J. King Saud Univ., Vol. 24, *Arch. & Planning* (1), pp.25-41, Riyadh (2012/1433H.)

Developing A Modern Technique for Clayey Construction

Mokhtar Ali Abdulhafiz Abdo
Assistant Professor, College of Engineering and Architecture,
University of Ibb, Yemen
E.mail: mokhtar_abdo@hotmail.com

(Received 07/07/2009; accepted for publication 23/12/2009)

Abstract. The fierce damages that were caused by the loam buildings due to the floods disaster in Wadi-Hadhramaut in 2008 and the interest of many employers to obtain modern loam walls of less thickness and high resistance to denudation factors, in addition to the unavailability of researches specialized in checking the effects of the climatic conditions on the loam resistance; all those were the most important motives to carry out this research.

For this, the researcher's aims have been summarized in gathering and documentation the information and lore about the loam construction in Yemen; not only to use them in conserving the existing buildings but also to develop loam building of modern lasting techniques which fulfills the requirements of the age. Moreover, the discovery of the effects of the climatic conditions on loam's resistance is considered the researcher's main goal in this topic.

Thus, the methodicalness of this research has concentrated on analyzing the techniques of the traditional loam construction in Yemen and carrying out lab experiments to examine the pressure resistance for many specimens taken from different loam mixtures and studying the effect of drying them under various climatic conditions; moreover, lab experiments were performed to examine the effect of slow drying through capillarity of protected covering walls, on different loam mixtures.

The most important results of this research is the proof that the loam construction elements that were dried under summer climatic conditions show shrinkage cracks more that of dried under winter climatic conditions, thus, it was emerged that the importance of adhering to traditional rule which says that the loam buildings should be built in winter not in summer. The second result is proving that thinning the "fat" and "semi-fat" loams should be used with crushed stone with max. nominal size in the sandy range not using sand with round granules.

Also, it has been reached through this research that it is necessary to developing the protecting covers of the loam walls to get a more resistance to denudation factors and to avoid the negativeness of lime or cement plaster to fall from loam walls due to the dissimilarity of factors of the thermal linear hygroscopic extension.

1. Introduction

The lack of resources and skyrocketing energy prices will obstruct the continuing of using the mechanization automation and advanced technology to produce buildings in developing countries in addition to the notable global increase in using energy which is directly associated with the problems of environmental pollution, which in turn will lead to enormous global climate changes and global warming.

Accordingly, the international community must take responsibility for reducing environmental pollution resulting from excessive use of energy resources to the lowest extent possible.

Regarding to the construction sector, while selecting construction materials and techniques in line with the climatic factors in each region, we can provide a large portion of energy.

Among the factors that are overlooked in many of researches and through it can provide a large part of the energy selection of building materials with low primary production energy. In the near future the building materials will not be evaluated according to their mechanical properties only (basic requirement), but also depending on the balance and environmental impact (Life-Cycle-Analyses), where they will play a big role in that the following factors:

- Environmental impact
- The energy required to produce
- The possibility of recycling
- The health effects

The Loam building material is considered from construction materials which have low primary production energy, in comparison between loam and

Table 1. Numbers for the whole groups of experimental specimens used in this research with the symbols, abbreviations and their meanings as well as the conditions of drying

No. of group of specimens experiments	Symbols & Abbreviations	Meaning of Symbols & Abbreviations
1	UL (T=25%) - N-S	The raw material (loam), the proportion of clay 25%, non- protected, dried under summer climatic conditions (temperature = 42 degrees Celsius, relative moisture = 23%)
2	UL+RS (T=10%) - N-S	The raw material + round-grained sand (0 - 2 mm), the proportion of clay 10%, non-protected, dried under summer climatic conditions (temperature = 42 degrees Celsius, relative moisture = 23%)
3	UL+BS (T=10%) - N-S	The raw material + crushed sand (0 - 2 mm), the proportion of clay 10%, non-protected, dried under summer climatic conditions (temperature = 42 degrees Celsius, relative moisture = 23%)
4	UL+RS+RK (T=10%) - N-S	The raw material + round-grained sand and gravel (0 -16 mm), the proportion of clay 10%, non-protected, dried under summer climatic conditions (temperature = 42 degrees Celsius, relative moisture= 23%)
5	UL+BS+Spl. (T=10%) - N-S	The raw material+ crushed sand and gravel (0 -16 mm), the proportion of clay 10%, non-protected, dried under summer climatic conditions (temperature = 42 degrees Celsius, relative moisture = 23%)
6	UL (T=25%) - N-W	The raw material (loam), the proportion of clay 25%, non- protected, dried under winter climatic conditions (temperature = 29 degrees Celsius, relative moisture= 36%)
7	UL+RS (T=10%) - N-W	The raw material + round-grained sand (0 - 2 mm), the proportion of clay 10%, non-protected, dried under winter climatic conditions (temperature = 29 degrees Celsius, relative moisture= 36%)
8	UL+BS (T=10%) - N-W	The raw material + crushed sand (0 - 2 mm), the proportion of clay 10%, non-protected, dried under winter climatic conditions (temperature = 29 degrees Celsius, relative moisture= 36%)
9	UL+RS+RK (T=10%) - N-W	The raw material + round-grained sand and gravel (0 -16 mm), the proportion of clay 10%, non-protected, dried under winter climatic conditions (temperature = 29 degrees Celsius, relative moisture= 36%)
10	UL+BS+Spl. (T=10%) - N-W	The raw material+ crushed sand and gravel (0 -16 mm), the proportion of clay 10%, non-protected, dried under winter climatic conditions (temperature = 29 degrees Celsius, relative moisture= 36%)
11	UL+BS (T=10%) - N-NB	The raw material + crushed sand (0 - 2 mm), the proportion of clay 10%, non-protected, dried for five days at a temperature of 20 degrees Celsius and then was accelerated dehydration at a temperature of 60 degrees Celsius until weight is stabilized.
12	UL (T=25%) – G-S	The raw material (loam), the proportion of clay 25%, protected, dried under summer climatic conditions (temperature = 42 degrees Celsius, relative moisture = 23%)
13	UL+RS (T=10%) - G-S	The raw material + round-grained sand (0 - 2 mm), the proportion of clay 10%, protected, dried under summer climatic conditions (temperature = 42 degrees Celsius, relative moisture = 23%)
14	UL+BS (T=10%) - G-S	The raw material + crushed sand (0 - 2 mm), the proportion of clay 10%, protected, dried under summer climatic conditions (temperature 42 degrees Celsius, relative moisture = 23%)
15	UL+RS+RK (T=10%) - G-S	The raw material + round-grained sand and gravel (0 -16 mm), the proportion of clay 10%, protected, dried under summer climatic conditions (temperature = 42 degrees Celsius, relative moisture= 23%)
16	UL+BS+Spl. (T=10%) - G-S	The raw material+ crushed sand and gravel (0 -16 mm), the proportion of clay 10%, protected, dried under summer climatic conditions (temperature = 42 degrees Celsius, relative moisture= 23%)

some different construction materials, where one cubic meter of loam needs to be moved and to prepared, approximately 1% only of the necessary primary production energy to produce one cubic meter of normal concrete and to 0.3% of the necessary primary production energy to produce one cubic meter of reinforced concrete, (Rauch, 2002), (Müller, 2005).

2. The problem of research and objectives

2.1. Analysis of the problem

Yemen is witnessing, like other developing countries, a large population growth, where population growth rate is approximately 3.5% (Statistical Yearbook, 2004). This means that in 2021 the population of Yemen will be expected 38 million people, (Abbas, 1997).

