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Properties of CLC According to Replacement Ratio of Cao-CSA Expansive Additive

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Abstract: According to the National Statistical Office's 2019 Population and Housing Survey in August 2020, the number of apartments, including apartments, was about 14 million last year, accounting for 77.2% of all houses, of which 11.287 million were 80.6% of apartments. Based on this change in housing trends, researchers have developed and studied cellular light-weight concrete (CLC) that can be cured at room temperature and normal pressure with advantages such as light weight, insulation, and construction. There have been several studies in Korea, including state-run projects, but they have not been commercialized, but the biggest reason is that stability has not been secured. Therefore, to improve the reliability of CLC that can be cured at normal temperature and pressure, this study attempts to analyze the properties of CLC by incorporating CaO-CSA expansive additive. Based on the drying density of 0.55-0.65 kg/m^3, cement, blast furnace slag, animal foaming additive and fiber are utilized to analyze the properties of CLC with CaO-CSA expansive and the results are as follows. By using the CaO-CSA expansive additive, it is determined that the formation of calcium hydroxide and ettringite fills the CLC between the tobermorite layers and the internal structure becomes dense. Currently, based on KS F 2701, the compression strength based on 0.6 items is more than 4.9 MPa, and the strength is about twice as strong as that of the existing CLC, and durability of the CLC are improved by incorporating CaO-CSA expansive additive.

Keywords: CaO-CSA expansive additive; cellular light-weight concrete (CLC); drying shrinkage; settlement; tobermorite

1 INTRODUCTION

1.1 Background

According to the National Statistical Office's 2019 Population and Housing Survey in August 2020, the number of apartments, including apartments, was about 14 million last year, accounting for 77.2% of all houses, of which 11.287 million were 80.6% of apartments of these, the proportion of condominiums increased 4.3 percent year-on-year, and demand for condominiums is increasing every year. With the changing housing trends reflecting the needs of the domestic market, construction changes are being made to maximize the availability of housing by actively responding to various demand for space utilization by consumers for sustainable housing culture such as well as durability [1]. In addition, due to interlayer noise problems when living apartments, 99.9% of private apartments completed between 2007 and 2017 and 96.8% of public apartments (Ministry of Land, Infrastructure and Transport, structure of 500 or more apartments nationwide) are continuing to be converted. If the columnar structure is applied, water, electricity, and gas parts, which can be freely planarly arranged according to the arrangement of the non-tolerant wall and which, need maintenance are not embedded in the concrete wall matrix but can be easily replaced and repaired.

Since the 2050 carbon, neutrality declaration promised the international community that greenhouse gases would be reduced by 40% from 2018 by 2030, zero energy building certification will be mandatory for public buildings with a total area of more than 1,000 square meters from 2020. In addition, from 2024, the mandatory targets will be expanded to include private buildings with a total area of more than 1,000 square meters or apartment houses with a size of more than 30 households. However, according to the Korea Institute of Construction Industry's report on the "Diagnosis and Challenges of Zero Energy Building Policy in Korea," he criticized, "The certification system for zero energy buildings was implemented in 2017, but it is still sluggish. In addition, the introduction of non-residential buildings such as shopping districts and office buildings will be delayed by 30 to 40 percent compared to existing construction costs and 4-8 percent higher than the standard construction cost limit for apartments. Currently, urethane foam, phenolic foam, PE foam, and Styrofoam, which are organic insulation materials used more than 80% compared to inorganic insulation materials, are utilized on the insulation side of the building. Although it has excellent insulation, easy construction and economic strength compared to weapons insulation, it is vulnerable to fire stability. Until recently, problems have been raised as the cause of fire incidents such as Incheon Logistics Warehouse Fire (2020) and Ulsan Column Fire (2020). In addition, the Ministry of Land, Infrastructure and Transport pointed out the cause of such large-scale fire accidents as the use of fire-resistant finishing materials, and is continuously strengthening regulations through the Ministry of Land, Infrastructure and Transport's Notice No. 2020-1053.

Thanks to this change in housing trends, lightweight, heat insulation and construction advantages (ALC) are widely used as indoor partitions, fire resistance, and insulation walls, and the annual usage is expected to expand to around 3 to 4 million m^2. ALC is a common name for lightweight foamed concrete made by adding cement and a foaming additive to silica sand and curing porous mixture through autoclave curing at high temperature and high pressure (180° 10 atmospheric pressure). However, ALC has difficulty entering the market due to its high initial investment in production facilities and requires autoclave curing in the production method, so manufacturing costs are high and acts as a factor to increase overall construction costs [2]. To solve this problem, a lightweight concrete (Cellular Light-weight Concrete) that can be cured at room temperature and normal pressure is developed as an alternative to ALC, and research has been conducted on this. There have been several studies in Korea, including state-run projects, but they have not been commercialized, but the biggest reason is that research progress and stability have not been secured enough to achieve Korean industrial standards such as ALC Block. Therefore, experiments are needed to ensure the stability of CLC.

