Mechanical and Thermal Behaviors of Cement Stabilized Compressed Earth Bricks

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Abstract: Cement stabilized compressed earth brick is an important industrial raw material, and its mechanical and thermal properties have not been fully studied. The mechanical properties can be characterized by compressive strength index and thermal properties can be characterized by thermal conductivity index. The experimental scheme is arranged to solve the relationship between the performance of cement stabilized compressed earth brick and the influencing factors. The experimental results show that the compressive properties of cement stabilized compressed earth bricks are negatively correlated with the water binder ratio, positively correlated with the \( \frac{m(\text{cement})}{m(\text{water})} \), and not significantly correlated with the \( \frac{m(\text{earth})}{m(\text{cement} + \text{water})} \) and the fiber content. The thermal conductivity of raw soil cement curing mechanism brick is negatively correlated with \( \frac{m(\text{earth})}{m(\text{cement} + \text{water})} \), positively correlated with water binder ratio, and not significantly correlated with \( \frac{m(\text{cement})}{m(\text{water})} \) and fiber content.

1. Introduction
The most basic raw material of cement stabilized compressed earth brick is raw soil. Raw soil refers to the soil that has not been roasted or the undisturbed soil material that has only been simply processed. It has been used for a long time in China to build houses. It has the characteristics of local materials, simple construction, low cost, heat preservation and insulation, which is conducive to environmental protection and ecological balance. It has suitable application orientation and full play space in housing construction in China, especially in poor rural areas. Compared with the wall materials of modern industrial production, there are obvious deficiencies in physical and mechanical properties durability of raw earth materials and their products, which affect the safety and durability of raw earth buildings and hinder the further development of raw earth buildings. In recent years, scholars at home and abroad have made remarkable progress in the research on the modification technology of raw soil and its products from both physical and chemical aspects, and have built modern buildings with raw soil blocks as the main building materials. At present, the research and development of bonding materials for raw soil block is relatively backward. The research shows that the bonding materials have an effect on the overall stability of masonry structure. The physical properties of raw earth wall materials mainly include durability, mechanical properties and thermal properties. Researchers at home and abroad mainly conduct a lot of research on improving the durability and mechanical properties of raw earth materials. Raw earth materials are precious wealth accumulated for us in the thousands of years of architectural civilization evolution history. Raw earth materials have excellent environmental protection and thermal properties, easy to obtain and preparation A series of advantages, such as simple art and low price, are common ecological materials.

Because of its porosity and interaction with water vapor, raw earth wall materials have "breathing function", which can adjust indoor temperature and humidity, and effectively improve indoor thermal and humidity environment. The thermal conductivity also increases with the increase of dry density.
The thermal conductivity increases slowly with the increase of dry density. The relationship between compressive strength and thermal conductivity is linear. We will list the four main factors that affect the thermal conductivity: wheat straw, lime and building cement, and rank them in order according to the degree of influence, because the thermal conductivity of these three substances is quite different. In particular, the thermal conductivity of wheat straw is large, and it also has the effect of pulling knot, so it has a great influence on the thermal conductivity of adobe brick. There is obvious correlation between lime and thermal conductivity, and the influence of building cement on thermal conductivity is relatively small. Because the dry density of the adobe sample indirectly reflects the combination of the microphase structure between the raw soil particles and wheat straw, lime, building cement from one side. Through raw material compounding and composition optimization, the new raw soil composite wall material will have the characteristics of high thermal resistance and high heat storage, excellent thermal performance and excellent mechanical performance and durability. The excellent thermal performance can improve the living comfort of residents, which is suitable for living, and is the pursuit of current living. This paper focuses on the mechanical and thermal properties of the cement stabilized compressed earth brick, providing guidance for the selection of residential building materials.