Due to this increasing of population, the necessity for residential buildings must increase too. The acute lack of ability to build houses because of the economic situation is deteriorated and a high inflation, which led to an increase in prices of construction materials, is considered a serious impediment against the expansion of building of adequate housing.

In Yemen different techniques of earth buildings are spread, in the eastern and southern regions the technique of raw mud-bricks (adobe) (Almadar) is used, while in the northern regions, the technique of (Zabur) is spread. At the regions of heavy rains the "protected method" has been developed, in which, the natural stone was used as " an outside - Facing "and "lining - inside" for the walls while the nuclei of the walls are poured using a gravelly mud, compare (Abdo, 2007).

Although the traditional techniques of the earth building have a lot of advantages, it has a lot of weak points; the most important of these ones are as follows:-

- The Rapid dryness of Zabur walls being recently constructed, or layers of Alyaboor and Almahdhah layer of adobe (Almadar) buildings lead to a lot of shrinkage cracks in it, especially during building in summer, see Fig. 1.
- The sudden and severe rainfall which, sometimes accompanied by hailstones and wind lead to flow of water quickly in the vertical shrinkage cracks and its edges, resulting in washing away of the outside layers of the loam walls and deforming its sight, see Figs. 2, 3.

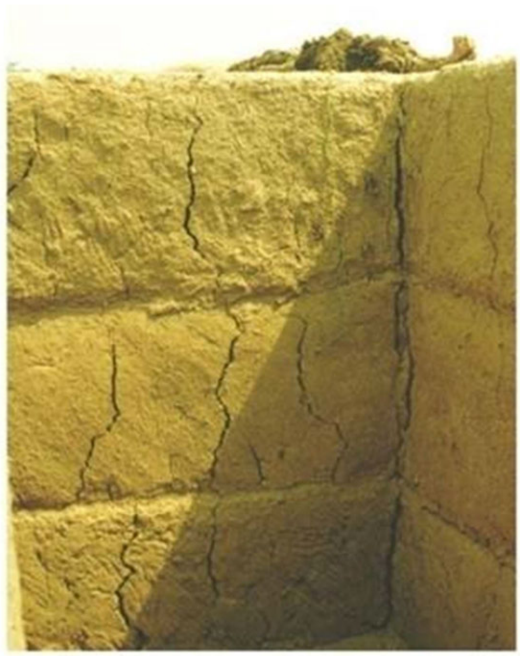


Fig. 1. Building under construction by technique of Zabur in Rahban - Saada was built in the summer and shrinkage cracks appear enormously.

Fig. 2. A Residential building in Hisn, Al Ahmad- Wadi-Hadhramaut and show the severe effect of rain water on layer Al-Mahdhah, especially at the shrinkage cracks, March 2009.

- Affecting of earth buildings more than the other facilities which use other buildings materials such as concrete by flood disasters like floods occurred in Wadi-Hadhramaut in 2008, where the total of the destroyed and damaged buildings reached 3450 buildings, (News Yemen, 2008), compare (Fig. 4).

Fig. 3. A loam Building build by technique of Zabur in Maswarah - Marib, appearance of the affection of washing away of rainwater down the coated areas and in vertical shrinkage cracks severely due to the increasing of run-speed, March 2009.

Fig. 4. Buildings affected by the flood disaster in Meshtah - Wadi Hadhramaut, March 2009.

- The intense solar radiation which is focused on the non-protected loam walls leading to a drying of the outer layers severely and shrinkage, which then become voracious absorption of rainwater and then increases their size. These different processes (drought first, then deep-water saturation II) lead to the occurrence of the phenomenon of what is called a "Foliation". The loss of the outer layers of the wall, where they are most vulnerable to the cliff by rainwater, especially because of its energy, accompanied by hailstones due to its mechanical energy.
- Excessive excess of thickness of the loam walls because of the coefficients of "fear" of the washing away and the affecting of rainwater.
- The layers of traditional plaster are so far failed to provide the ideal solution to protect the walls from denudation for the following reasons:-
  - Poor implementation.
  - Different coefficient of thermal and hygroscopic linear expansion between plaster layers and loam walls on the bottom, which leads to cracks in the plaster layers and its separation from the wall and then falling down as well as deforming the buildings' faces where this phenomenon occurred, compare Fig. 5.

Fig. 5. Example of falling of lime plaster at the Palace of Hantoot - Tarim - Wadi Hadhramaut, March 2009.

These weak points that affect the construction techniques of traditional earth buildings and still making many of employers and construction companies to the turning away from continuing to build using the loam and their preference for modern materials such as normal concrete, reinforced concrete, iron, aluminum and baked bricks, and others, although the bulk of these materials are imported from abroad, which leads to more the construction market in Yemen hostage of import and price fluctuations in world market as well as the high cost of buildings significantly, compare Fig. 6.

Fig. 6. Invasion of Reinforced Concrete for Valley of Clay Architecture - Tarim - Wadi Hadhramaut, March 2009

- The addition of straw to the clay for reducing shrinkage cracks at the same time may lead to low compressive strength and for this reason the thickness of the traditional loam walls become large.

2.1. Research objectives

Research objectives can be summarized in the following points:-

- Collecting and documenting information and knowledge on loam construction in Yemen is not only for use in the maintenance of existing buildings, but also to develop techniques for sustainable and modern loam building responsive to the requirements of modernity.
- Finding the affection of climatic conditions on the compressive strength of different loam mixtures and testing this effect at the slow drying for those mixtures specimens by capillarity for appropriate protected walls covers.

3. Research methodology

To achieve the aforementioned objectives, the following methods and approaches will be used:-

- Carrying out laboratory experiments and tests the compressive strength for many of the specimens taken from different loam mixtures, and study the effect of drying under different summer and winter climatic conditions.
- Conducting laboratory experiments to examine the effect of slow drying, by capillarity for appropriate protected walls covers.

4. Studies and previous researches on loam and earth building

4.1. The effect of addition of straw to the loam compressive strength

The researches that made by Professor Minke and his work team at Kassel University in Germany has proved that the addition of straw to the Loam mixtures leads to the reduction of its compressive strength, (Minke, 2001), compare Table 2.

Table 2. Reduction of compressive strength of the loam while adding straw (5cm) (Minke, 2001)

Percentage of Straw in the loam mixture [%]	R ρ Density [kg/m^3]	compressive strength βD [N/mm^2]
0	1882	2.2
1	1701	1.4
2	1571	1.3
4	1247	1.1
8	872	0.3

4.2. The influence of moisture content inside the material of loam on its compressive strength

In the Department of Structural design and constructions at the Technical University in Berlin, the influence of the moisture content of loam as well as the relative humidity of the environment to compressive strength were tested. Figure 7 shows the fall compressive strength under the influence of increasing of relative humidity. It has been discovered that the moisture content of the loam increases with relative humidity and then leads to lower compressive strength of Loam, see Figs. 8 and 9.

4.3. About the clay and clay minerals

4.3.1. Size of clay minerals

Loam is considered a mixture of clay, silt and sand, which can also contain some gravel and stones, (Minke, 2001). Clay represents a connected material in the loam, so the information and knowledge about its properties is considered a very important for those who are interested in earth building.

The following sections will display the most important knowledge and research findings and studies on the clay and clay minerals, which are directly related to the topic of this research, which will provide the reader with the scientific basis to understand the evaluation and explanation the results of experiments in the following paragraphs of this research.

