

# EFFECT OF COMBINED BINDER ADDITIVES ON IMPROVEMENT OF ADOBE BRICK CHARACTERISTICS

Hashmatullah RASA<sup>\*1</sup>, Naoki MISHIMA<sup>\*2</sup>, and Shigemitsu HATANAKA<sup>\*3</sup>

## ABSTRACT

It has been emphasized that adobe bricks has some serious disadvantages such as low mechanical properties and poor moisture resistance; stabilization of soil for the production of adobe bricks is therefore strongly recommended. In the previous studies, addition of cement improved general characteristics of adobe; on the other hand, gypsum stabilized samples showed poor erosion resistance, however compressive strength improved. In this paper, study has been conducted by using combined binders, cement and gypsum, as additional material for production of stabilized adobe.

**Keywords:** adobe, combined binder, weight loss, drying shrinkage, compressive strength, erosion

## 1. INTRODUCTION

Adobe is one of the oldest and most widely used building materials in the world. Adobe has been a traditional construction material especially in developing countries and/or rural regions because of its simplicity and low cost and approachable building material. Approximately 30% of the world present population still lives in earthen structures [1].

Earth is an ecologically sound, environmentally friendly, thermally performable, and abundantly available building material. Despite all these merits, adobe has some serious disadvantages such as low mechanical properties and poor moisture resistance. Photo 1 shows multistory adobe house at Marib, Yeman [2], which was destroyed by a heavy rainfall.

In the last decades, there has been considerable work carried out on the improvement of earthen materials. Most of these researches are generally focused on improvement of physical and mechanical properties of adobe through addition of binder or application of confinement methods [3-5]. A series of laboratory tests has been conducted to investigate the general characteristics of unstabilized [6], cement stabilized [7], and gypsum stabilized adobes [8]. It has already been mentioned that general characteristics of adobe improves by cement stabilization, though reduction in compressive strength of low cement content specimens was observed. Although gypsum stabilization improves compressive strength to some extent, some negative effects were also recognized, e.g. increase of shrinkage, enhancing of weight loss, creation of dimensional instability and worsening of moisture response of the specimen. The mechanism is not obvious as yet. In this paper, study is conducted by using combined binders, i.e. cement and gypsum, as stabilizing material for production of optimized adobe.



Photo 1 Adobe house destroyed by heavy rainfall [2]

## 2. PROPERTIES OF STABILIZED ADOBE WITH COMBINED ADDITIVES

### 2.1 Method of Experiment

#### (1) Materials

Local powdered clay was obtained from Toki city, Gifu prefecture with the chemical property and X-ray diffraction shown in Table 1 and Fig.1, respectively. Dried river sand with particle size of smaller than 0.6mm and density of 2.55gr/cm<sup>3</sup> was used. Cement (OPC) and gypsum (CaSO<sub>4</sub> \* 1/2H<sub>2</sub>O) were added to the soil mixture as combined stabilizers in this experiment. Fig.2 portrays grain size distribution of sand, clay, cement and gypsum used in this research.

#### (2) Experimental conditions

Table 2 illustrates the experimental conditions carried out in the present research.

\*1 Graduate Student, Div. of Architecture, Mie University, JCI Member

\*2 Assist. Prof., Div. of Architecture, Graduate School of Engineering, Mie University, Dr. Eng., JCI Member

\*3 Prof., Div. of Architecture, Graduate School of Engineering, Mie University, Dr. Eng., JCI Member

Mortar flow test (JIS R 5201) has been conducted to design optimal water/solid ratio for casting unstabilized and stabilized specimens [7]. Also sand/solid ratio was decided base on the previous experimental data that had been focused on the effects of sand volume on general characteristics of unstabilized specimens [6]. Compressive strength as cement stabilized specimens was obtained from the gypsum stabilized adobe at same testing levels.

Therefore, in present research, smaller amount of cement (i.e.  $v_{cem}/(v_{cem}+v_{clay})=R_{cem}=0.05$ ) was added into the gypsum stabilized mixture and the ratio kept fix in all levels of experiment.

