The Effects of Water Content and Material Composition on Behavior of Adobes under the Compressive Load

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***Abstract*— In this experimental study, the earth blocks (adobes) in five different compositions were investigated by determining its physical, mineralogical and mechanical (their behaviors under compression) properties. Thus, it was seen that higher compressive strength could be obtained with orientation of both materials' workability conditions as compaction water content, unit mass etc. and material composition. In this direction, the findings were discussed detailed.**

***Keywords*— Adobe, Compressive strength, Water content, Cations, Compaction**

I. Introduction

The human population in the world is increasing gradually and the energy sources are being run out. That the origin of these energy sources are usually carbon based fossil fuels also causes damaging of ecological equilibrium because of increment of CO2 amount in the atmosphere. At this rate, the world can encounter not only energy bottleneck but also ecological disaster in near future. The situation in building sector that is one of the locomotive sectors of modernization is similar to this, especially for production and application of structural materials. One of the missions of the scientists against this threat, in point of civil engineering, is to introduce the structural materials and methods that are applicable with less energy and less ecological damage. The earth block (adobe), the oldest structural material of humanity, has an advantage in respect of energy and ecology in production, application and use (at building) stages. In addition, if it is thought that today 1.5 billion people lives in adobe buildings [1] it is accepted that this structures should be designed under engineering disciplines.

If it is compared in respect of energy saving, it should not be forgotten that 100-m3 adobe could be produce with the energy needed for producing 1 m3 concrete [2]. Moreover, this situation for solid brick is about 1/250 in adobe's favor. In addition, during service life, the adobe, especially light adobe, continues saving energy with its low thermal conductivity in building [3].

As load-bearing component, with the adobes having 2.5 N/mm2 in compressive strength, theoretically, the buildings 100 m in height can be thought to build [1].

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However, because of the tensile strength of pointing stuff in horizontal joint is low, it should be accepted that 1/6 of this height is at realizable level [1].

Therefore, this results show that five or six stories buildings can be built by using adobe blocks without carcass. Actually, five stories adobe (earth) building in Weilburg City (Germany) has been standing since 1828 and it has still being used. It is possible to build higher buildings as in Yemen, as high as eleven stories, by increasing wall thickness. As seen in this study, some adobe samples have the compressive strength higher than 5.0 N/mm2. On the other hand, in the view of structural engineering, adobe structures can resist to earthquake effects [4].

If the adobes are taken into consideration in the view of construction physic, the studies [1-2] says that they do not show worse properties, except humidity, in comparison with burned brick and concrete.

In this study, the compression tests were realized with five different adobe mixtures that have different gradations and mineral compositions. The strain – stress behavior and the compressive strength of these were also determined. In addition, while compression tests were being realized, six different test series were used for every adobe sample by changing the workability (compaction) water content. Six cubic samples were prepared for every test series, thus, 180 compression tests were realized in total. These tests were realized in University of Hannover Labs (Germany) with the earth samples provided from this territory.

It was seen clearly that the workability (compaction) water content is important for these materials as concrete technology. Excess of water in adobe causes to increase of shrinkage rate, to form the cracks, to increase pore volume and so to decrease the compressive strength [5]. Consequently, the main object of this study is that bring up what extent the compressive stress and strength changes with varying water content (w, % by mass). Naturally, that the strain rate increases as the compressive strength decreases in moister mixtures was observed.

It is known that the fibers are used against shrinkage danger that decreases the adobe's strength [5, 6]. In addition, the sources [7] say also that its strength and durability could be increased by adding cement, lime, bitumen etc. However, the other object of this study is to determine additive-free adobe mixture's properties.

II. Materials and Methods

For the compression test, five different adobe (earth) samples were used. The adobe samples were named as A1, A2, A3, A4, A5 and their different granulometric compositions are seen in Figure 1. The sample having the highest clay content or the richest is A5 with 34% (by mass). On the other hand, the most meager adobe is A4 with 12% (by mass) clay content. All of the adobe (earth) samples were obtained from the plains of North Germany and they were products of glacier movement periods. However, these samples had gained different mineral structure by continuing of alteration at later periods (Table 1).