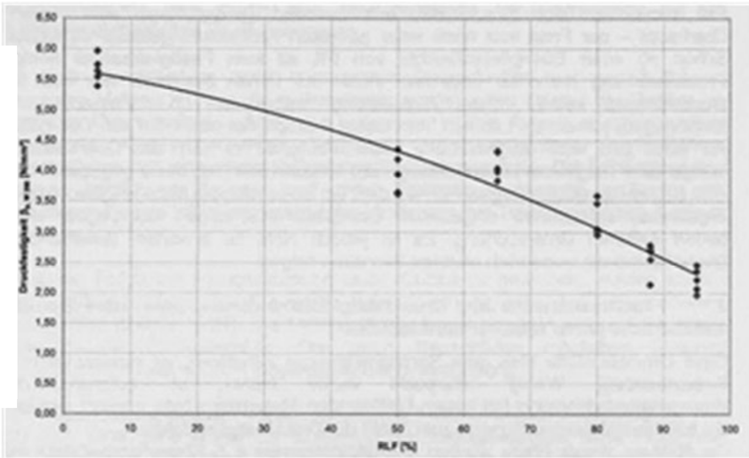


Fig. 7. Fall of loam compressive strength by the increase of the relative humidity surrounding it. (Dierks; Ziegert, 2000).

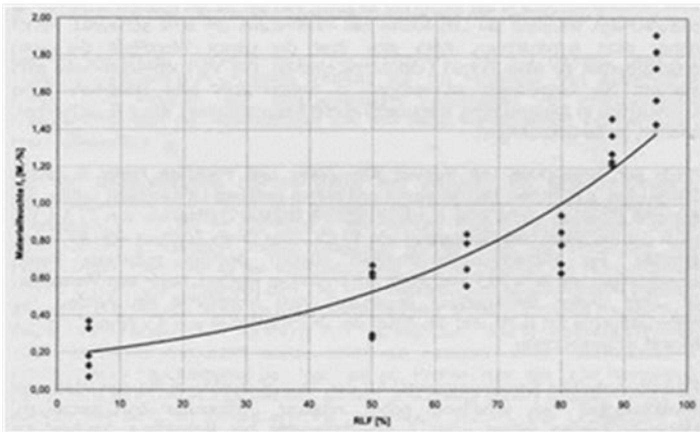


Fig. 8. Increasing of moisture content of the loam by the increasing of the relative moisture surrounding it. (Dierks; Ziegert, 2002).

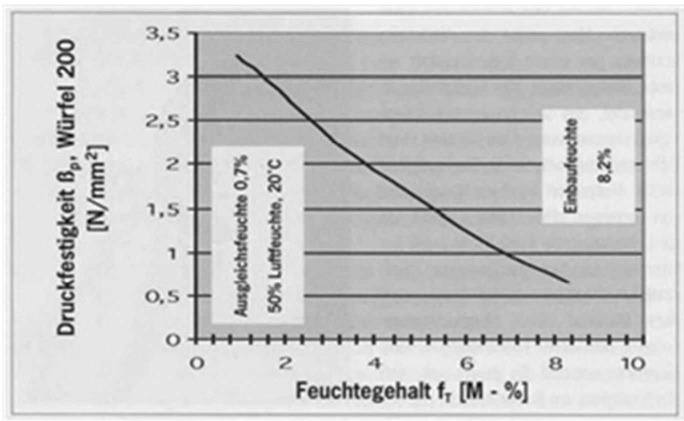


Fig. 9. Fall of loam compressive strength by the increase of the moisture content surrounding it, (Dierks; Ziegert, 2000).

4.3.2. Collecting and compaction Platelets of Clay

The correlation and final collection of the clay platelets with each other after drying depends on its initial state in the mixture. Accordingly, the interaction of clay particles in the mixture together depending on pH-value of the mixture, temperature, the efficiency of ion exchange and the concentration of the solution, built different structures and patterns of clay platelets after drying, compare Fig. 10.

The correlation and collection of clay platelets together may be dotty, linear or areal, see Fig. 11.

4.3.3. DLVO Theory

DLVO theory describes the colloidal dispersion by means of electrostatic interactions between negative ions of the edges of clay platelets and the ions spreading in the spaces between them. The spreading of positive ions between the clay platelets depends on temperature.

Because the surfaces of clay platelets are charged with negative electrostatic charge, the electrostatic repulsion between their surfaces will happen. At adjacent, what it called Born's repulsion which its affects forces reversed the strength of van–der–Waal of attraction, where the forces of attraction overcome all recent repulsion forces when they are very close distance between the platelets
of clay, compare Fig. 12.

4.3.4. The influence of pH-value and temperature on compaction of platelets of clay

It has been known that the pH-value of water (mixing water and water pores in the clay mixtures) is extremely relating to the temperature. The pH-value increases by the increase of the temperature.

What was striking that the clay platelets compacting and correlating closer to each other whenever the pH-value decreased, see Fig. 13.

Also, as the increasing of temperatures, a lot of positive ions leaves the edges of clay's granules and spread in the separated in-between distances and form them. In this way, clay platelets diverge from each other more and more, which leads to be compacted far from each other after drying, as a result, the clay-

A) Optimum dispersion

parallel and densely

B) Convergence of surfaces of the dispersed clay platelets dropped packets to each other

C) Funicular Adhesion for clay platelets

Disassembled Sedimentation

D) Adhesion and arrangement like house of cards

Disassembled Sedimentation

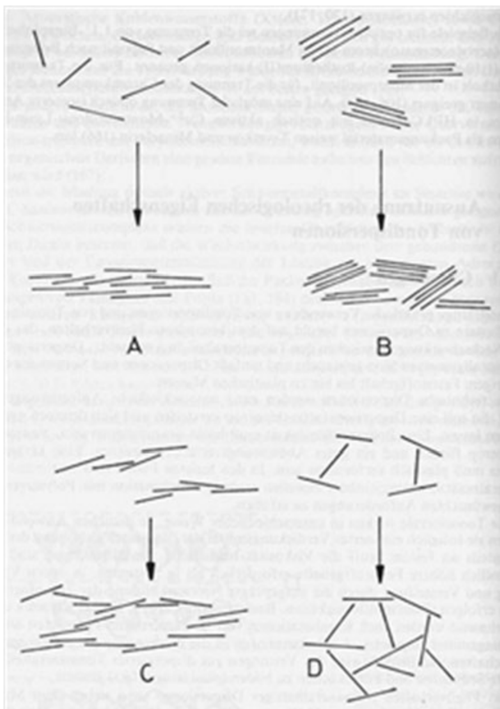


Fig. 10. Different forms of sediment of clay particles and its relation to their initial state in a solution (Lagaly, 1993).

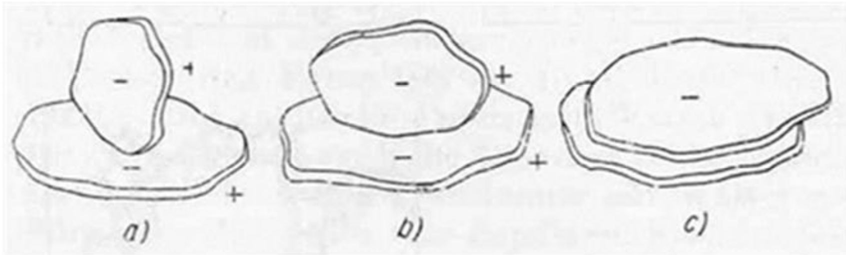


Fig. 11. The possible forms of connection between the clay particles (Kezdi, 1993).