(3) Factor and testing levels

Table 3 demonstrates factor and testing levels of present research. Gypsum replaces clay volume in two levels, i.e.  $v_{gyp}/(v_{gyp}+v_{clay})=R_{gyp}=0.15$  and  $R_{gyp}=0.25$ , respectively.

(4) Mix proportion

Table 4 and Fig.3 portrays the mix proportion. Illustration is used to simplify design mechanism of the mix proportion. Judging from the mix proportion and illustration, water/solid ratio was kept fixed in all levels. Clay volume replaces with stabilizers in different levels, while cement/clay ratio was kept fixed in all levels of experiment.

Table 1 Chemical property of clay

SiO <sub>2</sub> (%)	TiO <sub>2</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	CaO (%)	MgO (%)	K <sub>2</sub> O (%)	Na <sub>2</sub> O (%)	Ig.loss
85.06	0.58	9.14	0.61	0.02	0.16	0.75	0.03	1.2

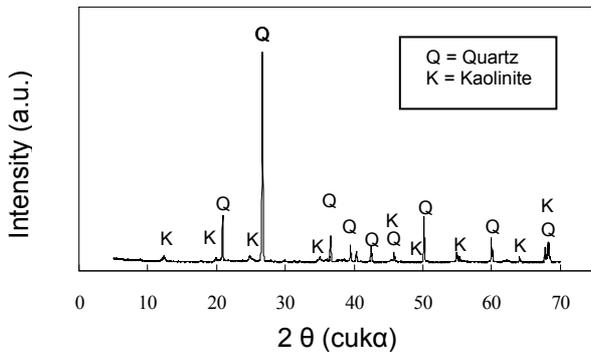


Fig.1 Clay mineral X-ray diffraction

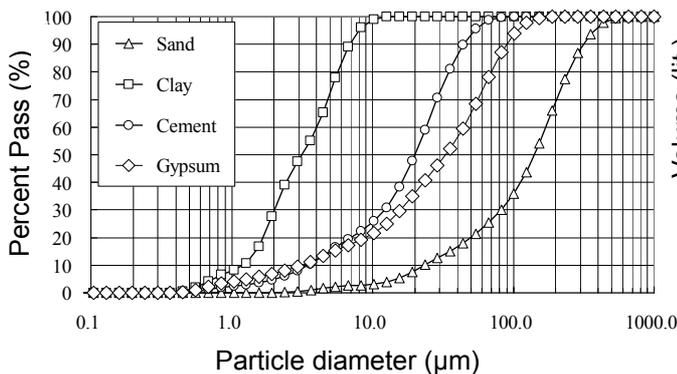


Fig.2 Grain size distribution

Table 2 Experimental conditions

Water / Solid	25% (Fixed)
$V_{sand} / V_{solid}$	0.5 (Fixed)
$V_{cem} / (V_{cem}+V_{clay})$	0.050
Clay	Oven-dried
Sand	Oven-dried, smaller then 0.6mm
Adobe dimension	60 x 100 x 200 mm , $\phi 100$ x 60 mm
Casting molds	Rectangular wooden mold
	Cylindrical plastic mold
Mixing method	Dual-type 30lit. mixer
Curing method	Dry curing
	20°C , RH 60%

