Properties of CLSM Separation Dike using Coal Ash

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KEYWORDS: separation dike, coal ash, CLSM, mix proportion

ABSTRACT

Taiwan Power Company (TPC) plans to substitute sea sand, the traditional construction material of ash pond dike, by Coal Ash - Controlled Low Strength Material (CACLSM) which consists of large amount of coal ash from thermal power plants and a little amount of cement. The purpose of such a plan is to develop a new utilization approach of coal ash to improve the quality and to reduce the cost of the dike construction. As a result, a few basic engineering properties of CACLSM as used in dike construction at the coastal site with shallow seawater are studied in the paper.

According to the design requirement of 40-60 kgf/cm^2 for 28-day compressive strength, two mix proportions of CACLSM are finally adopted based on a series of mix trial tests. The one contains higher ratio of fly ash to bottom ash and another higher ratio of bottom ash to fly ash. Afterward, several test items are conducted including slump flow, flow cylinder, setting time, compressive strength, splitting tensile strength, sulfate attack, one dimensional consolidation, influence of dry-wet cycle in seawater together with wave action, erosion of wind with coal ash particles, and placement into water.

For the given two mix proportions, the 28-day compressive strengths of CACLSM mixtures are 36.8 kgf/cm^2 and 37.1 kgf/cm^2, respectively, as flow cylinder is 150±5mm. Around 40-day age, their compressive strengths can reach 40 kgf/cm^2 or more. In additional, their 28-day splitting strengths are 4.32 kgf/cm^2 and 4.14 kgf/cm^2, respectively. The two mixtures show good resistance to sulfate attack, however, the mixture with higher ratio of fly ash to bottom ash has less material segregation than ones with higher ratio of bottom ash to fly ash. After a testing period of 90 days, both dry-wet cycle in seawater together with wave action, and erosion of wind with coal ash particles do not cause the detrimental effect on either the appearance or the strength of CACLSM mixtures.

INTRODUCTION

Coal ash is the by-product of thermal power generation and, in general, around 80% of coal ash is fly ash and 20% bottom ash in Taiwan. The Environmental Protection Administration in Taiwan has officially announced coal ash as a kind of general industrial wastes. Since 1992 the annual production amount of coal ash from the thermal power plants of TPC has been more than 1.5-million tons and the utilization options of TPC coal ash have included concrete, CLSM, highway base, highway pavement, site backfilling, etc. (Hun *et al*., 2009). Due to lower and lower utilization rate together with more and more dumped ash in recent years, TPC intends to construct an ash pond at the Chung-Hua Coastal Industrial Park for the ash treatment of Taichung thermal power plant and to build a separation dike of 1,570 m in length for the construction need of ash pond. The site of the dike locates at a near-ocean area generally with 2-m deep seawater.

Recently, Taiwan Power Research Institute (TPRI) of TPC has actively implemented the study in light of CLSM (Quo *et al.*, 2009; Quo *et al.*, 2008) and obtained viable application in the backfilling of pipe trench (Quo *et al*., 2011). To cope with the above-mentioned dike construction, TPRI undertakes a comprehensive follow-up program to study the suitable mix proportion, material placement, engineering properties of CACLSM mixtures both in the lab with simulated site condition and at outdoor similar sites. These results are provided for the dike construction plan at a site with shallow seawater. This paper aims to make a brief introduction in terms of lab test results as well as site on-going construction.

EXPERIMENTAL DESIGN

Experimental parameters

To develop the CACLSM meeting economy as well as construction requirements, as above-mentioned, TPRI has executed a series tests on mix proportions and on the relevant basic engineering properties under the given 28-day compressive strength of 40-60 kgf/cm^2. The test results indicate that CACLSM mixtures with more bottom ash have lower strength but the lower strength can be offset by using more cement. Taking into account of design requirements for the part of dike beyond seawater possible different from that below seawater, two mix proportions which meet the strength requirement are then selected in the paper to further evaluate more of their engineering characteristics. As shown in Table 1, No 1 CACLSM contains higher ratio of fly ash to bottom ash and No 2 CACLSM higher ratio of bottom ash to fly ash.