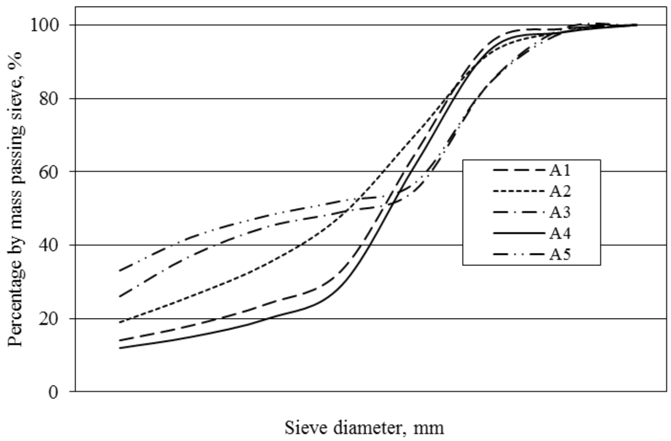

Figure 1. The grain sizes of the adobes

TABLE I. SEMI-QUANTITATIVE MINERAL CONTENTS (%, BY MASS)

Adobe	Illite	Vermiculite	Kaolinite	Smectite	Quartz
A1	25	20	15	25	15
A2	30	25	15	15	20
A3	25	15	35	15	10
A4	35	20	15	10	20
A5	30	15	25	20	10

The specific mass (ρs, g/cm3), compaction ability (proctor density, ρpr) and water-binding ratio (according to Enslin method) of adobe samples were determined. Besides, dry unit mass (ρd, g/cm3) of the cubic samples showing the highest compressive strength and their compaction water content (Wre, by mass) during molding process were also determined (Table 2). In addition, bonded and loosen cation ratio that is one sign of cohesion ability increasing factor and cation exchange capacity were determined (Table 3). Because, the cations having high valence augment the cohesion ability and so the strength. The uniaxial compressive tests constitute main part of the study (Figure 2). Besides, the some other tests, mentioned below, were conducted. The cubic samples for compressive tests were produced by compacting with different water contents. Here, workability water content should be considered in two categories. At first, the water should be added to the adobe (earth) mixture in certain dosage as much as dampen the mixture completely and provide adequate workability to mix it with the tools (trowel, shovel, rod etc.). Later, it needs to be waiting for lessening the water by evaporating by the time reaching desired cast and compaction consistency. Meanwhile, the mixture needs to be occasionally mixed with a suitable tool for preservation of the mass. The material should be matured between 2 or 14 days depending on their clay and water content before molding. This waiting process is called as acidification. It is known that during this process, the granules of the mixture are covered completely by the water molecules and meanwhile, the cation interchange is completed on large scale. Thus, the adobe gains more homogeneous structure by mixing and on the other hand, with electrical load equilibriums, it reaches the highest cohesion. Meanwhile, the examples that were compacted after cast in one specific consistency to moulds were removed from them in 1 or 3 days depending on their moisture and they were left to dry in laboratory conditions. The drying process is continued as soon as reaching balance masses. If the adobe does not lose its mass, anymore, with evaporating, this mean, it has reached balance mass. This process continued about 1 and 2 weeks. It should be avoided from drying in high temperature and wind impression or under direct sun light. Otherwise, the danger of shrinking and cracking can be encountered.

The compressive tests were conducted on dried adobe samples according to DIN 1045, DIN 1048 and withdrawn standard DIN 18952 [8]. During these tests, the loading rate was chosen as 2.0 mm/minute, in addition, lower and upper limits of load force were also chosen between 0.0 and 50.0 kN. Thus, six test series were prepared for per adobe sample with different water content and these results were shown separately in a graphic. In addition, the tables near every stress-strain graph show the relationships between water content (% mass), dried unit mass (g/cm3), shrinkage (% volume) and compressive strength (Figures 3 to 7).