2. Experimental materials and methods

2.1 Experimental materials

The physical properties of raw soil materials refer to some special properties after the interaction between soil particles with different chemical components and water. These properties play a decisive role in the engineering application of raw soil materials, and also have different degrees of influence on the forming effect and various performance indexes of raw soil blocks. The three main physical properties are plasticity, liquid limit and plasticity. Plasticity refers to that the soil can be shaped into any shape under the action of external force without damaging the connection force between soil particles. When the external force is removed, the shape of the soil remains unchanged, also known as plasticity. When the water content of the soil increases and reaches the upper limit of plasticity, the soil becomes a fluid state, then the water content of the upper limit of plasticity is called the liquid limit. The liquid limit index minus the lower limit water content of plasticity is the plasticity index, so the plasticity index can reflect the plasticity of soil quantitatively. Raw soil: it comes from rural areas of Fujian Province and is naturally dried. It's hard to break it off by hand. Grind the soil and sift it through 0.5mm sieve. Mineral powder: Fujian Yixin Iron and Steel Co., Ltd., with a density of 2.88g/cm3 and a specific surface area of 421 m²/kg. NaOH, Tianjin Beilian Fine Chemicals Development Co., Ltd., white granular solid, with NaOH content more than 96.0%, carbonate (calculated by Na₂CO₃) content less than 1.5%; Na₂SiO₃·9H₂O, Tianjin Fuchen chemical reagent plant, white granular solid, the ratio of Na₂O and SiO₂ content is 1.03 ± 0.03. Water glass is a glass like fusion of alkali silicate. According to the different kinds of alkali metal oxides, there are mainly sodium water glass and potassium water glass. Its chemical composition can be expressed by general formula. Generally speaking, it refers to alkali metal oxide, such as or from, etc., and refers to modulus of water glass. It is an important parameter of water glass. It is the ratio of molar amount of substance in water glass to molar amount of alkali metal oxide substance in water glass. The industrial water glass used in this experiment was sodium water glass, and its modulus was 3:1.

2.2 Experimental methods

Taking the plain soil in Fujian Province as the research object, we selected Na₂SiO₃: NaOH = 1:1 mixed activator to analyze the influence of the quality ratio of raw soil content, mineral powder and fly ash on the mechanical properties of cement stabilized compressed earth bricks. At the same time, the influence of sisal fiber on the mechanical properties of the modified adobe brick was analyzed by adding sisal fiber under the same factors. The content of sisal fiber was 0.5% of the air-dried soil quality of each group. The specific test scheme is shown in Table 1.
Table 1. Experimental scheme

| order | m (earth): m (cement + water) | Water binder ratio | m(cement): m (water) | fiber content |
|-------|-------------------------------|--------------------|----------------------|--------------|
| 1     | 2.0                           | 0.25               | 4:1                  | 0.5          |
| 2     | 2.0                           | 0.25               | 3:2                  | 0            |
| 3     | 2.0                           | 0.25               | 2:1                  | 0.5          |
| 4     | 2.0                           | 0.25               | 3:1                  | 0            |
| 5     | 2.5                           | 0.25               | 4:1                  | 0.5          |
| 6     | 2.5                           | 0.25               | 3:2                  | 0            |
| 7     | 2.5                           | 0.25               | 2:1                  | 0.5          |
| 8     | 2.5                           | 0.25               | 3:1                  | 0            |
| 9     | 3.0                           | 0.25               | 4:1                  | 0.5          |
| 10    | 3.0                           | 0.25               | 3:2                  | 0            |
| 11    | 3.0                           | 0.25               | 2:1                  | 0.5          |
| 12    | 3.0                           | 0.25               | 3:1                  | 0            |

We calculated the amount of each group of materials according to the designed proportion, and added them to the mixer in the order of raw soil, mineral powder, fly ash, standard sand, sisal fiber and activator solution for mixing. After mixing, we take out the mixture from the mixer and put it into the test mould. The size of the test piece is 240mm * 115mm * 53mm. After placing for at least 24 hours, the mould shall be removed. After removing the mould, the compressive strength of the adobe brick shall be measured by natural curing for 60 days under indoor conditions. The number of uniform design tests is equal to the level number of factors, which is an excellent test design method to greatly reduce the number of tests. In recent years, domestic scholars have done a lot of research on the theory of uniform design, and various disciplines have also introduced the uniform design method into experimental design. Especially when the model is complex, the number of uniform design tests is small and the uniformity is good, and the nonlinear and linear models are well estimated and analysed.