[Note] cem\*: cement

Table 3 Factor and testing levels

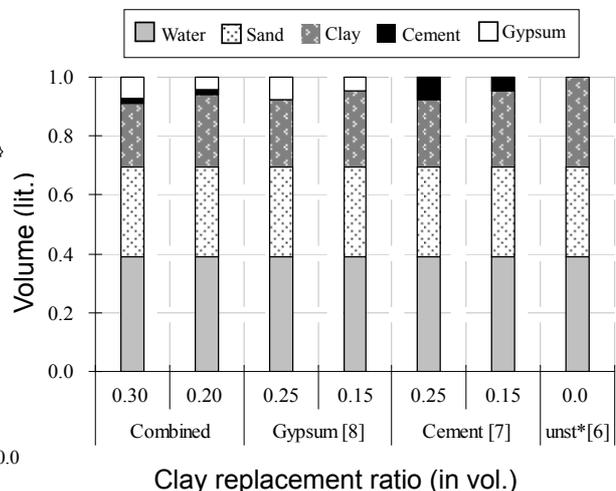
Factors	Testing levels
gypsum replacment ratio against clay ( $V_{gyp} / (V_{gyp}+V_{clay})$ )	0.00 , 0.15 , 0.25
Dry curing length (day)	10 , 20

[Note] gyp\* : gypsum

Table 4 Mix proportion

Unit weight (g/L)				
Water	Clay	Cem. *1	Gyp. *2	Sand
389.3	778.6	0.0	0.0	778.6
	628.7	48.3	101.8	
	554.7	48.3	169.7	

[Note] \*1 : Cement ; \*2 : Gypsum



Clay replacement ratio (in vol.)

Fig.3 Mix proportion illustration

## 2.2 Testing Programs

### (1) Shrinkage

Fig.4 demonstrates the shrinkage measuring method. Shrinkage was measured after pre-curing of three days. Caliper was used to read the longitudinal top surface for manifesting total contraction. As can be seen in the figure, three locations were decided to measure the average shrinkage value.

Due to the time constraints it was not possible to carry out shrinkage measurement for desirable length, but measurement was made up to 20 days in this experiment.

### (2) Weight loss

Fig.5 represents initial weight of the fresh specimens based on unit weight measuring method. Measurement of weight loss was made after pre-curing period of three days for 20 days.

### (3) Compressive strength measurement

Direct compressive load was applied to specimens and gradually increased. The measurement pattern can be seen in Photo 2. Specimens were tested on a 60x100mm face and loading surfaces were formed with sulfur capping. Strain gauges of length 60mm were glued on both sides of specimen to measure the stress-strain relation.

### (4) Accelerated erosion testing [9-10]

Fig.6 shows the testing method for erosion. Cylindrical shape specimens were cast for this purpose as can be seen in Fig.6(a).

Sulfur coating was applied around the specimens to protect specimens' height while undergoing accelerated water pressure test. Specimens without sulfur coating were difficult to measure the real erosion depth, due to the height deterioration of specimen. Eroded depths of specimens were measured by using a laser displacement meter. Specimens' surfaces were marked with cross lines to determine an exact direction of measurement. The cross line was made with an oily pen carefully so as not damages the specimens' surface.

One hour water pressure of 0.0375 MPa was applied to each specimen. Eroded depth of specimen, due to accelerated water pressure test, was measured in three levels for an hour i.e. each 20 minutes. Quantitative discussion on the relation between durability and erosion will be carried out in the future.

