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Investigation of the Physical Properties of Silica Aerogel Reinforced Architectural Building Material

[1]Tuba ARKAN DEMİRÖRS, [2]*Hakan GÖKMEŞE

[1]Faculty of Fine Arts and Design, Architecture Program, KTO Karatay University, Turkey
[2]Seydisehir Ahmet Cengiz Engineering of Faculty, Necmettin Erbakan University, Seydisehir-Konya, Turkey
*Corresponding Author's E-mail: hakan1440@gmail.com

***Abstract* - Studies carried out to improve the thermal insulation of architectural structures are made possible by the development and use of innovative building materials thanks to modern technology. In this study, it was aimed to obtain superior thermal insulation properties by adding silica aerogel powders with excellent thermal insulation ability to plaster (plaster of paris), which is a classic building material. Thus, within the scope of the study, experimental plaster samples were prepared by adding silica aerogel material, synthesized with superhydrophobic properties using commercial casting sand, at low reinforcement ratios of 0 wt%, 0.5 wt%, 1 wt%, 2 wt%, and 5 wt% into the plaster material. After a waiting period of 28 days, thermal conductivity and water absorption tests were performed to examine the effect of superhydrophobic silica aerogel additive on experimental plaster samples and to determine their physical properties. As a result of the experiments, it was observed that increasing the amount of superhydrophobic silica aerogel reinforcement positively affected the thermal conductivity and water absorption properties of the material, and it was understood that the properties of the material could be improved. With the use of superhydrophobic silica aerogel as an additive material to plaster building material, this study provides innovative information to the literature related to architectural building materials and applications.**

Keywords: Superhydrophobic silica aerogel, plaster, thermal conductivity.

I. INTRODUCTION

In parallel with the development of materials science in line with scientific and technological advances, the production of new and superior materials and the development of existing materials are on the agenda in the field of architecture. Developments in materials science allow to improve the physical, chemical, and mechanical properties of traditional building materials and to obtain innovative building materials with the desired properties [1]. Together with technology, the performance of traditional building materials can be improved, and many features such as thermal insulation, acoustic insulation, and hydrophobic can be added to the content of building materials [2]. In addition, the developments in technology are causing an important interaction between architectural building materials. This situation provides an opportunity for interdisciplinary studies and the content of the materials can be analyzed in this way. Thus, the application-oriented designs of innovative building materials with different properties are becoming one of the significant factors in the development of advanced technologies today. It is thought that this situation will bring a new understanding, in which the boundaries are removed, to the field of architecture [3].

The construction sector is responsible for 42% of the total energy consumption [4]. It becomes necessary to produce solutions to some problems, such as the rapid decrease in natural resources, environmental pollution, climate change, and the need for high costs for energy due to high energy consumption in architectural structures. Environmental and economic problems caused due to unconscious energy consumption are being solved with the concept of energy efficiency in architectural structures [5].In order to ensure energy efficiency in architectural structures, it is primarily necessary to reduce energy losses in structures and conserve heat. The most effective way for this is to improve the thermal insulation of architectural structures [6]. Instead of providing thermal insulation of architectural structures by traditional methods, the use of new-generation building materials with improved thermal insulation ability, which can provide heat preservation, is an important step taken to ensure energy efficiency and cost savings in structures. Therefore, the combination of technological and innovative silica aerogel material and plaster powder, which is a traditional material, offers a new understanding of sustainable content and shaping in buildings [3].