The cement stabilized compressed earth bricks produced in the experiment are shown as follows:

![Figure 1. Cement stabilized compressed earth bricks produced in the experiment](image)

3. Mechanical behaviors of cement stabilized compressed earth bricks

3.1 Experimental principles of mechanical behaviors

In the process of making raw brick, the density of the modified raw earth material can be effectively changed by pressing the modified raw earth material under the forming pressure of the manufacturing process. The modified raw soil material itself is a kind of loose porous material. Under the effect of
external pressure compaction, there will be movement and dislocation between the particles of the material, the gas in the pores of the modified raw soil material will be squeezed out, and the reduction of the pore volume shows the increase of the density of the modified raw soil material. When the modified raw soil material with high density is subjected to external load, the particles of each particle size component of the modified raw soil material are effectively arranged and occluded with each other. The cohesive force inside the matrix limits the deformation caused by the external force and improves the bearing capacity of the material. Compressive strength is one of the main indexes to characterize the mechanical properties of raw soil materials, which indicates the ability of raw soil materials to bear vertical load. As one of the most important mechanical properties of building materials, the research on the compressive strength of raw soil materials has always been the focus of researchers at home and abroad. Through a large number of tests, it is found that the compressive strength of raw soil material is affected by the mineral composition, particle size distribution, moisture content, forming pressure, density and other factors. Although it is very difficult to establish a unified guidance manual for the construction of raw soil buildings due to the differences of soil properties, it can provide guidance and reference for the construction process of raw soil buildings to find out the action law of various influencing factors on the compressive strength and determine the influence range. When the high-density raw soil material is subjected to the external load, the soil particles of each particle size component are effectively arranged and occluded with each other. The cohesive force inside the matrix limits the lateral deformation caused by the external force and improves the bearing capacity of the material.

3.2 Experimental results of mechanical behaviors

The experiment was designed by uniform test design method, and the results are shown in Table 2. We use SPSS software to analyze the correlation first, and get the factors that affect the compressive strength. Then we use the density factor and a small amount of modified materials to make one-dimensional nonlinear fitting, and get the relationship between multiple factors and compressive strength index.

Table 2. Different compressive strengths of different experiments

| order | m (earth): m (cement + water) | Water binder ratio | m(cement): m (water) | fiber content | compressive strength (MPa) |
|-------|-------------------------------|--------------------|----------------------|--------------|---------------------------|
| 1     | 2.0                           | 0.25               | 4:1                  | 0.5          | 20.06                     |
| 2     | 2.0                           | 0.25               | 3:2                  | 0            | 19.52                     |
| 3     | 2.0                           | 0.25               | 2:1                  | 0.5          | 19.84                     |
| 4     | 2.0                           | 0.25               | 3:1                  | 0            | 17.49                     |
| 5     | 2.5                           | 0.25               | 4:1                  | 0.5          | 15.19                     |
| 6     | 2.5                           | 0.25               | 3:2                  | 0            | 18.54                     |
| 7     | 2.5                           | 0.25               | 2:1                  | 0.5          | 15.68                     |
| 8     | 2.5                           | 0.25               | 3:1                  | 0            | 16.32                     |
| 9     | 3.0                           | 0.25               | 4:1                  | 0.5          | 17.24                     |
| 10    | 3.0                           | 0.25               | 3:2                  | 0            | 16.09                     |
| 11    | 3.0                           | 0.25               | 2:1                  | 0.5          | 17.38                     |
| 12    | 3.0                           | 0.25               | 3:1                  | 0            | 19.85                     |

3.3 Results analysis of mechanical behaviors

Correlation analysis means that there is a certain relationship between variables, but the number is not strictly corresponding to the dependency. This kind of correlation can be simulated by regression model. The correlation between this phenomenon is often shown as the causal relationship between the corresponding external factors of materials and the performance of materials. The determination coefficient $R^2$ is used to determine the goodness of fit of regression equation in autocorrelation.
Generally, it can be considered that the regression equation obtained when $R^2$ is greater than 0.9 fits well, while when $R^2$ is less than 0.5, it is difficult to explain the dependence between variables. $F(1,10) = 4.96$. For a given significance level, there is a very small possibility that $f$ is greater than $F(1,10)$. But now it is larger than that. According to the principle of practical inference, we reject the hypothesis that the regression equation is significant. Otherwise, we think the regression equation is not significant.

