The 2023 World Congress on
Advances in Structural Engineering and Mechanics (ASEM23)
GECE, Seoul, Korea, August 16-18, 2023

Field Applicability Evaluation of CLSM using Coal ash as Aggregate

Yong-Soo Lee[1)], Tae-Yeon Kim[2)], Bong-Jik Lee[3)]
and *Seongwon Hong[4)]

[1)] *Taeyoung E&C, 111 Yeouigongwon-ro, Seoul 07241, Korea*
[2)] *Institute of Construction and Environmental Technology, Korea National University of Transportation, 50 Daehak-ro, Chungju-si, Chungbuk 27469, Korea*
[3)] *Department of Civil Engineering, Korea National University of Transportation, 50 Daehak-ro, Chungju-si, Chungbuk 27469, Korea*
[4)] *Department of Safety Engineering, Korea National University of Transportation, 50 Daehak-ro, Chungju-si, Chungbuk 27469, Korea*
[4)] shong@ut.ac.kr

ABSTRACT

Controlled Low Strength Materials (CLSM) are flowable substances used for backfilling, known for their self-compaction, self-leveling, and flowability properties. Current research is actively exploring the potential of utilizing coal ash, an industrial by-product similar to sand, for both environmental protection and resource recycling. However, the reuse of bottom ash, another type of coal ash, is limited, leading to its disposal in ash ponds. This study aims to assess the feasibility of using bottom ash as an aggregate in CLSM by varying the mixing ratios of its constituents, including an eco-friendly soil binder, weathered granite soil, domestically sourced bottom ash, and fly ash. Additionally, the study evaluates the practicality of incorporating bottom ash in CLSM by subjecting it to strength tests after undergoing repeated cycles of freezing and thawing.

1. INTRODUCTION

With the recent expansion of urban areas and the proliferation of high-rise buildings, the need for burying pipelines (e.g., water and sewage, gas, and oil) underground has grown significantly. However, this practice comes with various challenges, such as difficulties in achieving proper compaction around underground facilities and reduced compaction efficiency. These issues often result from buried pipes overlapping during backfilling or gaps between joints and the lower portion of pipes,

[1)] Project manager
[2)] Researcher
[3)] Professor
[4)] Associate Professor

leading to road subsidence. The problem also extends to structures with poor compaction efficiency, such as box structures, retaining walls, and bridge abutments. To address these issues, controlled low-strength material (CLSM) has emerged as a typical solution (Lin et al., 2007).

CLSM offers numerous advantages over fillers using sand, including self-horizontality, self-compaction, flowability, controlled strength, ease of re-excavation after construction, cost reduction, and shorter construction periods (ACI 229 2005). Recently, researchers have been actively investigating the use of coal ash in CLSM, as it shares engineering properties similar to sand, aligning with environmental protection and resource recycling goals (Park et al., 2019). Coal ash, an industrial byproduct of thermal power generation, has seen continuous recycling efforts, especially in the case of fly ash, applied in various fields. However, bottom ash, another type of coal ash, is less amenable to recycling and is usually disposed of in ash ponds, creating a growing demand for finding recycling opportunities.

The primary objective of this study is to explore the potential of using bottom ash as an aggregate in CLSM by varying the mixing ratios of its components. These components include an eco-friendly soil binder, weathered granite soil, domestically sourced bottom ash, and fly ash. Additionally, the study seeks to evaluate the feasibility of incorporating bottom ash in CLSM by subjecting it to strength testing after undergoing repeated cycles of freezing and thawing.

2. CLSM Design criteria

2.1 CLSM design criteria

According to ACI committee 229 (2005), CLSM's compressive strength should not exceed 8.3 MPa. However, to allow for future re-excavation, the uniaxial compressive strength is recommended to be below 2.1 MPa, and the Transportation Research Board (2008) recommends a uniaxial compressive strength ranging from 0.35 to 1.0 MPa. In Japan, the strength of CLSM varies significantly, ranging from 0.1 MPa to 0.6 MPa, depending on its intended use. For backfilling buried pipes under roadways, a strength of at least 0.14 MPa is required immediately after traffic opening, while no more than 0.6 MPa is needed after 28 days. Small-scale cavity filling necessitates a strength of at least 0.3 MPa, whereas underground cavity filling requires a strength of 0.1 MPa or more (Japan Civil Engineering Research Institute 2007).

2.2 Application criteria of this study

Given that CLSM is predominantly employed for backfilling foundations or underground facilities, it is recommended to maintain the uniaxial compressive strength at 0.7 MPa or below, considering the possibility of future re-excavation. Additionally, to fulfill the need for rapid curing properties of CLSM, the strength should reach a minimum of 0.1 MPa after 1 day and at least 0.3 MPa after 7 days from the time of application.