V_A: van-der-Waals-interaction

V_B: Born's repulsion

V_T: Electrostatic Repulsion

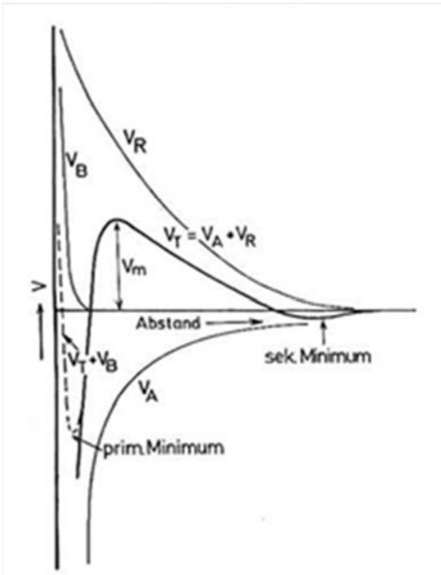


Fig. 12. The interaction of clay particles in the colloidal solution according to DLVO theory (Lagaly, 1993).

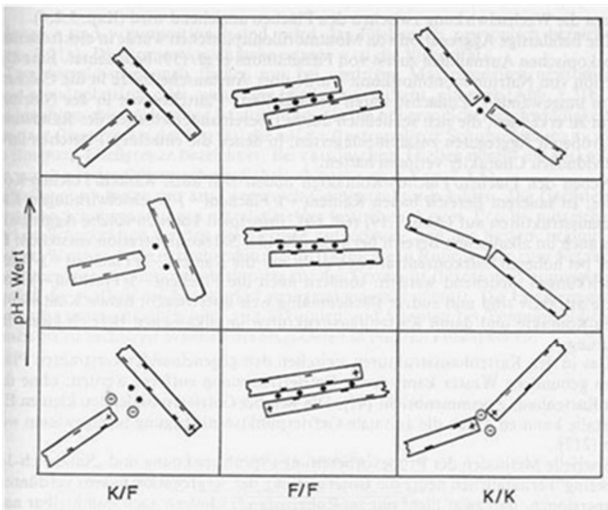


Fig. 13. Forms of correlation and arrangement of clay platelets with each other and the relationship with the pH- value, (Lagaly, 1993)

containing material has low compressive strength, (Lagaly, 1993).

5. Test of the influence of climatic condition in summer and winter on the compressive strength for different loam mixtures

5.1. Methods of Test Implementation

For the purpose of carrying out this test, five different clay mixtures were used. From each mixture, two groups of specimens were produced; each group of specimens composes from five testing cubes with measures of 20x20x20 cm. Half of specimens were dried, (five cubes from each one of the five different mixtures), under summer climatic conditions of Wadi Hadhramaut, (Maximum average of temperature degree = 42 degrees Celsius, and average of relative humidity = 23%). The other half of the specimens, which are similar to the first one in formation, were dried under winter climatic conditions of Wadi Hadhramaut, (Maximum Average of temperature degree = 29 degrees Celsius, a average of relative humidity = 36%). The drying was done in a conditioned room by required climatic factors till the weight of the specimens would be stable.

5.2. Materials that subjected to testing for this purpose

- The raw material: It is a loam that contains a proportion of clay type of (Kaolinite) 25% of its weight, see Fig. 14. The percentage of clay has been determined through the sieving way and sedimentation as well as the method roentgen diffractometry.
- Aggregates:
  - Round-grained sand (0 - 2 mm)
  - Crushed Sand (0 - 2 mm)
  - Round-grained Gravel (2-16 mm)
  - Crushed Gravel (2 - 16 mm)
- Leveling Material of compression surface for the specimens: It is a mixture of sulfur according to the European Code DIN EN 12390-3 supplied by the company Infra Test-Prueftechnik GmbH
- Covers of protection: They were formed from Ytong - Planbauplatten PP p 10 by Chainsaw electric the thickness of 3 cm and glued together as in Fig. 15.

5.3. Specification of the consistency mixtures used

Set the consistency of mixtures used in the plastic

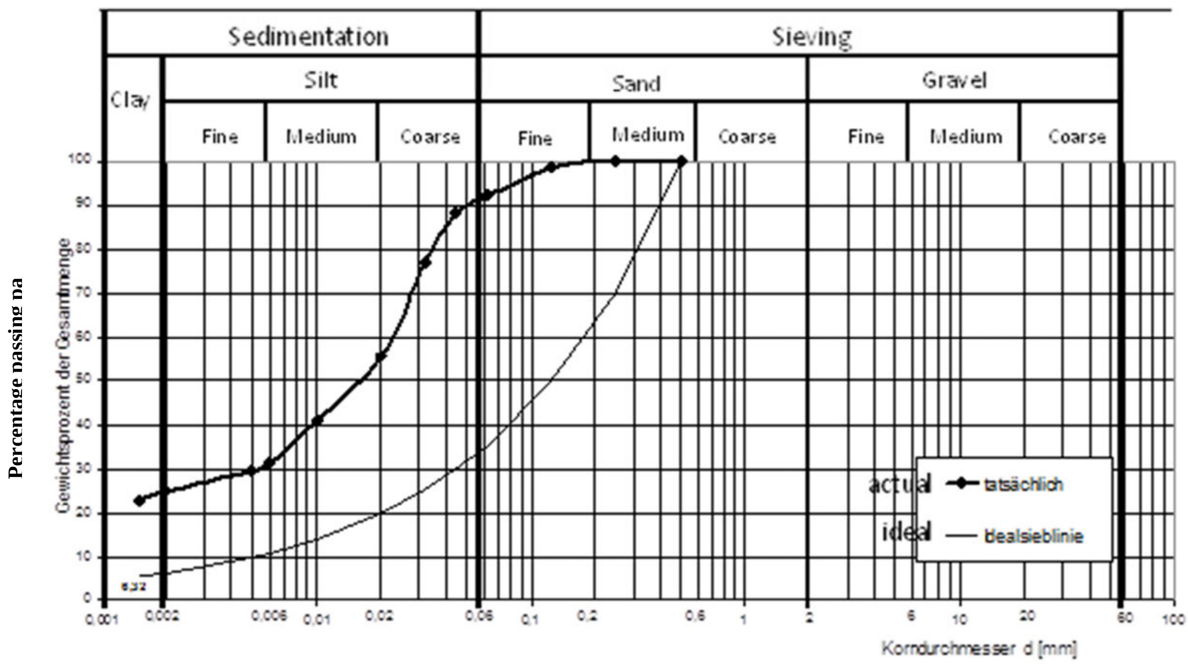
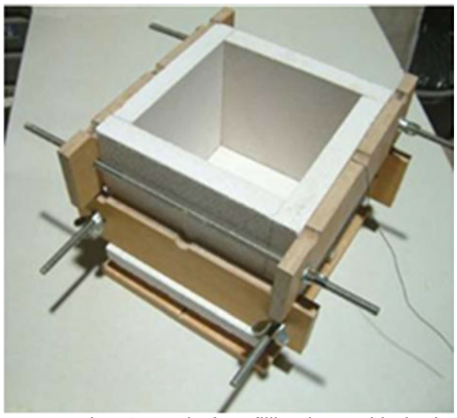