Table 3. Correlation analysis table of mechanical behaviors

| variable | m (earth): m (cement + water) | Water binder ratio | m (cement): m (water) | fiber content |
|----------|-------------------------------|--------------------|------------------------|--------------|
| $R^2$    | 0.361                         | 0.955              | 0.910                  | 0.148        |
| $F$      | 1.521                         | 8.661              | 7.958                  | 1.323        |

The results show that the determinable coefficient between m (earth): m (cement + water) and compressive strength is 0.361, indicating that there may be a slight correlation between the two variables. However, assuming that the F-test value of the two variables is 1.521, less than 4.96, we accept that there is no significant correlation between the correlation coefficient of m (earth): m (cement + water) and compressive strength. It can be concluded that there is no significant correlation between m (earth): m (cement + water) and compressive strength.

From the correlation analysis results shown in Table 3, it can be seen that the determinable coefficient between water binder ratio and compressive strength is 0.955, indicating that the two variables are highly correlated. At the same time, if the F-test value of the two variables is 8.661, that is, $F = 8.661$, then we reject the original hypothesis and accept that the two variables are significantly correlated at the level of $\alpha = 0.05$. It can be concluded that there is a high negative correlation between the water binder ratio and the compressive strength, that is, the less the water binder ratio, the higher the compressive strength.

From the correlation analysis results shown in Table 3, it can be seen that the determinable coefficient between m(cement): m (water) and compressive strength is 0.910, indicating that the two variables are highly correlated. At the same time, if the F value of the two variables is 7.958, the original hypothesis is rejected and the two variables are significantly correlated at the level of $\alpha = 0.05$. It can be concluded that there is a high positive correlation between the density and the compressive strength, that is, the higher the density is, the higher the compressive strength is.

From the correlation analysis results shown in Table 3, it can be seen that the determinable coefficient between fiber content and compressive strength is 0.148, indicating that there may be a slight correlation between the two variables. However, if the two variable F test value is 1.323, far less than 4.96, the original hypothesis is rejected. We think that there is no significant correlation between fiber content and compressive strength.

4. Thermal behaviors of cement stabilized compressed earth bricks

4.1 Experimental principles of thermal behaviors

The outdoor climate affects the indoor environment by its effect on the building envelope. The thermal performance of the building envelope has a great influence on the indoor thermal environment and the energy consumption of heating and air conditioning. The improvement of thermal performance of building wall materials has a positive effect on the improvement of thermal performance of the wall, and the use of reasonable thermal insulation structure has a more obvious effect on the improvement of thermal performance of the building wall. In the thermal design of rural residential buildings, considering the local climate characteristics and economic conditions of cold winter and hot summer, the paper puts forward energy-saving structural measures suitable for local residents, which is very important for improving the living conditions of local residents and improving the energy-saving level of residential buildings. The reference values of thermal insulation construction form and thickness of thermal insulation materials provided in the standard take thermal insulation energy-saving wall blocks as wall materials, which are not applicable in Turpan, Xinjiang. The reason is that these energy-saving wall blocks are porous or hollow wall materials, and their thermal conductivity is generally low, which is conducive to the wall insulation in winter, but it is very unfavourable to the thermal stability of the
wall, which seriously restricts the weakening effect of the wall on the outdoor temperature fluctuation in summer. By simultaneous interpreting the physical characteristics of the unsteady heat transfer of the sample, the temperature change rate of the specimen surface is collected at high speed through the test film with the heating and high-precision temperature sensors. The temperature change rate is related to the heat transfer coefficient. The thermal conductivity is calculated through a mathematical model with the national invention patent. Because the testing principle is only related to the thermal characteristics of the material, it only acts on the shallow layer of the material surface during the testing, and it does not need to reach the steady state of heat flow like the traditional heat conduction instrument, and it needs to know the temperature difference between the two sides to test. Therefore, it can be used to measure the solid materials and powder materials from gas gelling to glass, which is beyond the reach of traditional thermal conductivity instrument. Compared with traditional steady-state testing method, this test method overcomes the surface thermal resistance error which is not overcome by simultaneous interpreting.