3. Experimental Procedure

3.1 Materials and experimental preparations

To assess the strength variation of CLSM with different aggregates, namely bottom ash and fly ash, and its response to freeze-thaw cycles, a series of CLSM samples were prepared. The environmentally friendly soil binder, as specified in Table 1, was utilized in the mixtures. The study considered the following variables: aggregate ratio (expressed as a percentage of aggregate weight to the total dry mixture weight) at three levels (25%, 50%, and 75%), aggregate type (bottom ash or weathered granite soil), fly ash replacement ratio (with respect to bottom ash) at three levels (0:10, 1:9, and 2:8), and the addition ratio of the environmentally friendly soil binder (expressed as a percentage of the binder's weight to the total aggregate weight) at three levels (3%, 5%, and 7%).

Table. 1 Mixture proportion of CLSM

Mixture type	Aggregate		Replacement ratio of fly ash (%)	Eco-friendly soil binder (%)	Curing period (days)
	Bottom ash (%)	Weathered granite soil (%)			
BA25WGS75	75	25	0, 10, 20	3, 5 7	1, 7, 14, 28
BA50WGS50	50	50			
BA75WGS25	25	75			

The specimens for the uniaxial compression test were manufactured following ASTM D 4832 (2016) guidelines. After mixing the materials according to the prescribed proportions, demolding took place one day into the curing process, followed by wet curing until reaching the desired age of the specimens. To ensure consistency and eliminate the influence of specimen size on strength during preparation, molds were constructed with a height of 200 mm and an inner diameter of 100 mm, maintaining a constant height-to-diameter ratio. Compression testing of the specimens was performed using strain control, applying a constant axial compression rate. The loading speed was adjusted to achieve 1% compression of the specimen height per minute. The test proceeded until the specimens failed, with axial load measurements taken at a constant strain rate throughout the process, as shown in Fig. 1.

(a) Curing specimen (b) Specimen after test completion

Fig. 1 Compressive strength test

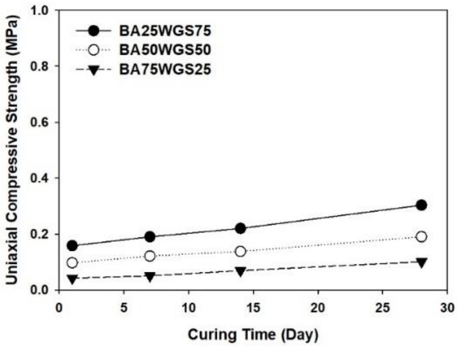
3.2 Strength changes by repeated freeze-thawing

To evaluate the impact of repeated freeze-thaw cycles on the strength of CLSM, a mixing ratio that met the CLSM criteria was chosen. Using the same mold utilized in the uniaxial compression test, specimens were prepared and subjected to wet curing for 7 days. The testing procedure followed ASTM D 560 (2003) guidelines. The freeze-thaw process was conducted over 12 cycles, involving freezing the specimens at -21 °C for 24 hours and thawing them at 21 °C for 24 hours in each cycle. For each cycle, three uniaxial compressive strength tests were performed to assess the strength variations.

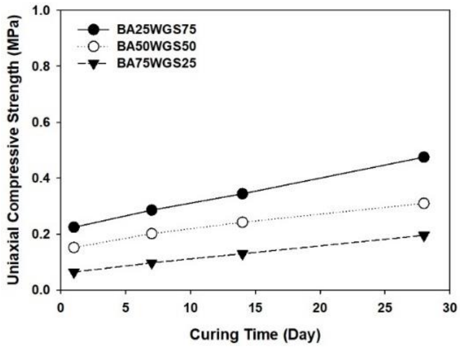
4. Results and discussion

4.1 strength change characteristics due to mixing proportions

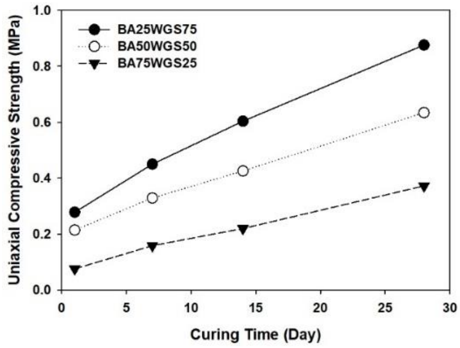
Figure 2 presents compressive strength of CLSM with curing time. Based on the results obtained from the uniaxial compression test concerning the mixing ratio of bottom ash and its age, it was observed that an increase in the addition ratio of the environmentally friendly soil binder led to a corresponding increase in the uniaxial compressive strength. Conversely, as the mixing ratio of bottom ash increased, the strength tended to decrease. Moreover, it was observed that the rate of strength increase with age showed a decline as the mixing ratio of bottom ash increased. This trend was more pronounced with higher addition ratios of the environmentally friendly soil binder. The possible explanation for these findings lies in the presence of sulfate, produced by the sulfur trioxide content in the bottom ash, which appears to impede the hydration reaction (Irassar 2005).