1.2 Case Study of the Research

1.2.1 In Korea

To identify domestic research trends, we categorized them by group for analysis of selected papers according to the inclusion and exclusion criteria in PRISMA Fig. 1. G1: Strength Improvement of Lightweight foamed Concrete, G2: Product Development and Practicalization, G3: Basic and Experimental Studies, G4: Carbonation, G5: Basic Physical Properties Analysis, and G6: Industrial By-product Utilization. Fig. 2 shows the proportion of papers by year, with 5 in 2017 and 2020, 1 in 2018, and 2 in 2019 and 2021, and Fig. 3 shows the number of papers by group. The research on product development and practicality in G1 3 (two academic papers, one Thesis), G2 1 (one academic paper), G3 2 (one academic paper, one Thesis), G4 2 (two academic papers), G5 2 (one academic paper, one degree paper), and G6 2 (two Thesis).

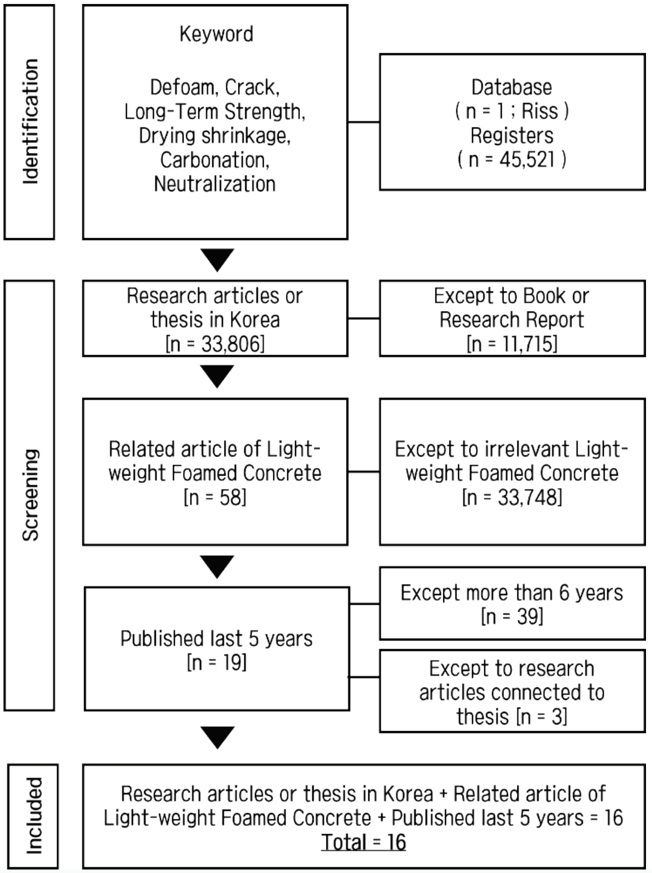


Figure 1 PRISMA Diagram

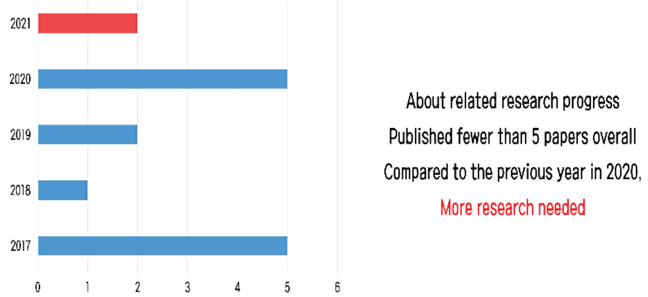


Figure 2 Research interest by year

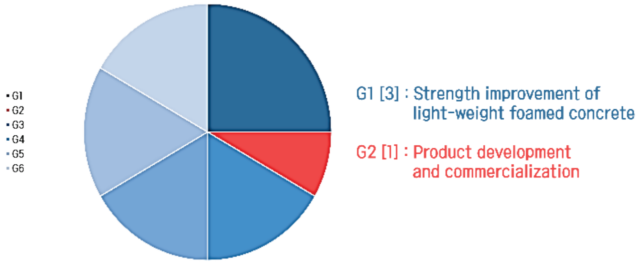


Figure 3 Research concentration by field

1.2.2 Foreign Cases

For comparative analysis based on the understanding of overseas cases due to the absence of CLC's domestic standards, foamed concrete blocks manufactured at room temperature in each country were analyzed.