Fig. 14. Grain size distribution for the raw material which is a loam consists of 25% clay "UL (T=25%)."

a) The different Parts of the Protection Cover which are disjointed of each other

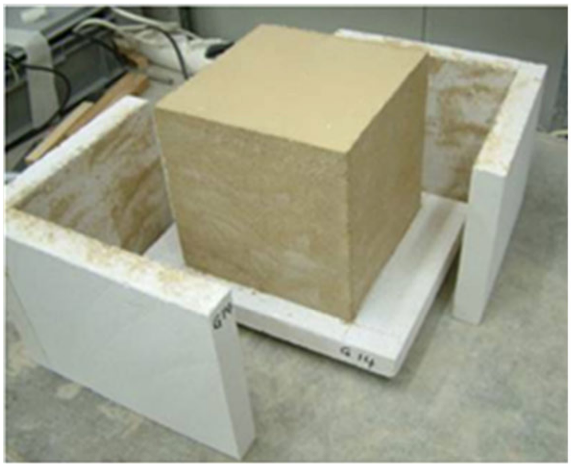


b) The Protection Cover before filling it up with the loam of the sample

c) The Protection Cover after filling it up with the loam of the sample

d) The sample is covered by the specified cover with a perfect connection with the specified wires for that

e) The Protection Covers during the drying process in the conditioned room specified for that



f) The sample after taking the protection covers away

Fig.15. The Different cases of the Protection Covers during their Usage.

state, as in the case of traditional earth construction techniques in Yemen, where the flow test (30 cm) was selected and determined according to European code DIN EN 12350-5.

5.4. Mixtures used in the experiments

Table 1 shows Numbers for the whole groups of experimental specimens used in this research with the symbols, abbreviations and their meanings as well as the conditions of drying.

5.5. Mixture & Fermentation

The loam mixtures that were used in the experiments were mixed separately each one of them for five minutes till a loam plastic mass was formed, after that it was stored for 48 hours in plastic vessels firmly closed to ensure the fermentation process (the distribution of moisture in the mixture homogenously) to stir up the correlation power in the loam.

5.6. Preparation of specimens

The specimens were produced immediately after obtaining the required consistency for the loam mixture (the flow test= 30cm) using the forms shown in Fig. 15, the forms for non-protected specimens were removed after one hour of production, and the dimensions of the specimens were 20x20x20 cm.

5.7. Drying of specimens

The specimens were dried until they reached the stage of weight stability and then their surfaces were leveled and tested.

5.8. Test of Compressive strength

The maximum load (F) was specified for breaking, which was obtained during the execution of the specimen's pressure. The breaking stress (б) resulted from maximum load for the breaking of the specimen (F) divided by the pressure area (A) for the specimen:

$$б = F/A \quad N/mm^2$$

Where:

б= the breaking stress and its unit [N/mm^2]

F= maximum breaking load and its unit in [N]

A= the pressure area of the specimen and its unit in [mm^2]

The compressive strength for the group of the specimens which consist of five specimens is the average value for the five values in the condition that the deviation of the compressive strength of each specimen should not be over the average value for the five values of 20%.

5.9. Reference test group

As a reference test group of specimens, a group of specimens of the loam mixture "UL+BS (T=10%)" were produced. This group was dried up according to the conditions of the Germanic Code DIN18952. This means the drying should be for five days under 20 Degree Celsius, after that it is important to speed up the drying process under 60 Degree Celsius till it reaches the stability of weight.

5.10. Evaluation of the experimental Results

All groups of specimens of the five different loam mixtures which were dried under the winter climatic conditions got a compressive strength more than the groups of specimens dried under the summer climatic conditions.

The compressive strength of the group of specimens No. (1) for the loam mixture "UL (T= 25%)"(the raw material with clay proportion of 25%) has reached , when drying it under the summer climatic conditions 2.01 N/mm2. Whereas, group of specimens No. (6) for the same loam mixture at the time of drying under the winter climatic conditions has reached 4.45 N/mm2 with an increase of about 121%.

As well, the compressive strength of the group of specimens No. (2) for the loam mixture that consists of the raw material plus round-grained sand "UL+RS (T= 10%)" and the clay proportion of 10%, and which was dried under summer climatic conditions 2.18 N/mm2 . Whereas, the group of specimens at the time of drying under the winter climatic conditions has reached 3.69 N/mm2 with an increase of about 69.3%, see Fig. 16.

And the compressive strength of the group of specimens that consists of the raw material plus crushed sand "UL+BS (T=10%)", and the clay proportion of 10%, which was dried under summer climatic conditions 2.5 N/mm2, whereas, under the winter climatic conditions has reached 4.57 N/mm2 with an increase of about 82.8%.

As well, the compressive strength of the group of specimens for the loam mixture that consists of the raw material plus round-grained sand (0–2mm) and gravel (2–16mm) "UL + RS + RK (T= 10%)" and the clay proportion of 10%, and which was dried under

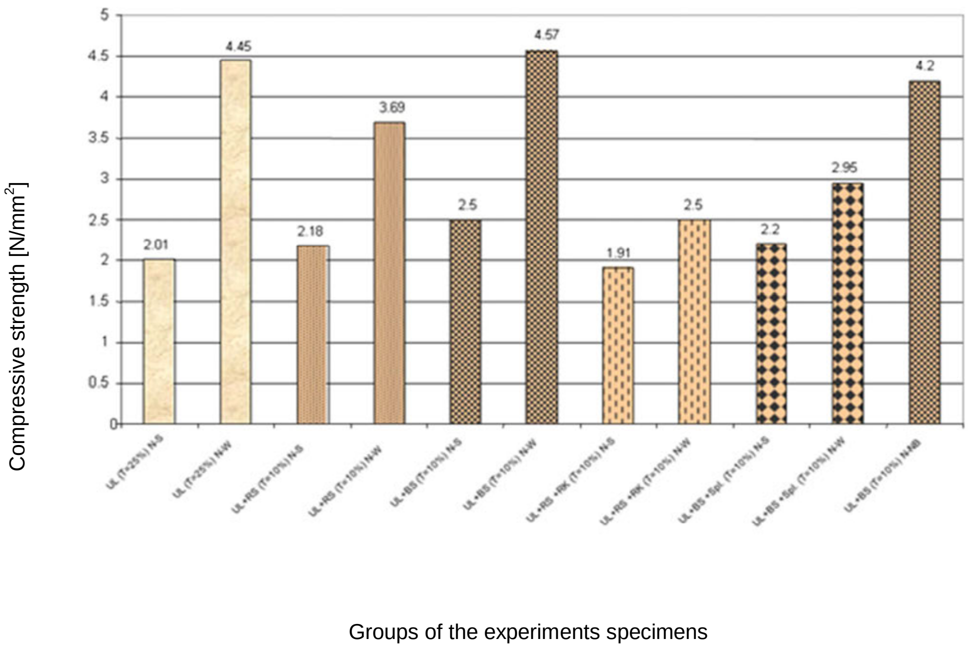


Fig. 16. The average value of compressive strength of the groups of the dried experiments specimens under the summer climatic conditions (the temperature is 42 Degree Celsius, and the relative humidity is 23%) and the dried ones under the winter climatic conditions (the temperature is 29 Degree Celsius, and the relative moisture is 36%) in comparison with the group of the experiments specimens No. 11 (the reference group specimens), which is dried at 60 Degree Celsius with a previous drying for five days at 20 Degree Celsius.

summer climatic conditions 1.91 N/mm2 .Whereas, the group of specimens at the time of drying under the winter climatic conditions has reached 2.5 N/mm2 with an increase of about 30.9%.

