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Physical Properties of Clc Based on Mixing Ratio of Silica Sand

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ABSTRACT: ***It has been found that the external insulation method using organic insulation materials has limitations in fire stability, requiring to secure fire stability by using inorganic insulation materials. The cellular light-weight concrete (CLC), one of inorganic insulation materials, has an economical advantage because it can be cured under room temperature and normal pressure, but it has limitations in its application as an inorganic insulation material due to problems arising from curing under the room temperature and normal pressure. It cracks due to volume reduction and continuous drying shrinkage before it hardens, which in turn causes deterioration in its thermal insulation performance, strength, and durability. Therefore, this study tried to suppress the settlement and crack of CLC by reducing water content per unit volume through the use of silica sand with a small specific surface area. Blast furnace slag was replaced with silica sand, and the experimental items according to the mixing ratio included the unit weight, bulk specific gravity, drying shrinkage, settlement, compressive strength, thermal conductivity, absorption, and flow. The experimental results showed that as the mixing ratio of silica sand increased, unit weight, bulk specific gravity, and thermal conductivity tended to increase, but absorption tended to decrease. In addition, when the mixing ratio of silica sand was 40%, the depth of the settlement and drying shrinkage were the lowest, but the compressive strength was the highest. In the case of flow, there was no significant change according to the mixing ratio of silica sand. Therefore, when the mixing ratio of silica sand was 40%, excellent physical properties and thermal insulation performance, and homogeneous performance were obtained through the suppression of the settlement and drying shrinkage, so that the optimal mixing ratio was judged to be 40%. Also, it is considered that further studies are required to be carried out in the future because an increase in the mixing ratio of silica sand caused defoaming due to the friction between the silica sand and foams. Furthermore, experiments on the thermal insulation performance and fire stability of organic-inorganic composite insulation materials combined with organic insulation materials will be carried out to supplement the insulation performance of CLC.***

Keywords: Cellular light-weight concrete, Thermal conductivity, Silica sand, Drying shrinkage, Settlement

1. INTRODUCTION

Currently, the standard for the design of domestic buildings is regulated according to the 'Standard for energy-saving design of buildings' for efficient building energy management. An external insulation method (Dryvit) using an organic insulation material characterized by excellent insulation performance is being applied to prevent heat loss from occurring in buildings(Song et al, 2021).

However, organic insulation materials are recognized as the main culprit of fire damage as they have been found to have limitations in fire stability. For instance, the generation of the high heat release rate and of much black smoke from organic insulation materials caused many casualties in the fire accidents in Uijeongbu in 2015 and at the project site of a refrigerated logistics warehouse in Incheon in 2020. In particular, the expanded polystyrene (EPS) and extruded polystyrene (XPS), insulation materials used in thermal insulation systems for building envelops as polymer substances, not only generate much black smoke and toxic gases when burned, but also release a great deal of heat when a fire occurs, resulting in many casualties and property damage. In addition, the external insulation method causes a stack effect, so that when a fire breaks out, the flames spread throughout the building along the outer walls(You et al, 2021: Choi et al, 2018). Therefore, it is required to use non-combustible inorganic insulation materials that can be mixed with combustible organic insulation materials, which are the main cause of fire damage.

Inorganic insulation materials are non-combustible materials, so they do not burn and release heat on their own, but they have the disadvantages of higher production costs and poorer insulating properties compared to organic insulation materials. According to a report from a research center at e-Best Investment & Securities Co., Ltd., as of 2022, organic insulation materials account for 76% or higher of the domestic building insulation market. If cellular light-weight concrete (CLC), the light-weight foamed concrete, is compared with autoclaved light-weight concrete (ALC), the existing light-weight foamed concrete, CLC not only doesn't require autoclave (high temperature and pressure) curing, but also can be cured under room temperature and normal pressure, reducing initial investment and production costs. In addition, it has high thermal insulation performance, compared to production costs, as foam groups produce independent foams that are relatively uniform(Lee, et al, 2021). However, it is difficult to manage the foams because it is cured after they are first foamed. The settlement occurs due to drying shrinkage, which leads to a decrease in volume, strength reduction, and heterogeneous performance, while CLC is curing. Also, in CLC, cracks occur due to drying shrinkage from low unit volume weight, lowering strength and causing defects in the future, so that it is used only for non-structural components and as a fill material.

