Characteristics and Energy Performance of Clay as Traditional Building material in Hadhramout Buildings

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Abstract
The effect of some additive materials on the physical characteristics of structural clay used in Hadhramout buildings are investigated in this research work. The thermal insulation of the material of such buildings is particularly studied through energy measurements. The objective sought from the experimental results is to find out if any improvement of the structural material performance is attained. On the other hand, the good thermal insulation and suitability of the material of structural clay to Hadhramout region is proved.

Keywords: Physical and Mechanical Characteristics, Structural Clay, Additive Materials, Energy Performance, Hadhramout Buildings

1. Introduction
The utilization of local construction materials is of great importance for underdeveloped countries like Yemen. In fact the type and pattern of architecture may consequently reflect the manner as well as to what extent this utilization is achieved. There are two main and essential construction raw materials available in Yemen; stones and clays. The stone architecture is frequently encountered in most districts of Yemen and particularly in mountainous regions. On the other hand, the clay architecture is also found in many regions of Yemen, with distinguished and special features. It is quite amazing to find up to seven storeys houses built by mere sun-dry clay bricks, yet they are still surviving in spite of the severe environmental impact. (7, 8)
An attempt is made to investigate in this paper rather the clay architecture because of its originality and splendid heritage of arts and experience, generations of builders had in this country. Even globally, nearly 30% of the world population live in clay houses. However this method of construction is still associated in mind with a practice reserved to the third world.
It is aimed from this paper to provide a real evidence of the new potential of earth architecture, by giving this material a new future through its improvement.

2- Historical Background
Clay is one of the most wide spread and earliest material utilized by Man. Its products explain the history of Man and therefore, the development of delicate artistry of the ancient civilization can be traced by its beautiful wares. (3) The construction of houses or other buildings with walls of earth is older than history itself. It has been carried out with various techniques in almost every country of the world.
In Biblical times and places earth was the main building material for the houses of people. Hence the earliest buildings of Chinese, Romans, and Arabs, were built with earth material.
The main advantage of the clay-wall construction is its durability. It has an additional attractions of being cool in summer, easily heated in winter, resistant to fire and to noise transmission, and if clay from the building site is used, the building can be made to blend into the landscape with minimal visual disturbance to the environment. In Yemen the builders knew those facts early and used the clay to build their houses which lasted for years and years. The use of clay in Yemen is very old, and it has a special way of construction that let the house to stay for more than 500 years. The houses built are frequently of the multi-storey types, which are not found anywhere except in Yemen. That is why they can be considered as the first sky-scrappers of their kind in the world.

3- Experimental Work
The experimental procedure of the tests for determining the soil properties are simply those described in most texts of soil mechanics. (1, 5)

4- Characteristics of Pure Clay
It is felt that it is necessary to study the soil used in this work by conducting intensive laboratory experiments, so that the various results and phenomena arising can be explained.(2) The laboratory experiments almost cover the entire set of experiments used in soil mechanics. The following properties which may also help in evaluating the results are further tested. These are namely:
- Natural evaporation
- Compressive strength
- Linear shrinkage
- Unit weight
The variation of these properties with time within a limited period, are observed depending upon the nature of the test.

The results of the first set of properties are listed in Table.1

<table>
<thead>
<tr>
<th>Table 1 Soil properties</th>
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<tbody>
<tr>
<td>Property</td>
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<tr>
<td>Moisture content</td>
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<tr>
<td>Plastic limit</td>
</tr>
<tr>
<td>Shrinkage limit</td>
</tr>
<tr>
<td>Liquid limit</td>
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<tr>
<td>Specific gravity</td>
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<td>Consolidation</td>
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4-1 Natural Evaporation
This experiment is conducted in the laboratory during the month of November, which is considered among the moderate months of the year. The aim of this experiment is to know the amount of water evaporated per day as well as after how many days the clay will become dry. The main aim however is of course to compensate this evaporated water while preparing the clay specimens. A sample of 200 grams of clay with moisture content between the liquid limit and the plastic limit is taken. It is exposed to natural weather and its weight is regularly and
daily taken, so that the percent of natural evaporation can be plotted against time Figure 1.
It is clear from the curve that the rate of evaporation is rapid in the first three days. After which it becomes constant.

![Graph of Evaporation Percentage against Time in Days]

Fig.1 Natural Evaporation in Pure clay.

4-2 Compressive Strength
The compressive strength of clay is obtained by casting 100mm cubes of clay, and testing them after 1 week, 2 weeks, 4 weeks and 8 weeks. The cubes made are also utilized to test other properties particularly:
- Linear Shrinkage.
- Unit Weight.
Figure 2 shows the variation of the compressive strength in N/mm² up to 60 days. It is quite obvious from the diagram, that the rate of strength development is rapid in the first two weeks and almost is stabilized after one month. However a slight increase is still observed. The average value obtained after one month is 2.7N/mm².

