

Characteristic of Cementitious Composite According to Replacement Ratio of Calcium Silicate and Zeolite

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Abstract

To achieve the national greenhouse gas reduction target for 2030, buildings are being designed with improved thermal insulation performance to reduce heating and cooling energy consumption. In line with this, regulations on thermal insulation performance are being strengthened, and buildings are becoming increasingly airtight. However, indoor air pollution is increasing due to pollutant emissions from building materials and insufficient ventilation. This study examined the characteristics of a cementitious composite with varying replacement ratio of calcium silicate and zeolite. The results showed that as the replacement ratio of calcium silicate and zeolite increased, thermal insulation and adsorption performance tended to improve. When the zeolite replacement ratio was 5%, the flexural strength was measured at 4.2 MPa, satisfying the minimum flexural strength requirement set by KS standards, and was therefore selected as the optimal mix.

Keywords: Calcium silicate, Zeolite, PM, CO₂, Thermal conductivity.

Introduction

Human indoor activities generate carbon dioxide and fine dust, which can reach concentrations up to approximately 1,000 times higher than outdoor levels and may cause fatigue, headaches, and dizziness[1]. In response, the government has limited pollutant emissions from adhesives and paints used in multi-use facilities and apartment buildings to 0.05mg/m²·h or 0.02mg/m²·h or less since 2017[1-2].

As government regulations on indoor pollutants and thermal insulation become strengthened and public interest in indoor air pollution continues to grow, there is an increasing need for the development of building materials capable of adsorbing indoor air pollutants. In response, studies have been conducted to apply adsorbent materials to building materials for the purpose of removing indoor pollutants. However, research in this area remains limited, and further studies using a wider range of adsorbent materials are needed[3-5].

This study examined the characteristics of a cementitious composite incorporating calcium silicate and zeolite, which have thermal insulation and adsorption performance. To this end, the physical properties of the cementitious composite were analyzed according to the replacement ratio of calcium silicate and zeolite. In addition, the thermal insulation performance and the adsorption performance for carbon dioxide and fine dust were evaluated.

Experimental Plan and Method

Experimental Plan

This experiment examined the characteristics of a cementitious composite according to the replacement ratio of calcium silicate and zeolite. To this end, the experiment was designed in two series:

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Series 1 examined the characteristics of the cementitious composite according to the calcium silicate replacement ratio, and Series 2 examined those according to the zeolite replacement ratio.

Examination of cementitious composite according to replacement ratio of calcium silicate(Series 1)

In this experiment, the characteristics of the cementitious composite were examined according to the replacement ratio of calcium silicate, and Table 1 presents the experimental factors and levels. The water-to-cement ratio (W/C) was determined to be 45%, and the replacement ratio of calcium silicate were set at five levels: 0%, 2.5%, 5%, 7.5%, and 10%. Curing was carried out in a constant-temperature and constant-humidity chamber maintained at 20 ± 2 °C and $60 \pm 5\%$ relative humidity. The test items included density, water absorption, air content, thermal conductivity, flexural strength, and compressive strength.

Table 1. Experimental Factors and Levels

Experimental factors	Experimental levels	Remarks
Binder	Ordinary portland cement	1
W/C (%)	45	1
Lightweight material	Calcium silicate	1
Replacement ratio of calcium silicate (%)	0, 2.5, 5.0, 7.5, 10	5
Curing conditions	Temperature: 20 ± 2 °C, Relative humidity: $60 \pm 5\%$	1
Experimental items	Air content, Thermal conductivity, Density, Water absorption, Flexural strength, Compressive strength,	6

Examination of Cementitious Composite According to Replacement Ratio of Zeolite(Series 2)

In this experiment, the characteristics of the cementitious composite were examined according to the replacement ratio of zeolite, and Table 2 presents the experimental factors and levels. The water-to-cement ratio (W/C) was fixed at 45%, and based on the results of Series 1, a calcium silicate replacement ratio of 7.5%, which yielded a flexural strength of 4 MPa or higher, was selected. The replacement ratio of zeolite were set at four levels: 2.5%, 5%, 7.5%, and 10%. Curing was conducted in a constant-temperature and constant-humidity chamber maintained at 20 ± 2 °C and $60 \pm 5\%$ relative humidity. The test items included density, water absorption, air content, thermal conductivity, flexural strength, compressive strength, fine dust adsorption, and carbon dioxide adsorption.