Experimental materials

The physical as well as chemical properties of experimental materials used in the paper are briefly introduced as follows:

1. Cement: Type 1 Portland cement produced by Taiwan Cement Corporation meets ASTM C150 standard.
2. Fly ash: The chemical properties of class F fly ash from Taichung thermal power plant are shown in Table 2.
3. Bottom ash: A few chemical properties and physical properties of bottom ash

from Taichung thermal power plant are listed in Table 2 and Table 3, respectively.

4. Mixing water:
   (1) Fresh water: Tap water meets CNS3090 standard.
   (2) Seawater: The water from Linkou thermal power plant has 0.8% of salt content.

Table 1 Two CLSM mix proportions

Type	Mix parameters		Mix amount (kg/m^3)		Unit weight (kg/m^3)
No 1 CACLSM	Water/Cement ratio	3.945	Cement	103	1,668
	Cement/Coal ash ratio	0.085	Fly ash	730	
	Bottom ash/Coal ash ratio	0.4	Bottom ash	487	
	—	—	Water	409	
No 2 CACLSM	Water/Cement ratio	3.323	Cement	124	1,647
	Cement/Coal ash ratio	0.105	Fly ash	450	
	Bottom ash/Coal ash ratio	0.62	Bottom ash	734	
	—	—	Water	413	

Table 2 Chemical properties of fly ash and bottom ash

Specimen No.		Bottom ash	Fly ash
Water content (%)		0.22	0.45
Dry basis	LOI (%)	6.2	7.6
	SiO_2 (%)	59.3	52.2
	Al_2O_3 (%)	19.4	19.5
	Fe_2O_3 (%))	9.5	7.4
	CaO (%)	2.8	5.3
	MgO (%)	0.76	1.83
	Na_2O (%)	0.19	0.75
	K_2O (%)	0.76	1.18
	SO_2 (%)	0.55	1.03
	PH Value	9.6	11.7

Table 3 Physical properties of bottom ash

Sieve No.	1/2"	3/8"	#4	#8	#16	#30	#50	#100	base
Residue weight percentage	2	1	8	25	20	9	8	10	18
Specific gravity=2.13; Water absorption (%)=3.4; Fineness（FM）=3.22									

Experimental items and apparatus

A few fresh mixture properties, hardened mixture properties and durability such as workability, setting time, strength, resistance to sulfate attack are investigated in the paper. The relevant test standards and test apparatuses are presented as follows:

1. Workability: Slump flow and flow cylinder are evaluated in accordance with ASTM-C143-98 and ASTM-D6103-97, respectively.
2. Setting time: Both initial and final setting time are measured based on ASTM-C403.

3. Strength: According to ASTM-D4832-95 and ASTM-C469-96, compressive strength and splitting tensile strength are evaluated, respectively, at the age of 7, 14, 28, 56 and 90 days.
4. Sulfate attack: After 28-day curing, the resistance of CACLSM specimens to sulfate attack is studied by ASTM-C1012.
5. Influence of dry-wet cycle in seawater together with wave action: A self-designed equipment shown in Figure 1 is made to simulate the change of seawater level and the action of wave by wind at the ash pond. Each cycle takes 8 minutes. After mold removal, specimens are placed in the tanks. The strength at the age of 1, 14, 28, 56 and 90 days are checked.