In the case of Germany, we checked NeoPor's products. Maximum compressive strength that can be expressed for 0.4, 0.6 and 0.8 and 1.0 products is described as 1.0, 2.0, 3.0, and 4.0 MPa. For other products, the maximum compressive strength that can be expressed in 0.4 products is specified as 2.3 MPa even in the case of LithoPore.

In the case of India, ICS2185 is specified as the "Starting Foamed Concrete Block". Cement, a residue material, fly ash, a foaming agent and an admixture are presented as the materials to be used, and a manufacturing method and a sampling method are also presented.

As the standard physical properties to be satisfied, density, compression strength, thermal conductivity and absorption rate of the dry state are provided.

2 EXPERIMENTAL PLANS

Most domestic light-weight foamed concrete studies consist of studies on ALC manufacturing methods and their properties. However, the economics of equipment and manufacturing methods have become a problem. Therefore, to improve the reliability of CLC that can be cured at normal temperature and pressure, this study tries to analyze the properties of CLC by incorporating CaO-CSA expansive additive. Properties of CLC by mixing expansive additive and inhibition of crack by reducing drying shrinkage are analyzed by using cement, blast furnace slag, animal foaming additive and fiber based on drying density 0.55-0.65 kg/m^3.

Table 1 Experimental factors and levels

Experimental factors	Experiment levels	
Binder	High-early-strength Portland cement, Blast furnace slag	2
W/B	45%	1
Replacement ratio of Cao-CSA	0, 5, 10, 15, 20 (%)	5
Dilution concentration of foaming additive	3 (%)	1
Replacement ratio of water-reducing additive	0.8 (%)	1
Replacement ratio of foam stabilizer	1.5 (%)	1
Addition ratio of PVA fiber	1 (%)	1
Curing condition	Temp. 20±2 °C, Hum. 60±5%	1
Experimental items	Density, Absorption ratio, Compressive strength, Flow test, Drying shrinkage, Settlement	6

2.1 Materials

2.1.1 High-Early Strength Portland Cement

High-early strength Portland cement has a high content of alite effective for short-term strength and excellent expression of initial strength. Initial setting is within 235 minutes, and the strength (around 30 MPa) of the three-day ordinary Portland cement reference reorder can be expressed in one day. Furthermore, it has effects such as reduction of drying shrinkage, enhancement of strength, and acceleration.

Table 2 Chemical component

Chemical component of high-early strength Portland cement (%)									
SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	SO_3	L.O.I	C_3S	C_2S	C_3A
20.5	5.0	62.3	3.4	3.6	2.1	2.4	53.1	18.5	7.8

2.1.2 Blast Furnace Slag

Blast furnace slag fine powder refers to the addition of gypsum to the furnace slag in accordance with KS F 2563 (Ground granulated blast furnace slag for use in concrete) or the drying and grinding of the furnace slag. When used as an alternative material for cement, it has a characteristic of continuously increasing strength over a long period of time due to its latent hydraulic, and has effects such as increasing seawater resistance, improving watertightness, etc.

Table 3 Chemical component

Chemical component of BFS (%)							
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	-

2.1.3 Animality Foaming Additive

In the case of an animal foaming additive, bone fine powder of livestock is mainly hydrolyzed with NaOH or the like, neutralized, and then filtered and preservative-treated to produce it. At the time of foaming, it exhibits a light tawny color and is formed of many independent fine foams of 0.2-0.8 mm inside the foam. An animal foam additive prepared by hydrolyzing an animal's sense of smell or the like to extract an animal protein and adding a foam stabilizer, a viscosity additive, a coagulation regulator, or the like is used [3, 4].

2.1.4 CaO-CSA Expensive Additive

Expansive additive used in this study is an ettringite-lime composite expansive additive that properly combines the reaction of Free CaO with Denka Power-CSA of domestic company C, which reduces drying shrinkage and affects watertightness.