Therefore, this study aimed to develop economically advantageous inorganic insulation materials that could be mixed with organic insulation materials. It was intended to analyze the physical properties and thermal insulation performance of CLC, based on the shrinkage and settlement suppressed by replacing blast furnace slag with silica sand. Figures 1 to 3 show the size of the domestic building insulation market, the picture taken at the time of the fire incident in Uijeongbu in 2015, and the settlement and crack of CLC, respectively.

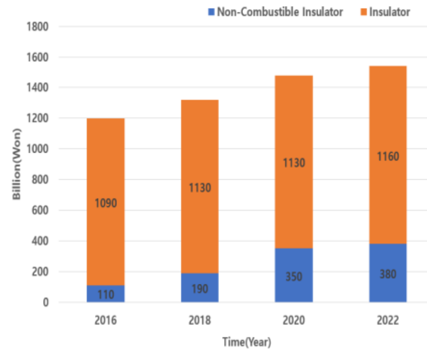

Fig. 1: Size of insulation market

Fig. 2: Fire incident in Uijeongbu in 2015

Fig. 3: Settlement and crack of CLC

2. LITERATURE REVIEW

Among light-weight foamed concretes, CLC has a particularly economical advantage and can be cast in place, so that it is used for non-structural components, such as walls, floors, etc., and as a fill material for insulation. However, its low strength and inconsistent performance continue to generate defects(Yim et al, 2006).

The volume of CLC is reduced by defoaming during the initial curing process and in the process of producing the foam slurry due to the low stability of the foam. The shape of foams is destroyed as the friction with the foams occurs in the aggregates and equipment inside, and the foams are defoamed before a binder undergoes initial curing. The decrease in volume not only deteriorates the thermal insulation performance and economical efficiency of CLC, but also causes its inconsistent performance. In addition, irregular internal pores reduce strength. Studies on both the stability of foams according to the type of foaming agents and the physical properties of CLC and on suppressing the defoaming of the foams through the addition of expansive agents have been conducted, but, currently, there are difficulties for them to be applied in the field(Kim et al, 2011;Cho et al, 2019;Han et al, 2017). In addition, attempts have been made to supplement the durability and performance of CLC, in addition to foams, but when the admixture is added, the foams are defoamed due to the friction between the foams and the admixture, resulting in a volume lower than the volume determined in the mixture design(Park et al, 2020;Ji et al, 2019). As a result, it not only causes additional costs, but also a carbon emission problem due to the waste of materials.

The performance of CLC is greatly influenced by the cracks of drying shrinkage because the ratio of the hardened body affected by stress is low, suggesting the need to prevent the drying shrinkage by reducing water content per unit volume. However, high flow is required due to the characteristics of CLC as the light-weight foamed concrete, so in the initial stage of the mixture design, the amount of concrete mixing water is large, and many foams are defoamed and then added to the concrete mixing water before curing, raising the need for measures to be taken to prevent drying shrinkage therefrom. In addition, insulation materials are vulnerable to moisture. In particular, CLC has a higher absorption than organic insulation materials because its durability is lowered due to volume reduction by the drying shrinkage and settlement, limiting its use as an insulating material.

3. EXPERIMENTAL PLAN AND METHOD

Blast furnace slag was replaced with silica sand because the silica sand has a smaller specific surface area than that of the other one in order to use CLC as an inorganic insulation material. It sought to achieve the enhancement of strength, improvement of durability, and consistent performance of CLC by using silica sand with a smaller specific surface area than that of blast furnace slag to suppress drying shrinkage through the reduction of both water content per unit volume and the quantity of water required for hydration reaction(Seung et al, 2016).