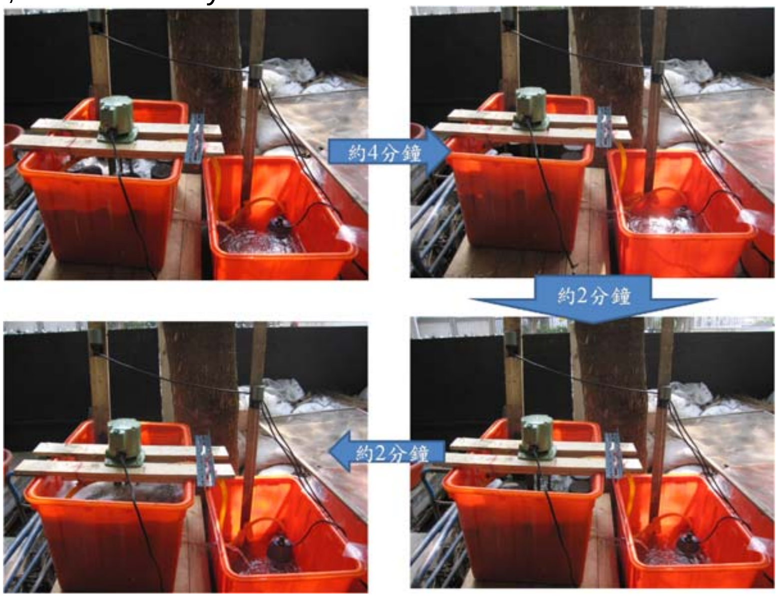


Figure 1 Dry-wet cycle test

6. Erosion of wind with coal ash particles: A self-designed equipment shown in Figure 2 is made to simulate the action of sand on specimen surface caused by strong wind with minimal speed of 20m/s. After mold removal, specimens are placed in the device. The change of appearance and weight of specimens are observed and measured at the age of 1, 14, 28, 56 and 90 days.

Figure 2 Erosion test of wind with coal ash particles

7. CLSM placing into water: A self-designed equipment with the size 150*150*20 cm shown in Figure 3 is made to simulate the placement of CACLSM into seawater in ash pond. Both the motion of CACLSM in the transparent tank and the segregation of CACLSM are observed. After a period of 28 days, then cores are taken at different parts of the solid block to investigate their compressive strength.

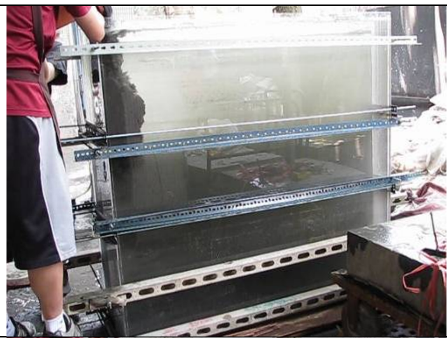
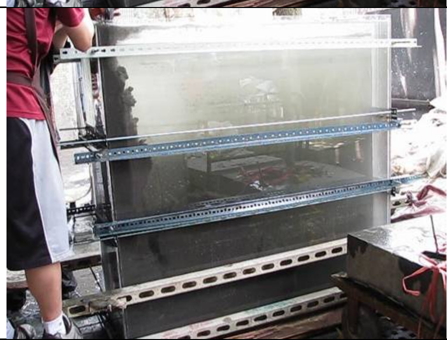
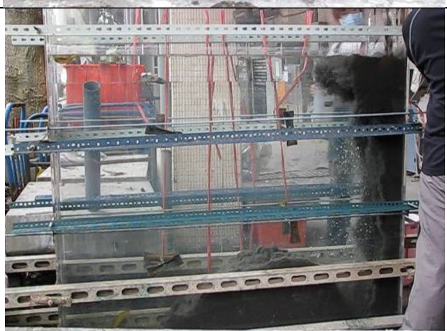
No 1 CACLSM	No 2 CACLSM
	
	
	
	

Figure 3 Acrylic apparatus for placement test into water

TEST RESULTS AND DISCUSSION

Workability

The workability of No 1 CACLSM and No 2 CACLSM is shown in Table 4. The purpose of slump flow test is to understand the flow ability of mixture. According to the results of slump flow test, No 1 mixture which has higher fly ash content exhibits inferior performance to No. 2. Because the particle size of fly ash is finer than that of bottom ash, fly ash having more surface area can absorb more mixing water, leading to poor flowability. The purpose of slump flow test is to realize the placeability of mixture. According to the results of flow cylinder test, both mixtures have good placeability to meet design requirement of 150mm. Taking into account of cost, surfactant is not adopted in the paper.