Silica aerogels were first discovered by Samuel Stephens Kistler in 1930. Kistler's first scientific article on the production of silica aerogel was published in the journal Nature in 1931[7,8]. Silica aerogels, known as the lightest solid material in the world, have been used in many fields

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such as chemistry, medicine, electricity and electronics, space applications, optics, and textiles since they were discovered [9,10]. It is known that in recent years, Silica aerogels have started to be used as thermal insulation materials by being included in building materials in architectural applications, especially thanks to their low density (0.003 g/m3), high porosity (99.8%), and low thermal conductivity properties (0.017 W/mK) [11,12,13]. The fact that silica aerogels have this superior thermal insulation ability and exhibit an effective insulation potential makes them remarkable in recent years [14].In addition, with the use of the surface modification agent in the synthesis of silica aerogel, as a result of binding of the solvent to the chemical structure of hydrophilic silica aerogels, the material surface becomes superhydrophobic. Thus, the fact that silica aerogels have superhydrophobic properties indicates that the material surface is in a structure that is not affected by moisture and water [15].

When the previous literature studies were examined in general, it was observed that silica aerogel reinforcement was used by incorporating it into cement-based building materials at high reinforcement rates of about 50%-60%. The analyses of experimental studies have shown that they focus on the thermal conductivity coefficient and compressive strength of cement-based material [16,17]. Few studies have examined the effect of high silica aerogel reinforcement on the thermal insulation performance of the material in plaster-based materials [18,19].

The purpose of this research was to prepare superhydrophobic silica aerogel powder at low reinforcement rates as experimental plaster samples and to evaluate its effect on thermal conductivity and water absorption rate.

II. MATERIAL AND METHOD

In the experimental studies, molding plaster produced in accordance with TS EN 13279-1.2 standards was used. To determine the physical properties (water absorption, thermal conductivity coefficient) of superhydrophobic silica aerogel mixed plaster samples at different reinforcement rates, five different experimental plaster samples were prepared. Superhydrophobic silica aerogel powder synthesized from commercial casting sand at low reinforcement rates was used in the production of experimental plaster samples. Silica aerogel reinforcement ratios were planned in a way that it would be at 0 wt%, 0.5 wt%, 1 wt%, 2 wt%, and 5 wt% levels. Table 1 shows the wt% mixing ratios of silica aerogel-added experimental plaster samples. The experimental samples were numbered based on the additive ratios. Since silica aerogels were produced from commercial casting sand (CCS), when naming each experiment sample, they were called CCSX. Then, the experimental sample with a silica aerogel additive of 0% was called CCS1, the experimental sample with a silica aerogel additive of 0.5% was called CCS2, the experimental sample with a silica aerogel additive of 1% was called CCS3, the experimental sample with a silica aerogel additive of 2% was called CCS4, and the experimental sample with a silica aerogel additive of 5% was called CCS5.

Table 1: Mixing ratios of plaster test samples (g)

Mixture	SilicaAerogel (g)	Plaster (g)	Water (ml)
CCS1	0.00	120,00	80.00
CCS2	0.60	119.40	80.00
CCS3	1.20	118.80	80.00
CCS4	2.40	117.60	80.00
CCS5	6.00	114.00	80.00

For the determination of physical properties, cylindrical molds with a diameter of 50 mm and a height of 20 mm were used when preparing experimental plaster samples. A total of 200 ml homogeneous aqueous mixture consisting of plaster, superhydrophobic silica aerogel, and water was prepared for each mold. The prepared aqueous mixture was poured into molds. After the experimental samples were dried at room temperature, they were removed from the mold. Then, the plaster samples produced in a cylindrical shape with a diameter of 50 mm and a height of 20 mm were dried in a drying-oven at a temperature of 105 ºC until they reached constant weighing. The samples removed from the drying-oven were left to wait in the laboratory environment for 28 days (Figure 1). After the waiting process was completed, the plaster samples were subjected to the thermal conductivity test and water absorption test, respectively. A flow diagram of the performed experimental studies is given in Figure 2.

Figure 1: Superhydrophobic silica aerogel reinforced plaster test samples

Within the framework of experimental studies, thermal conductivity analyses were performed with superhydrophobic silica aerogel-reinforced plaster samples prepared in 5 different reinforcement ratios. Thermal conductivity coefficient analysis was performed with the RDC-143 Thermal Conductivity device. The unit of thermal conductivity coefficient is W/MK. It is important that the upper surface of the experimental samples is smooth when thermal conductivity analysis is performed. The thermal conductivity measurements of the plaster samples were performed in a way that the measurement of each sample would be three repetitions. The thermal conductivity value of the plaster samples was determined by taking the arithmetic

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mean of the obtained thermal conductivity measurement results.