3.1 Experimental Plan

This experiment evaluated the drying shrinkage, settlement, physical properties, and thermal insulation performance of CLC in which blast-furnace slag was replaced with silica sand. The mixing ratio of the blast furnace slag, fiber, foam stabilizer, and water reducing agent was selected through prior experiments(Lee et al, 2016;Park et al, 2020). No.7 silica sand, which has a small particle size, was used to prevent the defoaming of foams during the production of the foam slurry, water-binder ratio (W/B) was fixed at 29%, and lastly the mixing ratio of the silica sand were 0, 20, 40, 60, and 80%. And the experimental items included the unit weight, bulk specific gravity, absorption, thermal conductivity, compressive strength, flow, drying shrinkage, and settlement. Table 1 shows the experiments and factors of CLC according to the mixing ratio of silica sand.

Table 1: Experimental factor and levels

Experimental factor	Experimental level	Remarks
Binder conditions	OPC, BFS	2
Foaming agent	3%	1
Water reducing agent	0.82%	1
Foam stabilizer	1.5%	1
Silica sand	0, 20, 40, 60, 80(%)	5
W/B	29%	1
PVA fiber	0.1%	1
Curing condition	Temperature (20±2℃), Relative humidity (60±5%)	1
Experimental items	Compressive strength, Thermal Conductivity, Bulk specific gravity, Flow, Unit weight, Absorption, Drying shrinkage, Settlement	8

3.2. Using Materials

3.2.1. Ordinary Portland Cement

It is powdered cement made by adding an appropriate amount of cement plasters to the clinker obtained by mixing and calcining raw materials, including lime, silica, aluminum, and iron oxide, which are the main components produced in accordance with the KS L 5201, in a proper ratio. Tables 2 and 3 show the physical and chemical properties of the ordinary portland cement, respectively.

Table 2: Physical properties of ordinary portland cement

Density (g/cm^3)	Blaine (cm^2/g)	Loss ignition (%)	Compressive strength(MPa)		
			3 days	7 days	28 days
3.15	3,413	0.97	22.7	29.8	38.8

Table 3: Chemical composition of ordinary portaland

Chemical properties (%)						
CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	TiO_2
63.8	22.1	5.0	3.0	1.6	2.0	0.3

cement

3.2.2. Blast furnace slag

It can be obtained by drying and then pulverizing the granulated blast furnace slag (GBFS) manufactured in accordance with the KS F 2563, which cement plasters are added as needed. And it is effective in enhancing long-term strength. Tables 4 and 5 show the physical and chemical properties of the blast-furnace slag, respectively.

Table 4: Physical properties of blast furnace slag

Types		**Density (g/cm^3)**	**Blaine (cm^2/g)**	**Particle size (mm)**	**Moisture**
granulated slag powder	3	2.91	4,464	12~16	Granulated slag powder

Table 5: Chemical composition of blast furnace slag

Chemical properties (%)							
MgO	CaO	SiO_2	Fe_2O_3	SO_3	Al_2O_3	TiO_2	Cl^-
2.1	52.6	28.7	0.6	4.1	9.5	0.7	-

3.2.3. Silica Sand

Silica sand produced in accordance with the KS D 2120 is a generic term for sands with a high content of SiO_2, the main component of the silica sand. And the silica sand has a SiO_2 content of over 70% and a clay content of less than 2%. Tables 6 and 7 show the physical and chemical properties of the No.7 silica sand, respectively.

Table 6: Physical properties of silica sand

Density (g/cm^3)	**Particle size(mm)**	**Melting temperature(℃)**	**Color**
1.5	0.17~0.25	1.713	White, Yellow

Table 7: Chemical composition of silica sand

Chemical properties (%)					
MgO	CaO	SiO_2	Fe_2O_3	Al_2O_3	S.K
0.7	1.3	91	1.4	2.1	34~35

3.2.4. Foam Stabilizer

The foam stabilizer prevents the defoaming phenomenon that may occur when mixed after foams are foamed in CLC.

3.2.5. Water Reducing Agent

It is an admixture added to concrete to improve its workability and to maintain the optimal W/B by reducing water content per unit volume.

