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Experimental Evaluation of Three Different Humidity Conditions to Physical and Mechanical Properties of Three Different Mixtures of Unfired Soil Bricks

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Abstract

Unfired brick is considered as a more environmentally friendly material than fired brick. It has lower mechanical properties than that of fired brick where humidity influences both bricks. Physical and mechanical properties of unfired bricks made of three kinds of mixtures were studied experimentally under three humidity conditions. The first kind of unfired brick was made only with soil and water while the second type was made of a mixture of soil, water and lime, and the third type was a mixture of soil, water, lime and uniform treated coir where 4% of lime mass was substituted with coir mass. Physical properties evaluation consisted of water content, absorption, volume shrinkage and density of those unfired bricks. Some variations occur in the third type of unfired bricks physical test results, where in general in more humid conditions there are tendency to have higher density, higher absorption, higher water content and less volume shrinkage compared to two other types of unfired bricks. Mechanical properties are evaluated by its modulus of rupture, compressive strength and modulus of elasticity. It is found that the addition of 4% treated 2.5 cm coir gives better mechanical properties in humid conditions compared to others types of unfired bricks.

Keywords: coir, humidity, mechanical property, physical property, unfired bricks

1. Introduction

Many studies on unfired soil brick have spread within the past decade. Compressive and flexural strength of earth bricks were improved by adding lime and rice husk ash [1]. A recent study on unfired clay materials shows good energy efficiency and suggests a formidable economical alternative to the firing of clay building components [2]. Composite boards were fabricated by using a heat press machine with the coir fiber as the reinforcement and the rubber as matrix [3]. The use of lime in combination with other materials have been and are still currently being studied. Lime-clay reactions in the expansive clay were recently studied using microscopic analysis [4]. The combinations of fly ash and lime granule have also showed to give excellent strength to unfired bricks [5]. Soil bricks are common products in most provinces in Indonesia. Fired clay
bricks that are produced, traditionally, by firing the bricks with woods are used for the construction purposes since hundred years ago in Indonesia. However, in some provinces like West Java, unfired soil lime bricks coexist with fired clay bricks. The use of unfired soil lime bricks for traditional landed houses in these regions can be attributed to the low productions costs, which lead to cheaper building materials. In general, only 2 weeks or 14 days after the production process, unfired soil lime bricks are available in the market for potential buyers. In the market, the bricks are subjected to different condition of storage placement depending on the seller depot availability. Some seller place the unfired bricks under the roof but partially in open air condition, others seller place unfired bricks in a partially close storage and the rest in open air condition. Same as fired bricks, the manufacturing process of traditional unfired soil lime bricks is done manually. The traditional mix itself consists of water that is added to a mixture of 4 parts volume of soil to 1 part volume of lime. The mixture is then thrown into a mold for manual pressing. However, after several interviews with several local brick makers, there is still no clear answer on the amount of mixing water that should be added to the mixture. The amount of water added by the brick makers serves only for the purpose of soil-lime paste making. It does not take into account existing water content of soil and lime, and does not consider future final strength of those unfired soil-lime bricks. Previous study [6] has proposed two mix designs, which are based on existing conditions and appropriate water proportion. The two mixtures could solve the above problem of fixing the amount of mixing water. From those two mixes, the mix design with the lower proportion of lime is used in this study for 2 kinds of mixture. The effect of ages to the strength of unfired bricks which were made from that kind of mixture was studied previously in several attempts. Compressive and bending strength of early ages unfired bricks containing uniform untreated fibers are in general higher than those containing non uniform untreated fibers [7]. 4% non uniform length of coconut fibers addition to the same mixture have been studied in accordance with bricks ages of 14, 28, 56, and 90 days [8]. Another study [9] with the same mixture but with an addition of 4% uniform length of coir has been studied in accordance to those same bricks ages. The second batch of soil and lime with different water content were taken from the site to the laboratory almost 10 to 14 months after studying bricks made from first batch of soil and lime. Using the same formulation of mix design based on mass proportion, influence of three different humidity conditions to physical and mechanical properties of three different mixtures of unfired soil bricks with or without coir will be studied in accordance to the above mentioned bricks ages. The different condition of bricks placement by the different bricks seller to storage the bricks in the market initiated this study.