4.2 Experimental results of thermal behaviors
The test is designed by uniform test design method, and the results are shown in the figure below. SPSS software can be used to analyze the correlation first, and the factors that affect the compressive strength can be obtained. Then, the density factor and a small amount of modified materials are fitted by one-dimensional nonlinear fitting, and the relationship between multiple factors and thermal conductivity index is obtained.

| order | m (earth): m (cement + water) | Water binder ratio | m(cement): m (water) | fiber content | W (m.k)⁻¹ |
|-------|-----------------------------|-------------------|---------------------|--------------|-----------|
| 1     | 2.0                         | 0.25              | 4:1                 | 0.5          | 0.621     |
| 2     | 2.0                         | 0.25              | 3:2                 | 0            | 0.376     |
| 3     | 2.0                         | 0.25              | 2:1                 | 0.5          | 0.517     |
| 4     | 2.0                         | 0.25              | 3:1                 | 0            | 0.734     |
| 5     | 2.5                         | 0.25              | 4:1                 | 0.5          | 0.231     |
| 6     | 2.5                         | 0.25              | 3:2                 | 0            | 0.562     |
| 7     | 2.5                         | 0.25              | 2:1                 | 0.5          | 0.674     |
| 8     | 2.5                         | 0.25              | 3:1                 | 0            | 0.599     |
| 9     | 3.0                         | 0.25              | 4:1                 | 0.5          | 0.411     |
| 10    | 3.0                         | 0.25              | 3:2                 | 0            | 0.678     |
| 11    | 3.0                         | 0.25              | 2:1                 | 0.5          | 0.355     |
| 12    | 3.0                         | 0.25              | 3:1                 | 0            | 0.446     |

4.3 Results analysis of thermal behaviors
Similar to the analysis of experimental results of mechanical properties, correlation analysis table of thermal behaviors is as follows:

| variable | m (earth): m (cement + water) | Water binder ratio | m(cement): m (water) | fiber content |
|----------|-------------------------------|-------------------|---------------------|--------------|
| R²       | 0.875                         | 0.922             | 0.247               | 0.351        |
| F        | 9.652                         | 10.441            | 3.526               | 2.991        |

From the correlation analysis results shown in Table 5, it can be seen that the determinable coefficient between m (earth): m (cement + water) and thermal conductivity is 0.875, indicating that the two variables are highly correlated. At the same time, if the F-test value of the two variables is 9.652, i.e. F= 9.652, the original hypothesis is rejected and the two variables are significantly correlated at the level of α = 0.05. It can be concluded that there is a high negative correlation between m (earth): m (cement
+ water) and thermal conductivity, that is, the less the content of m (earth): m (cement + water), the higher the thermal conductivity.

From the correlation analysis results shown in Table 5, it can be seen that the determinable coefficient between water binder ratio and thermal conductivity is 0.922, indicating that the two variables are highly correlated. At the same time, if the F value of the two variables is 10.441, the original hypothesis is rejected and the two variables are significantly correlated at the level of α = 0.05. It can be concluded that there is a high positive correlation between density and thermal conductivity, that is, the higher the density is, the higher the thermal conductivity is.

The results show that the determinable coefficient between m(cement): m (water) and thermal conductivity is 0.247, indicating that there may be a slight correlation between the two variables. However, assuming that the F-test value of the two variables is 3.526, less than 4.96, we accept that there is no significant correlation between the coefficient of thermal conductivity and the coefficient of thermal conductivity. It can be concluded that there is no significant correlation between m(cement): m (water) and thermal conductivity.

From the correlation analysis results shown in Table 5, it can be seen that the determinable coefficient between fiber content and thermal conductivity is 0.351, indicating that there may be a slight correlation between the two variables. However, if the two variable F test value is 2.991, far less than 4.96, the original hypothesis is rejected. We think that there is no significant correlation between fiber content and thermal conductivity.

5. Summary and prospect
In this paper, the mechanical properties and thermal properties of cement stabilized compressed earth bricks are studied by experiments, and the relationships between properties and factors are revealed. The experimental results show that the compressive properties of cement stabilized compressed earth bricks are negatively correlated with the water binder ratio, positively correlated with the m(cement): m (water), and not significantly correlated with the m (earth): m (cement + water) and the fiber content. The thermal conductivity of raw soil cement curing mechanism brick is negatively correlated with m (earth): m (cement + water), positively correlated with water binder ratio, and not significantly correlated with m(cement): m (water) and fiber content. In this study, we only test the compressive strength and thermal conductivity of the main mechanical properties, but lack of other performance indexes. In the future, other indexes of mechanical or thermal properties can be added, and the regression analysis method can be used.

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