(a) 3% soil binder

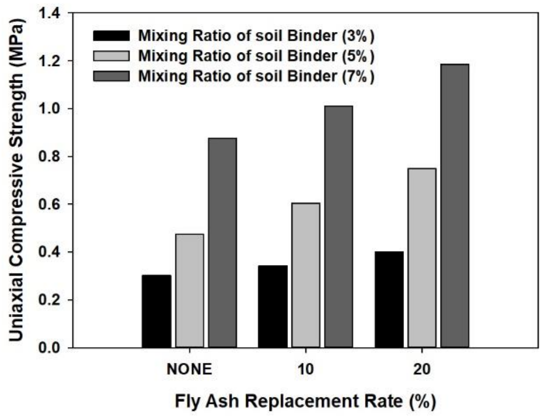


(b) 5% soil binder

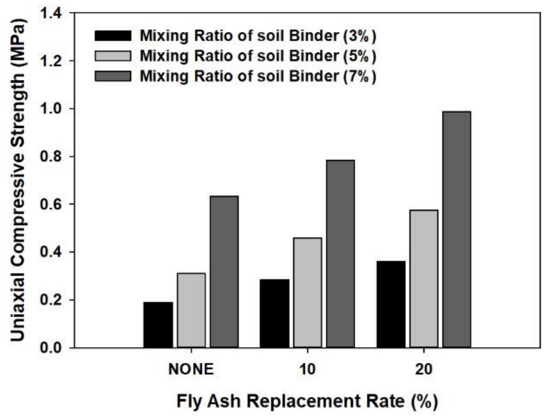


(c) 7% soil binder
Fig. 2 Compressive strength of CLSM with curing time

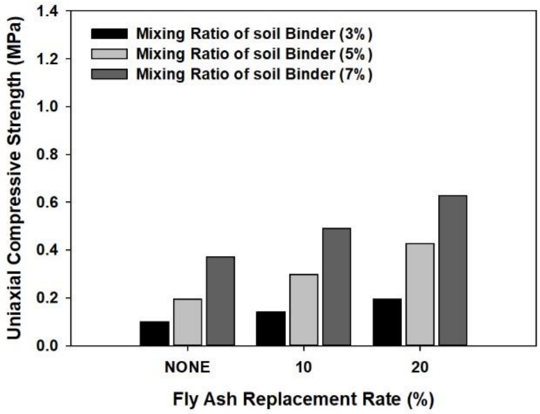
Figure 3 demonstrates change in compressive strength of CLSM according to replacement ratio of fly. When both the bottom ash mixing ratio and the addition ratio of the environmentally friendly soil binder remained constant, the uniaxial compressive strength showed an increase with higher fly ash replacement ratios. This trend became more prominent as the addition ratio of the environmentally friendly soil binder and the bottom ash aggregate ratio increased. The probable reason behind this observation is that the substitution of bottom ash with fly ash led to a reduction in sulfate production, which, in turn, hindered the hydration reaction. Additionally, the addition of fly ash further activated the hydration and polymerization reactions (Lim et al., 2016). Based on the test results of uniaxial compressive strength, aimed at identifying a suitable soil binder addition ratio and mixing ratio that align with the CLSM criteria, the most favorable combinations were determined for CLSM utilizing coal ash as the aggregate. Four optimal mixing ratios were selected, as presented in Table 2.