2. Experimental and Methods

Soil properties. The study uses similar materials to those materials used to produce traditional unfired soil lime bricks in West Java Province, Indonesia. Soil was taken from the hills at a small village called Galuga. The second batch of soil which was used in this study, was taken not far from the excavation location of the first batch soil. Properties of the soil from the first batch were investigated using two laboratory tests. A triaxial test on hand-boring specimens taken from the site was performed to show the shear strength, cohesion and angle of internal friction of the soil. These parameters are only used to help classify the soil. A grain size distribution test of the soil was also performed to show the type and gradation of the soil. Triaxial test on specimens taken from the site gives an angle of internal friction of 36° and cohesion of 0.25 kg/cm². The grain size distribution of the soil, which is used for the unfired soil lime bricks, spans from clay to medium grained sands. From three samples, approximately 60% to 80% of the soil, by mass, consists of fine to medium grained soils. These results are reciprocal. The grain size distribution of the second batch soil is almost similar to the first batch with approximately 75% to 85% of fine to medium grained soils as presented in Figure 1.

Water contents of the first and second batch of soil are 30% and 40.581% respectively. The specific gravity of the second batch of soil is about 2.464. By conducting Atterberg limits test on the specimen taken from the second batch, it shows that its shrinkage limit is at 32.44%, liquid limit at 52.778%, plastic limit at 37.031%, and plasticity index at 15.75%. These results categorize the soil specimen as clay.

Recent characterization [8], [10] of the soil minerals from the first and second batch of soil has resulted that Muscovite, Kaolinite, Cristobalite and Hematite are the four main source minerals of the soil.

![Average Grain Size Distribution of Second Batch Soil](image_url)
Although there is a slight mineral difference percentage, the two batches of soil have similar minerals configuration. As shown in Table 1 from the grain size distribution test and minerals configuration results these 2 batches are indeed have similar properties. By this condition, the mix design applied to the first batch of soil can be also used to the second batch of soil.

**Lime and mixing water.** Both batches of lime were bought from a lime home-plant near Bogor. The lime was produced in its own traditional kiln. The properties of lime are shown in Table 2. The mixing water for the mixture was taken from the Laboratory in the University.

**Coconut fibers.** Coconut fibers were bought from a coconut fiber home industry in Depok, West Java. Coconut fibers were manually separated from the coconut’s shell and outer skin. Those fibers were then separated and cut manually to the targeted lengths. Untreated fibers were left in room temperature before any tests. Untreated fibers are fibers which are not being treated with water or chemical or other substance. To get water content, five samples of untreated fibers that have similar lengths were dried in an oven for 2 days at a temperature of 50 °C.

Treated fibers were obtained by washing the surface of the fibers, then letting the water drains gravitationally from the fibers for 24 hours in room temperature and drying them in an oven for one day. To get the water content, five samples of treated fibers were again dried in an oven for one day more at a temperature of 50 °C. Table 3 presents water content for untreated and treated fibers.

**Brick making and storage.** The mix itself consists of water that is added to a mixture of soil and lime, and with or without coir. The mixture is then thrown into a mold for manual pressing as shown in Figure 2a. To have a repetitive pressure, a manual indicator showing the load is placed between the crank and mold. Table 4 shows the Mix Proportion for Each Mixture

Table 1. Soil Properties

<table>
<thead>
<tr>
<th></th>
<th>First batch</th>
<th>Second Batch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain size distribution of fine to medium grained soils</td>
<td>60% to 80%</td>
<td>75% to 85%</td>
</tr>
<tr>
<td>Mineral composition:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscovite</td>
<td>56%</td>
<td>56.9%</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>19.4%</td>
<td>18.1%</td>
</tr>
<tr>
<td>Cristobalite</td>
<td>15%</td>
<td>13%</td>
</tr>
<tr>
<td>Hematite</td>
<td>9.6%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Table 2. Lime Properties

<table>
<thead>
<tr>
<th></th>
<th>First batch</th>
<th>Second Batch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>2.708</td>
<td>2.708</td>
</tr>
<tr>
<td>Water content</td>
<td>35%</td>
<td>35.047%</td>
</tr>
</tbody>
</table>

Table 3. Coconut Fibers Water Content

<table>
<thead>
<tr>
<th></th>
<th>Untreated</th>
<th>Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>5.379%</td>
<td>8.108%</td>
</tr>
<tr>
<td>Lowest</td>
<td>4.636%</td>
<td>7.192%</td>
</tr>
<tr>
<td>Highest</td>
<td>6.228%</td>
<td>9.028%</td>
</tr>
</tbody>
</table>