Table 4 Chemical Component

Chemical Component of CaO-CSA EA (%)					
SiO_2	CaO	Fe_2O_3	SO_3	Al_2O_3	F_CaO
1.0	70.6	0.6	18.5	7.2	49.8

2.2 Experimental Methods

2.2.1 Mixing

Fig. 4 shows the method of blending for CLC production in this study is as follows. High-early strength cement, blast furnace slag, foam stabilizer, PVA fiber and level-specific silica sand or CaO-CSA expansive additive are mixed and charged into a mixer, and then a psoriasis beam is advanced for 35 rpm 1 minute. At the same time, 3% animal foam additive is mixed in water, and an appropriate amount of foam is put into a cup by using a foamed generator. After the psoriasis beam is finished, water and a water reducing additive are put into a mixer, foams are put into the primary beam for 30 seconds, and the secondary beam is placed at 45 rpm for 30 seconds for a total of 120 seconds.

2.2.2 Density and Absorption Ratio

To measure the density and absorption, a test specimen was prepared using 40 × 40 × 160 mm. To measure the water absorption, the cured specimen is demolded, dried in a dryer for 24 hours, and then the weight is measured.

2.2.3 Compressive Strength

To measure compressive strength, a matrix is prepared by placing paste on a cylindrical mold 100 mm in diameter and 200 mm in height and a cubic mold 100×100×100 in accordance with KS F 2459. The curing of the matrix strength was measured on the 7th and 28th of the second order. The compressive strength test was performed by increasing the load to 2,400±200 N/s.

2.2.4 Flow Test

Flow test of non-solidified paste was conducted in accordance with KS L 5111. After the flow mold is arranged on the fluid table plate, paste is filled into the flow mold in three installments, each layer is spirally hardened 20 times, and then the flow mold is vertically lifted to measure three places, and then the average is measure.

2.2.5 Thermal Conductivity

For CLCs manufactured according to the replacement ratio of silica sand or CaO-CSA expansive additive, the thermal conductivity after 28 days of reorder was measured and the thermal conductivity test was conducted in accordance with ISO 22007. The thermal conductivity measuring instruments used Hot Disk M1 (Germany), which uses the TPS method.

2.2.6 Drying Shrinkage

In the drying shrinkage test, paste is placed on a 100×100×400 mold, cured for two days, and then demolded. After that, the surface of the CLC is subjected to surface treatment with sandpaper for smooth installation, and then the strain gauge connected to the data logger is fixed. After that, a test is advanced for seven days under temperature conditions of –5 °C to 30 °C and a change period of two cycles per day using a constant temperature and humidity chamber.

2.2.7 Settlement

In the settlement test, paste is placed in a cylindrical mold with a diameter of 100 mm and a height of 2000 mm in accordance with KS F 2459. After that, 200 mm 4 is divided into the upper end part, the middle upper end part, the middle lower end part and the lower end part, and the sinking accuracy is measured through the respective weights.

