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Study on Properties of Coal Gangue Derived SiO_2 Aerogel and Composite Mortar

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***Abstract*—In the paper, a kind of SiO_2 aerogel based on coal gangue was synthesized and its physical properties were investigated. The properties of the composite mortar prepared with the synthesized aerogel as aggregate were further discussed. The results showed that the aerogel gained has a specific surface area of 690 m^2/g, a porosity of >90%, an average pore size of 20-50 nm, a density of 0.19 g/cm^3, and a thermal conductivity of 26.5×10^{-3} W/(m·K). The composite mortar was designed by the volume method. The performance of composite mortar with different aerogel content was studied. The results showed that the thermal conductivity, compressive strength and flexural strength of 28 days reached 0.06 W/(m·K), 3.81 MPa and 2.23 MPa, respectively.**

Keywords—SiO_2 aerogel; composite mortar; preparation technology; coal gangue

I. INTRODUCTION

With the rapid development of the social economy, energy saving and emission reduction have become important issues that need to be resolved urgently. China is a big country with huge coal production, and coal gangue is a large amount of solid waste discharged during coal mining. The coal gangue piles seriously threaten the living environment of human beings [1]. Therefore, the use of industrial waste coal gangue for recycling can not only turn waste into treasure, but also control environmental pollution, which is of great significance [2].

Aerogel is a low-density porous material with a porosity of 95%-99.8%, a specific surface area of 500-1200m^2/g, and a density range of 0.001-0.5g/cm^3, and the thermal conductivity can reach 0.005W/(m·K) [3]. These unique properties have become the hotspot in the field of thermal insulation [4]. Moreover, these excellent properties determine that aerogel materials become star materials in the field of heat preservation and energy conservation, fire prevention and disaster reduction, and have a very wide range of application prospects[5]. But, a large number of high-cost nanomaterials are used in construction projects, the resulting performance effects will be greatly suppressed due to the increase in economic costs [6]. Therefore, how to use the existing laboratory technology for low-cost processing to prepare a low-cost, high-performance energy-saving building insulation material is the hot topic in the field of aerogel research.

II. MATERIALS AND METHODS

A. Raw Materials

In this work, ordinary Portland cement 52.5 was provided from Jiangsu Yangzi Cement Ltd, and silica fume was producted from Changzhou Hutang Thermoelectricity Group Company. Raw coal gangue was provided from Jintan Coal Mining Ltd, Changzhou, China, which was crushed by hammer crusher and sieved below 0.3mm for accelerating reaction between coal gangue and reaction liquid. Hydrochloric acid was obtained by Cancheng Chemical Ltd, China, which was used to remove impurity metal ions in gangue. Ethanol was used as the organic solvent, and Chlorotrimethylsilane of Lingfeng Chemical Ltd was used to enhance the hydrophobization of the aerogels.

B. Synthesis of SiO_2 Aerogel

The acid-leaching coal gangue was used as a silicon source material for aerogel preparation. A 4 mol/L H_2SO_4 solution was mixed with a silicon source material. The filtrate was placed in a prepared plastic box and aged at room temperature. The sol was extremely unstable in acidic medium and the solution was a SiO_2 hydrogel after 15 min. The hydrogel after gel was aged at room temperature for 24 hours, and then the aged hydrogel was placed in ethanol, n-hexane and TMCS solution and modified at 50°C for 24 hours. Finally, the modified gel was placed in a constant temperature drying oven under atmospheric pressure of 50°C. and 80°C. drying 2 h, so that the solvent was slowly evaporated at a low temperature, and then dried at 120°C. and 180°C. for 30 minutes. SiO_2 aerogel can be obtained by steaming all the remaining solvents. Physical properties of coal gangue-based SiO_2 aerogels are reported in Table I.

