- Technical Paper -

FUNDAMENTAL STUDY ON CEMENT STABILIZED ADOBE BRICK

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ABSTRACT

Most of the buildings in developing countries are made out of low quality traditional adobe bricks. These materials, however, do not have sufficient strength and durability. In the previous study, basic physical properties of unstabilized adobe were clarified. In this paper, effect of stabilization on adobe brick by addition of ordinary Portland cement (OPC) has been investigated. It is concluded that there is possibility of both strength improvement and dimensional stability by adding small amount of OPC, and water curing can improve both strength and durability of cement stabilized adobe.
Keywords: adobe, stabilization, weight loss, shrinkage, compressive strength, erosion test

1. INTRODUCTION

Adobe has been used in the construction of shelters for thousands of years and approximately 30% of the world present population still lives in earthen structures [1]. Earth is a cheap; ecologically sound, environmentally friendly, thermally performable and abundantly available building material. It has been used extensively for masonry dwelling in developing countries and particularly for wall construction around the world [2].

Photo 1 shows multistory adobe houses in Yeman. Adobe structure is the oldest type of earthen construction dating back to 5000 B.C. The word "adobe" has come down from Arabic 'at-tub', with the meaning 'mud-brick' that defines the earth in a malleable state, which is often improved by the addition of straw or other fibers, molded into a brick form, and dried under the sun [3], as shown in Photo 2.

With the arrival of the industrial modern materials, adobe construction was abandoned, especially in the most developed countries. In the less developed countries, it was never stopped being used [4].

Earth Building Research Forum has provided a comprehensive range of tests relating to the adobe and earthen construction [5]. A.W. Hendry and K.Sandin used hydrated lime in making masonry mortar and render to obtain improvements in workability and cohesiveness [6][7]. Bilge ISIK, by adding 10% gypsum and 2%lime, could improve the compressive strength of adobe to 4.2MPa [8]. P.Walker stabilized adobe by adding cement into the soil and by compress machine, which could improve compressive strength of adobe to 6MPa [9].

Adobe has been manufactured as not engineering material and used for masonry construction in most parts of the world, which can case huge casualties to the life of civilian during natural hazards e.g. earthquake, rainstorm.

In the previous study, physical properties of unstabilized adobe brick have been clarified [10]. Low compressive strength (0.7MPa-2.3MPa) and poor erosion response have been obtained from the experiment results.

In the present paper, ordinary Portland cement (OPC) is selected as stabilizer, and results of a couple of experiments I and II are reported. In the experiment I, effect of OPC as an additive to soil for

Photo 1 Multistory adobe housing, Senaa, Yeman

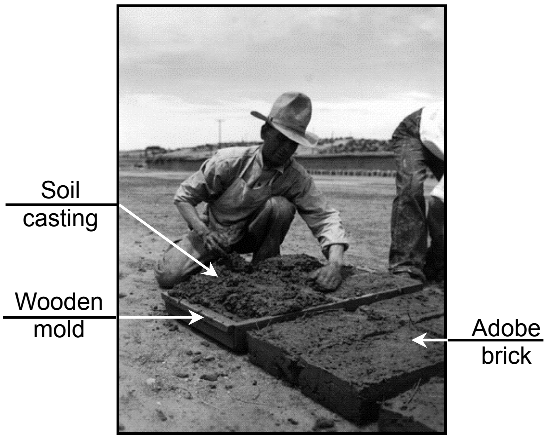

Photo 2 Casting and curing of adobe brick

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manufacturing adobe brick is discussed. In the experiment II, effect of water curing for adequate hydration on the compressive strength development of cement stabilized adobe bricks is discussed.

2. PROPERTIES OF OPC STABILIZED ADOBE (EXPERIMENT I)

2.1 Method of Experiment

2.1.1 Materials

Soil was fabricated in the laboratory by using ground dried clay and sand. Clay from the Toki city, Gifu Prefecture with the grain size of 20μm and density of 2.55 g/cm^3, and river sand with particle size of smaller than 0.6mm and density of 2.55g/cm^3 were used. Chemical properties of clay used are shown in Table 1. OPC is selected as a stabilizer in this experiment. Fig. 1 shows the grain size distribution of sand, clay and OPC.