Table 2. Experimental Factors and Levels

Experimental factors	Experimental levels	Remarks
Binder	Ordinary portland cement	1
W/C (%)	45	1
Absorption material	Zeolite	1
Replacement ratio of calcium silicate (%)	7.5	1
Replacement ratio of zeolite (%)	2.5, 5.0, 7.5, 10	4
Curing conditions	Temperature: 20 ± 2 °C, Relative humidity: $60 \pm 5\%$	1
Experimental items	Air content, Thermal conductivity, Density, Water absorption, Flexural strength, Compressive strength, CO ₂ adsorption, Fine dust adsorption	8

Using Materials

Calcium Silicate

Calcium silicate is a compound of silicon dioxide(SiO₂). The calcium silicate used in this study was supplied by company D. It is typically found as an amorphous white solid and may also exist in hydrated forms. Its chemical formula is Ca₂SiO₄. It is synthesized by calcining or melting a mixture of calcium

oxide(or calcium carbonate) and silicon dioxide at high temperatures. The material has a density of approximately 2.9g/cm³.

Zeolite

Zeolite is a microporous silicate mineral that is primarily used as an adsorbent and catalyst. In this study, zeolite provided by domestic company B was used. It has a density ranging from 1.9 to 2.3g/cm³ and a melting point exceeding 1600°C.

Experimental Method

Specimen fabrication, as well as tests for air content, density, water absorption, flexural strength, and compressive strength, were conducted in accordance with KS F ISO 679 and KS L 3136. Details of the thermal conductivity and adsorption tests are provided in Sections 2.3.1 and 2.3.2.

Thermal Conductivity

The thermal conductivity test was performed using the Hot Disk M1, which employs the transient plane source(TPS) method in accordance with ISO 22007. Specimens measuring 50×50×50 (mm) were used, and the measurement was carried out for 10 minutes.

CO₂ Adsorption and Fine Dust Adsorption

Carbon dioxide and fine dust adsorption experiments were conducted using a small chamber. Carbon dioxide and fine dust were injected into a sealed chamber, and a curing agent containing an adsorbent, a fan, and measuring devices for carbon dioxide and fine dust were placed prior to measurement. The fan was used to circulate air within the chamber. The concentrations of carbon dioxide and fine dust were measured at 30-minute intervals for a total duration of 180 minutes. Figure 1 shows the small chamber and the fine dust measuring device.



Figure 1. Small Chamber and The Fine Dust Measuring Device.

Experimental Results and Analysis

Examination Of Cementitious Composite According To Replacement Ratio Of Calcium Silicate(Series 1)

Density and water absorption

Figure 2 shows the density and water absorption of the cementitious composite according to the replacement ratio of calcium silicate. As the replacement ratio of calcium silicate increased, the density tended to decrease, while the water absorption tended to increase. This is considered to be due to the low density of calcium silicate, which led to the formation of internal pores, resulting in lower density and higher water absorption.

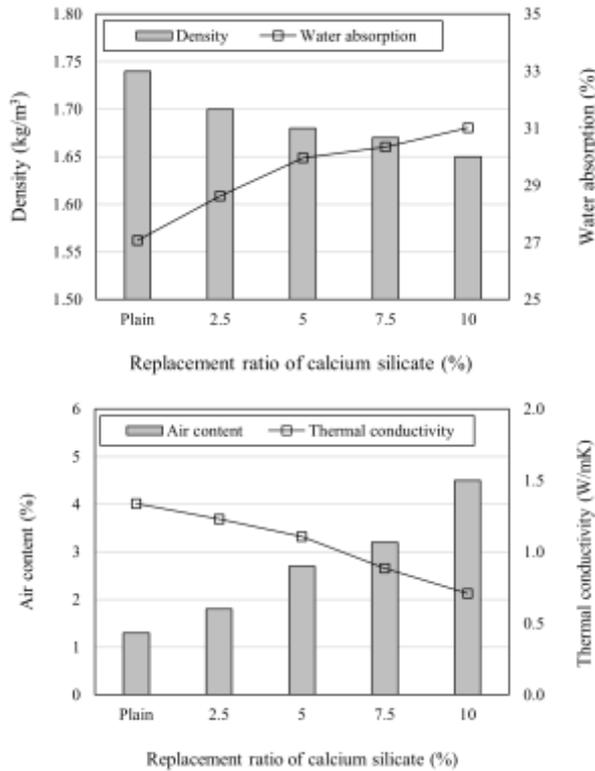


Figure 2. Density and water absorption **Figure 3. Air content and thermal conductivity**

Air Content and Thermal Conductivity

Figure 3 shows the air content and thermal conductivity of the cementitious composite according to the replacement ratio of calcium silicate. As the replacement ratio of calcium silicate increased, the air content tended to increase, while the thermal conductivity tended to decrease. This is considered to be due to the internal pores within the calcium silicate, which resulted in increased air content and decreased thermal conductivity.