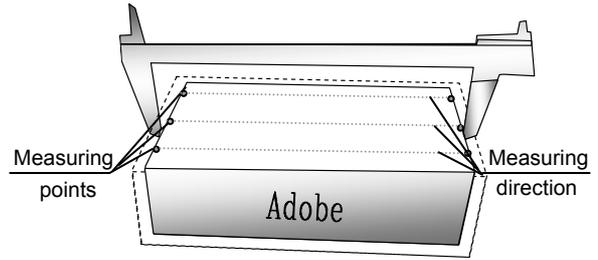


Fig. 4 Shrinkage measurement

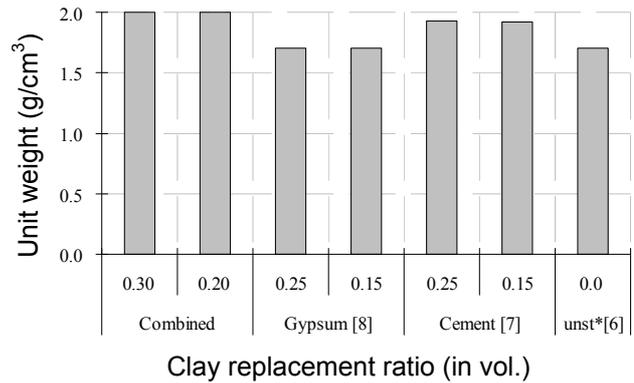


Fig.5 Unite weight of fresh adobe

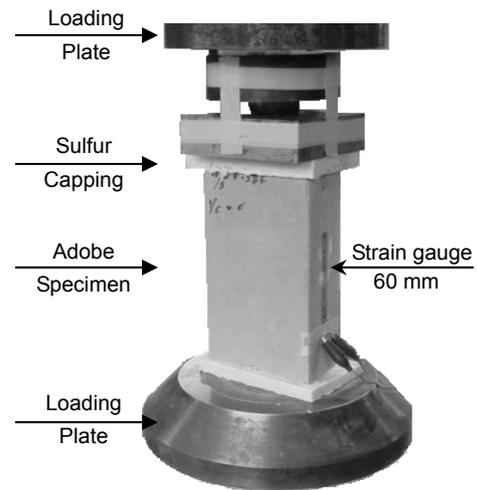
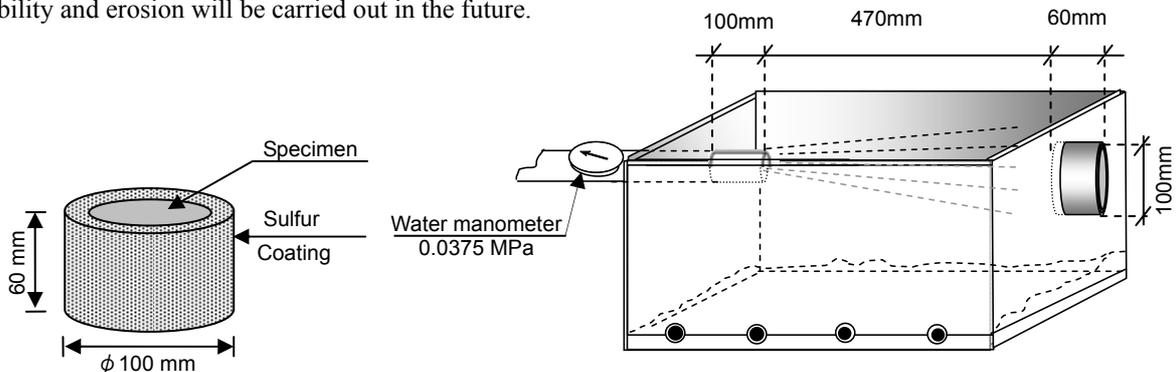


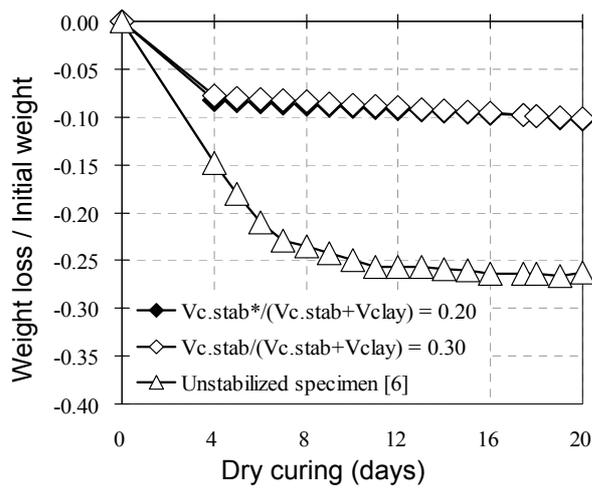
Photo 2 Compressive strength measurement