Table 1 Chemical Properties of the clay

SiO_2 (%)	TiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	MnO (%)	P_2O_5 (%)	Ig.loss
85.06	0.58	9.14	0.61	0.02	0.16	0.75	0.03	0	0	1.2

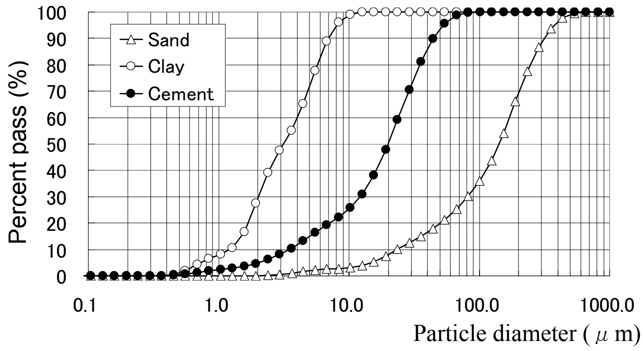


Fig.1 Grain size distribution of sand, clay and cement

2.1.2 Testing Programs

(1) Shrinkage

Photo 3 shows shrinkage measurement method. Adobe specimens were cast and cured in air conditioned room where the temperature and humidity were kept constant. Measurement of shrinkage was made after pre-curing of three days. Due to time constraints it was not possible to carry out the shrinkage test for as long as desirable, but measurement was made up to 20 days in the present experiment.

Caliper is used to read the longitudinal top surface shrinkage for manifesting total contraction.

(2)Weight loss

Simultaneously, shrinkage and weight loss measurements were attained within curing period. Initial weight of adobe specimens has been calculated from mix proportion and specimen's volume.

(3)Compressive test

Direct compressive load was applied to the specimens and gradually increased as shown in Photo 4. The specimens were tested on a 60x100mm face. Loading surfaces were formed with sulfur capping and strain gauges of length 60mm were glued on both sides, in order to measure the stress- strain relationship.

(4) Accelerated erosion [11]

Cylindrical adobe specimens were cast for carrying out accelerated erosion test, as shown in Photo 5. One hour accelerated erosion was applied to each specimen and erosion depth of specimen was measured in three levels, i.e. each 20 minutes for an hour. Sulfur coating was applied around specimens to