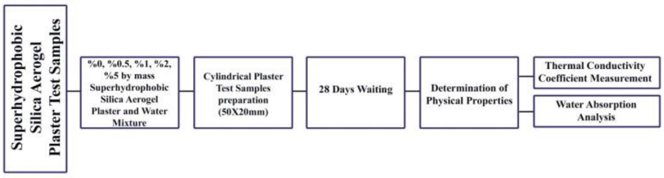

Figure 2: Experimental studies flow chart

The samples analyzed for thermal conductivity were reused for determining the water absorption rate, and no samples were produced separately for the determination of water absorption rate. In order to determine the water absorption rates of the superhydrophobic silica aerogel-added plaster samples, the experimental samples prepared in 5 different reinforcement ratios were first dry-weighed. After the weighing process was completed, the experimental samples were kept in a container filled with water for 2 hours. Then, the wet masses of the experimental samples removed from the water were weighed. In order to determine the total water absorption rate of the experimental samples whose weighing processes were completed, the ratio of the difference between the wet mass and the dry mass to the dry mass was calculated.

III. RESULTS AND DISCUSSIONS

The chemical components of the moulding plaster used in experimental studies are given in Table 2 as a result of XRF analysis. Superhydrophobic silica aerogel powders synthesized from commercial casting sand (CCS) were used in the production of plaster samples. The production of superhydrophobic silica aerogel powder has been carried out within the scope of scientific studies previously [20]. XRF analysis was performed to determine the chemical components of superhydrophobic silica aerogel, and the analysis result is given in Table 3.

Table 2: Chemical composition of plaster (%)

Sample	SiO_2	Fe_2O_3	Al_2O_3	MgO	SO_3	CaO	SrO	P_2O_5
Plaster	0.36	0.050	0.10	0.37	55.00	38.40	0.39	0.0053

The analysis result showed that there was a silicon content of 90.02% in superhydrophobic silica aerogel powder.When the general properties of silica aerogel synthesized from commercial casting sand were examined, it was found that its density value was 0.590 g/cm^3 and the surface area was 213.379 m^2/g [20].The contact angle value of the synthesized silica aerogel surface was measured as 167°, which indicates that the material surface has a superhydrophobic property [20]. The general properties of superhydrophobic silica aerogel material are shown in Table 4.

Table 3: Chemical composition of superhydrophobic silica aerogel (%)

Sample Name	SiO_2	Na_2O	Al_2O_3	Fe_2O_3	TiO_2	NiO
Superhydrophobic SilicaAerogel	90.02	3.370	1.45	0.166	0.102	0.04

Table 4: General properties of superhydrophobic silica aerogel

Sample Name	SurfaceArea	Density	ContactAngle
Superhydrophobic SilicaAerogel	213.379 m^2/g	0.590 g/cm^3	167°

The total water absorption analysis results of the plaster samples produced with superhydrophobic silica aerogel powder at different reinforcement ratios are shown in Table 5. The analysis results showed that the total water absorption rates measured in the plaster samples were between 27.33% and 14.54%.