a) Cylindrical shape specimen for erosion test

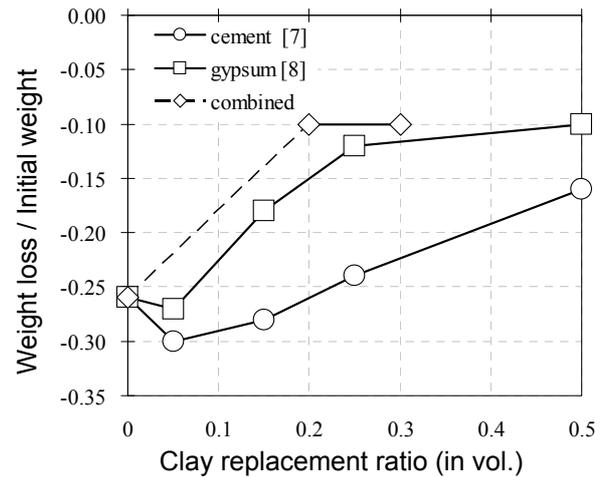
b) Water erosion test device

Fig. 6 Accelerated water erosion test device and testing specimen



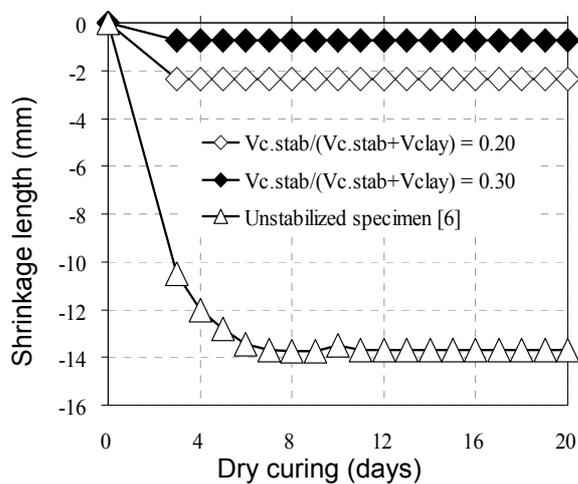
[Note] c.stab\* : combined stabilizer

a) Weight loss improvement on combined stabilization

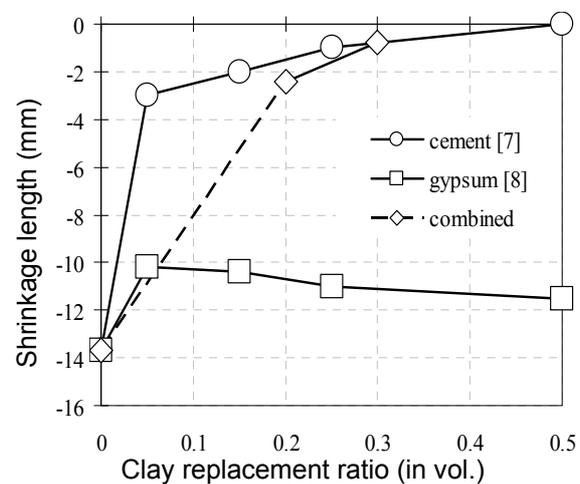


b) Effects of stabilizers on weight loss improvement

Fig. 7 Effect of combined stabilization on weight loss improvement



a) Combined stabilization improvement on shrinkage



b) Effects of stabilizers on shrinkage improvement

Fig. 8 Effect of combined stabilization on improvement of shrinkage

### 3. RESULT AND DISCUSSION

#### (1) Weight loss

Fig.7 represents the results of weight loss measurement for unstabilized and stabilized specimens. Fig.7(a) demonstrates a significant improvement on weight loss reduction by the combined stabilization than those of unstabilized specimens. Fig.7(b) shows the effects of stabilizers on weight loss reduction. Broken line is used for the range of smaller than 0.20 on combined stabilized specimens, because the tendency in that range has not been carried out yet. Analytical data from the previous experiment show that stabilization can significantly reduce weight loss, however higher weight loss has been obtained by smaller stabilizer/clay replacement ratio.