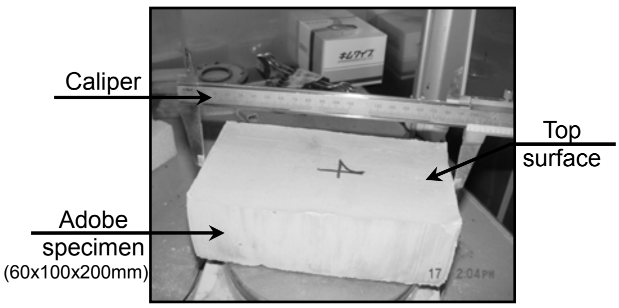


Photo 3 Shrinkage measurement

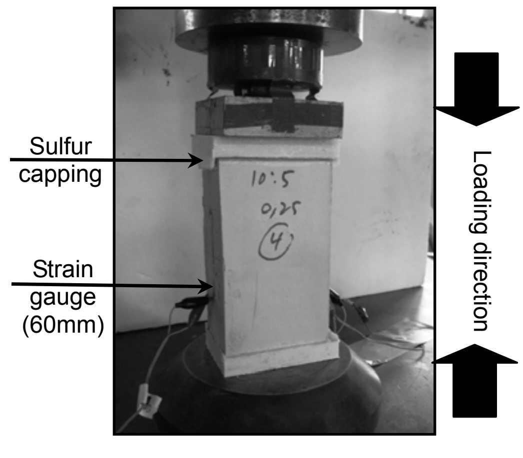


Photo 4 Specimen under compressive loading

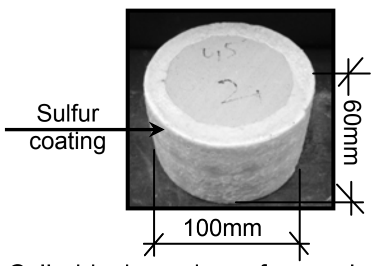


Photo 5 Cylindrical specimen for erosion test

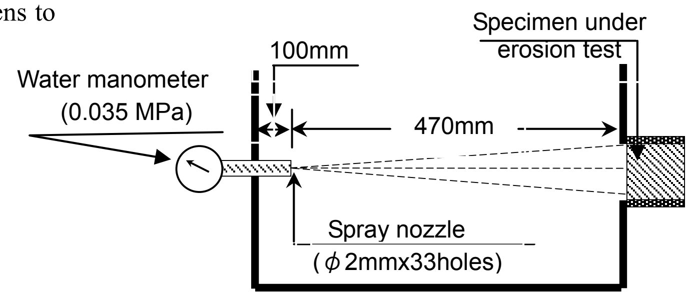


Fig.2 Erosion testing machine

protect the specimen while undergoing accelerated erosion test. Fig. 2 shows the erosion testing machine developed for applying accelerated erosion. Depth of erosion was measured by using a laser displacement meter. Erosion testing shows performance of adobe when exposed to rain, storm etc. which cause deterioration. Quantitiative discussion on the relation between durability and erosion will be carried out in the future.

2.1.3 Experimental Conditions

Table 2 shows experimental conditions. Trial and error test was conducted to modify workable states of soil for hand casting, and the water/soil ratio was decided based on the flow test as shown in Photo 6.

Flow value of 115mm-130mm provided good workability for soil to be placed into the mold by hands as shown in Photo 7.

Sand/soil ratio were decided from the first experiment, which focused on the influence of sand/soil ratio on general characteristics of unstabilized adobe brick [10].

OPC was used as a stabilizer and expected to increase cohesion between soil particles, increasing compressive strength, durability and hardness of the adobe brick.

Dual-type Mixer was used to mix fresh adobe with OPC and wooden molds of dimension 60x100x200mm were used to cast adobe, measuring shrinkage, weight loss, and compressive strength, while plastic molds of dimension ϕ100x60 were used to cast cylindrical shape specimens.

Cylindrical shape adobe specimens were used for carrying out accelerated erosion test in order to clarify erosion response of unstabilized and stabilized adobe specimens.

Hand casting and hand compaction method was applied to place soil into the mold.

Steady temperature and humidity room was used for pre-curing and curing of adobe bricks, where the temperature and humidity were kept at 20℃ and RH60%, respectively.

2.1.4 Factors and Testing Levels

Table 3 shows factors and testing levels. OPC additive as stabilizer replaced clay by volume in four levels of 0.05, 0.15, 0.25, and 0.50. While OPC substituted clay volume in the process of stabilization, water/solid and sand/solid volume ratio were kept fixed.

It has been contemplated that curing length affects compressive strength and durability of specimens, therefore two levels of curing, 10 and 20 days, respectively, were applied to measure the effect of curing length on stabilized adobe specimens. Pre-curing length, three days estimated from the casting time, is included in total curing length of the specimens.

2.1.5 Mix Proportion

Table 4 shows the mix proportion carried out in this experiment. The main target of designing aforementioned mix proportion was to clarify the effect of OPC as stabilizer on adobe; although water and sand content of soil also influence adobe characteristics, water/solid and sand/solid ratio was kept fixed and OPC replaced clay.

Photo 6 Flow test

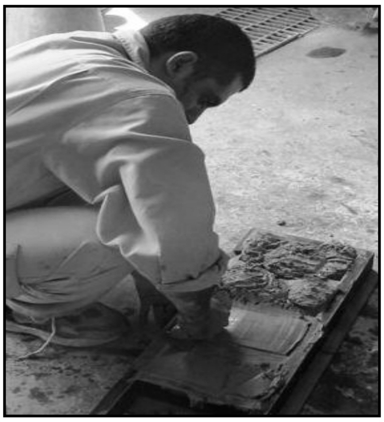


Photo 7 Casting and compaction of adobe

Table 2 Experimental conditions

Water/Solid	25 (%) (Fixed)
V_{sand}/V_{solid}	0.5 (Fixed)
Cement	Portland Cement (OPC)
Clay	Oven-dried
Sand	Oven-dried, smaller then 0.6mm (contains 15-25 % silt)
Adobe dimension	60 X 100 X 200mm , ϕ100 X 60mm
Mold	Wooden mold , Plastic mold
Mixing method	Dual-type 30L. Mixer (Mixing time : 4 minuts/batch)
Curing method	Dry curing under the temperature and humidity of 20℃, RH60% ; Water curing