TABLE I. BONDED AND LOOSEN CATION RATES (MVAL/100 G)

Adobe	Ca		Mg		Na		K	
	Bonded	*Loosen*	*Bonded*	*Loosen*	*Bonded*	*Loosen*	*Bonded*	*Loosen*
A1	4.10	0.10	1.48	0.04	0.07	0.03	0.27	0.01
A2	9.17	0.33	2.24	0.10	0.16	0.08	0.33	0.01
A3	-	3.10	-	0.71	-	11.6	-	0.42
A4	5.31	0.39	1. 00	0.07	0.16	0.08	0.29	0.01
A5	13.10	1.80	1.93	0.31	0.79	1.38	0.62	0.06

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TABLE II. PHYSICAL PROPERTIES OF ADOBES

Adobe	Specific mass (ρ_s, g/cm^3)	Proctor density (ρ_{pr}, g/cm^3)	Proctor water rate (W_{pr}, %m)	Water binding rate (W_b, %m)
A1	2.67	2.14	8.70	36.0
A2	2.68	2.12	9.20	40.0
A3	2.68	2.09	8.90	46.0
A4	2.67	2.02	8.50	35.0
A5	2.69	2.09	12.00	47.0

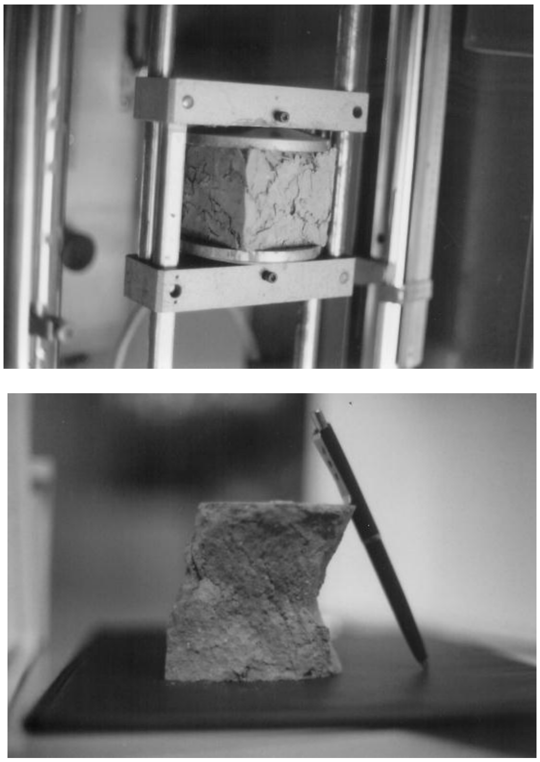


Figure 2. Compressive test and tested cubic adobe sample

III. RESULTS AND DISCUSSIONS

Uniaxial compressive test results give some important clues about the behavior of adobes under mechanical loads (Figures 3 to 7):

1. From beginning to one specific point, as water content increase a little, unit mass and compressive strength increases, too.

2. However, from this point to further, increase of water decreases the unit mass and, depending on this, compressive strength. In addition, this same reason increases unit length (strain) according to compressive strength.

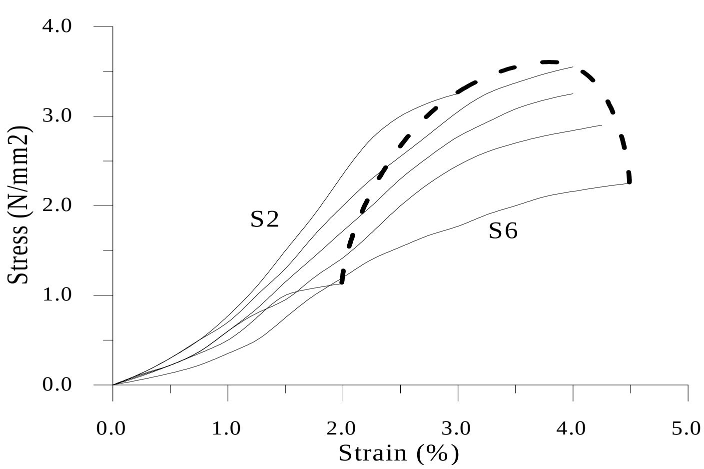
3. As workability water content increases, shrinkage increases and compressive strength decreases.

4. Under compressive stress, one semi-elliptic curve is obtained by joining the breaking points in the graphs obtained from the test series with smooth lines.

Certainly, the results above have reasons originated from materials properties. To compact the adobe samples in a higher rate, their consistency (Table 2) should be chosen nearly as high as soil dampness [9]. However, to provide this, the material has to be suitable respect of both physical properties and mineral composition. To obtain a higher strength, firstly, the grading should be show appropriate continuity.