When mixing raw material with the crushed sand (0–2mm) and the crushed stones (2–16mm) "UL + BS + Spl. (T=10%)", and the clay proportion of 10%, the compressive strength when drying the group of specimens under the summer climatic condition has reached 2.2 N/mm2, whereas, under the winter climatic conditions has reached 2.95 N/mm2 with an increase of about 34.1%.

The results of experiments have shown that the highest increase of the compressive strength of the groups of dried specimens under the winter climatic conditions compared with the groups of specimens dried under the summer climatic conditions has reached 121.4% of the loam mixture for the raw material which contains 25% of clay "UL (T= 25%). While the minimum increase of the compressive strength 30.9% of the loam mixture that consists of the raw material plus aggregates of round-grained sand (0–2mm) and gravel (2-16mm) "UL + RS + RK (T=10%)" and which consists of 10% of clay, see Fig. 16.

What is amazing is the increase of the compressive strength with the average of 8.8% for the group of specimens No. (8), which is a loam mixture is consisting of the raw material plus crushed sand (0–2mm) , and the clay proportion was 10%, which was dried under the winter climatic conditions "UL+BS (T= 10%)-N-W", of the group of specimens for the same loam mixture which was dried at 20 Degree Celsius for five days, then speeded up the drying at 60 Degree Celsius till reaching the stage of weight stability "UL+BS (T= 10%)-NB" according to the Germanic Code DIN 18952 B1. 2.

The increasing of compressive strength dried specimens under the winter climatic conditions with comparison of that one which was dried under the summer climatic conditions could be referred to the following reasons:-

- The groups of dried specimens under the summer climatic conditions showed more shrinkage cracks in the number and the shape greater in comparison with groups of dried specimens under the winter climatic conditions.
- The increasing of pH-value of the mixture water

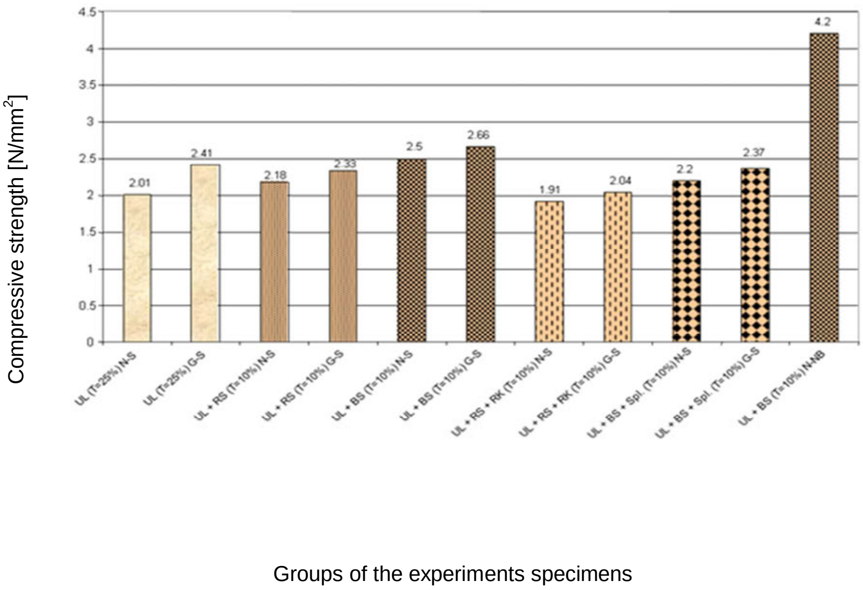


Fig. 17. The average value of compressive strength for the experiments protected, non-protected and dried specimens under the summer climatic conditions (the temperature 42 Degree Celsius, and the relative humidity is 23%) in comparison with the groups of the experiments specimens No. (11) (the reference group specimens) which is dried at 60 Degree Celsius with a previous drying for five days at 20 Degree Celsius.

and the water existing in the loam mixture pores because of the high temperature under summer which leads to the compaction of the clay platelets separately, the composed material becomes less in density and then its compressive strength will reduce.

- The high temperature under summer leads to increase the separate distance among the clay platelets due to the increase of the ionic spreading distance among them as a result of the departure of the positive ions for the clay platelets edges because of getting the dynamic energy due to high temperature, and the opposite occurs when drying under the winter climatic conditions.

The overcome of the attraction forces among the clay platelets (van-der-Waals forces) over the electrostatic repulsion forces among them when the separate distance is very short at the time of drying under the winter climatic conditions according to the (DLVO-Theory).

6. Test of the influence of protection covers on the compressive strength for different loam mixtures

6.1. The method of the test implementation

To examine the influence of drying slowly on the compressive strength of the groups of specimens for different loam mixtures, there are five test cubes were produced from all different loam mixtures, mentioned previously with the same method which was demonstrated in item (5), however the covers of specimens have not removed after one hour but the drying process of specimens under the summer climatic conditions (the temperature =42 Degree Celsius, and the relative humidity =23%) has been continued in the protection covers which were produced by Ytong material till reaching the stage weight stability according to the Code EN ISO 12570.

6.2. Evaluation of Experiments

In Fig. 17 the results of compressive strength of the protected groups of specimens were shown from No. (12) to No. (16) in comparison with the non-protected groups of specimens from No. (1) to No. (5), which were shown in item (5) for the same loam mixtures.

In general, we can say that all the protected groups of specimens for the dried loam mixtures in the protection covers (without exception) got compressive strength more than the specimens which are not dry up in the protection covers for the same loam mixtures.

The compressive strength of the group of specimens No. (12) for the loam mixture that consist of the raw material "UL (T= 25%)" and the clay proportion was 25%, which were dried inside the protection covers under the summer climatic conditions 2.41 N/mm^2, with an increase of 19.90%, over the compressive strength of the group of specimens which were dried without the protection covers, in which it has reached only 2.01 N/mm^2.

Also, the compressive strength of the group of specimens for the loam mixture that consists of the raw material plus round-grained sand (0–2mm) "UL+RS(T=10%)" and the clay proportion was 10%, which were dried inside the protection covers under summer climatic conditions 2.33 N/mm2 , with an increase of 6.88%, over the compressive strength of the same group of specimens which were dried without the protection covers.

In the state of the group of the protected specimens for the loam mixture that consist of the raw material plus crushed sand (0–2mm) "UL + BS" (T= 10%) and the clay proportion was 10%, which was dried inside the protection covers under the summer climatic conditions the compressive strength has reached 2.66 N/mm^2, with an increase of 6.4% , over the compressive strength of the non-protected group of specimens for the same loam mixture which were dried without the protection covers.

On the other hand the loam mixture that consists of the raw material plus round-grained aggregates (0–16mm) "UL + RS + RK (T= 10%)", and the clay proportion is 10%, in which the compressive strength of the group of the protected specimens was increased with an average of 6.81% in comparison with the group of the non-protected specimens.

While the compressive strength of the group of the protected specimens was increased with an average of 7.73% in comparison with of the non-protected group of specimens for the loam mixture that consists of the raw material plus crushed aggregates (0–16mm).

We can summarize from this evaluation that the regular and drying slowly of the group of specimens in the protection covers leads to the increase of the compressive strength for those specimens.

In this regard, it is attractive that the positive influence for the protection covers increases with the increase in the percentage of the clay in the loam mixture.