Table 3 Factors and testing levels

Factors	Testing levels
$V_c/(V_c+V_{cl})$	0.0 , 0.05 , 0.15, 0.25 , 0.50
Curing days	10 , 20

Note : V_c : Cement volume ; V_{cl} : Clay Volume

Table 4 Mix proportion

No.	$(V_c) / (V_c+V_{cl})$	Unit weight (g/L)				Unit Vol. (cm^3/L)			
		W	C	Cl	S	V_w	V_c	V_{cl}	V_s
1	0.00	496	0	643	643	496	0	252	252
2	0.05		40	610			13	239	
3	0.15		119	546			38	214	
4	0.25		199	482			63	189	
5	0.50		398	321			126	126	

Note: V : Volume, C : Cement, Cl : Clay, W : Water S : Sand

2.2 Experiment Results

(1)Weight loss

Fig.3 (a) shows the total weight loss of un-stabilized and stabilized adobe specimens. The value is given by the ratio of weight loss to the initial weight. Weight loss of unstabilized specimen is higher than those of stabilized specimens; however the specimens with inferior stabilizer replacement ratio [replacement ratio $<$ 0.25 , 0.50 in this experiment] were in the same range of the unstabilized specimens.

(2)Shrinkage

Fig.3 (b) shows the total shrinkage of un-stabilized and stabilized adobe specimens. Initial drying shrinkage took place mostly in the first week of curing, and then the specimens were stabilized with negligible further movement up to 20 days.

Specimens with inferior amount of stabilizer shrink to some extent, although the shape and dimensions of the specimens maintained. The unstabilized specimen shrank drastically, while shape and dimensions of the specimens erratically deformed.

(3) Compressive strength

Fig.4 shows measured results of compressive strength of adobe specimens in this experiment.

Fig.4 (a) shows relation between strength and cement replacement ratio. Water curing length totally affects total compressive strength of specimens as well. Specimens with 10 days curing length displayed deficient and lower compressive strength than the specimens cured for 20 days.

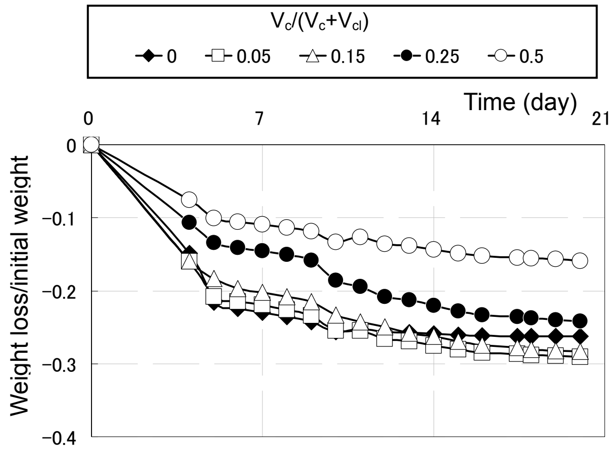
It's quite interesting that OPC as additive within all levels of stabilization could reduce shrinkage, see Fig.3, but the inferior mixing quantity of OPC (0.05, 0.15, in this experiment) could not response well in compressive strength development. Considering the mechanism of stabilization, cement works as binder skeleton in a specimen and the binder between the soil particles. Inferior amount of stabilizer (0.05, 0.15, in this experiment) could not improve compressive strength of adobe specimens; instead it reduced the compressive strength and increased weight loss of specimens. On the other hand, specimens with additive exceeding inferior quantity (0.25, 0.50, in this experiment) showed a reasonable improvement in compressive strength. Fig. 4 (b) shows relation between Young's modulus and compressive strength. We can observe good linear relation. In this figure, the curve for the concrete is also shown, which is derived by the calculation of Eq.(1). Adobe seems to have comparatively lower Young's modulus than the concrete, because adobe does not contain coarse aggregate, just a little amount of OPC being used to increase the cohesion between the sand particles and to develop the compressive strength.