#### (2) Shrinkage

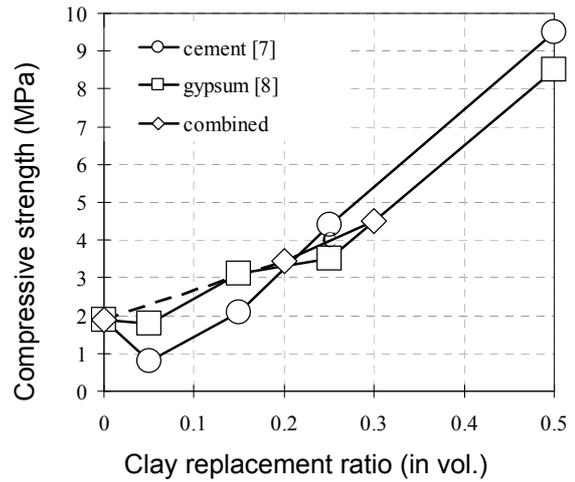
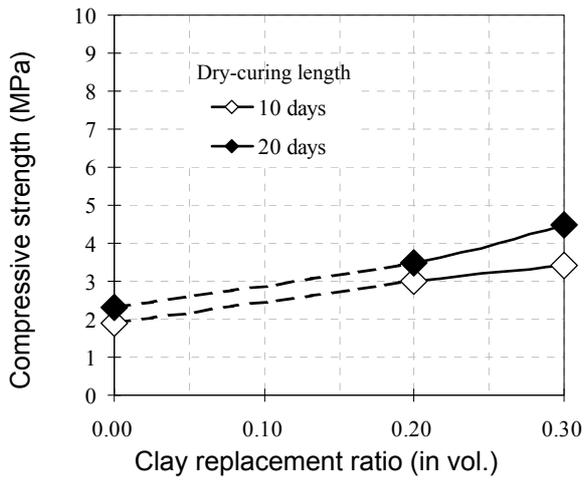
Fig.8 illustrates results of the shrinkage for unstabilized and stabilized specimens. Fig.8(a) shows the effect of combined stabilization on shrinkage

improvement. Higher shrinkage value has been obtained from the unstabilized specimen that caused on shape instability, surface cracking and crack bridging in the specimens [6]. Fig.8(b) compares the effects of cement, gypsum and combined stabilizers on shrinkage improvement. Gypsum stabilized specimens were recorded with higher shrinkage compared to unstabilized and cement stabilized specimens. Shrinkage has been improved in all testing levels by cement stabilization.

#### (3) Compressive strength measurement

Fig.9 portrays the effects of combined stabilization on compressive strength improvement. Broken line is used for the range of smaller than 0.20 on combined stabilized specimens because the tendency in that range has not been carried out yet.

Fig.9(a) shows the effect of combined stabilizer on compressive strength improvement and further strength development was obtained by application of length dry-curing. Lower compressive strength has been observed from unstabilized specimens.



a) Effects of dry-curing age on strength development

b) Effects of stabilizers on strength improvement

Fig. 9 Effects of combined stabilization on compressive strength improvement

Fig.9(b) shows the effects of stabilization on compressive strength improvement. Lower compressive strength has been obtained from the specimens with smaller amount of stabilizer than unstabilized specimens. However, improvement on compressive strength was obtained by increasing the amount of stabilizer in the mix. Fig.10 shows the relation between Young's modulus and stabilizers ratio in the mix. Combined stabilized specimen was observed almost with the same Young's modulus as of cement and gypsum stabilized specimens.

(4) Accelerated erosion test

Photo 3 shows unstabilized and stabilized specimens before undergoing accelerated water pressure test. Photo 4 demonstrates unstabilized and stabilized specimens after an hour of accelerated water pressure test. Unstabilized specimen was deeply eroded, while gypsum stabilized specimen was completely eroded.