As it was shown in item (5) that the loam mixture which is consisted of crushed aggregates got a compressive strength higher than the loam mixture which is consisted of the aggregates round grains. The reason of that refers to the increase in the specific surface of the crushed aggregates in comparison with the aggregates of round grains, then the availability of more cohesive areas for the clay platelets at those loam mixtures.

It is obvious from these experiments that the groups of specimens that consist of the raw material plus aggregates with max. nominal size in the sandy range got a compressive strength higher than the groups of specimens that consist of the raw material plus aggregates with max. nominal size in the gravelly range, which have the same proportion of the clay 10%. The reason of that refers to the state of the sand aggregates the clay covering layer is lower in thickness than those in the state of the aggregates with max. nominal size in the gravelly range, at the time of the stability of clay percentage in all mixtures. In which the clay platelets became arranged in the first stage parallel to the surfaces of the aggregates particles, while in the second stage the clay platelets became arranged and correlated together in the form of (edges with surfaces), which leads to the formation of a material lesser in density and hence its compressive strength will reduce.

7. Results and Recommendations

7.1. The Results

- The rule of the traditional construction stipulated the necessity of constructing the earth buildings at the winter and not at the summer, because if this rule cannot be followed will not only lead to the damages in the loam construction items of the recent constructions due to the heavy rains accompanied by hailstones under the summer, but also to decrease the resistance of those items. In which the experiments showed that in some of the mixtures may lead to the decrease of the loam compressive strength with about 54%.
- The thinning of the "fatty" and "semi-fatty" loam to reduce the mixture water and then the ratio of shrinkage and the shrinkage crack should be done with aggregates their nominal size is located in the sandy range which leads to decrease the thickness of the clay layer around the aggregates particles which caused the arrangement of the clay platelets parallel to the surfaces of the aggregates particles and hence the increase of the compressive strength. It is preferred to use the crushed aggregates to increase the specific surface of the aggregates particles in comparison with the aggregates round

particles that leads to the increase of the compressive strength for the same reason.

- The slowly drying for the items of the loam construction is very necessary, not only in the first stage of the drying but also during the full process of drying.
- Developing the protection covers for the loam walls has a very important significance, in which these covers will include the slowly drying for the loam walls the thing which leads up to decrease the stresses of shrinkage consequently decrease the shrinkage cracks, hence the resistance of the walls will increase.
- The positive influence of the protection covers increase whenever the average of the clay increases in the loam mixture.

7.2. Recommendations

7.2.1. Primary suggestions and solutions for the protection covers, being determined to industrialize

A modern technique should be developed for the loam construction, which provide the procedures of a good protection for the loam construction to avoid the quick dry, the direct solar radiation and the washing away due to the rainfall and the hailstones, also the mechanic damages resulted from the crash of the solid substances and blowing of the wind loaded with the sand particles to avoid the extreme increase in the thickness of the walls which are ostensibly shown in the traditional loam buildings.

In the Figs. 18 to 22 the suggestions for the protection covers have been shown, where they could be produced by the local materials.

Choosing the raw materials to produce the covers and design their final shapes, need detailed researches and tests in future. With regard to the studies and researches in future, the following notes have an important significance:

- The ability of developing the covers that protect the loam walls, which have to be made by the materials which are able to conduct the mixture water via the capillarity, also those covers must be resistible due to the influence of the moisture resulted from the mixture water and the rainfall.
- Get the advantage of the experience existed in Yemen to produce the traditional pottery to produce protection covers, by which this technique can be used to produce precise dimensional protection covers. It is necessary to test the ability of using the idea of (water clay vessel) to cool the loam mixtures for obtaining the highest resistance for the loam walls, even if it is built under the summer.
- The ability of producing the protection covers from the traditional mixtures of the plaster of lime being used in Wadi Hadhramaut, where its white color will be used to reflect 70-80% from the solar radiation and then reduce the thermal stress which the buildings are exposed in order to save the energy.

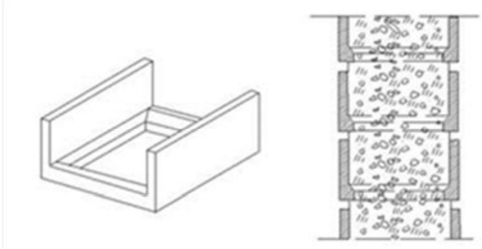


Fig. 18. Suggestion of the protection covers for the internal walls.

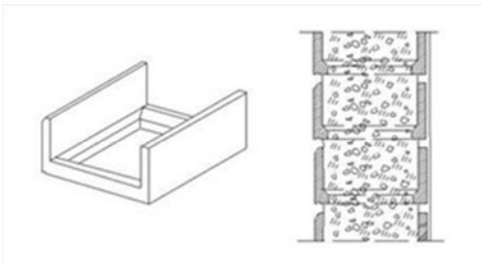


Fig. 19. Suggestion of the protection for the accessories rooms, the balconies and the terraces walls …etc.

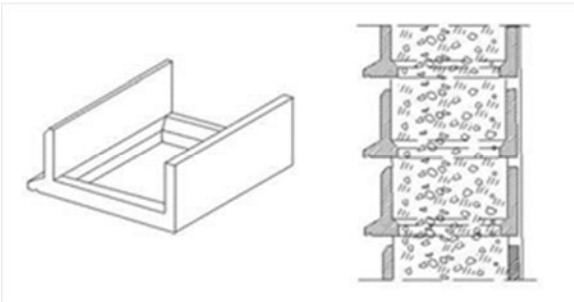


Fig. 20. Suggestion of the protection covers form the external walls with prominences for the protection of the solar radiation.

The 1st alternative: Partial shadow elements for external walls.

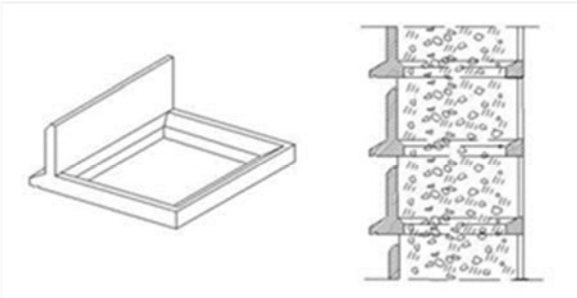


Fig. 21. Suggestion of the protection covers form for the external walls with prominences for the protection of the solar radiation.
The 2nd alternative: Elements in the form of the letter (L) with partial shadow for the external walls

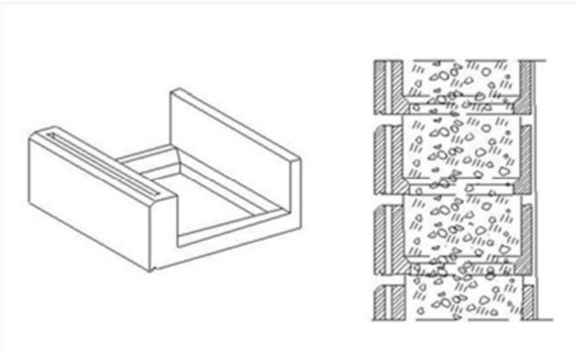


Fig. 22. Suggestion of the protection covers form to protect the external walls with the implementation of the protection from the direct solar radian.
The 3rd alternative: Elements in the form of the letter (U) with complete shadow for the external walls

References and Sources*

Abbas, S. "Geographic Population of Yemen Republic." (Arabic: *al-goghrafia al-sukania llgumhuria al-yamania*), Obadi Studies & Publishing Center, Sana'a, Yemen, (1997).