$$E_c=21 \times (\rho/2.3)^{1.5} \times (Fc/20)^{1/2} \quad (1)$$

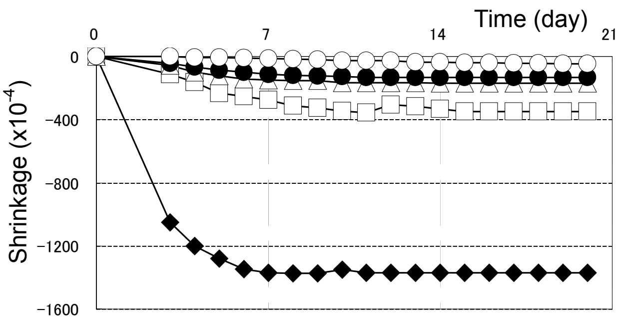
Where; ρ : density (g/cm^3)

Fc: Compressive strength (MPa)

Ec: Young's modulus of concrete (GPa)

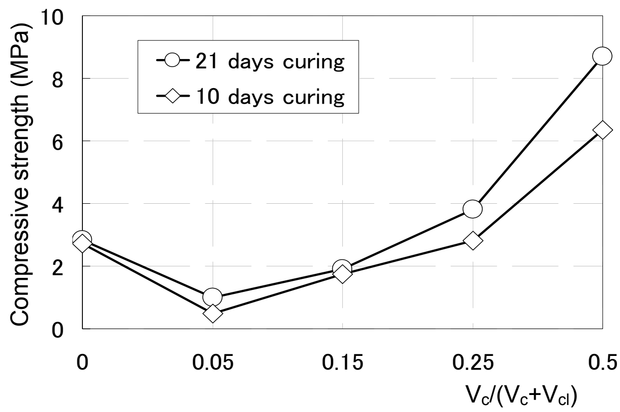


(a)Relation between weight loss and time

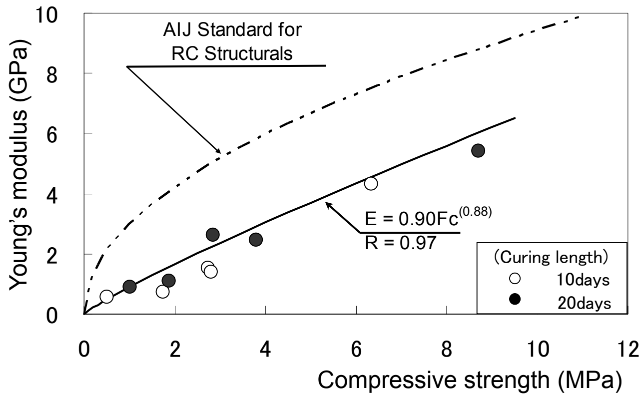


(b)Relation between shrinkage and time

Fig.3 Effect of OPC on weight loss and shrinkage



(a)Relation between strength and OPC ratio



(b)Relation between Young's modulus and strength

Fig.4 Effect of OPC on adobe compressive strength

(4) Accelerated erosion

Photo 8 shows the effect of stabilization on erosion response of stabilized adobe specimens. Mix with inferior addition of OPC obtained lower compressive strength than unstabilized specimens (0.7~2.3MPa), but very good erosion resistance. Stabilized adobe specimen with cement/clay replacement ratio of 0.05, produced small amount of erosion as shown in Photo 8 (b), while specimens with cement/clay replacement ratio of 0.15~0.50 had no erosion as shown in Photo 8(c). Fig. 5 shows the erosion results. Fig.5 (a) shows eroded shape of the exposure surface after testing. Fig.5 (b) shows the maximum depth of erosion from the exposure surface.

3. EFFECT OF WATER CURING ON STRENGTH DEVELOPMENT (EXPERIMENT II)

3.1 Method of Experiment

Identical material of experiment-I was used in experiment-II. The differences between experiment-I and experiment-II were as following:

(a) Factor and testing levels

In the experiment-II, cement/clay replacement ratio of 0.25 and 0.50 were used only, because specimens with inferior replacement ratios e.g. 0.05, 0.15 deteriorated during the water curing and neglected.

