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Properties of Cementitious Composites Mixing Perlite and Carbonized Cork

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Abstract

In this study, a cementitious composite was fabricated using perlite and carbonized cork, which are eco-friendly lightweight aggregates, and its physical properties and fire stability performance were analyzed. The objective of the study was to examine the mechanical strength and thermal insulation performance of perlite and carbonized cork, as well as to evaluate their pollutant adsorption performance for improving indoor air quality in buildings. Experimental results showed that as the mixing ratio of perlite and carbonized cork increased, the compressive and flexural strengths of the cementitious composite generally decreased. In particular, the reduction in strength was more significant when carbonized cork was used compared to perlite. Meanwhile, as the proportion of perlite increased, the pollutant adsorption performance improved, although the thermal insulation performance decreased slightly. Conversely, increasing the proportion of carbonized cork led to a decrease in adsorption performance but showed a tendency to improve thermal insulation. Through comprehensive experimental analysis, the optimal mixing ratio of carbonized cork to perlite was determined to be 3:2, suggesting that the proposed cement cementitious composite can contribute to improving both indoor air quality and the thermal insulation performance of buildings.

Keywords: *Carbonized Cork, Pearlite, Adsorption Performance, Insulation, Cementitious Composite.*

Introduction

From past to present, the continuous increase in the concentration of fine dust (PM2.5) and carbon dioxide (CO_2) has raised global concern about the need to improve air quality. According to statistics from the Organization for Economic Co-operation and Development (OECD), the Republic of Korea's average concentration of fine dust in 2020 was 25.3 μg/m^3, ranking among the lowest-performing countries surveyed and nearly twice the OECD average (12.1 μg/m^3)[1]. This indicates that the Republic of Korea is internationally recognized as a country with severe find dust pollution. Since fine dust can affect human cardiovascular and respiratory systems, it is necessary to reduce its high concentration. As for carbon dioxide, the International Energy Agency (IEA) reported in the "2023 Global CO_2 Emissions Report" that global CO_2 emissions reached approximately 37.4 billion tons in 2023, an increase of 410 million tons compared to 2022. The report also noted that this upward trend has been continuing annually[2]. Rising atmospheric CO_2 levels are identified as major contributors to global warming, ocean acidification, and ecosystem disruption. Therefore, the architectural field has actively pursued research aimed at reducing air pollutants. Various studies have been conducted, including ones on the pollutant adsorption properties of cork and the thermal insulation performance of perlite. This study analyzes the thermal insulation and adsorption potential of a cementitious composite mixing carbonized cork, which has pollutant adsorption properties, and perlite, which possesses thermal insulation properties. Through this, the study seeks to examine the potential of the cementitious composite to improve indoor air quality and prevent indoor pollution. Understanding the properties of a cementitious composite mixing carbonized cork and perlite can serve as fundamental data for building

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material research aimed at improving the indoor environment

Theoretical Review

Perlite is a naturally occurring glassy volcanic rock that has the property of expanding when heated to high temperatures. The porous structure formed during this process makes perlite extremely lightweight and highly porous, which is a key reason for its excellent thermal insulation and sound absorption performance. It also has a high absorption rate and excellent water retention capacity, making it widely used as a soil conditioner.

Carbonized cork is a type of biochar obtained by carbonizing cork, and it is properties by a more developed porous structure through high-temperature treatment while maintaining the properties of a natural organic material. This fine and complex porous structure forms a large specific surface area, which provides the ability to effectively adsorb particulate matter such as fine dust. Furthermore, similar to perlite, the lightweight nature and internal pores of carbonized cork lead to excellent thermal insulation performance, contributing to the improvement of the thermal properties of building materials. Therefore, carbonized cork can be used not only as an eco-friendly lightweight aggregate but also as a functional building material through its pollutant adsorption performance.

Experimental Plan and Materials

Experimental Plan

This study examined the physical performance of cementitious composite using carbonized cork and perlite at various replacement ratio and evaluated their thermal insulation and adsorption performance according to different mixing ratio to determine the optimal mixing ratio. The experiment was conducted in two stages (replacement ratio and mixing ratio) and the experimental factors and levels are presented in Table 1. To prevent a reduction in flow table due to the content of carbonized cork and perlite, the water-to-cement ratio (W/C) was determined to be 45%. The materials used in our study were carbonized cork and perlite. To determine the optimal replacement ratio, five levels were selected: 0%, 2.5%, 5%, 7.5%, and 10%. Preliminary tests were conducted, through which 5% was selected as the optimal replacement ratio. The selected replacement ratio was divided according to the mixing proportions of carbonized cork and perlite, namely 1:4, 2:3, 3:2, and 4:1, and experiments were conducted based on these four levels. Water curing was applied, and six test items were measured: bulk density, flow table, compressive strength, flexural strength, thermal conductivity, and fine dust adsorption performance. All tests were conducted in accordance with Korean Standards (KS), and the fine dust adsorption performance was measured using a simplified testing method[3].