Table 4 The properties of fresh and hardened CACLSM mistures

Item	workability (mm)		compressive strength (kgf/m^2)					splitting tensile strength (kgf/m^2)				
	slump flow	flow cylinder	7 d	14 d	28 d	56 d	90 d	7 d	14 d	28 d	56 d	90 d
No.1	300	155	18.9	30.5	36.8	44.0	49.8	2.9	3.8	4.3	5.1	5.3
No.2	400	165	20.1	28.6	37.1	37.4	47.0	3.1	3.8	4.1	4.6	4.8

Setting time

The setting times of No 1 CACLSM and No 2 CACLSM are illustrated in Figure 4. The cement content of No 2 mixture is 124kg/m^3, higher than103kg/m^3 of No 1. Also, the ratio of water to cement of No 2 mixture is lower than that of No 1. As a result, No 2 mixture exhibits faster setting behavior. The initial and final setting times of No 2 mixture are 5hr (400psi) and 16hr (4000psi), respectively faster than 8hr and 18hr of No 1.

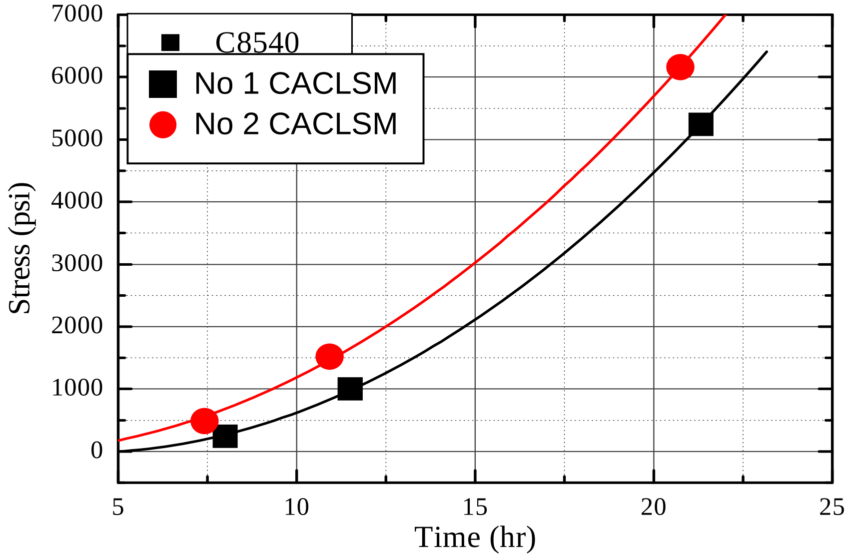


Figure 4 Setting time of No 1 CACLSM and No 2 CACLSM

Strength

The compressive strength and splitting tensile strength of the CACLSM mixtures are listed in Table 4 and plotted in Figure 5 and Figure 6. As compared to No 2 mixture, based on Figure 5, No 1 has lower early compressive strength but higher at later age. It can be explained that No 1 contains less amount of cement, resulting in lower early strength, and contains less bottom ash which is porous as well as brittle material, leading to higher strength at later age. As to splitting tensile strength, based on Figure 6, similar results to compressive strength can be observed.

