Pilot Scale Test for the Application of Controlled Low Strength Materials Made from Coal Ashes

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ABSTRACT

In Korea, more than 6 million tons of coal ashes from thermal power plants are produced every year, of which 3.5 million tons (58%) are used as an alternative material to cement, with the remaining 2.5 million tons (42%) sent to landfill. The accumulated total amount of coal ash generated by power plants in Korea has now reached approximately 72 million tons, and due to the high cost of purchasing an appropriate site, the operation of landfills in Korea has become difficult. This study investigated the development of controlled low strength materials for the reclamation of public water utilizing pond ash, with the results of field tests also presented. Field tests were conducted to evaluate the strength and environmental effects of the developed materials. As a result of this study, controlled low strength materials for the reclamation of public water were found to exhibit excellent strength and have no detrimental effects on the environment.

KEYWORDS: controlled low strength materials (CLSM), pond ash, reclamation, field tests, cone penetration test.

1. INTRODUCTION

Much construction material, such as reclaimed or embanking materials, is required in Korea due to recent large scale coastal reclamation works. Of these materials, a shortage of aggregate and reclaimed material goes against the preservation of the nation's land environment as it is directly linked with natural damage due to the operation of borrow pits. Also, as large scale public water surface reclamation works rely on dredged soil as reclaimed material, the enormous construction period and expense caused by dredging can only cause tremendous loss to the nation. At present, an alternative material to replace dredged reclaimed soil is urgently required due to the shortage of dredged reclaimed soil in Korea, which has increased the price of reclaimed soil; therefore, the issue of utilizing coal ashes as a replacement for dredged soil for large scale reclamation works has surfaced.

Annually, in the case of Korea, 10 thermoelectric power plants produce about 6 million tons of coal ashes as a by-product, of which 58% (3.5 million tons) is used as a replacement material for cement, with the remaining 42% (2.5 million tons) buried in adjacent coal ash landfills. Of these coal ashes, although fly ash is recycled, the total quantity of bottom ash is buried in landfills as its utilization is difficult. As the capacities landfills in which coal ash has been buried reach their limits, some power plants may encounter an emergency, as a worst case, where the generation of electricity may have to be stopped.

Accordingly, our aim was to solve the difficulty in obtaining construction material, as well as the efficient use of national land, coupled with environmental protection due to the effective use of industrial wastes, with a reduction in the size of ash stockpiled by utilizing coal ash for coastal reclamation work, which would otherwise be abandoned.

In this study, the content related to evaluation of the applicability of the development of CLSM to the field of public water surface reclamation for the effective utilization of large quantities of coal ash. Therefore, a Pilot Scale Test of CLSM for public water surface reclamation was performed at an actual public water surface reclamation work site, with changes in the strength measured over time.

2. BACKGROUND

2.1 CLSM

CLSM is a highly flowable material, typically composed of water, cement, fine aggregates, and possibly fly ash or other by-product materials. CLSM is used in a wide range of highway construction applications, where its ability to flow into and fill voids without the need for compaction, provides significant benefits over the use of compacted fill. There are various inherent advantages of using CLSM instead of compacted fill in these applications, including reduced labor and equipment costs (due to self-leveling properties and lack of need for compaction), faster construction, and the ability to place the material in confined spaces (NCHRP, 2008).

2.2 ENGINEERING CHARACTERISTICS of CLSM

The representative factors that determine the engineering characteristics of Controlled Low Strength Material (CLSM) are its flow value and unconfined compressive strength, which are the criteria for liquidity and judging whether re-excavation is possible, respectively (TRB, 2008). As the minimum specified flow value is 0.2 m (≒ 8 in) in ACI 229 Committee (1994); therefore, the same standard as applied in previous investigations, i.e. a standard flow value determined as 0.2 m or higher, was also used in this study.

Standards for unconfined compressive strength differ from each other. According to the ACI 229 Committee (1994), the scope of unconfined compressive strength of CLSM is between 2 to 8 MPa (≒ 300 to 1200 psi) with respect to the 28 day material age, but the ASTM (2002) specifies the minimum strength required in cases of re-excavation should be carried out using an excavator, such as a backhoe, at about 1.38 MPa (200 psi). Also, Amon (1990) suggested 1.05 MPa (150 psi) or lower as the standard strength, which allows re-excavation, and Sumio Horiuchi (1996) once estimated the strength required for construction of an artificial island to be 0.84 MPa (122 psi). The standards for unconfined compressive strength presented in several similar previous investigations have shown a little difference depending on whether the material is going to be excavated, and whether this excavation would be by machine or man. Based on such a result, the standard unconfined compressive strength of CLSM intended for use in this study was estimated to be 1.0 MPa (≒ 70 to 150 psi), which would allow easy re-excavation and a given strength to be achieved.