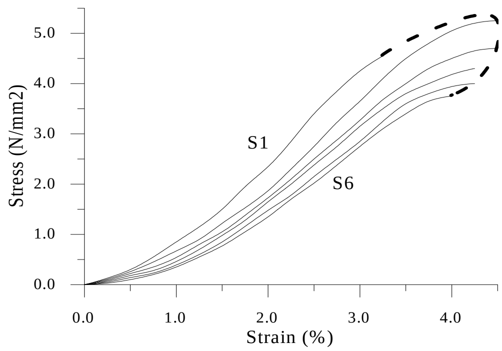
The best example of this situation is K2 that has 53% (in mass) sand. In addition, owing to including 18% (in mass) clay, this sample has a strong inter-tie. Because, it is known that higher clay content makes workability more difficult. In addition, 28% (in mass) silt rate helps to filling the gaps between sand grains. According to clay mass, K2 sample constitutes from 1.00 clay, 1.48 silt and 2.80 sand.

On the other hand, the gaps between the grains of A3 and A5 samples that have higher rate clay contents were decreased by using up more energy and tamping any more. Thus, the unit masses arrived at acceptable higher values.



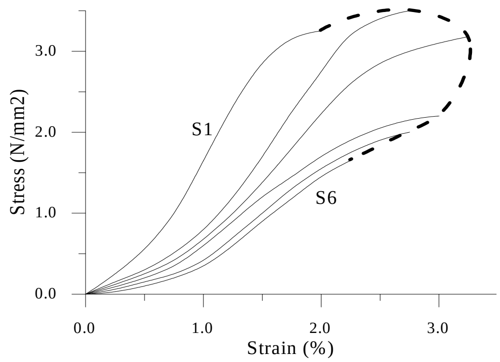
Series	Compress. strength (N/mm^2)	Water content (w, %m)	Dry unit mass (ρ, g/cm^3)	Shrinkage (s, % v)
S1	3.25	10.00	2.22	2.00
S2	3.80	17.00	2.36	8.27
S3	3.27	28.25	2.09	20.27
S4	2.95	38.50	1.71	27.60
S5	2.25	54.50	1.88	40.50
S6	1.10	76.60	1.64	54.42

Figure 3. Stress – strain graph of A5 sample and relationship between compressive strength and water content, unit mass, shrinkage.



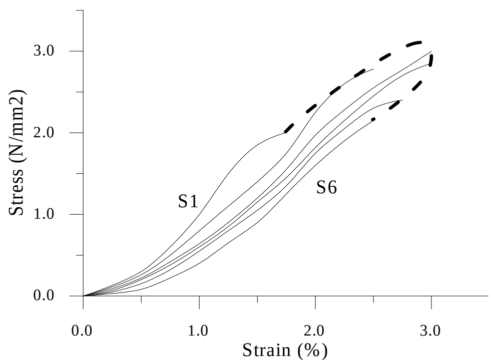
Series	Compress. strength (N/mm^2)	Water content (w, %m)	Dry unit mass (ρ, g/cm^3)	Shrinkage (s, % v)
S1	4.50	6.00	1.94	2.2
S2	5.27	9.00	2.09	3.2
S3	4.68	13.25	2.24	6.4
S4	4.25	16.00	2.16	7.4
S5	3.95	18.25	2.12	9.7
S6	3.70	20.20	2.06	13.3

Figure 4. Stress – strain graph of A2 sample and relationship between compressive strength and water content, unit mass, shrinkage.



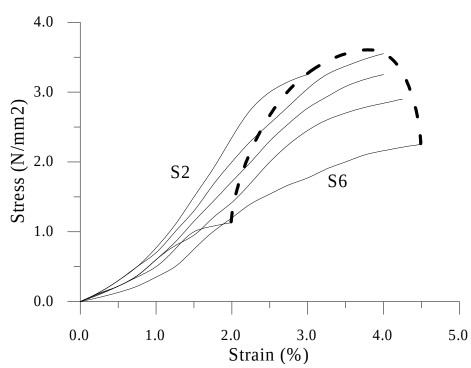
Series	Compress. strength (N/mm^2)	Water content (w, %m)	Dry unit mass (ρ, g/cm^3)	Shrinkage (s, % v)
S1	3.25	4.38	2.30	0.6
S2	3.50	6.58	1.88	1.0
S3	3.15	9.13	1.84	4.8
S4	2.24	19.75	1.82	9.4
S5	2.04	23.80	1.79	11.8
S6	1.65	30.50	1.76	17.8

Figure 5. Stress – strain graph of A3 sample and relationship between compressive strength and water content, unit mass, shrinkage.