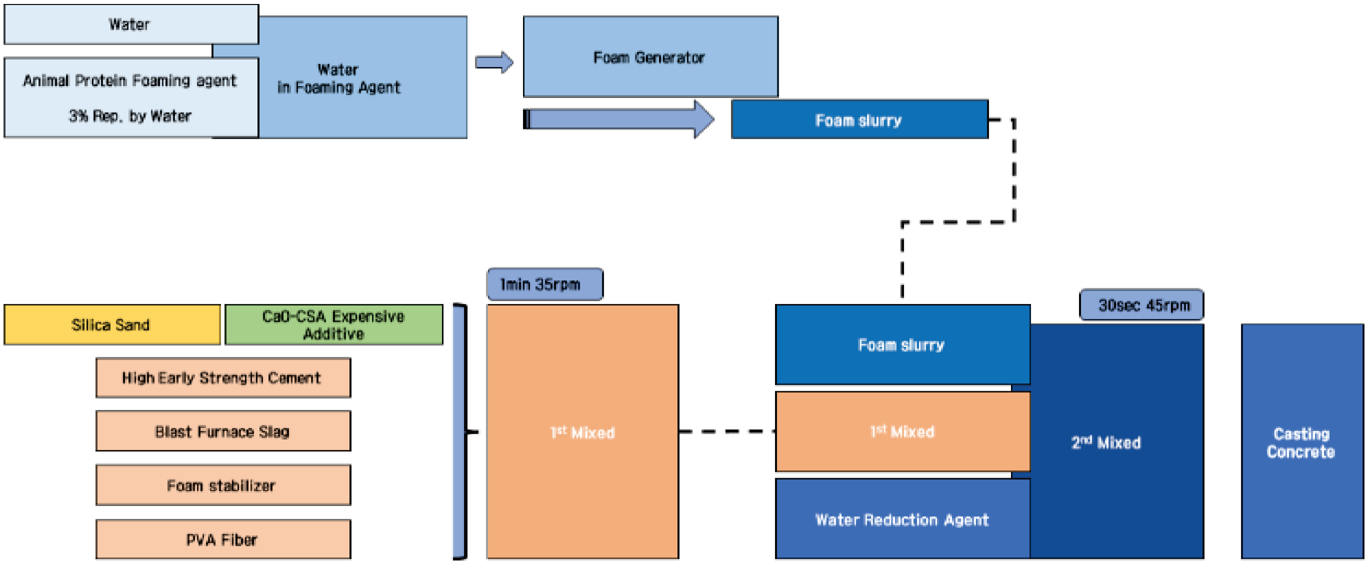


Figure 4 Mixing flow chart

Table 5 Chemical component of CLC by replacement ratio of CaO-CSA EA expansive material

Element	Replacement ratio of CaO-CSA EA (%)		
	0	60	80
	Weight (%)	Weight (%)	Weight (%)
C K	11.29	8.23	5.99
O K	54.18	53.14	51.17
Mg K	0.93	1.74	0.90
Al K	2.71	2.31	1.73
Si K	8.02	6.69	7.79
S K	1.31	1.76	2.54
K K	0.47	0.54	0.65
Ca K	20.23	24.24	28.31
Fe K	0.87	1.34	0.93
Totals	100.00	100.00	100.00

3 EXPERIMENTAL RESULT AND ANALYSIS

3.1 SEM and EDS Analysis

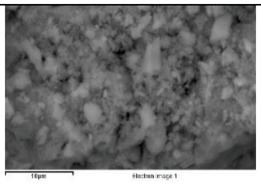
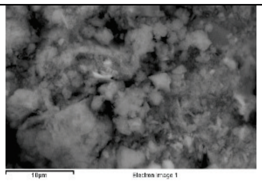
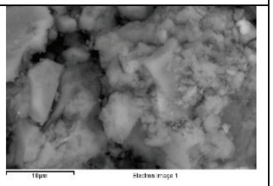
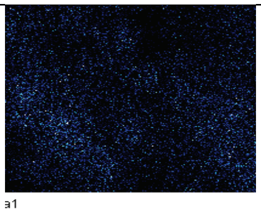
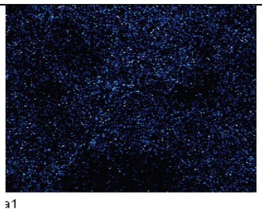
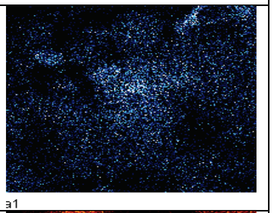
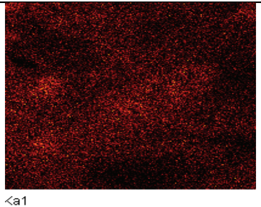
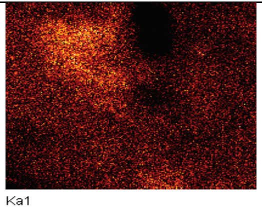
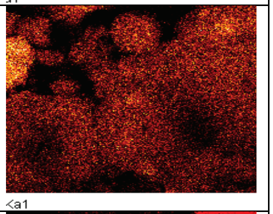
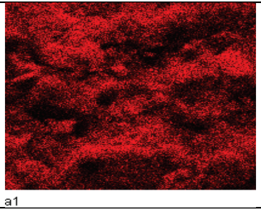
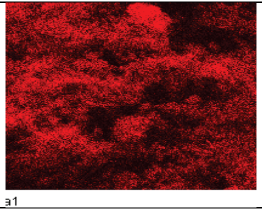
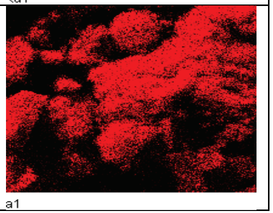
Tab. 5 and Tab. 6 are chemical components and photographs obtained by deriving CLCs of CaO-CSA expansion material replacement rates 0, 10, 20 (%) through SEM and EDS photography. As the replacement rate of the CaO-CSA expansion material increases, the total mass of S, Ca, and O in the chemical components tends to increase. This is determined to be the influence of calcium hydroxide (Ca(OH)) and etringite ($Ca_6Al_2(SO_4)3(OH)_{12}×26H_2O$) formed by reacting with internal surplus water by replacing CaO-CSA expansion material in CLC. If you look at the EDS, you can see that it is distributed evenly within the CLC.