4-3 Linear Shrinkage
Clay has large linear shrinkage. The test is done by measuring the dimensions of 100 mm cube with a vernier every day, so the percent of linear shrinkage is obtained as:

\[
\left( \frac{L_i - L_f}{L_i} \right) \times 100 \%
\]

Where:
Li- Initial length.
Lr- Reduced length.
The values are plotted against time as shown in fig.3.
4-4 Unit Weight

Before conducting the compressive strength on the cube, its unit weight is determined by simply dividing the weight of the cube by the apparent volume. The apparent volume is obtained by measuring the actual dimensions. The results are illustrated in Fig.4. The first point corresponds to the unit weight of clay immediately after mixing. The curve is linear. The unit weight decreases slowly with time. This is evidently expected since the sample dries up with time, although the volume of the specimen decreases.

Fig.2 Compressive Strength of Pure Clay.

Fig.3 Linear Shrinkage Evolution in Pure Clay.
The clay used in the experimental work was all brought from Hadhramout region. The samples were taken from a depth of 30 to 35 cm from the ground surface. Attempts are made to improve the physical and mechanical properties of the clay by adding the following materials:

- Straw.
- Saw-dust.
- Sand.
- Lime.
- Cement.

Due to limited scope, only the straw-clay and cement-clay mixtures are considered in this paper. Similarly, due to many experimental results, all results are compressed in indicative single diagrams and only one concentration value from each material is illustrated. The additives considered are straw with 0.2 % concentration and cement with 2 % concentration. Figure 5, Figures 6, Figure 7, illustrate the evolution of compressive strength, linear shrinkage and unit weight respectively with time.
Fig. 5 Compressive Strength of Clay / Straw and Clay / Cement Mixtures.

Fig. 6 Linear Shrinkage of Clay / Straw and Clay / Cement Mixtures.
Fig. 7 Unit Weight of Clay / Straw and Clay / Cement Mixtures.

6- Consumption of Electrical Energy

Wadi Hadhramout climate is classified within the desert climate. It is characterized by the increase of the temperature at the middle summer. The highest average reaches 43 degree centigrade in July and the lowest is 9.4 degree centigrade in January. The difference between night and day temperatures reaches its highest level in October of about 20.05 degree centigrade. (6)

The field temperature measurements show heat differences between inside of clay house and its outside in May, proves that the temperature in the clay house almost keeps its stability during the day with slight increase during noon hours recording heat difference at the rate of 3.8 degree centigrade between night and day. The difference is found bigger outside the clay house and under shade, it reaches 18.1 degree centigrade. (4)

During the study of the consumption of electrical energy for the clay house and comparing it with another one made of cement displayed to the same conditions, the inhabitants of the clay house consume little amount of electrical energy to soften the air inside the house for thermal comfort. This is because of the thermal secular delay feature in the clay material. The clay house provides thermal comfort and suitable temperature almost stable during all day. See Figure 8 and Figure 9.
Fig. 8 Temperature distribution inside and outside clay house. (4)

Fig. 9 Temperature distribution inside and outside cement house. (4)
7- Conclusions

1. The experimental results obtained in this paper can be exploited for the proper choice of stabilizing materials and additives for the structural clay, particularly straw and cement.

2. Considering the straw effects, the following point can be stated: The compressive strength of 0.2 % of straw / clay mixture improves the performance of the clay. Hence from this result, the optimum percentage of straw to be used in practice can be proposed.

3. The cement / clay mixture improves economically the performance of the structural clay up to 6 % concentration; the maximum value to be recommended in practice.

4. Electrical energy consumption of clay houses compared with that of cement is considerably low. This is attributed to the thermal secular delay in clay material, and hence the good thermal insulation of structural clay in Hadhramout buildings is practically proved.
References


الخواص الفيزيائية لطين البناء في مباني حضرموت

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الملخص
توّقّعت في هذه الورقة، تأثيرات بعض المواد المضافة على الخواص الفيزيائية للطين الأنشائي المستخدم في مباني حضرموت. كما تطرق البحث إلى موضوع العزل الحراري في هذه المباني، ولكن عن طريق قياس معدلات الاستهلاك من الطاقة الكهربائية. إن الهدف المتوخى من البرنامج المختبري المكلف في هذه الدراسة هو محاولة إيجاد أي تحسينات ممّية تطرأ على طبيعة مادة الطين الأنشائي المستخدم في مباني وادي حضرموت، كما برهنت هذه الدراسة من خلال القياس بالدراسات الموجهة لاستهلاك الطاقة الكهربائية ومقارنتها بيوتوس مبنية من الخرسانة توافق و التناسب مادة الطين مع طبيعة و مناخ وادي حضرموت.

كلمات مفتاحية: خواص فيزيائية و ميكانيكية، طين إنشائي، مواد مضافة، أداء حراري، مباني حضرموت