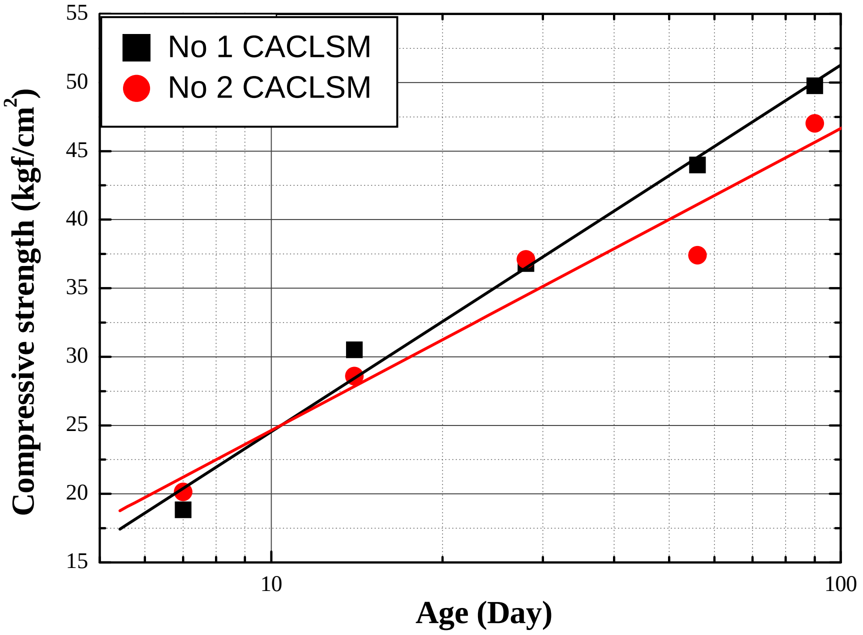


Figure 5 The development of compressive strength

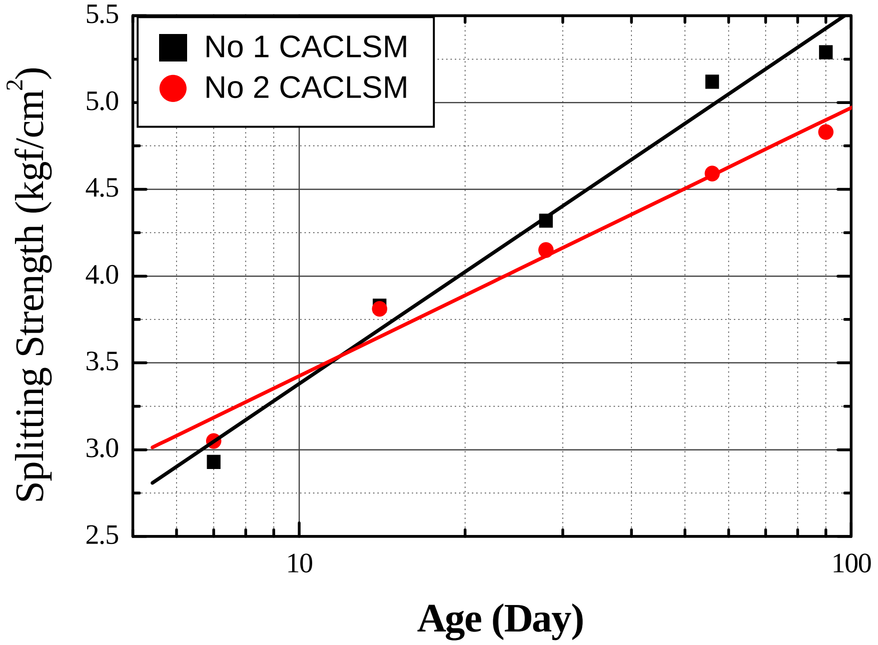


Figure 6 The development of splitting tensile strength

Sulfate attack

The weight variation of the CACLSM mixtures during sulfate attack test is presented in Figure 7. As seen, both mixtures have similar weight variation and specimen weight is increased with cycle no. Although the weight is increased 20% at the end of cycle 15, specimens still have as good as original appearance. It can be explained that the specific weight of CACLSM mixture is much lower than that of normal concrete, implying more pores in CACLSM mixture. During test, sulfate salt crystallization can occupy these pores, leading to no collapse by swelling.