3. MATERIALS

3.1 POND ASH AND FLY ASH

In this study, pond ash buried at a thermoelectric power plant was used. In thermoelectric power plants, pond ash is buried without distinguishing bottom ash and fly ash and; as the engineering properties of the two ashes are different, those passed through a no. 4 sieve (mesh size 4.75 mm) were used as a replacement for fine aggregate. The preliminary test result showed that, if CLSM for public water surface reclamation is manufactured using only pond ashes, it would be difficult to achieve the required strength and liquidity due to the occurrence of material segregation; therefore, fly ash was added in this study. Table 1 shows the physical and chemical characteristics of the pond and fly ashes.

Table 1. Physical and chemical characteristics

Physical properties			
Specific gravity		L.O.I(%)	
Pond ash	Fly ash	Pond ash	Fly ash
1.84	2.23	6.78	3.12
Chemical compositions(%)			

component	Pond ash	Fly ash	component	Pond ash	Fly ash
Sio2	50.6	52.8	Al2O3	24.7	22.7
Fe2O3	11.5	9.28	CaO	5.91	7.43
K2O	1.75	2.33	TiO2	1.72	1.55
MgO	0.85	1.17	Na2O	0.37	0.57

3.2 OPC

The cement used in this study was Ordinary Portland Cement (OPC), which is widely used in Korea; the quality test results are shown in Table 2.

Table. 2 Ordinary Portland Cement (OPC) characteristics

Fineness (m2/kg)	Specific gravity	Stability (%)	Compressive strength(kPa)		
			3days	7days	28days
348.8	3.15	0.08	21,966	30,204	39,618
Initial setting time (min)			231		
Final setting time (min)			407		

3.3 MIXING RATIO

From a preliminary test to calculate the optimal mixing ratio, it was found that the requirement for the addition of cement would be inevitable, as the standard unconfined compressive strength was unable to be satisfied with coal ashes only (pond ash and fly ash). Accordingly, to minimize the cement content, a cement content of about 3.2 % of the total weight was selected. Because the mixing ratio of pond ash and fly ash in buried coal ash is not consistent, a relative weight ratio of pond ash and fly ash was estimated to be 70:30. Also, as CLSM shows considerably different liquidity, depending on the water content, the water content was set at 31 % of the total weight via a preliminary test. Table 3 shows the mixing ratio of CLSM for use in public water surface reclamation.

Table. 3 Mixing ratio of CLSM

Component	Wt(%)
Pond ash	45.5
Fly ash	19.5
OPC	3.2
Water	31.8
Total	100

4. PILOT SCALE TEST

A Pilot Scale Test was carried out for the purpose of evaluating the field applicability of CLSM for use in public water surface reclamation. The field applicability evaluation focused on changes in the strength over time, and was performed at the Incheon Public Water Surface Reclamation Work Site; the field test site is shown in Figure 1. The field test was carried out at the site, which had a size of 100m(L)×20(W)×3m(D), by placing developed public water surface CLSM after excavating a trench. The test was carried out for a total of 5 cases; namely: CASE 1, the control group; CASE 2, pond ash; CASE 3, CLSM for public water surface reclamation (not pressurized); CASE 4, CLSM for public water surface reclamation (pressurized, water content of 29%) and CASE 5, CLSM for public water surface reclamation (pressurized, water content 31%). Figure 2 shows the field test floor plan. The test of the CLSM for public water surface reclamation was carried out using purpose built CSP equipment.