3.2.6. PVA Fiber

The PVA fiber is one of fibers that are effective in enhancing tensile strength. It is added to concrete to increase tensile strength after it cracks.

3.2.7. Animal Foaming Agent

The animal nature foaming agent is manufactured through the filtration and preservative treatment of the livestock's bone powders hydrolyzed and neutralized with NaOH, etc. In the past, it was restricted in use because it might corrode steel or copper pipes, but it is now commonly used as it has been found to be non-corrosive.

3.3. Experimental Method

3.3.1. Settlement

An experiment on the depth of the settlement was conducted according to the KS F 4039 (cast-in-place foamed concrete). It poured the samples to the top of a transparent acrylic container with an inner diameter of about 145mm and a height of 300mm and then measured the depth of the settlement two hours after the remainder of the top was removed horizontally. Figure 4 shows an experiment for the depth of the settlement.

Fig. 4: Settlement test

3.3.2. Drying Shrinkage

An experiment on drying shrinkage was conducted according to the JIS A 1129 [13]. An encased strain gauge was installed in the middle of a prismatic mold (100×100×400(mm)) to automatically measure the drying shrinkage strain of CLC. The encased strain gauge is a PMFL-60-5LJRTA type manufactured by Tokyo Sokki Kenkyujo, which can measure up to 20,000με. For this experiment, three specimens were prepared for each of mixing conditions. A change in length was measured for 48 hours immediately after casting to measure the degree of initial shrinkage before curing, and a change in length was also measured for 7 days in the constant temperature and humidity chamber (temperature on 20 ± 1 °C and relative humidity on 60 ± 5%)(Seo et al, 2016;Kim et al, 2017). Figures 5 and 6 show a drying shrinkage test and a strain gauge, respectively.

Fig. 5: Drying shrinkage test

Fig. 6: Strain gauges

4. EXPERIMENTAL RESULT AND ANALYSIS

4.1. Bulk Specific Gravity and Unit Weight

Figure 7 shows the experimental results for the unit weight and bulk specific gravity of CLC according to the mixing ratio of silica sand. As the mixing ratio of silica sand increased, the bulk specific gravity and unit weight tended to increase. As the mixing ratio of silica sand increased, the amount of high-density silica sand increased, compared to foams, and the shape of the foams was destroyed due to the friction between the foams and silica sand during the process of producing the foam slurry. Therefore it was judged that the unit weight and bulk specific gravity increased as the high-density silica sand and binder increased compared to foams per unit.

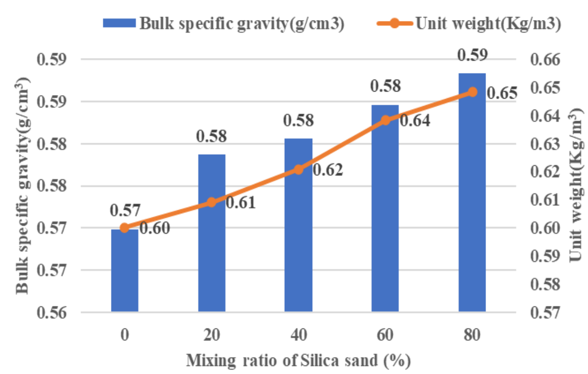

Fig. 7: Bulk specific gravity and unit weight

4.2. Drying Shrinkage

Figure 8 shows the experimental results for the drying shrinkage of CLC according to the mixing ratio of silica sand. When the mixing ratio was 40%, the due to drying shrinkage tended to be the smallest. It is judged that the length change due to drying shrinkage was reduced by reducing the unit quantity of silica sand with a small specific surface area. In addition, 60% of over-mixing ratio shows a high length change due to drying shrinkage.