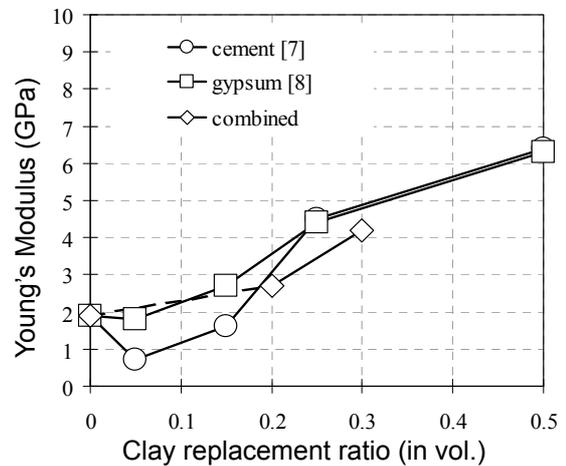
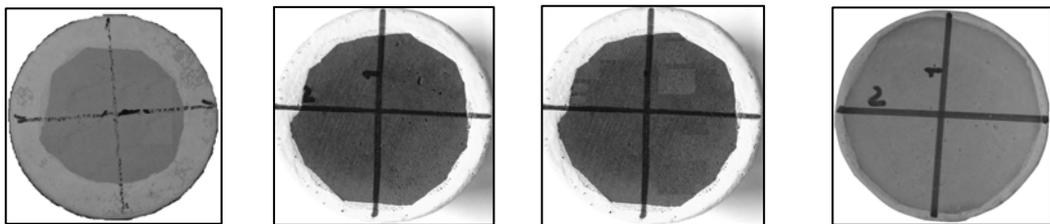
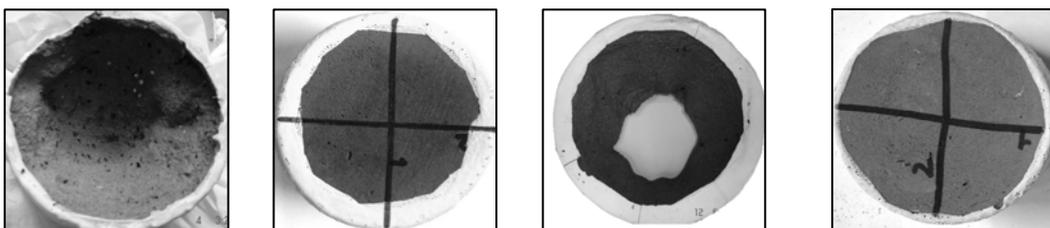


Fig.10 Relation between Young's modulus and stabilizer replacement ratio



a) unstabilized b) cement stabilized c) gypsum stabilized d) combined stabilized

Photo 3 Unstabilized and stabilized specimens before erosion test



a) unstabilized b) cement stabilized c) gypsum stabilized d) combined stabilized

Photo 4 Unstabilized and stabilized specimens after erosion test

Fig.11 represents the total eroded depth of unstabilized and stabilized specimens after an hour of accelerated water pressure test. As can be seen from the photos and figure, erosion response of adobe was improved by cement stabilization in all testing levels. Furthermore, it was observed that combined stabilization also improved erosion response.

#### 4. CONCLUSIONS

Present research was designed based on the previous experimental data. It has been concluded that addition of cement as stabilizer in soil mixture improves shrinkage and erosion response even with the smaller quantity. On the other hand, the same compressive strength has been obtained as cement stabilized specimens from gypsum stabilization. Gypsum as stabilizer, however, could not improve shrinkage and erosion characteristics. The mechanism is not clear, but this result shows that adobe property can not be judged by only compressive strength. However, curing methods influence compressive strength of cement stabilized specimens.

The main objective of the present experiment is combining the stabilizers (i.e. cement and gypsum) and improving general characteristics of adobe to its optimal. Following statements can be drawn from the present study.

- (1) Weight loss, shrinkage and erosion response of gypsum stabilized specimens can be totally improved by addition of smaller amount of cement into the gypsum mix.
- (2) Combined stabilized specimen shows the same compressive strength as cement and gypsum stabilized specimens.
- (3) Combined stabilization might be more economical than cement stabilization.