3.2 Density and Absorption Ratio

Fig. 5 is the result of measuring the density and absorption ratio of CLC due to CaO-CSA expansive additive incorporation by 0.6 item reference level. At CaO-CSA expansive additive replacement ratios 0, 5, 10, 15, 20 (%) the single weight of the foamed slurry is 0.74, 0.68, 0.71, 0.73, 0.68 (kg/m^3), and the nodal dry density is 0.63, 0.56, 0. and 0.55 (kg/m^3). As the specific gravity of the CaO-CSA expansive additive, which is lighter than the blast furnace slag, is increased, it is judged that the density decreased as the replacement ratio of the expansive additive increased. Furthermore, the density difference before and after curing is reduced to 1.20-1.29 times width. The absorption ratio due to CaO-CSA expansive additive incorporation by level tends to decrease to 8.68, 7.51, 4.23, 4.11, 4.04 (wt.%) when measured 24 hours, respectively. By mixing the CaO-CSA expansive additive, the inter-tobermorite layer is filled to form a stable structure of CLC, and it is determined that the absorption ratio decreases as the replacement ratio increases

[5, 6].

Table 6 SEM and EDS photographs of CLC based on CaO-CSA expansive additive replacement rate (×5,000)

		Replacement ratio of CaO-CSA EA (%)		
		0	10	20
SEM				
EDS	S K			
	Ca K			
	O K			

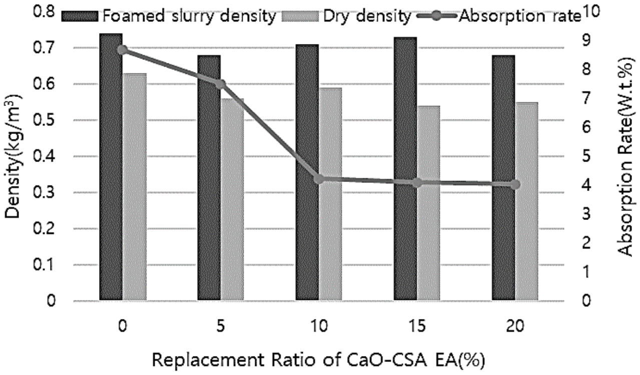


Figure 5 Density and Absorption ratio

3.3 Compressive Strength

Fig. 6 is the result of measurement of compressive strength of the circumferential specimen on the 28th day of the reorder when the CaO-CSA expansive additive is replaced by five levels of high loss lag ratio 0, 5, 10, 15, 20 (%) based on the blending of CLC 0.6 kg/m^3. From 0 to 10%, the expansive additive tends to increase to 6.84, 7.13, and 7.88 (MPa) as the replacement ratio of the expansive additive increases, but from then on, the compressive strength decreases to 3.94 and 3.51 in 15 to 20%. Compression strength is increased as the tissue of CLC becomes dense by the formation of calcium hydroxide and ettringite up to 10% CaO-CSA expansive additive replacement ratio, and compression strength is reduced due to excess product from 15% or more. It is judged that although the intensity of a fixed tendency is expressed as a whole, it is judged to be a result of reducing voids due to excess water evaporation and suppressing drying shrinkage by filling between the tobermorite layers.

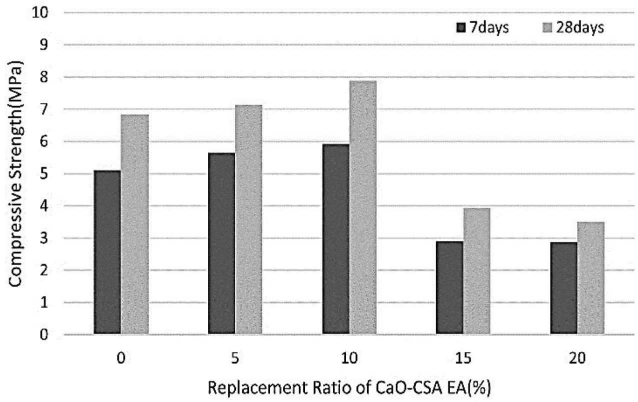


Figure 6 Compressive strength (100×200)

Fig. 7 is the result of measurement of compressive strength of the cube specimen of CLC when the 0.6 item reference CaO-CSA expansive additive is mixed in comparison with the blast furnace slag. The 28-day strength of CaO-CSA expansive additive replacement ratios 0, 5, 10, 15, 20 (%) is 8.25, 8.67, 9.51, 4.73, 4.21 (MPa), respectively, and the strength is about 1.2 times higher than that of a cylindrical specimen [7].