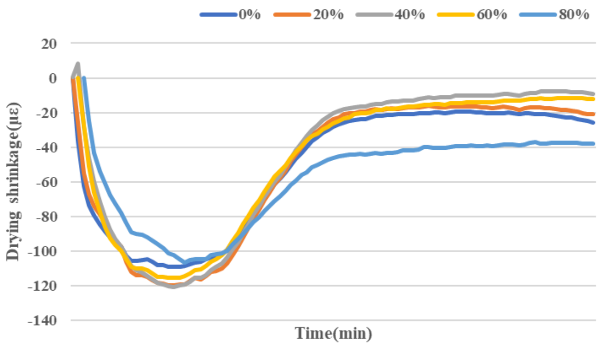

Fig. 8: Drying shrinkage (9 days)

4.3. Settlement

Figure 9 shows the experimental results for the depth of the settlement of CLC according to the mixing ratio of silica sand. No settlement occurred when the mixing ratio of silica sand were 0, 20 and 40 (%). It was judged that no settlement occurred because the shape of foams was stably maintained during curing due to the small initial shrinkage. However, settlements occurred when the mixing ratio of silica sand was 60% or higher. It was judged that foams were defoamed as the initial shrinkage occurred, causing the settlements.

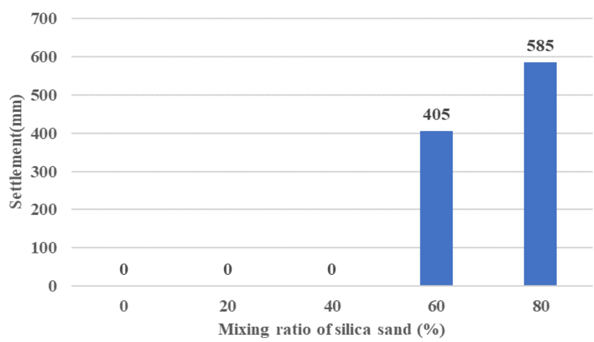

Fig. 9: Settlement

4.4. Compressive strength

Figure 10 shows the experimental results for the compressive strength of CLC according to the mixing ratio of silica sand. The compressive strength tended to increase until the mixing ratio of silica sand was 40% and then to decrease from 60% or higher. It was judged that the compressive strength was improved as cracks and settlements were suppressed according to the suppression of drying shrinkage. In addition, it was judged that an increase in the density and in the ratio of the blast-furnace slag subjected to the reaction of hydration by $Ca(OH)_2$ generated in the hydration reaction of cement contributed to the enhancement of the compressive strength. It was judged that the compressive strength was reduced by the uneven stress distribution and an increase in cracks caused by volume reduction due to an increase in the settlement and drying shrinkage from the mixing ratio of silica sand at 60% or more.

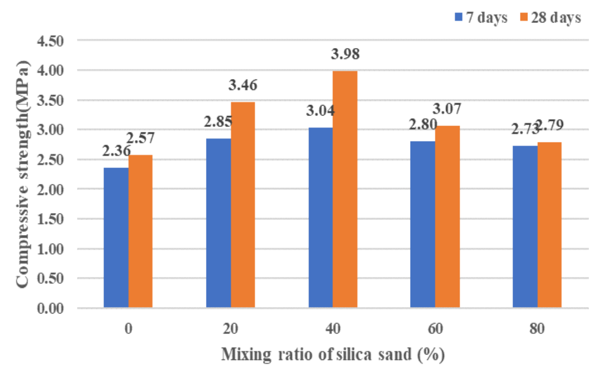

Fig. 10: Compressive strength

4.5. Thermal Conductivity and Bulk Specific Gravity

Figure 11 shows the experimental results for the thermal conductivity and bulk specific gravity of CLC according to the mixing ratio of silica sand. The thermal conductivity tended to increase as the mixing ratio of silica sand increased. It was judged that the bulk specific gravity increased as the mixing ratio of silica sand increased, and the number of media for heat conduction increased due to a decrease in pores inside the CLC, thereby increasing the thermal conductivity.