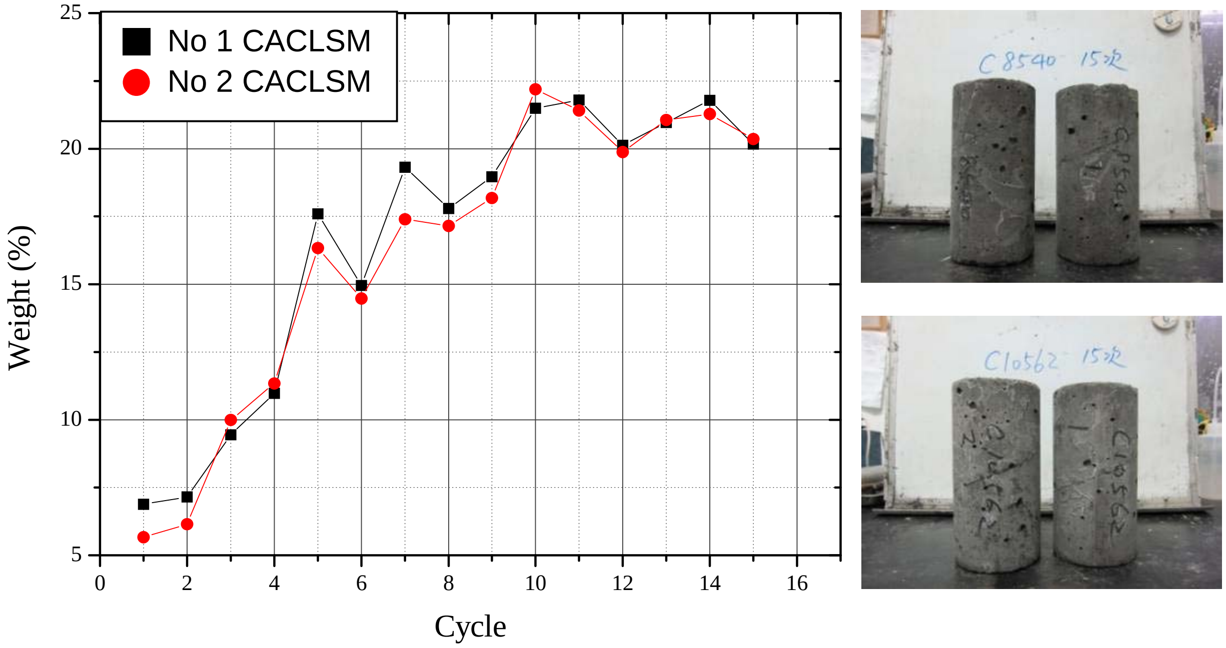


Figure 7 Weight variation during sulfate attack test

Influence of dry-wet cycle in seawater together with wave action

The compressive strength development of the CACLSM mixtures during the influence test of dry-wet cycle in seawater together with wave action is given in Figure 8. The test results show that such compressive strength is higher, averagely 16%, than that of specimen under normal curing condition. The reason is chloride in seawater which is used as soaking water during the test can enhance the strength development.

Erosion of wind with coal ash particles

The weight variation of the CACLSM mixtures during erosion test of wind with coal ash particles is shown in Figure 9. As observed, weight loss is same for both mixtures and weight loss can reach 22% at 14 days. In the paper to simulate the site condition and to prevent the damage to strength from drying, specimens are not dried in the beginning of test. It is clear that early significant weight loss results from the loss of moisture inside specimens and from the loss of surface due to significant bleeding. After 14 days, the extra weight loss is kept around 0.5%, indicating no severe erosion of wind with coal ash particles to CACLSM mixtures.