Abdo, M. *Zum Lehmbau im Jemen unter besonderer Beruecksichtigung der klimatischen Bedingungen*, Fakutaet fuer Architektur, Uni-Karlsruhe, Germany, (2007)..

Dierks, K. and Ziegert, C. "Materialprüfung und Begleitforschung im tragenden Lehmbau". In: Steingass. P.: *Lehm 2000* : Beiträge zur 3. internationale Fachtagung Lehmbau des Dachverbands Lehm e.V.. 17.-19. 2000 in Berlin. Overall Verlag Berlin, Berlin, Germany, (November 2000).

Dierks, K. and Ziegert. C. (2002) "Neue Untersuchungen zum Materialverhalten von Stampflehm". In: Steingass. P.: *Moderner Lehmbau 2002* : Internationale Beiträge zum modernen Lehmbau. Fraunhofer-IRB-Verlag, Stuttgart, Germany.

DIN 1048 Teil 1 (Juni 1991) "*Prüfverfahren für Beton* : Frischbeton". Beuth-Verlag, Berlin, Germany.

DIN 18952 (Vornorm) (1956) *Baulehm. Blatt 1: Begriffe – Arten. Blatt 2 : Prüfung von Baulehmen*. Beuth-Verlag, Berlin, Germany.

DIN EN 12350-5 (Oktober 1999) "Prüfung von Frischbeton; Teil5: Ausbreitmaß". CEN Brüssel.

http://www.newsyemen.net/view_news.asp?sub_no=40_2008_12_02_2396

Kapfinger, O. *Rammed earth : Martin Rauch : Lehm und Architektur*. Birkhäuser, Basel; Boston; Berlin, (2001).

Kezdi. A. *Handbuch der Bodenmechanik : Band I Bodenphysik*. VEB Verlag für Bauwesen, Berlin, Germany, (1969).

Kramar, U. *Quantitative Mineralbestimmung. Untersuchungsbericht für das Ausgangsmaterial" Universallehm" im Auftrag des Institut für Tragkonstruktionen*". Institut für Mineralogie und Geochemie – Universität Karlsruhe (TH), Karlsruhe, Germany, (14. Mai 2004).

Lagaly, G. "Reaktionen der Tonminerale. In: Jasmund. K.; Lagaly. G.: *Tonminerale und Tone : Struktur. Eigenschaften. Anwendungen und Einsatz in Industrie und Umwelt*". Steinkopff Verlag, Darmstadt, Germany, (1963).

Ministry of Planning & Inter. Coop., Central Statistical Organ (2004), "Statistical year-book 2003", Almethak, Sana'a, Yemen.

Minke, G. *Das neue Lehmbauhandbuch : Baustoffkunde . Konstruktionen . Lehmarchitektur*. Ökobuch Verlag, Staufen bei Freiburg, Germany, (2001).

Minke, G. *Das neue Lehmbauhandbuch : Baustoffkunde . Konstruktionen . Lehmarchitektur*. Ökobuch Verlag, Staufen bei Freiburg, Germany, (2004).

Müller, H. "Baustoffkunde und Konstruktionsbaustoffe : *Skriptum zu den Vorlesungen von Prof. Dr.-Ing. Harald S. Müller*". Universität Karlsruhe (TH), Karlsruhe, Germany, (2005/2006).

Rauch, M. (2002) "Rammed Earth – Anwendungsbeispiele. Probleme und Potentielle. In: Steingas. P.: *Moderner Lehmbau 2002 : Internationale Beiträge zum moderner Lehmbau*. Fraunhofer – IRB –Verlag, Stuttgart, Germany, (2002).

Saeed, M. "Re-evaluation of the History of the Iraq", (Arabic: *E'-adat Taqyeem Tarikh Al-I'rak*), *A~fak Arabia, (7-8) 1998* p. 64-65, Bagdad, Iraq, (1998).

Schneider, U.; u. a. (1996) *Lehmbau für Architekten und Ingenieure : Konstruktion. Baustoffe. Prüfungen und Normen. Rechenwerte* Düsseldorf, Germany.

Walker, P. "Erosion Testing of Compressed Earth Blocks". In: *Proceedings of the 5th International Masonry Conference*, (1998).

.

*Note: All the charts, figures, pictures and diagrams which their sources were not mentioned in this research, their source is the researcher of this thesis himself.

تطوير تقنية حديثة للبناء الطيني

مختار علي عبد الحفيظ عبده

أستاذ مساعد في كلية الهندسة والعمارة، جامعة إب، اليمن

mokhtar_abdo@hotmail.com

(قدم للنشر في ٢٠٠٩/٧/٧ ؛ وقبل للنشر في ٢٠٠٩/١٢/٢٣)

ملخص البحث. لقد كانت الأضرار الشديدة التى لحقت بالمباني الطينية نتيجة كارثة السيول في وادي حضرموت عام ٢٠٠٨م وكذا رغبة الكثير من أرباب العمل في الحصول على جدران طينية حديثة ذات سماكة أقل ومقاومة عالية لعوامل التعرية بالإضافة إلى عدم وجود أبحاث مخصصة لفحص تأثير الظروف المناخية على مقاومة الطين من أهم الدوافع لإنجاز هذا البحث.

لهذا تلخصت أهداف الباحث في جمع وتوثيق المعلومات والمعارف عن البناء الطيني في اليمن وذلك ليس فقط لاستخدامها في صيانة المباني القائمة ولكن أيضاً لتطوير تقنيات بناء طيني مستدامة حديثة ملبية للمتطلبات العصرية ، كما أن إكتشاف تأثير الظروف المناخية على مقاومة الطين يعتبر هدفاً رئيسياً للباحث في هذا الموضوع.

لهذا تم التركيز في منهجية هذا البحث على تحليل تقنيات البناء الطيني التقليدية في اليمن وتنفيذ تجارب معملية لاختبار مقاومة الضغط للعديد من العينات المأخوذة من خلطات طينية مختلفة، ودراسة تأثير تجفيفها تحت ظروف مناخية متباينة، كما تم إجراء تجارب معملية لاختبار تأثير التجفيف البطيء، عبر الخاصية الشعرية لجدران أغلفة حماية، على خلطات طينية مختلفة.

ولقد كانت أهم نتائج هذا البحث هو إثبات أن عناصر البناء الطيني المجففة تحت الظروف المناخية الصيفية في اليمن تُظهر شروخ انكماش أكثر من تلك المجففة تحت الظروف المناخية الشتوية وعليه فإنه تبرز أهمية الالتزام بالقاعدة التقليدية والتي تنص على أن المباني الطينية تُبنى في فصل الشتاء وليس في فصل الصيف. أما النتيجة الثانية فهي إثبات أن تخفيف الأطيان الدسمة وشبه الدسمة يلزم أن يتم باستخدام ركام كسارات يقع مقاسه الاعتباري في النطاق الرملي وليس باستخدام ركام ذي حبيبات مستديرة.

كما تم التوصل في هذا البحث إلى ضرورة تطوير أغلفة حماية للجدران الطينية للحصول على مقاومة أعلى لها لعوامل التعرية ولتجنب سلبية تساقط التلابيس الجيرية أو الأسمنية من على الجدران الطينية نظراً لاختلاف معاملات التمدد الطولي الحراري والهيجروسكوبي.