(b) Curing method

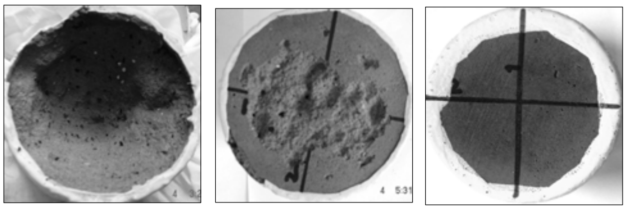
In the experiment-II, the specimens were placed into the air conditioned room with the temperature and humidity of 20℃ and RH60%, respectively, during the curing length of 7 days. Then the specimens were put into the water for curing length of 21 days. After water curing, two levels of dry curing were carried out, 10 and 60 days, respectively.

(c) Testing Method

In the experiment-II, just compressive strength and stress-strain curve of the specimens were measured.

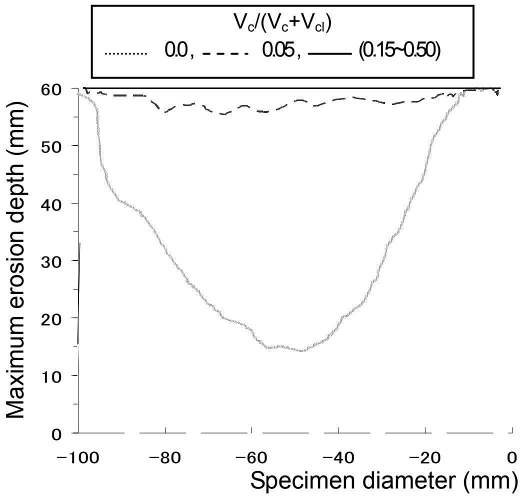
3.2 Experiment Result

Fig.6 shows the effect of water curing on strength improvement. Compressive strength was measured in three levels; just after water curing, after 10 days of the dry curing, after 60 days of the dry curing, respectively. Cement/clay replacement ratio

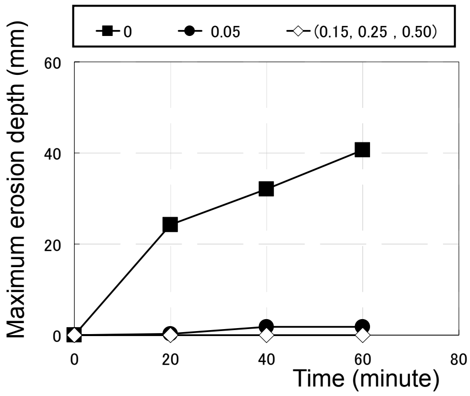


(a) Replacement ratio = 0.0 (b) Replacement ratio = 0.05 (c) Replacement ratio = 0.15 ~0.50