(a) BA25WGS75



(b) BA50WGS50



(c) BA75WGS25
Fig. 3 Compressive strength of CLSM according replacement ratio of fly ash

Table. 2 The optimal mixing ratios of CLSM

Mixture type	Aggregate		Replacement ratio of fly ash (%)	Eco-friendly soil binder (%)
	Bottom ash (%)	Weathered granite soil (%)		
CASE 1	25	75	10	5
CASE 2	50	50	20	5
CASE 3	50	50	0	7
CASE 4	75	25	20	7

4.2 Strength change by repeated freeze-thawing

To examine the impact of repeated freeze-thaw cycles on the strength of CLSM produced at the four mixing ratios that meet the CLSM criteria, test specimens were manufactured using the same mold used for the uniaxial compression test. Subsequently, the specimens underwent testing, and the results are presented in Fig. 4, illustrating the variations in compressive strength as a function of the number of freeze-thaw cycles. As a result of the repeated freeze-thaw cycles at all mixing ratios, the strength exhibited an increasing trend up to 9 cycles, followed by a decrease up to 12 cycles. Moreover, across all cases, the maximum strength attained after repeated freeze-thawing was slightly higher than the strength of the specimens produced under the same mixing conditions and wet cured for 28 days. This observation suggests that the repeated freeze-thaw cycles did not have a significant influence on the strength of CLSM utilizing bottom ash as the aggregate.

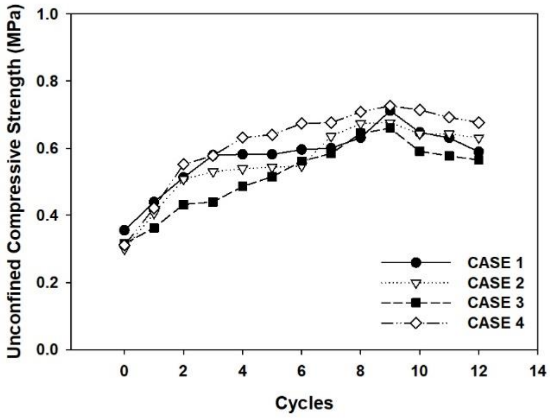


Fig. 4 Change in compressive strength of CLSM with freeze-thawing cycles

5. CONCLUSIONS

The strength variations of CLSM, utilizing both bottom ash and fly ash as aggregates, were evaluated along with the influence of repeated freeze-thaw cycles. Several specimens were prepared with different mixture conditions, and experiments were conducted, yielding the following summarized results:

1. As the curing period and the proportion of the environmentally friendly admixture increased, the uniaxial compressive strength also showed an increase. However, it was observed that the strength decreased with an increase in the proportion of bottom ash.

2. Additionally, when the proportion of bottom ash and the mixture ratio of the environmentally friendly admixture remained constant, the uniaxial compressive strength displayed an upward trend with higher fly ash replacement ratios.

3. Moreover, it was noted that the strength change of CLSM, using bottom ash as an aggregate, due to repeated freeze-thaw cycles was considered to be negligible.

In conclusion, the mixture proportions of CLSM, particularly the proportion of bottom ash and fly ash, significantly affected the uniaxial compressive strength. However, the repeated freeze-thaw cycles did not appear to have a substantial impact on the strength of CLSM when bottom ash was utilized as an aggregate.

REFERENCES

ACI 229 (2005), “Controlled Low Strength Materials (CLSM)”, *Am. Concr. Inst*., 229R-2, 1-12.

ASTM D4832 (2016), “Standard test method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders”, *ASTM Int*., West Conshohocken, PA.

ASTM D560-03 (2003), “Standard test methods for freezing and thawing compacted soil-cement mixtures”, *ASTM Int*., West Conshohocken, PA.

Irassar, E.F., Bonavetti, V.L., Trezza, M.A. and González, M.A. (2005), “Thaumasite formation in limestone filler cements exposed to sodium sulphate solution at 20 °C”, *Cem. Concr. Compos*., **27**(1), 77–84.

Japan Civil Engineering Research Institute (2007), “Technical Notes of Fluidization Surplus Soil”.

Lim, S.H., Choo, H.W., Lee, W.J. and Lee, C.H., (2016), “The characterization of controlled low strength material (CLSM) using high CaO fly ash without chemical alkaline activator”, *J. Korean Geo-Environ. Soc*., **17**(12), 17–26.

Lin, D. F., Luo, H. L., Wang, H. Y. and Hung, M. J. (2007), “Successful Application of CLSM on a Weak Pavement Base/Subgrade for Heavy Truck Traffic”, *J. of Perform. of Const. Facil*., **21**(1), 70-77.

Park, G. H., Kim, T. Y. Lee, Y. S. and Lee, B. J. (2019), “Engineering Characteristics of CLSM Using Bottom Ash and Eco-friendly Soil Binder”, *J. of the Korean Geo-Environ. Society.*, **20**(5), 23-29.

Transportation Research Board (2008), “Development of a recommended practice for use of controlled low strength material in highway construction (NCHRP report 597)”, The National Academies Press, Washington D.C.