TABLE I PHYSICAL PROPERTIES OF SIO_2 AEROGEL

Physical properties	ρ_{bulk}	$\rho_{skeleton}$	Aerogels porosity	S_{BET}	V_{pore}	D_{pore}	Thermal conductivity
Numerical value	0.19 g/cm^3	2.21±0.02 g/cm^3	91.4%	690 m^2/g	4.81 cm^3/g	27.5 nm	0.0265 W/(m·K)

C. Preparation of Aerogel Mortar

In the paper, the volume method was used to design the mix proportion. The specific mix design of SiO_2 aerogel mortar are shown in Table II. The apparent density, compressive strength, flexural strength, water absorption and thermal conductivity were tested at the age of 28 days according to China standards JGJ70—2009 [7].

TABLE II. MIX DESIGN OF SIO_2 AEROGEL MORTAR[G]

Sample	Cement	Water	Silica Fume	Water Reducer	Methyl Cellulose	Dispersant	Fibre	Aerogel	Aerogel Fraction
1	800	320	64	8	4	20	2.4	0	0
2	800	320	64	8	4	20	2.4	40	40%
3	800	320	64	8	4	20	2.4	59	50%
4	800	320	64	8	4	20	2.4	88	60%
5	800	320	64	8	4	20	2.4	138	70%
6	800	320	64	8	4	20	2.4	236	80%

III. RESULTS AND DISCUSSION

A. Micro-morphology of SiO_2 Aerogel

Figure I shows the micro-morphology of aerogel samples. It can be seen that SiO_2 aerogel (20-50nm) is a typical mesoporous structure material with uniform distribution, forming a three-dimensional structure with pore sizes of several nanometers and one hundred nanometers. Figure II hydrophobicity effect diagram of SiO_2 aerogel prepared from coal gangue. The results show that the contact angle test is spherical, non-wetting, and the contact angle is about 130 degrees, which has strong hydrophobicity. This helps to maintain the unique properties of aerogels, such as low density and thermal conductivity, which will help us to further study the high adiabatic SiO_2 aerogels in the future.

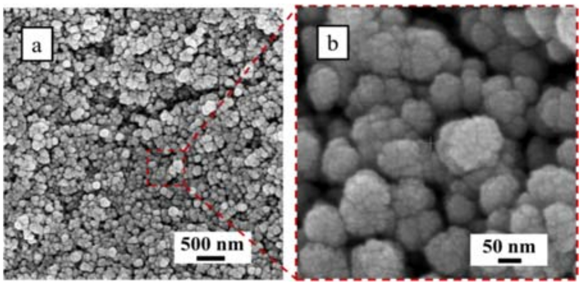

FIGURE I. SEM IMAGES OF AEROGEL MATERIALS AT (A) 50,000 X

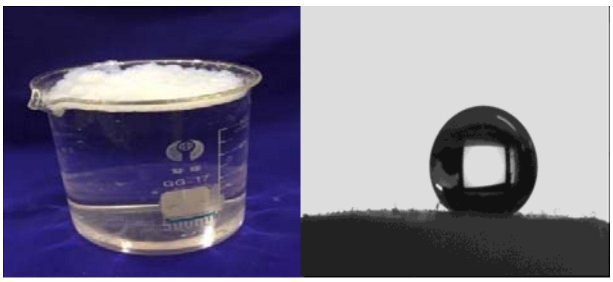

FIGURE II. HYDROPHOBICITY OF SIO_2 AEROGELS AND (B) 400,000 X MAGNIFICATIONS

B. Apparent Density of Mortar

Figure III shows that as the aerogel content increases, the density of the mortar decreased. The density of the control group (no aerogel added) was 1740 kg/m^3, and when the volume content of aerogel was 80%, the density was the smallest, reaching 582 kg/m^3, a decrease of 66.55%, which proved the lightweight aggregate with the incorporation of aerogel, high-performance lightweight composite mortar can be prepared to meet the engineering needs.

