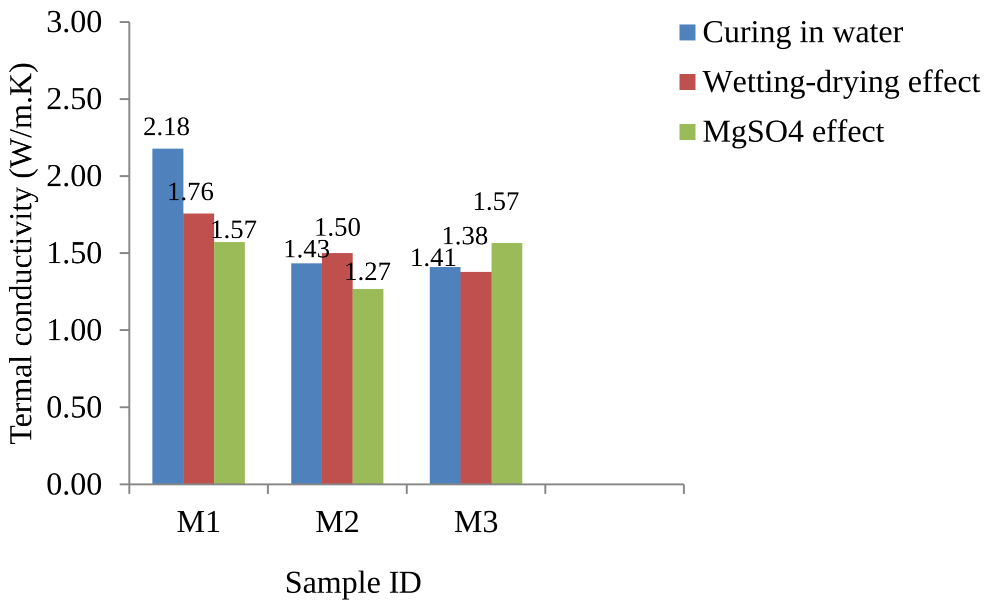

Fig. 1. Thermal conductivity test results

Finding and Arguments

Pore Contents

In the study, three types of pores, namely gel pore, capillary pore and macro pore, were examined. Gel pore < 10nm, capillary pore 10-10,000nm, macro por>10,000nm represents the size range [20]. Gel pore, capillary pore and macro pore levels of cement based mortars are presented in Table 2.

Finding and Arguments

Pore Contents

Table 2. Pore content of mixtures (%)

(a) Gel pores

Mixture No	Curing in water	Wetting-drying effect	$MgSO_4$ effect
M1	21.92	9.57	9.45
M2	21.42	11.97	13.69
M3	21.15	12.10	7.75

(b) Capillary pores

Mixture No	Curing in water	Wetting-drying effect	$MgSO_4$ effect
M1	68.49	82.50	77.92
M2	68.70	73.81	77.50
M3	68.21	77.65	84.58

(a) Macro pores

Mixture No	Curing in water	Wetting-drying effect	$MgSO_4$ effect
M1	9.59	7.93	12.63
M2	9.88	14.23	8.81
M3	9.64	10.25	7.67

Finding and Arguments

Pore Contents

When the gel, capillary and macro pore levels of the mortar samples cured in different environments are examined, the 0.25% aerogel added M2 sample, which completed the curing process in $MgSO_4$ solution with the lowest thermal conductivity coefficient with 1.27 W/mK, is also the sample with the highest gel pore level in the same curing environment. The thermal conductivity coefficients of the samples subjected to the wetting-drying cycle are also compatible with the gel pore levels.

Finding and Arguments

Pore Contents

For this curing group, the M3 sample with 0.50% aerogel addition, which has the lowest thermal conductivity coefficient with 1.38 W/mK, is the sample with the highest gel pore level in this group. Thermal conductivity coefficients and gel pore levels of M1 and M2 samples cured under the effect of wetting-drying are compatible with each other. From this point of view, it can be stated that gel pore levels are effective in determining thermal conductivity for samples that complete the curing processes in $MgSO_4$ solution and under the effect of wetting-drying cycle.

Conclusions

0.25% and 0.50% aerogel was added to cement based mortars prepared by replacing cement with 40% fly ash and cured in water, under the effect of wetting-drying and $MgSO_4$ and their thermal conductivities were investigated. The following results were obtained:

Conclusions

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- The thermal conductivity coefficient decreased with increasing aerogel content in the samples that were cured in water and exposed to the wetting-drying cycle. The lowest thermal conductivity coefficient for these two cure groups was measured from the M3 sample with 0.50% aerogel content.

Conclusions

- The lowest thermal conductivity coefficient among all curing environments was obtained from the M2 sample with 1.27 W/mK with 0.25% aerogel addition, which completed the curing process in $MgSO_4$ solution. Among the samples cured under the $MgSO_4$ effect, the highest gel pore level belongs to this sample.

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Conclusions

Among the samples that complete the curing processes under the effect of wetting-drying and $MgSO_4$, the sample with the lowest thermal conductivity coefficient also has the highest gel pore level. Therefore, it can be stated that gel pore levels are effective in determining the thermal conductivity for these two curing environments.