Flexural Strength and Compressive Strength

Figures 4 and 5 show the flexural strength and compressive strength of the cementitious composite according to the replacement ratio of calcium silicate. As the replacement ratio of calcium silicate increased, both flexural and compressive strengths tended to decrease. This decrease in strength is considered to be due to the low density of calcium silicate and its lack of participation in the hydration reaction.

In addition, both flexural strength and compressive strength showed an increasing trend with curing age. This is due to differences in the extent of the hydration reaction depending on the curing age.

Based on the above results, it is considered that the thermal insulation performance increases as the replacement ratio of calcium silicate increases. However, according to KS standards, the flexural strength must be at least 4 MPa. Therefore, a calcium silicate replacement ratio of 7.5% (4.5 MPa) is considered the appropriate replacement ratio.

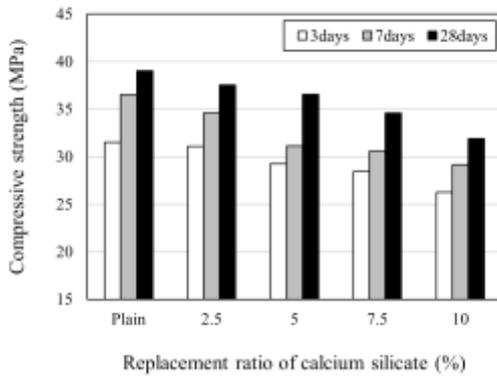
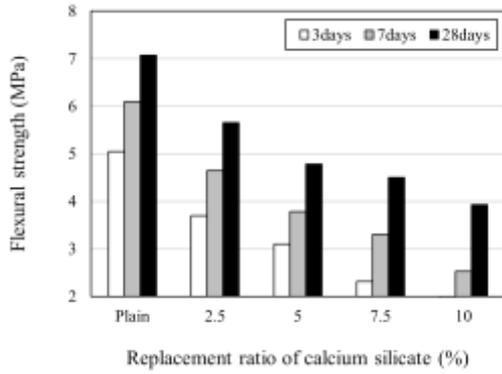


Figure 4. Flexural strength

Figure 5. Compressive strength

**Examination of Cementitious Composite According to Replacement Ratio of Zeolite(Series 2)
Density and Water Absorption**

Figure 6 shows the density and water absorption of the cementitious composite according to the replacement ratio of zeolite. As the replacement ratio of zeolite increased, the density tended to decrease while the water absorption tended to increase. This trend is similar to that observed with calcium silicate and is attributed to the low density of zeolite.

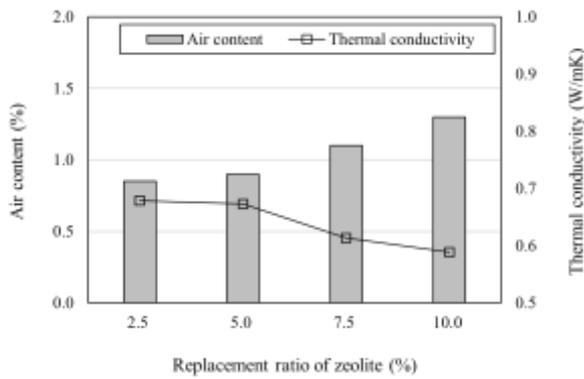
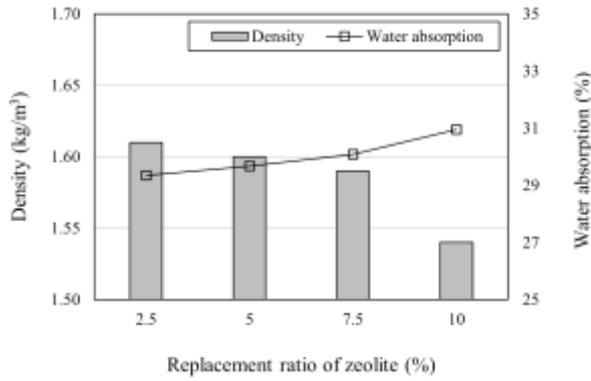


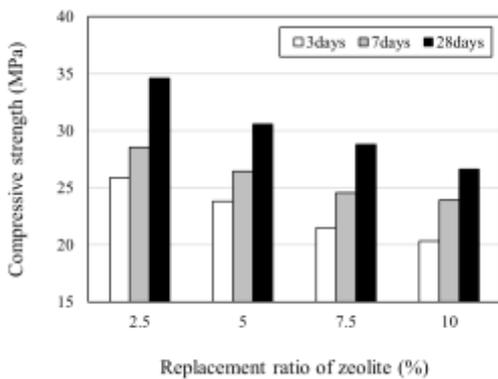
Figure 6. Density and water absorption **Figure 7. Air content and thermal conductivity**

Air Content and Thermal Conductivity

Figure 7 shows the air content and thermal conductivity of the cementitious composite according to the replacement ratio of zeolite. As the replacement ratio of zeolite increased, the air content tended to increase, while the thermal conductivity tended to decrease. This is considered to be due to the decrease in density associated with the increased replacement ratio of zeolite.