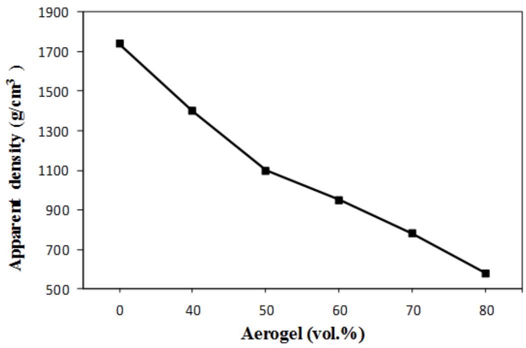

FIGURE III. DENSITY OF SIO2 AEROGEL COMPOSITE MORTAR

C. Coefficient of Water Absorption

Figure IV shows that with the increase of SiO_2 aerogel particle content, the water absorption rate also increases. The main reasons are: on the one hand, the incorporation of SiO_2 aerogel particles causes the pores inside the mortar to increase, and the structure Inhomogeneity, the water absorption rate increases with the increase in the amount; on the other hand, since the aerogel particle changes the surface hydroxyl group to a methyl group in the modification process, it has a strong hydrophobicity, so the original colloidal particles are unlikely to absorb water, but the interior of the particles is not completely modified, and there will be some hydroxyl groups.

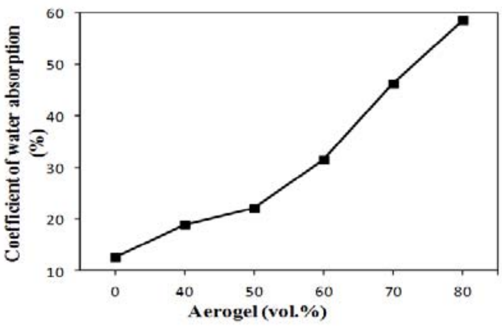

FIGURE IV. WATER ABSORPTION OF SiO_2 AEROGEL COMPOSITE MORTAR

D. Compressive Strength and Flexural Strength of Mortar

Figure V reflects the compressive strength and flexural strength of mortars with different aerogel content, and the dotted line shows the compressive strength. Due to the weak texture of the aerogel, the strength of the mortar tends to be similar to the density. With the increase of the aerogel content, the compressive strength and flexural strength of mortars have gradually decreased. Similar to vitrified microbeads, it is a typical brittle failure. The compressive strength and flexural strength of the reference group were 35 MPa and 4.72 MPa, respectively; when the aerogel content was 80%, the compressive strength and flexural strength were 0.82 MPa and 0.68 MPa, respectively, a decrease of 97.66% and 85.69%, respectively. The main factors affecting the intensity change: due to the strong hydrophobicity of the aerogel particles, there is a certain gap between the cement-based and aerogel particles; the cement is related to the silica fume binder, along with the aerogel content increases in cement content leads to a relative decrease in the content of cementitious materials. The main controlling factors of mortar strength gradually shift from cement-based materials to aerogel particles. Figure VI shows that as the aerogel content increases, the compressive strength and flexural strength gradually approach one another, consistent with the reaction in Figure V. Considering the strength requirements of the composite mortar project, the volume content of aerogel can be appropriately reduced. When the aerogel volume production is 60%, the compressive strength and flexural strength are 3.81 MPa and 2.23 MPa, respectively which meet the specification requirements of thermal insulation mortar.