Table 4. Mixture Proportion

<table>
<thead>
<tr>
<th>Material</th>
<th>Soil</th>
<th>Water</th>
<th>Lime</th>
<th>Coir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture 1</td>
<td>1</td>
<td>6.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixture 2</td>
<td>1</td>
<td>5.7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Mixture 3</td>
<td>1</td>
<td>5.7</td>
<td>1</td>
<td>4%</td>
</tr>
</tbody>
</table>
Those bricks will be compared to plain bricks made of only soil and water as mentioned in the previous subchapter. Compressive strength and modulus of rupture at 4 different ages were tested and compared. The tests conducted are in accordance with ASTM Designation: C 67–03a [12]. Half bricks were used in the compression test while full bricks were used in the bending test. Six half brick specimens were used for the compression test, while six full bricks were tested to obtain modulus of rupture. From compression test using...
6 cube specimens with a dimension of 5 cm x 5 cm x 5 cm, modulus of elasticity of the bricks were obtained.

**Physical properties evaluation of bricks.** Three half bricks were used for the absorption test, while six full bricks were used to indicate volume and density change of the bricks along 90 days. The absorption of the bricks is obtained according to ASTM Designation: C 67–03a [12]. Volume change and density identification were conducted when age of unfired bricks for all humidity condition is at 3, 7, 14, 28, 56, and 90 days, while water content and absorption were evaluated at age 14, 28, 56, and 90 days. Those numbers of days represent early, medium and long time ages of bricks. At ages of 3 and 7 days, unfired bricks made of mixture 1 can’t be tested as those bricks were crumbled during the water content and absorption tests. Figures in the subsequent paragraph are presented by medium, low and high humidity order as medium humidity represents existing real humidity at the Laboratory when the test are conducted. The benchmark taken for this study is the closest percentage to 100% among all percentage obtained from all kind of bricks. Others figures do not show benchmark as no corresponding results are near 100%.

3. Results and Discussion

**Physical properties evaluation of unfired bricks.**

**Volume shrinkage.** Figure 5a, 5b and 5c present volume history of three kinds of bricks made of three different mixtures as function of days. Shrinkage by means of brick volume change along 90 days, of three kinds of bricks represented by mixture 1, 2, and 3 shows similar phenomenon where the average volume of all type of bricks for all humidity condition decrease with time but with different rate of volume shrinkage. For facilitating the comparison, volume of unfired brick made of mixture 2 at low humidity condition is placed as benchmark which is 100%. It can be seen that the volume of unfired brick made of mixture 1 decrease rapidly in low and medium density but not in high humidity condition as its water content will decrease slowly. Volume of unfired brick made of mixture 2 decreases slowly along 90 days while unfired brick made of mixture 3 performs the best for all humidity condition as the coir inside the brick confine the brick which in turn delay the volume change.

**Water content of unfired bricks.** Figure 6a, 6b, and 6c present present water content history of three kinds of bricks made of three different mixtures as function of days. For medium humidity condition, bricks made of mixture 3 show a slow decrease of water content. However for this kind of bricks at age of 56 days as it was rainy season, the coir inside the bricks seems to raise the water content. The coir inside the bricks made by mixture 3 contributes also for the increase of water content in the high humidity condition but at age of 56 and 90 days water content of brick made of mixture 3 become relatively stable. Bricks made of mixture 1 and 2 show its average water content decrease as becoming older.

**Absorption of unfired bricks.** Figure 7a, 7b and 7c present average absorption history of three kinds of bricks made of three different mixtures as function of days. As shown in the Figures there are no big changes in absorption capacity for all kind of bricks mixtures along 90 days time. Average absorption of unfired brick made of mixture 1 decrease slowly as function of days. Unfired bricks made of mixture 3 show an important increase of absorption as bricks become older. The existence of the coir inside unfired bricks made of mixture 3 increase the bricks absorption as it has the capacity to absorb water. At early age as soil lime bricks still wet, water inside the coir will not escape from the bricks.