Table 5: Water absorption analysis results of test samples

Sample Name	SilicaAerogelAdditive Percentage (%)	Total Water Absorption (%)
CCS1	% 0	27.33
CCS2	% 0.5	23.08
CCS3	% 1	20.14
CCS4	% 2	16.42
CCS5	% 5	14.54

As seen in Table 5, it was found that the water absorption values of the plaster samples decreased clearly as the amount of superhydrophobic silica aerogel reinforcement increased. The water absorption rate was found to be 27.33% in the plaster sample without the superhydrophobic silica aerogel additive. However, compared to the plaster sample without superhydrophobic silica aerogel reinforcement (0%), it was observed that the total water absorption percentage decreased to 14.54% in the plaster sample with the highest level of silica aerogel additive (5%). When the literature studies were examined, it was found that there were no experimental studies on the analysis of the water absorption rate of materials containing superhydrophobic silica aerogel in particular. However, in a study, analyses were performed on the effect of using boron waste in variable additive amounts on the water absorption property of plaster board production, and it was found that there was a decrease in the total water absorption percentage of the plaster board samples containing boron waste [21].In parallel with the experimental results obtained in the literature, in this study, it was observed that

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there was a decrease in the total water absorption values due to the superhydrophobic property of silica aerogel in all experimental samples (CCS2, CCS3, CCS4, and CCS5) due to the increased amount of superhydrophobic silica aerogel reinforcement. The decreases in total water absorption values are because of the water-repelling properties of superhydrophobic silica aerogel grains. In conclusion, it can be seen that the presence of superhydrophobic silica aerogel powder in the structure of the plaster samples causes a significant decrease in the total water absorption values of the material.

Within the scope of thermal conductivity coefficient measurements as a physical property of the plaster samples, experimental plaster samples produced with non-reinforced and low amounts of superhydrophobic silica aerogel powder were used. The thermal conductivity coefficient results obtained from these experimental samples are shown in Table 6.

Table 6: Thermal conductivity results of test samples

Sample Name	SilicaAerogelAdditive Percentage (%)	ThermalConductivity Coefficient (W/mK)
CCS1	% 0	0.48
CCS2	% 0.5	0.45
CCS3	% 1	0.41
CCS4	% 2	0.38
CCS5	% 5	0.32

When literature studies are examined, it is generally observed that such architectural building materials exhibit a thermal conductivity coefficient of 0-1 W/mK[22].When the range of the thermal conductivity coefficient measurement obtained in all experimental samples was examined (Table 6), it can be seen that it is between 0.32-0.48 W/mK and consistent with the literature studies. In addition, it was found that there was an obvious decrease in thermal conductivity coefficient results depending on the increased reinforcing silica aerogel content, and the lowest thermal conductivity coefficient value was determined as 0.32 W/mK. The decrease in thermal conductivity coefficient in all experimental samples produced with increasing silica aerogel contents compared to the material prepared without additive reveals the effectiveness and efficiency of silica aerogel material use in terms of material insulativeness.

IV. CONCLUSION

In this study, using commercial casting sand, the production of sample plaster, an architectural building material, was carried out by reinforcing with superhydrophobic silica aerogel material, which attracts attention with its lightweight and superior properties recently. Findings of the study are summarized below;

Based on the results of XRF analysis, it was found that superhydrophobic silica aerogel material contains 90.02% silicon. The density and surface area values of silica aerogel synthesized from commercial casting sand were determined as 0.590 g/cm^3 and 213.379 m^2/g, respectively. The material contact angle was measured as 167° and this value indicates that the surface of the material has a superhydrophobic property. It was observed that the water absorption values of the plaster samples decreased clearly as the amount of superhydrophobic silica aerogel reinforcement increased, and it was determined that the decrease in the percentage of water absorption of the experimental plaster sample with a 5% silica aerogel additive was 14.54%. An obvious decrease in the thermal conductivity coefficient results was observed due to the increased reinforcing silica aerogel content; thus, the lowest thermal conductivity coefficient value was found to be 0.32 W/mK.

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AUTHORS BIOGRAPHY

Tuba ARKAN DEMİRÖRS,
Dr. in Architecture, Faculty of Fine Arts and Design, KTO Karatay University, Turkey.

Hakan GÖKMEŞE,
Associate Professor in Machine Engineering, Seydisehir Ahmet Cengiz Engineering of Faculty, Necmettin Erbakan University, Turkey.

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