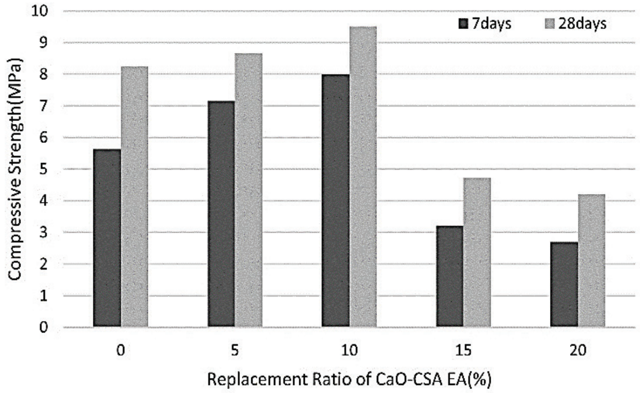


Figure 7 Compressive strength (50×50×50)

3.4 Flow Test

Fig. 8 shows the results of the flow test measurement of CLC due to the incorporation of CaO-CSA expansive additive by 0.6 item reference level. As the replacement ratio of the CaO-CSA expansive additive increases, the flow of the foamed slurry tends to decrease to 240, 220, 187, 156 and 139 (mm), respectively. As the CaO-CSA expansive additive replacement ratio increases, the decrease in excess water of the foamed slurry is large and the flow tends to decrease. A product, ettringite and calcium hydroxide is determined to have little effect on the enhancement of flow [8].

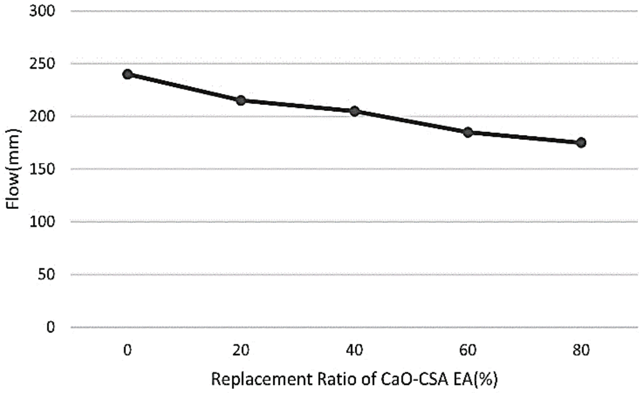


Figure 8 Flow

3.5 Thermal Conductivity

Fig. 9 shows the thermal conductivity measurement result of CLC by CaO-CSA expansive additive incorporation by 0.6 item reference level. Thermal conductivity tends to increase as CaO-CSA expansion material replacement rate increases. Thermal conductivity from 0-10% to 0.021 W/mK is judged to have increased sharply due to structural collapse of CLC due to overproduction of calcium hydroxide and ethrin gate.

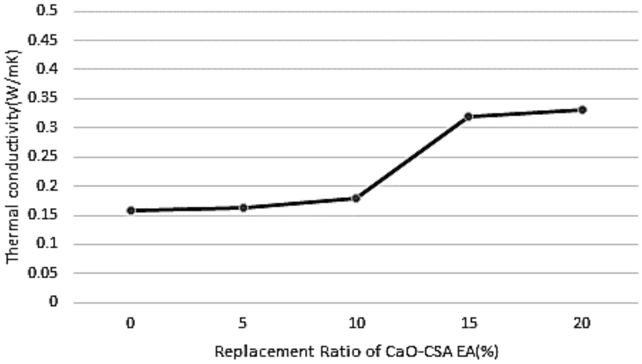


Figure 9 Thermal conductivity

3.6 Drying Shrinkage

Fig. 10 is the result of measuring the drying shrinkage ratio of CLC due to the mixing of CaO-CSA expansion material by level. As the replacement ratio of the CaO-CSA expansion material increases, the drying shrinkage ratio tends to be reduced and stabilized up to 15%. However, 20% shows the highest variation over time, which is judged to be the result of tissue relaxation due to excessive production [9, 10].