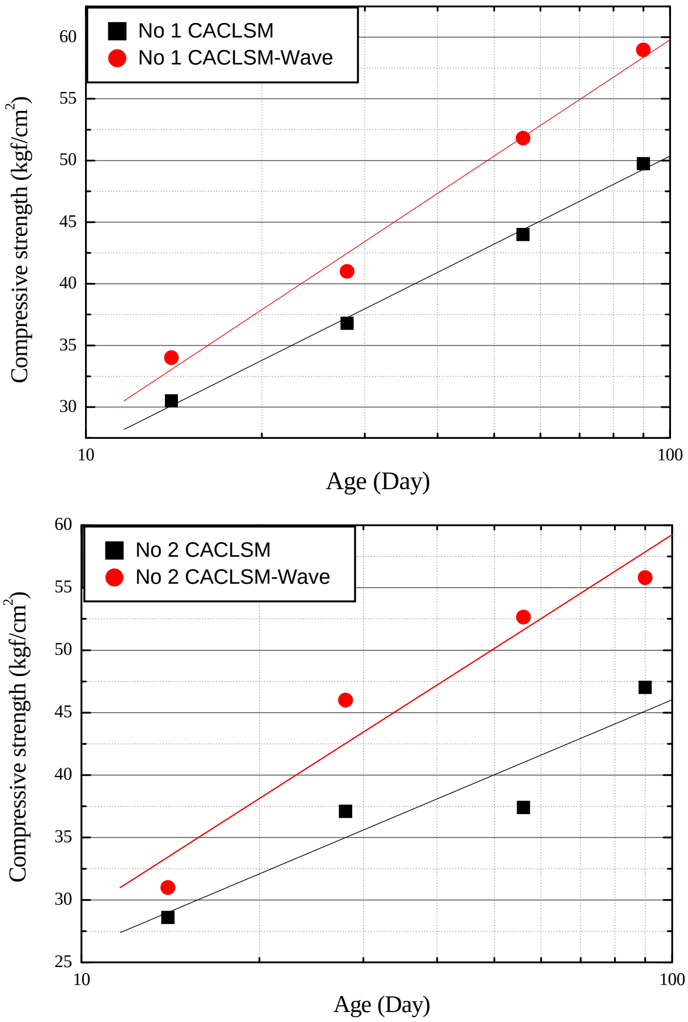


Figure 8 Compressive strength development during the influence test of dry-wet cycle in seawater together with wave action

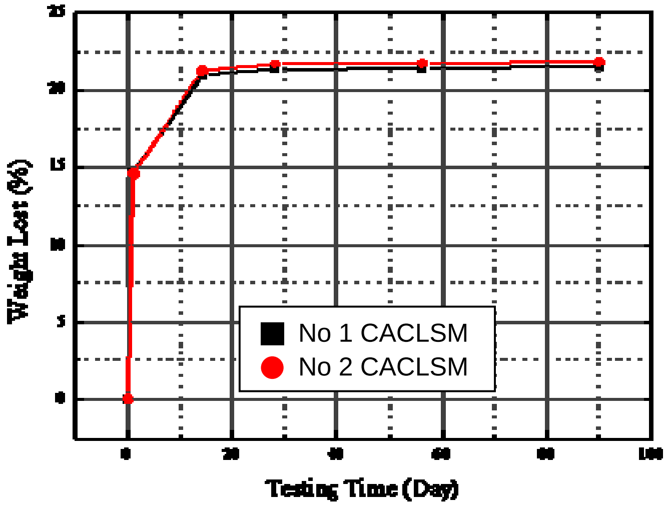


Figure 9 Weight variation during erosion test of wind with coal ash particles

Placement into water
After 28 days of placement, as shown in Figure 10, acrylic tank is removed and a few cores are taken to be investigated their compressive strength. Since CACLSM is placed at one fixed corner, it results in significant material segregation due to different particle weight of fly ash and bottom ash. Especially for No 2 CACLSM with more bottom ash, even some cores cannot be taken at the part of the block with little of fly ash.

Figure 10 CACLSM block

CONCLUSIONS AND ON-GOING CONSTRUCTION

Conclusions
Based on the above experimental materials and methods, the conclusions are obtained as follows:

1. The 28-day compressive strength of CACLSM made by a little amount of cement as well as large amount of coal and mixed by fresh water can be higher than 35 kgf/cm^2. After 40 days, the compressive strength can be higher than $40kgf/cm^2$ and splitting tensile strength higher than 4 kgf/cm^2.
2. CACLSM mixtures show great resistance to sulfate attack without any collapse after 15 cycles.
3. Out of consideration of the initial moisture loss inside specimen and surface weight loss resulting from bleeding, the weight loss remains 0.5% in the period of 14 days to 90 days, indicating no severe erosion of wind with coal ash particles to CACLSM mixtures.
4. In case of placement into water, CACLSM with more fly ash exhibits better performance to reduce material segregation in water.
5. CACLSM made by a little amount of cement as well as large amount of coal ash and mixed by fresh water can be used in dike construction to save the consumption of natural materials such as gravel and sand which are traditional materials in dike construction.

On-going construction
Based on the test results of a comprehensive CACLSM program conducted by TPRI, CACLSM made by a little amount of cement as well as large amount of coal ash and

mixed by fresh water has been used in a separation dike construction at the Chung-Hua Coastal Industrial Park since 2012. The dike is 1570 m in length, 6m in height, and 10m as well as 20m in breadth for top section and bottom section, respectively. Lots of blocks are also fabricated by CACLSM used as mold during placement, as Figure11 shows.

Figure 11 Photos of construction site

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