There is an ever increasing demand for construction in the world due to population expansion and shortage of building materials. The use of local materials and skills for building has a positive impact on local and regional economies, environment especially in rural regions. Adobe is a good alternative in developing countries because of its adaptation to the local climate and social conditions. However traditional adobe construction does not answer our current need. For this reason, more research is needed to improve the engineering properties of adobe. From the present study, it can be state that the use of combined stabilizer would be beneficial to improve weaker properties of adobe.

#### ACKNOWLEDGEMENT

We would like to acknowledge and extent our heartfelt gratitude to the following persons who have made the completion of this experiment possible:

Mr. Hiroshi WATO, technical assistant, for his cooperation and assistance during the experiment and Mr. Sunil PRADHAN for language assistance.

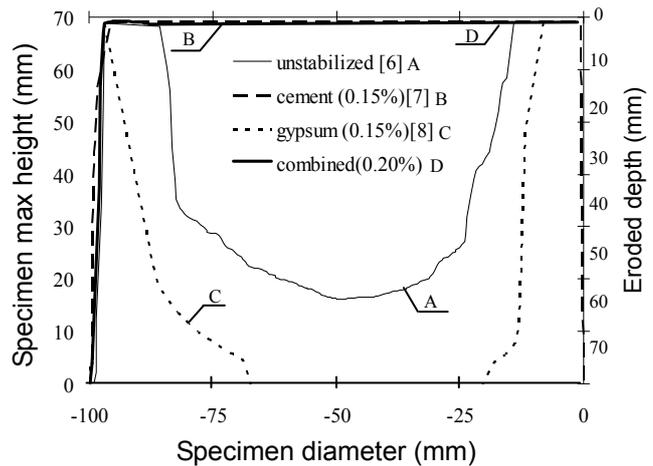


Fig.11 Effect of combined stabilization on erosion

#### REFERENCES

- [1] Auroville Earth Institute website, <http://www.earth-auroville.com>
- [2] [www.encyclopedia.com/topic/Marib.aspx](http://www.encyclopedia.com/topic/Marib.aspx)
- [3] McHenry PG. Adobe and rammed earth buildings, design and construction, Tusco, The university of Arizona press; PP.217, 1984.
- [4] Morel JC, Mesbah A, Oggero M, Walder P. Building house with local materials; means to drastically reduce the environmental impact of construction. Building Environ 2001; 36(10), PP.1119-1126, 2001
- [5] Kafescioglu R, Gurdal E, GunerA, Akman MS, Adobe blocks stabilized with gypsum, proceedings of symposium on appropriate building materials for low cost housing, African regions, sponsored by CIB and RILEM, PP.3-11, 1983, 11
- [6] H.Rasa, N.Mishima, S.Hatanaka, T.Hanazato, Fundamental study on characteristics of adobe brick, effect of sand volume on adobe characteristics, summaries of technical papers and annual meeting AIJ, A-1, pp. 763-764, 2007
- [7] H.Rasa, N.Mishima, S.Hatanaka, T.Hanazato, M.Taneichi, Fundamental study on stabilization of hand-made adobe brick effect of opc as stabilizer, Architectural research meeting, AIJ Tokai, pp. 93-96, No.46, Feb.2008
- [8] H.Rasa, N.Mishima, S.Hatanaka, Fundamental study on characteristics and stabilization of adobe, effect of gypsum additive on adobe bricks, summaries of technical papers of annual meeting AIJ, pp. 187-188, 2008
- [9] Regazzoni, P., Marot, D., Courivaud, J., Hanson, G.J., Wahl, T.L. 2008. Soil erodibility: A comparison between the jet erosion test and the hole erosion test, Proceeding of the inaugural international conference of the engineering mechanics institute, Minneapolis, Minnesota. PP.1-7, 2008, 5
- [10] Earthbuild 2002, international earth building conference, 2002, 1