Flexural Strength and Compressive Strength

Figures 8 and 9 show the flexural strength and compressive strength of the cementitious composite according to the replacement ratio of zeolite. As the zeolite replacement ratio increased, both flexural and compressive strengths tended to decrease, while they tended to increase with curing age. This is considered to be due to the reduction in density caused by the increased replacement ratio of zeolite, and the differences in the extent of the hydration reaction depending on the curing age.



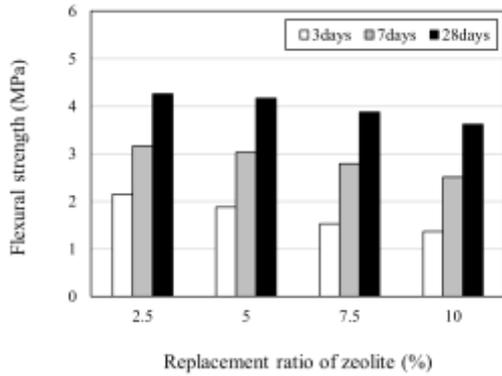


Figure 8. Flexural strength

Figure 9. Compressive strength

CO₂ Adsorption and Fine Dust Adsorption

Figures 10 and 11 show the concentrations of fine dust and carbon dioxide in the cementitious composite according to the replacement ratio of zeolite. As the zeolite replacement ratio increased, the concentrations of both fine dust and carbon dioxide tended to decrease. This is considered to be due to the electrostatic attraction between the zeolite and the fine dust and carbon dioxide, which promoted their adsorption.

Based on the above results, it was found that as the replacement ratio of zeolite increased, both thermal insulation and adsorption performance improved. However, similar to calcium silicate, physical performance deteriorated, indicating that it is important to select an appropriate replacement ratio.

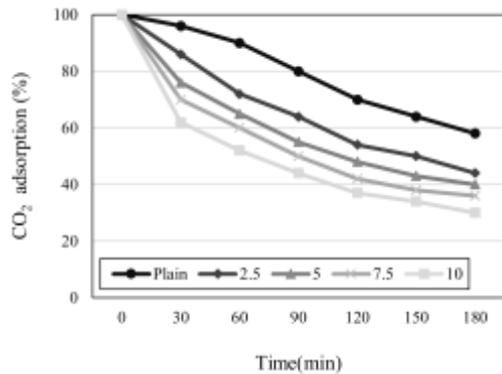
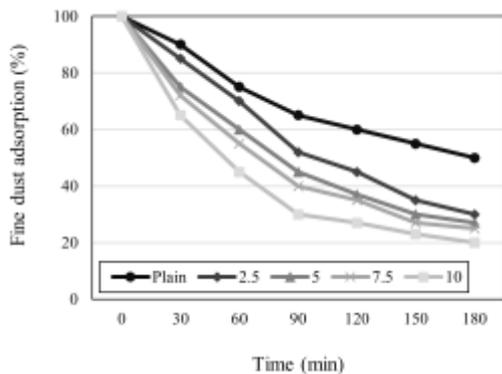


Figure 10. CO₂ adsorption

Figure 11. Fine dust adsorption



Conclusion

This experiment examined the characteristics of the cementitious composite according to the replacement ratio of calcium silicate and zeolite, and the results are as follows.

- (1) As the replacement ratio of calcium silicate and zeolite increased, the density tended to decrease, while the water absorption tended to increase.
- (2) As the replacement ratio of calcium silicate and zeolite increased, the air content tended to increase, while the thermal conductivity tended to decrease.
- (3) As the replacement ratio of calcium silicate and zeolite increased, both flexural strength and compressive strength tended to decrease.
- (4) As the replacement ratio of zeolite increased, the adsorption performance for fine dust and carbon dioxide tended to increase.

Based on the above results, it was found that increasing the replacement ratios of calcium silicate and zeolite tends to improve thermal insulation and adsorption performance, while physical characteristics tend to deteriorate. Therefore, it is important to design the mix considering these trade-offs. When the zeolite replacement ratio was 5%, the flexural strength was 4.2 MPa, which satisfied the minimum standard required by KS, and was thus selected as the optimal mix.

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