Table 1. Experimental Factors and Levels

Experimental factors	Experimental levels	Remarks
Binder	Ordinary portland cement	1
W/C (%)	45	1
Mixing materials	Perlite, Carbonized cork	2
Optimal replacement ratio (%)	5	1
Mixing ratio	1:4, 2:3, 3:2, 4:1	4
Curing condition	Water curing	1
Experimental items	Unit weight, Thermal conductivity, Flexural strength, Compressive strength, Flow table, Find dust adsorption (PM 2.5, 10)	6

Using Materials

Ordinary Portland Cement

The main components of cement are calcium oxide (CaO), silicon dioxide (SiO_2), alumina (Al_2O_3), and ferric oxide (FeO_3). Cement is classified into five types depending on its properties and intended use. In this study, Type I ordinary Portland cement manufactured by domestic Company S was used. Its density was 3.15 g/cm^3, and its fineness was 3,200 cm^2/g.

Carbonized cork

The bulk density of carbonized cork is 0.15 g/cm^3, and the particle size was set to a small range of 3-5 mm, classifying it as a fine particle. The moisture content was 6%, and the absorption rate was very high at 106%.

Perlite

The expanded perlite used in this experiment was a product from domestic Company S. Its main chemical components are silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), ferric oxide (FeO_3), sodium oxide (Na_2O), and potassium oxide (K_2O).

Experimental Methods

Unit Weight

The unit weight test of the fabricated specimens was conducted in accordance with KS F 2409, "Standard Test Method for Unit Weight and Air Content (Gravimetric) of Fresh Concrete."

Flow Table

The flow table test was conducted in accordance with KS L 5111, "Flow Table for Use in Tests of Hydraulic Cement." The diameter of the paste was measured before and after 25 drops. The table was dropped 25 times by rotating the handle at a rate of 100 r/min.

Flexural and Compressive Strength

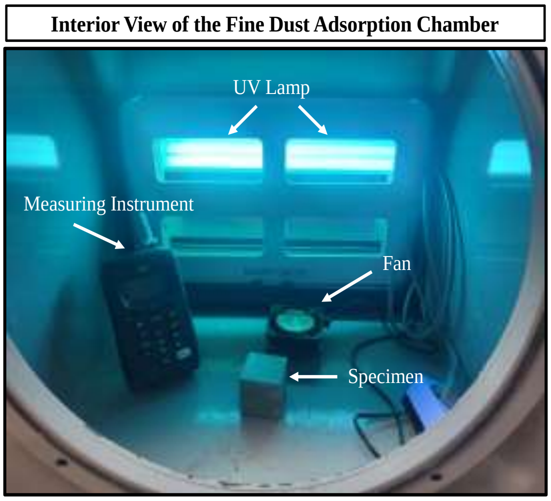
The flexural and compressive strength tests were conducted in accordance with KS ISO 679, "Cement - Test methods - Determination of strength." The tests were performed under the condition of three measurements for flexural strength and six measurements for compressive strength.

Thermal Conductivity

The thermal conductivity test was conducted in accordance with ISO 22007, "Plastics – Determination of Thermal Conductivity and Thermal Diffusivity." The test utilized specimens with dimensions of 50 mm x 50 mm x 50 mm, and three identical specimens were measured for each material composition.

Adsorption

Figure 1 shows the chamber used for the fine dust adsorption test. The adsorption test for fine dust (PM2.5, PM10) was conducted using the chamber method proposed by Hanbat National University[4]. The test specimen and a fine dust concentration meter were placed inside a regular hexagonal chamber. To minimize measurement errors potentially caused by microorganisms within the chamber, a UV lamp was operated for sterilization and disinfection. The adsorption of fine dust was measured a total of six times at 20-minute intervals from the commencement of the test.