**Density of unfired bricks.** Figure 8a, 8b and 8c show density history of three kinds of bricks made with three different mixtures as function of days. For facilitating the comparison, density of unfired brick made of mixture 2 at medium humidity condition is placed as benchmark which is 100%. Density along 90 days, of three kinds of bricks represented by mixture 1, 2, and 3 shows similar phenomenon where the average density of all type of bricks for two humidity conditions, low and medium humidity, decrease with time but with different rate of density loss. It can be explained that the water has been escaped from the bricks. The decreasing in water content along 90 days is the main cause of this density loss. From the beginning, average density of

![Figure 5. Volume Changes for 3 Kind of Unfired Bricks Along 90 Days for Low, Medium and High Humidity Condition](image-url)
unfired bricks made of mixture 3 is already below the two others type of unfired bricks as there was mass substitution of lime to coir. At early age, coir that substituted the lime mass was the coir containing some water inside. As those bricks containing coir become older, water gradually escaping from the coir and soil-lime which implies the density loss.

(a) Medium humidity            (b) Low humidity               (c) High humidity

Figure 6. Water Content for 3 Kind of Unfired Bricks Along 90 Days for Low, Medium and High Humidity Condition

(a) Medium humidity             (b) Low humidity                    (c) High humidity

Figure 7. Absorption History for 3 Kind of Unfired Bricks Along 90 Days for Low, Medium and High Humidity Condition

(a) Medium humidity             (b) Low humidity                  (c) High humidity

Figure 8. Density History for 3 Kind of Unfired Bricks Along 90 Days for Low, Medium and High Humidity Condition

(a) Medium humidity             (b) Low humidity                  (c) High humidity

Figure 9. Compressive Strength of the Three Types of Bricks in Accordance with Ages and Three Humidity Conditions
Mechanical properties evaluation of unfired bricks. During the compression, bending and modulus elasticity evaluation, at ages of 3 and 7 days, unfired bricks made with mixture 1 can’t be tested as those bricks were crumbled during the testing.

Compressive strength of unfired bricks. Compressive strengths of the three types of unfired bricks with respect to four different ages were investigated. Figure 9a, 9b, and 9c show unfired bricks made of three different mixture give different average compressive strength at 14, 28, 56 and 90 days. Unfired bricks made with mixture 1 and 3 show degradation of average compressive strength after 56 days for all humidity condition. It is related to abrupt change of density at those days as shown at Figure 8a and 8b for both types of bricks.

After 28 days for high humidity condition, unfired bricks made of mixture 3 show an increase of average compressive strength as the presence of coir inside the bricks will give a kind of confinement to the soil-lime matrix in facing the compression. This is also partially valid for unfired bricks made of mixture 3 in medium humidity condition as the compressive strength decrease a little after 56 days. However in low humidity condition, as water content of the bricks and also the coir drastically decreasing, the tensile strength of the coir will be diminishing which in turn affect the confinement capacity of the coir to soil-lime matrix.
Figure 14. Unfired Bricks Made of Mixture 1 at 56 Day: (a) Humidity 91%, (b) 55%-65%, and (c) 64%-91%

Figure 15. Unfired Bricks Made of Mixture 3 at 28 Days: (a) Humidity 91%, (b) 55%-65%, and (c) 64%-91%

Figure 16. Unfired Bricks Made of Mixture 2 at 28 Days: (a) Humidity 91%, (b) 55%-65%, and (c) 64%-91%

Figure 17. Unfired Bricks Made of Mixture 1 at 28 Days: (a) Humidity 91%, (b) 55%-65%, and (c) 64%-91%

Figure 18. Iso-compressive Strength Curves of Unfired Bricks Made of Soil and Water Mixture in Accordance with Ages and Three Humidity Conditions
Figure 19. Iso-compressive Strength Curves of Unfired Bricks Made of Soil, Lime and Water Mixture in Accordance with Ages and Three Humidity Conditions

Figure 20. Iso-compressive Strength Curves of Unfired Bricks Made of Soil, Lime, Coir and Water Mixture in Accordance with Ages and Three Humidity Conditions