Series	Compress. strength (N/mm^2)	Water content (w, %m)	Dry unit mass (ρ, g/cm^3)	Shrinkage (s, % v)
S1	2.00	5.00	1.79	1.1
S2	2.85	8.63	2.16	1.3
S3	3.00	11.50	2.40	2.1
S4	2.65	14.50	1.93	6.3
S5	2.38	18.37	1.84	8.8
S6	2.10	24.37	1.81	11.3

Figure 6. Stress – strain graph of A4 sample and relationship between compressive strength and water content, unit mass, shrinkage.



Series	Compress. strength (N/mm^2)	Water content (w, %m)	Dry unit mass (ρ, g/cm^3)	Shrinkage (s, % v)
S1	1.10	10.00	2.22	2.00
S2	3.25	17.00	2.36	8.27
S3	3.80	28.25	2.09	20.27
S4	3.27	38.50	1.71	27.60
S5	2.95	54.50	1.88	40.50
S6	2.25	76.60	1.64	54.42

Figure 7. Stress – strain graph of A5 sample and relationship between compressive strength and water content, unit mass, shrinkage.

However, this samples' strength could not reach to A2's (Figures 5 to 7) because of occurred small cracks and discontinuity of grain framework (Figure 1). In that case, to increase the strengths, not only increase unit mass, but also fulfill some conditions like preventing to crack [10].

With compared to clay content, in A1, there are 1 clay, 1.43 silt, 4.07 sand. In A3, there are 1 clay, 0.86 silt, 2.0 sand. In A4, there are 1 clay, 1.33 silt, 6.0 sand. Another sample A5 having the highest clay rate with 33% by mass resembles to A4 with respect of discontinuity of silt class materials (Figure 1). The mass rates of A5 are 1 clay, 0.58 silt and 1.46 sand. Generally, A1 and A3 samples also have low silt class materials.

Vermiculite mineral should be available largely in clay. Because, this mineral helps occurring higher valence loaded cation milieu and so, undertakes a mission increasing the cohesion.

One another reason effecting the compressive strength is, certainly, mineral rates. Vermiculite content was the highest in A2 with 25% by mass. It is reality that the electrical loads of this sample were higher and held more valance cation (Tables 1 and 3) in milieu [11]. Thus, it increases cohesion with stronger ties. Because of the fact that vermiculite rate was higher in A2, Mg ions (2.24 mval /100g) and Ca ions (9.17 mval/100g) were also higher in this mixture (Table 3). Although, there are high valance cations in A5, there are also low valance minerals like illite and kaolinite. In addition, it should not be forgotten that A5 has the highest clay content (33%). Consequently, higher compressive strength had not been obtained from this sample, and its strain had increased rapider according to strength (Figure 7). The kaolinite and illite minerals high in A3 show tendency of coagulation (Table 1) and form honeycomb texture. Thus, micro gaps increase in the mass and they become an effect on decreasing the strength. In addition, these minerals do not hold high valance cations because of their low cation exchange capacity. Indeed, bonded cation rate could not be determined for A3 sample (Table 3). This situation had influenced cohesion strength and so compressive strength negatively.

In addition, A4 sample with 12% (by mass) clay content had presented a weak binding properties. For this sample, sand mass was six times of clay mass. Thus, it had showed only 3.0 N/mm2 of compressive strength (Figure 3). However, because of its superior properties, compressive strength of A2 sample had reached 5.35 N/mm2.

IV. CONCLUSIONS

Three important conclusions were obtained from this study. Without adding any admixture, the behavior under compressive loads of adobes can be improved by orienting both material contents and workability conditions.

1. Compaction water content should be held at plastic limit and near to proctor water rate. Moreover, the adobe should be compacted by any method like tamping. Thus, the compacity increases and shrinkage rate decreases.

2. With compared to clay content, the mass rates should be chosen as 1 clay, 1.5 silt, and 3 sand.

3. Vermiculite mineral should be available largely in clay. Because, this mineral helps occurring higher valence loaded cation milieu and so, undertakes a mission increasing the cohesion.

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