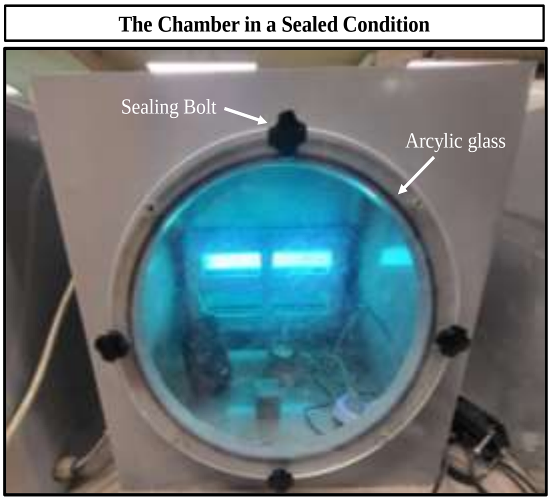


Figure 1. Fine Dust Adsorption Chamber

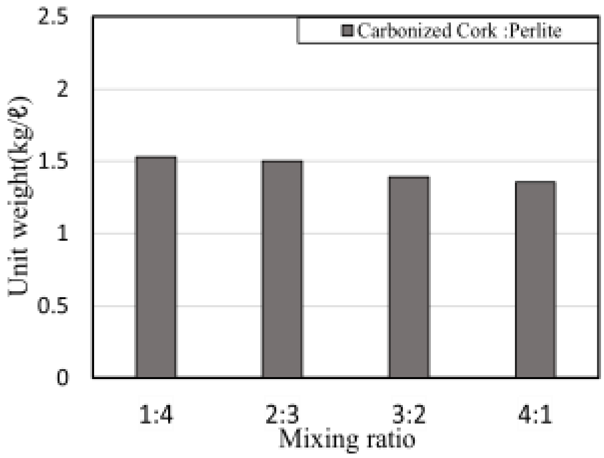
Experimental Results and Analysis

Unit weight

Figure 2 shows the bulk density according to the mixing ratio of carbonized cork and perlite. As the proportion of carbonized cork increases and that of perlite decreases, the bulk density tends to decrease. The bulk density at a mixing ratio of 4:1 was 1.531 kg/ℓ, which is approximately 12% lower than that at a 1:4 ratio (1.354 kg/ℓ). This decrease in bulk density is considered to be due to the lower specific gravity of carbonized cork compared to that of perlite.

Flow Table

Figure 3 shows the flow table according to the mixing ratio of carbonized cork and perlite. The Cementitious Composites with a mixing ratio of 1:4 showed a value approximately 6% lower than that of the 4:1 mixture, which was 1.531 kg/ℓ. This is considered to be due to the higher absorption rate of carbonized cork compared to perlite, which leads to the absorption of a large amount of water during the mixing process, thereby reducing flow table.



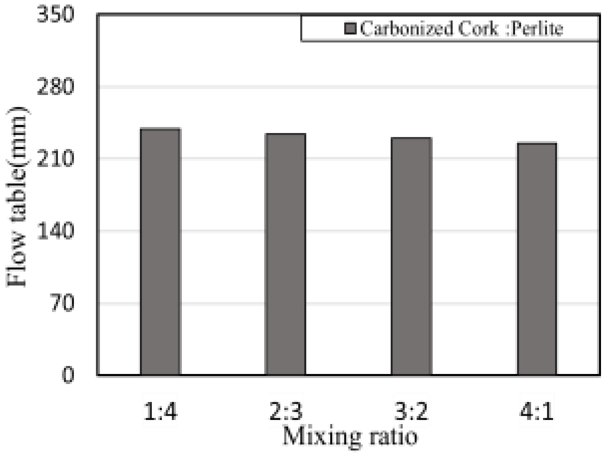


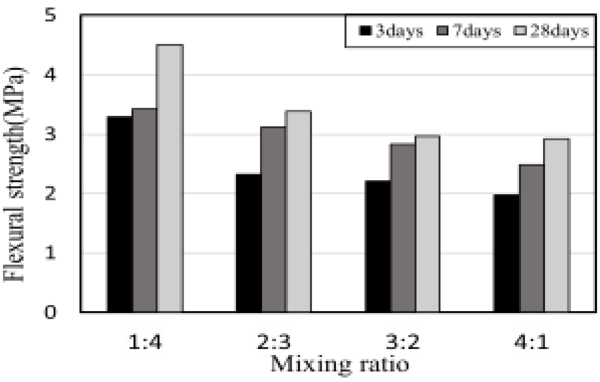
Figure 2. Unit Weight **Figure 3. Flow Table**

Flexural Strength

Figure 4 shows the flexural strength according to the mixing ratio of carbonized cork and perlite. As the proportion of carbonized cork increased and that of perlite decreased, the flexural strength decreased. After 28 days of curing, the mixture with a carbonized cork to perlite ratio of 1:4 showed a flexural strength of 4.51 MPa, whereas the 4:1 mixture showed a value of 2.93 MPa, representing a decrease of approximately 35%. This decrease is considered to result from the lower strength and density of carbonized cork compared to perlite, which leads to a reduction in flexural strength as the proportion of carbonized cork increases.

Compressive Strength

Figure 5 shows the compressive strength according to the mixing ratio of carbonized cork and perlite. As the proportion of carbonized cork increased and that of perlite decreased, the compressive strength decreased. the mixture with a carbonized cork to perlite ratio of 1:4 showed a compressive strength of 11.79 MPa, whereas the 4:1 mixture showed a value of 5.76 MPa, representing a decrease of approximately 51%. When carbonized cork replaced perlite in greater proportions, the strength tended to decrease significantly, which is considered to be due to the same reason observed in the case of flexural strength.