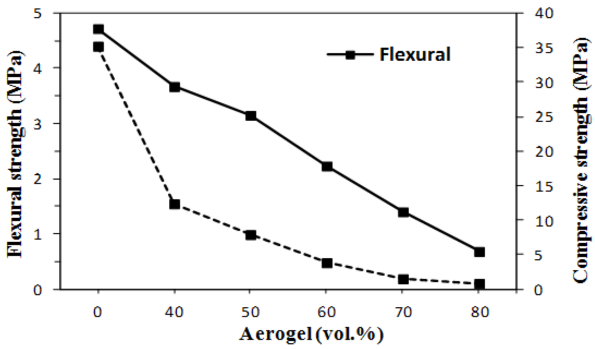

FIGURE V. COMPRESSIVE STRENGTH AND FLEXURAL STRENGTH OF SiO_2 AEROGEL COMPOSITE MORTAR

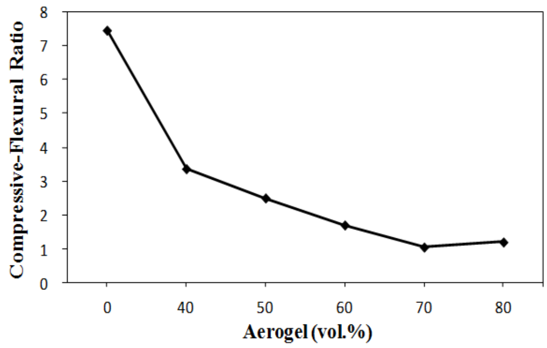

FIGURE VI. RATIO OF COMPRESSIVE STRENGTH TO FLEXURAL STRENGTH OF SiO_2 AEROGEL COMPOSITE MORTAR

E. Thermal Conductivity

The SiO_2 aerogel has a low thermal conductivity of about 0.01-0.03 W/(m·K). Therefore, by incorporating aerogel particles into a mortar, a high-performance heat-insulating composite material can be prepared. Figure VII reflects the thermal conductivity of SiO_2 aerogel mortars at different aerogel loadings. The reference group has a high thermal conductivity, which is caused by the inherently high thermal conductivity of the cementitious material. When the aerogel content was 80%, the thermal conductivity of aerogel mortar decreased from 0.6W/(m·K) to 0.04W/(m·K), and the decrease rate was 93.33%. Recent studies have shown that the aerogel breaks during the stirring process and loses part of the thermal insulation properties, so the thermal insulation performance of the aerogel mortar can be further improved. Although the adiabatic performance of the aerogel mortar gradually decreases as the aerogel content increases, its strength also decreases. Therefore, to achieve a balance, when the aerogel content is 60%, the thermal conductivity is 0.06 W/(m·K), to meet the insulation requirements of thermal insulation mortar, coat on the surface of the external protective structure of the building, can greatly reduce the heat dissipation of the building to achieve the effect of thermal insulation and energy conservation.

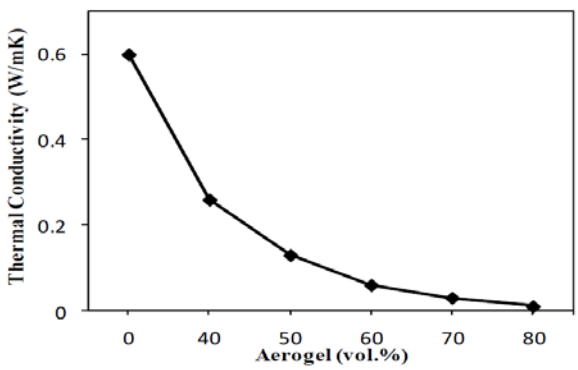

FIGURE VII. THERMAL CONDUCTIVITY OF SiO_2 AEROGEL COMPOSITE MORTAR

IV. SUMMARY

The specific surface area of SiO_2 aerogel prepared from coal gangue is 690 m^2/g, the porosity is more than 90%, and its density is 0.19 g/cm^3. The final aerogel product has good thermal insulation properties and a thermal conductivity of 0.0265 W/(m·K).

SiO_2 aerogel composite mortar is light mortar. When the volume content of aerogel is 80%, the density is the smallest, which is 582 kg/m^3. This shows that aerogel composite mortar is a high-performance lightweight composite mortar.

When the aerogel content is 60%, the thermal conductivity, compressive strength and flexural strength of the aerogel mortar are 0.06 W/(m·K), 3.81 MPa, and 2.23 MPa, respectively.

ACKNOWLEDGMENTS

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