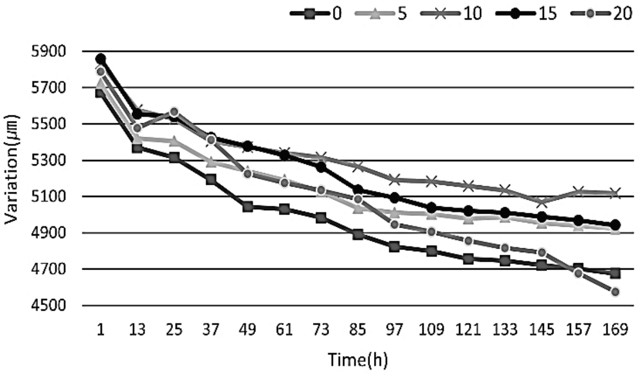


Figure 10 Drying shrinkage

3.7 Settlement

Fig. 11 is the result of measuring the degree of deposition of CLC by weight due to mixing of CaO-CSA expansive additive by level. A specimen demolded from a circular specimen of 1500 mm height is divided into upper, middle, middle, lower and lower stages by 200mm. Because of weight measurement, sedimentation occurred before CaO-CSA expansive additive was mixed, and the weight difference between the upper and lower stages was 353.9 g. After that, as the CaO-CSA expansive additive replacement ratio increases, there is no weight reduction, and it is determined that the upper and lower end error ratios are insufficient to reduce the settlement. By incorporating CaO-CSA expansive additive, drying shrinkage is suppressed by reacting with excess water inside the CLC, and the resulting calcium hydroxide and ettringites fill the void inside the CLC to increase durability, and it is judged that similar weight is expressed without settling [11]. However, it is determined that at 20% CaO-CSA expansive additive replacement ratio, relaxation of CLC tissue occurs due to excessive product, and the weight difference between the upper end part and the lower end part is 80.2 g.

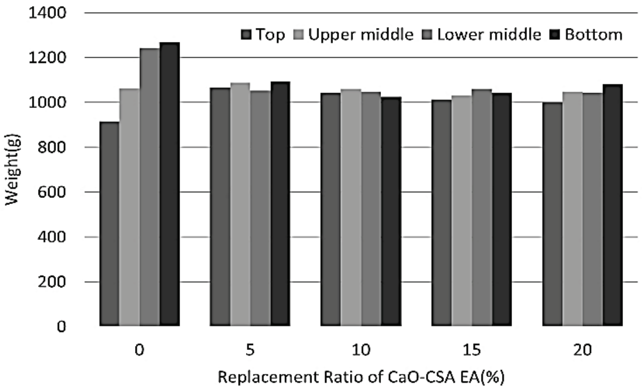


Figure 11 Settlement

4 CONCLUSION

To improve the reliability of CLC, which can be cured at normal temperature and pressure, the properties of CLC by incorporating CaO-CSA expansive additive are analyzed by utilizing cement, blast furnace slag; animal foam additive and fiber based on a drying density of 0.55-0.65 kg/m^3 and the results are as follows:

(1) The CaO-CSA expansive additive tends to increase in the range of 0-10 (%) as the replacement ratio of the CaO-CSA expansive additive increases. Compression strength is increased as CLC tissue becomes dense due to the formation of calcium hydroxide and ettringite, and it is judged that the compression strength is reduced due to excess production from over 15% of the replacement ratio.

(2) As the replacement ratio of the CaO-CSA expansive additive increases, the density and absorption ratio tend to decrease. As the specific gravity of the CaO-CSA expansive additive lighter than the blast furnace slag is increased to the density, it is determined that the density decreases as the replacement ratio of the expansive additive increases, and that the absorption ratio decreases.

(3) Liquidity tends to decrease as the replacement ratio of the CaO-CSA expansive additive increases. As a result, it is judged that the decrease in excess water of the foamed slurry is large and the fluidity is reduced, and the ettringite and calcium hydroxide as the producing substances have little influence on the fluidity enhancement.

(4) As the replacement ratio of the CaO-CSA expansive additive increases, infiltration does not occur. In the 0-10% range, the resulting potassium hydroxide and ettringites filled the inside of the CLC, causing no precipitation and affecting strength enhancement, but after 15% it is judged that tissue relaxation occurred due to excessive production.

(5) As the replacement ratio of the CaO-CSA expansive additive increases, the drying shrinkage ratio tends to be reduced and stabilized up to 15%. However, 20% shows the highest variation over time, which is judged to be the result of tissue relaxation due to excessive production.

By using the CaO-CSA expansive additive, it is determined that the formation of calcium hydroxide and ettringite fills the CLC between the tobermorite layers and the internal structure becomes dense. Currently, based on KS F 2701, the compression strength based on 0.6 items is more than 4.9 MPa, and the strength is about twice as strong as that of the existing CLC, and durability of the CLC are improved by incorporating CaO-CSA expansive additive.

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