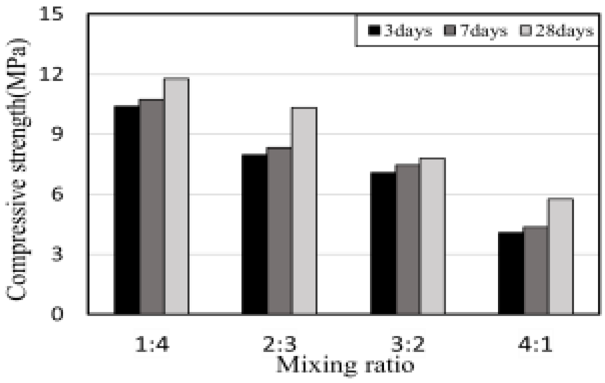


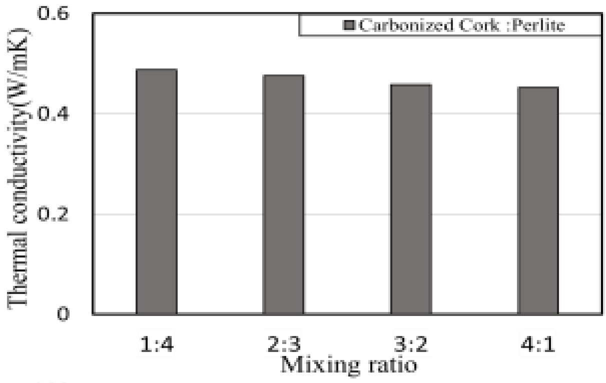
Figure 4. Flexural Strength **Figure 5. Compressive Strength**

Thermal Conductivity

Figure 6 shows the thermal conductivity according to the mixing ratio of carbonized cork and perlite. As the proportion of carbonized cork increased and that of perlite decreased, the thermal conductivity decreased to a certain extent. This reduction is attributed to the fact that carbonized cork absorbed more water than perlite during the mixing process, which led to the formation of pores during the curing process as the mixing water was released and evaporated, thereby affecting the thermal conductivity. In addition, the lower density of carbonized cork compared to perlite contributed to greater thermal insulation, and the high porosity of perlite also suggests that increasing the proportion of carbonized cork results in decreased thermal conductivity.

Fine Dust Adsorption (PM2.5, PM10)

Figure 7 shows the fine dust adsorption performance according to the mixing ratio of carbonized cork and perlite. As the proportion of carbonized cork increased and that of perlite decreased, the adsorption performance was analyzed to increase. This is considered to be due to the fact that carbonized cork has a higher-density micro-porous structure than perlite, which increases the available surface area for fine dust adsorption. As a result, the amount of fine dust removed increased with higher replacement ratio of carbonized cork.



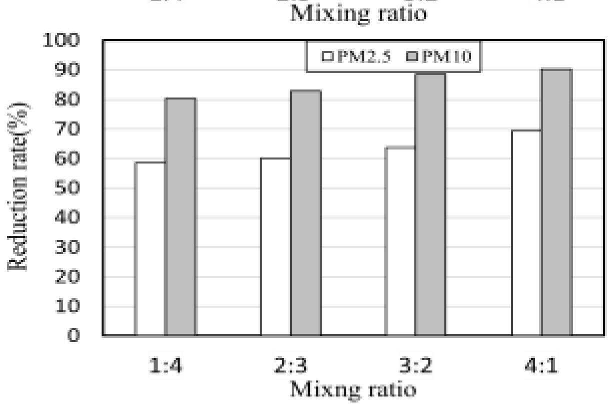


Figure 6. Thermal Conductivity **Figure 7. Fine Dust Adsorption**

Conclusion

This study comprehensively evaluated the physical and environmental performance of a cementitious composites composite mixing eco-friendly materials, carbonized cork and perlite. As the mixing ratio of carbonized cork increased, the bulk density decreased due to its low specific gravity; however, workability limitations were observed as the flow table declined because of its high water absorption rate. In addition, due to the inherently low strength of carbonized cork, the flexural and compressive strength significantly decreased by up to 35% and 51%, respectively.

On the other hand, positive effects were observed in terms of functional aspect. The low density and internal porosity of carbonized cork contributed to a reduction in thermal conductivity, thereby improving thermal insulation performance [5]. Furthermore, the high-density micro-porous structure of carbonized cork improved fine dust adsorption, which had a beneficial effect on indoor air quality. These findings confirm a clear trade-off between mechanical strength and thermal insulation and adsorption performance.

Considering this trade-off comprehensively, the optimal mixing ratio that satisfies both mechanical and physical performance was determined to be 3:2. Therefore, this cementitious composite is expected to have great potential for use as a sustainable and eco-friendly building material, particularly in interior applications where thermal insulation and indoor air quality improvement are required.

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