**Bending strength of unfired bricks.** Modulus of rupture (MOR) representing bending strengths of the three types of unfired bricks with respect to four different ages were investigated. Figure 10a, 10b and 10c show unfired bricks made of three different mixtures give different average bending strength at 14, 28, 56, and 90 days. As it is related to abrupt change of bricks density in accordance of ages, modulus of rupture of all types of bricks, are also degraded as bricks become older. For unfired bricks made with mixture 3, pattern of descend of modulus of rupture is almost similar for low and medium humidity conditions. As humidity and temperature vary with time, the moisture content of the brick varies where in turn will influence compressive strength and modulus of rupture of the bricks. The decrease of moisture content in turn increases voids in soil-lime bricks. The existence of more voids weakened axial and bending resistance of the bricks in facing external load applied on the bricks. However confinement effect which is given by the coir will slow the degradation of bending strength compared to two others type of unfired bricks. All kind of bricks exhibit higher decreasing rate in bending strength in accordance with ages compared to decreasing rate in axial strength as presented in Figures 9 and 10. Facing to the internal forces caused by bending moment, the existence of voids in the tensioned part of bricks gave birth of micro cracks that transformed rapidly to cracks and dropped bending strength of the bricks. In case of axial load applied vertically to half bricks, in early stage of loading the existence of voids bring bricks to experience some sort of consolidation as the water has escaped during the closure of the voids.

**Modulus of elasticity of unfired bricks.** Modulus of elasticity of the three types of unfired brick cubes with
respect to four different ages were investigated using brick cubes 5 x 5 x 5 cm$^3$. Figure 11a, 11b, and 11c show unfired brick cubes made of three different mixture give different average modulus of elasticity at 14, 28, 56, and 90 days.

Modulus of elasticity of all type of specimens at 3 different humidity condition exhibits similar curve pattern, where at 28 days or 56 days it achieves the highest elasticity modulus ranging from 60 to 250 MPa, and decreasing afterward in a range of 50 to 190 MPa. These conditions are in accordance with the compressive and bending strength history along 90 days, except for unfired cube made with mixture 3 for high humidity condition. The difference might come from the coir that is not well distributed in the small specimen like those cubes.

**Crack patterns of unfired bricks.** Figure 12, 13, and 14 show some sample of unfired bricks at age of 56 days after the compression test. The figures show crack pattern of the bricks from the side of the bricks, which are its width and thickness. In general, unfired bricks made of mixture 1 exhibit more cracks than those two other types for all humidity conditions.

Figures 15, 16, and 17 present overview of some sample of unfired bricks at age of 28 days after the bending test. In general, the crack pattern for all specimens made of different mixtures exhibit similar crack pattern at the middle of unfired bricks.

**Evaluation of the existence of lime and coir in soil water mixture.** Iso-compressive strength curves have been employed to evaluate the effect of the existence of lime and coir to the compressive and bending strength as function of three condition of average humidity and 14, 28, 56, and 90 days age.

Those equal strength curves could give insight on the effect of the addition of lime to soil-water mixture, and on the effect of the addition of coir to soil-lime-water mixture. The curves are obtained from the interpolation and extrapolation of the results of both compression and bending tests. The humidity showed on the ordinate is obtained from an average of humidity ranges. Figure 18, 19 and 20 show iso-compressive strength curves from three different mixtures. From Figure 18 and 19, it can be seen that iso-compressive strength curve of 1 MPa widen to the left and right side at age of 28 days. This condition is caused by the existence of lime which contributes to widen the iso-compressive strength of 1 MPa. From Figure 19 and 20, iso-compressive strength curve of 1 MPa vanishes and of 2.7 to 3.3 MPa emerges. Here the addition of coir contributes to increase the compressive strength in accordance with three conditions of humidity and brick’s ages. Area of lime and coconut fiber influences can be seen at the Figures.

4. **Conclusions**

Several experimental studies of the influence of humidity to the physical and mechanical properties of three type of unfired bricks made with three different mixture were conducted. The main conclusion of this study is as below: (1) The physical and mechanical properties of the unfired bricks in low and medium humidity condition decrease along the 90 days with different rate of degradation; (2) The addition of lime to soil-water mixture retards the rate of degradation of physical and mechanical properties of the unfired bricks at low and medium humidity conditions; (3) The addition of coconut fiber to soil-lime-water mixture retards moderately the rate of degradation of physical and mechanical properties of the unfired bricks at low and medium humidity conditions; (4) High humidity condition is relatively in favor of the physical and mechanical properties of unfired bricks made of specific studied soil, lime, coconut fibers and water mixture; (5) At the low and medium humidity condition, water content of the unfired bricks plays important role for the properties of the bricks.

**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

**Acknowledgement**

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