Fig. 1. Site

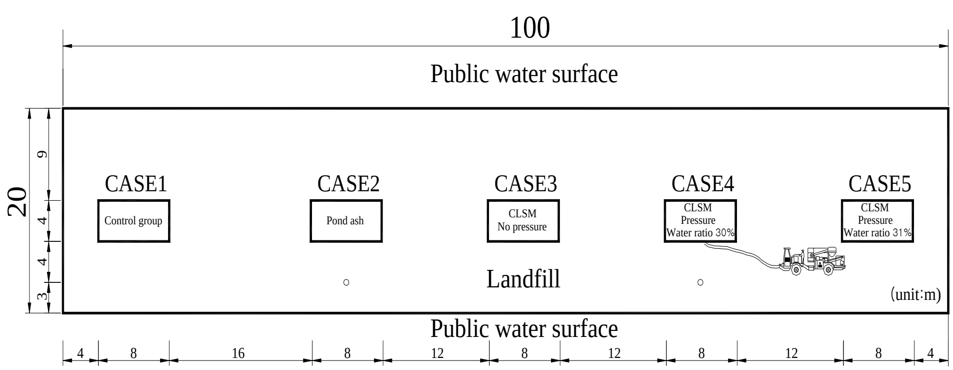


Fig. 2 Plan view

(a) set up (b) excavation (c) mixing

(d) pumping (e) construction end (f) investigation

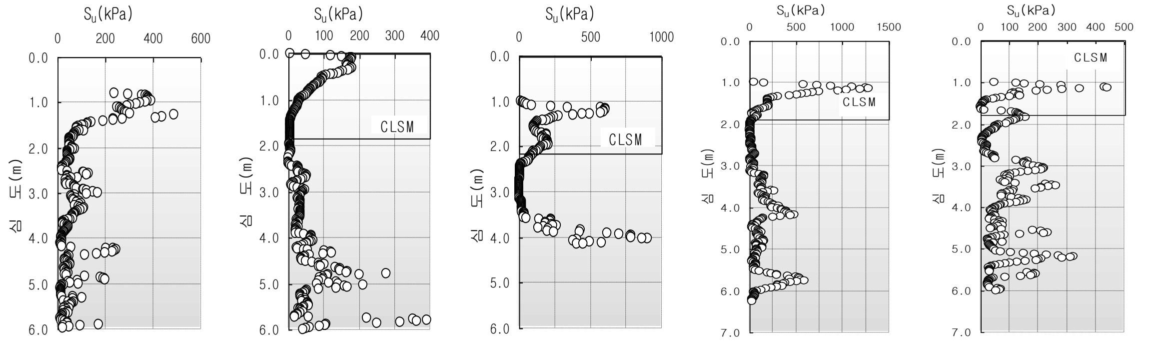
Fig. 3 construction process

5. RESULTS

5.1 CONE PENETRATION TEST

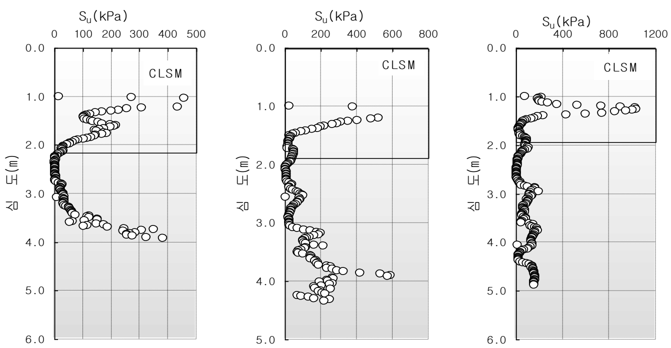
To measure the changes in the strength of the CLSM for public water surface reclamation over time, a Cone Penetration Test (CPT) was executed. CPTs were executed after 7, 14 and 21 days had passed, with the undrained shear strength obtained via the cone penetration resistance value. The undrained shear strengths of CASE 1 (dredged and reclaimed ground) and CASE 2 (pond ash) were 615.5 and 180.0 kPa, respectively. The ground of CASE 1 exhibited considerable bearing capacity over time from being dredged and reclaimed. The undrained shear strength of CASE 2 ground, reclaimed using only pond ash, was observed to be considerably low compared to that of the dredged and reclaimed ground, showing a mere 180.0 kPa. The undrained shear strength of CASE 3 (not pressurized) ground changed from 608.5 to 661.6 kPa over time, showing that the change in strength after revelation of the initial strength was not that big. The undrained shear strength of CASE 4 (pressurized) ground changed from 1,279.9 to 1,310.7 kPa over time.