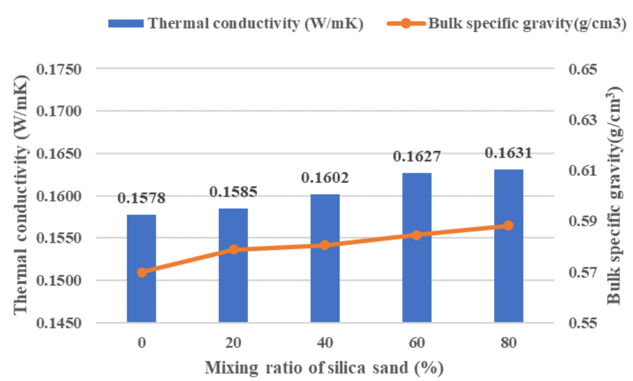

Fig. 11: Thermal conductivity and bulk specific gravity

4.6. Absorption and Bulk Specific Gravity

Figure 12 shows the experimental results for the absorption and bulk specific gravity of CLC according to the mixing ratio of silica sand. The absorption of CLC tended to increase as the mixing ratio of silica sand increased. It was judged that the bulk specific gravity increased as the mixing ratio of silica sand increased, and the occurrence of cracks was suppressed by the reduction of pores and the mixing of blast-furnace slag with silica sand in CLC, thereby decreasing the absorption.

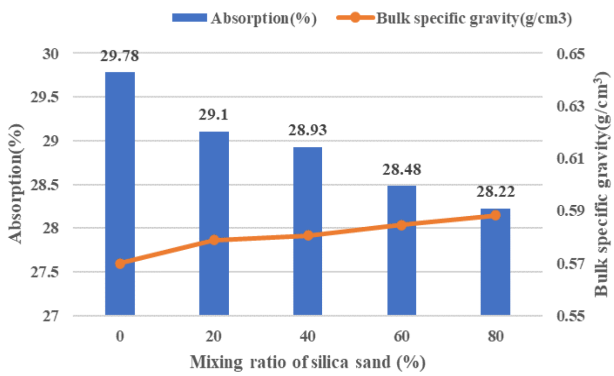

Fig. 12: Absorption and bulk specific gravity

4.7. Flow

Figure 13 shows the experimental results for the flow of CLC according to the mixing ratio of silica sand. No significant change was observed in flow. Before foams were mixed, the flow of the mortar tended to increase by the ball bearing phenomenon of aggregates, but after that, no significant change was observed in the flow of the foam slurry.

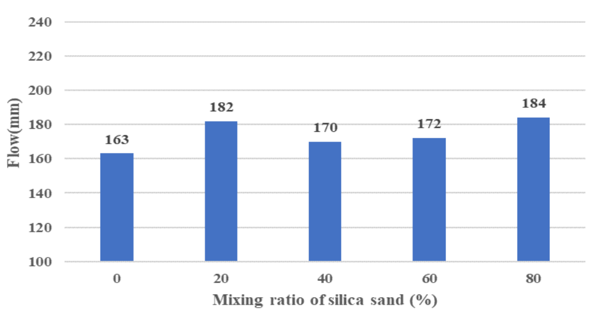

Fig. 13: Flow

5. CONCLUSION

This study analyzed the drying shrinkage, depth of the settlement, physical properties, and thermal insulation performance of CLC according to the mixing ratio of silica sand. The experimental results showed that the unit weight, bulk specific gravity, and thermal conductivity increased, but the absorption decreased as the mixing ratio of silica sand increased. When the mixing ratio of silica sand was 40%, the depth of the settlement and drying shrinkage were the lowest, but the compressive strength was the highest. There was no change in flow according to the mixing ratio of silica sand. Therefore, it was judged that the optimal mixing ratio of silica sand for both the development of economically advantageous inorganic insulation materials, the purpose of this study, and the expression of consistent performance was 40%, and that the optimal mixing conditions were the compressive strength of 3.98 MPa and thermal conductivity of 0.1602 W/mK. However, as the mixing ratio of silica sand increased, an error with the initial mixing conditions occurred due to the defoaming of foams generated during the manufacturing process of the foam slurry, so it is considered that further studies on the stability of the foams need to be performed in the future. Experiments on the thermal insulation performance and fire stability of organic-inorganic insulation materials, combined with organic insulation materials, will be conducted in the future in order to supplement the thermal insulation performance of organic-inorganic insulation materials by combining organic insulation materials with CLC.

6. ACKNOWLEDGEMENTS

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