Photo 8 Effect of stabilization on erosion

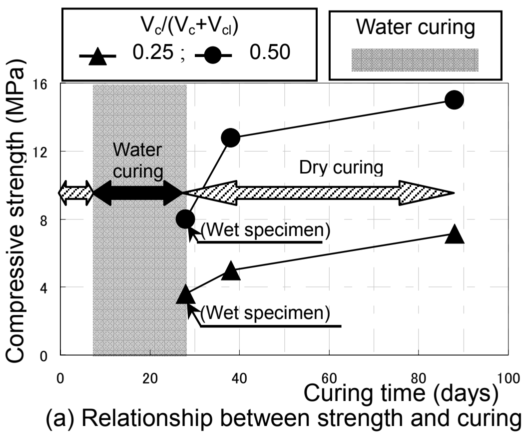


(a) Eroded shape of exposure surface to erosion

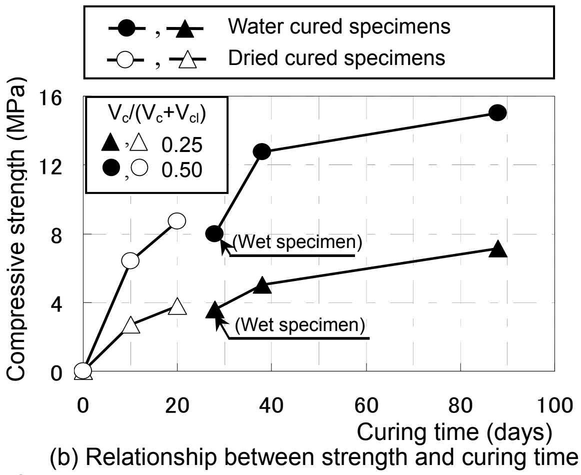


(b) Relation between maximum erosion depth and time

Fig.5 Erosion test result



(a) Relationship between strength and curing time



(b) Relationship between strength and curing time

Fig.6 Effect of water curing on strength improvement of cement stabilized adobe specimens

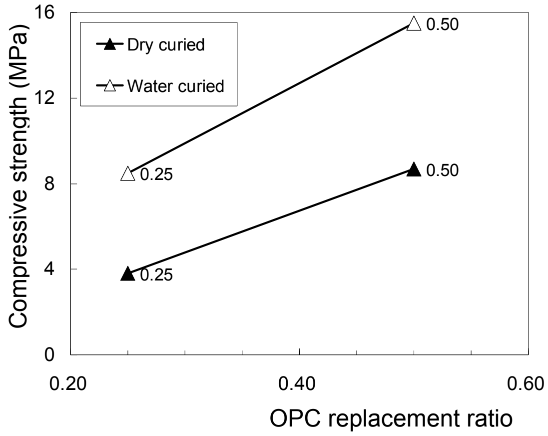


Fig.7 Effect of OPC replacement ratio on strength

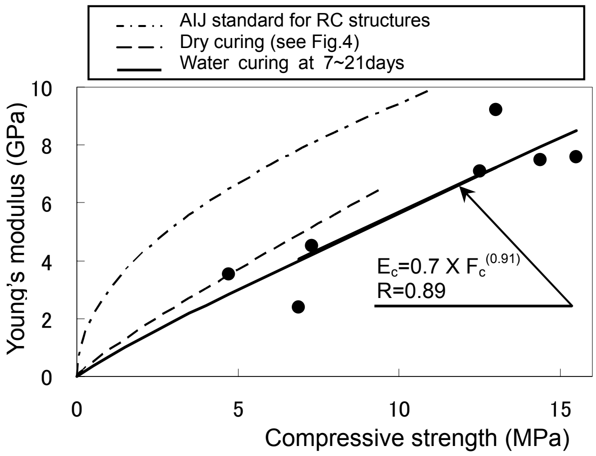


Fig.8 Relation between Young's modulus and compressive strength

affects the compressive strength in both methods of curing, dry curing and water curing, as shown in Fig.7.

Fig.8 shows the relation between Young's modulus and strength. Application of water curing on stabilized adobe shows comparatively higher strength than dry curing at the same Young's modulus.

4. Conclusions

The experiments conducted to study the effect of ordinary Portland cement addition on some properties of adobe conclude as follows.

(1) Addition of ordinary Portland cement reduces the drying shrinkage and weight loss of adobe due to the efficient cohesiveness imparted by the cement particles.

(2) By the addition of Portland cement, e.g. $V_{cement}/(V_{cement}+V_{clay})$=0.15, erosion of the adobe totally stopped and compressive strength increased to some extent, while at $V_{cement}/(V_{cement}+V_{clay})$=0.25 and 0.50, compressive strength improved from 0.7~2.3MPa to 6~8MPa, drastically reduced the shrinkage and stopped the erosion.

(3) Water curing improved compressive strength of Portland cement stabilized adobe, compared to air curing Portland cement stabilized adobe.

(4) There is linear relationship between Young's modulus and compressive strength for the adobe stabilized with the Portland cement.

(5) Cement stabilized adobe seems to have less Young's modulus at the same compressive strength than the concrete, because adobe does not contain coarse aggregate, just a little amount of ordinary Portland cement being used to increase the cohesion between the sand particles and to develop the compressive strength.

From this study, the ordinary Portland cement may be effectively utilized in soil to get improvement in compressive strength, cohesion and improvement in erosion response.

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