When CASE 3 (not pressurized) and CASE 4 (pressurized) were compared, the strength of CASE 4 was shown to be about two times greater than that of CASE 3, which means the ground strength can be doubled by pressurizing the material during its placement, without changing the material. Figures 4 to 6 show the undrained shear strength of each CASE over time. CASES 3 to 5 were found to be far superior to CASE 1 in terms of strength, as CASES 3 to 5 exhibited far larger undrained shear strengths than in CASE 1 (615.5 kPa) after 21 days. Also, CLSM is thought; without question, to be adequate for public water surface reclamation, because when attempts were made to excavate after 120 days, it was able to be excavated using a fork crane.



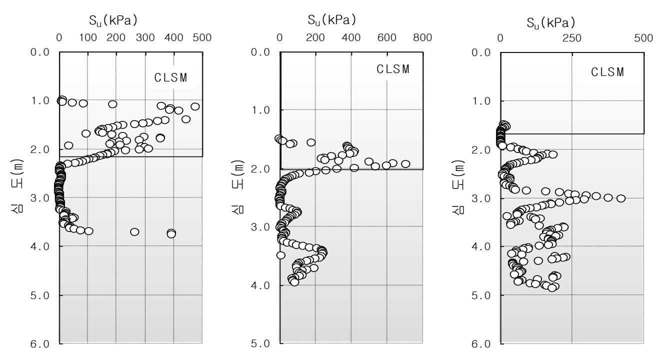
(a) CASE1 (b) CASE2 (c) CASE3 (d) CASE4 (e) CASE5

Fig. 4. Undrained shear strength of CLSM(After 7days)



(a) CASE3 (b) CASE4 (c) CASE5

Fig. 5. Undrained shear strength of CLSM(After 14days)



(a) CASE3 (b) CASE4 (c) CASE5

Fig. 6. Undrained shear strength of CLSM(After 21days)

5.2 CHANGE in UNIT WEIGHT DEPENDING on DEPTH

Unit weight is closely related to ground strength. In this study, specimens were installed at different depths prior to placement of the CLSM in order to check the changes in the unit weight depending on the depth when CLSM was placed for public water surface reclamation. and the specimens were collected after completion of the test (after 120 days) to check the unit weight. From measuring the unit weight of the specimens after 120 days, it was shown that the deeper the ground surface, the larger the increase in the unit weight for all the sections (CASES 3 to 5) into which CLSM had been placed. Also, the unit weight showed values between 16.15 and 16.27 kN/m3 in all the CASEs. Especially, when CASE 3 (not pressurized) and CASE 4 (pressurized) were compared, the unit weight was greater when the CLSM being placed was pressurized, which made the ground more compact. Figure 7 shows the changes in the unit weight with respect to depth.

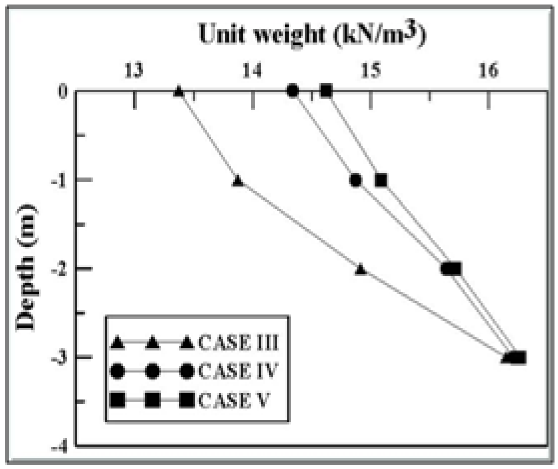


Fig. 7. Change in the unit weight as depth

6. CONCLUSION

In this study, the field applicability of CLSM for public water surface reclamation for effectively utilizing coal ash on a large scale was evaluated. The following conclusions were drawn:

1) When the ground constructed using only pond ash was compared with dredged and reclaimed ground, the undrained shear strength of the pond ash ground was considerably insufficient.

2) In the case of CLSM (not pressurized), an undrained shear strength similar to that of dredged and reclaimed ground was achieved.

3) The effect of pressurization was confirmed, because CLSM (pressurized) exhibited undrained shear strength at least twice that of CLSM (not pressurized).

4) Also, CLSM, without question, would be adequate for public water surface reclamation, because when attempts were made to excavate the CLSM after 120 days, it was able to be excavated using a fork crane.

5) The unit weight was confirmed to increase with increasing depth.

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