The Physical and Thermal Properties of Adobe Brick Containing Bagasse for Earth Construction

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Abstract

A form of natural architecture built with environmentally friendly materials, earth construction provides indoor protection from outside temperature conditions. In Thailand, adobe brick that contains rice husk is the most widely used material in earth construction. It is important to consider the strength and moisture absorption capacity of adobe brick. This research focuses on the feasibility of using agricultural by-products such as rice husk and bagasse in adobe brick mixtures with a percentage replacement of 0, 1, 2, 3 and 6% by weight of materials. The study explores the level at which replacing rice husk and bagasse in adobe brick effects optimal compressive strength, shrinkage, thermal conductivity, and moisture absorption. The results provide a guideline for producing adobe brick containing agricultural by-products with improved strength and lower moisture absorption. Adobe brick with performance improved in these ways will be beneficial for developing low-cost architecture for local people and for building hotels and recreation facilities for the tourism industry.

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1. Introduction

Industrial development has wrought far-reaching changes in Thailand, transforming many rural villages into cities and thereby ruining local ways of life, damaging the environment, and depleting natural resources. Of specific concern in this study is that construction industries have used and continue to use high amounts of energy manufacturing (Lertwattanaruk & Tungsirisakul, 2007). And, high energy use is by now accepted as one of the most important, if not the most important, factors implicated in global warming. Given the publicity that global warming has received and the body of knowledge pertaining to it that is now available, people have started to care more about protecting the natural environment and have come to understand that working against trends that promote global warming is the key to doing so. Thailand, for example, is located in the tropical zone, which means that the country experiences high temperatures and high levels of humidity. The average temperature is around 30–35 °C and humidity is around 70–80% conditions that are generally taken into account in efforts to construct buildings that are comfortable for users.

Earth construction offers a way for people to feel and actually become more meaningfully connected to nature because it is a form of natural architecture built with environmentally friendly materials (Taylor, 2009). Binici et al. (2007) studied the thermal isolation of fiber reinforced mud bricks as wall materials. Their results showed that the fiber reinforced mud brick house results in a temperature of 56.3% cooler than the concrete brick house in the summer and 41.5% warmer in the winter.

In Thailand, the most widely used material in earth construction is adobe brick containing rice husk (Lertwattanaruk &Tungsirisakul, 2007). However, the price of rice husk increased recently. In addition, rice husk is constituted of as much as 90% silica (SiO_2), the humidity-absorbing ability of which causes more humidity in the brick (Carter, Cannor, & Mansell, 1982; Chatveera & Lertwattanaruk, 2009). An alternative to rice husk is another agricultural material, bagasse, which can be used to make the bricks stronger and reduce humidity levels. The bagasse fiber has a fluff feature and does not have any compound that absorbs humidity; therefore, it renders the brick more efficient than rice husk in terms of offsetting humidity levels. This is beneficial for developing alternative low-cost architecture.

This research focuses on the use of agricultural by-products —specifically rice husk and bagasse—in producing adobe brick with enhanced properties that make it more suitable for construction than are materials used currently for this purpose. The objective of this research is to study the influence of agricultural rice husk and bagasse on the properties of adobe brick including compressive strength, shrinkage, and thermal properties. The percentage replacement of the agricultural fibers in adobe brick were 0, 1, 2, 3 and 6% by weight. The adobe brick samples were oven-dried for 24 hours. The moisture absorption of the adobe brick walls was studied in comparison with the lightweight concrete masonry.

1.1 Clay

The most fine-grained soil, clay is flexible when wet. It can absorb water and capable of holding nutrients and exchanging them at a high rate (Hall & Djerbib, 2004). On the basis of these qualities, clay is recommended for rice planting because it can accumulate water in the long term. It contains three types of particles: sand, silt, and clay. Of these the largest particle is sand, which is an incoherent granular soil and a good ventilate. The mid-sized particle is silt, which is brittle and invisible to the naked eye. Clay, the smallest particle, hardens when dry, is plastic when sufficiently wet, has high porosity, and prevents air and water from circulating (Ministry of Natural Resources and Environment, 2009).

1.2 Quality changes in clay

The properties of clay depend on the amount of water in clay. The amount of water divided by the conditions of clay is called the Atterberg's Limits; this includes the Liquid Limit (L.L), the minimum amount of water whereby formerly plastic soil is considered to have become semi-liquid. The Plastic Limit (P.L.) is the minimum amount of water required to transform soil from a semi-solid state to a plastic state. And, the Shrinkage Limit (S.L.) is the maximum water content at which a reduction in water content does not cause an appreciable reduction in volume of the soil mass (Terzaghi, Brazelton, & Gholamreza, 1996).

The values of all three limits can be used to analyze the properties of soil in accordance with the Plasticity Index (PI). The PI value indicates the relative plasticity of clay and represents the toughness of the clay and its sensitivity to changing soil-mass conditions. Soil with a low PI value, such as clay that contains a high percentage of silt, is highly sensitive to changing soil mass; that is, a small amount of water can cause the soil condition to change from semi-solid to liquid. And, PI value can represent the soil's activity. The relative toughness of clay is related to 2 factors: its percentage of particles smaller than 0.002 mm, which is the size of clay fraction, and its percentage of clay minerals.

Description	Activity
Inactive clays	< 0.75
Normal clays	0.75–1.25
Active clays	1.25–2.00
Highly active clays	>2.00

Source: Terzaghi, Brazelton, & Gholamreza, 1996.

Table 1. Activity of clays.

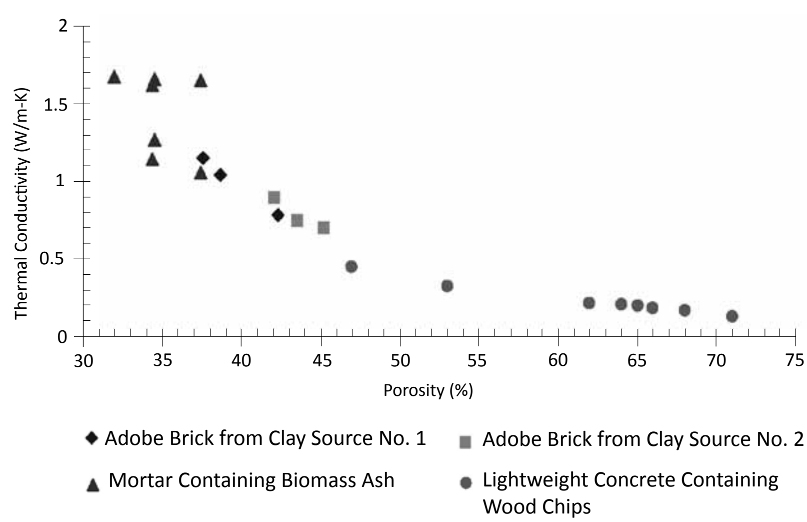
The clay's activity can be calculated from the ratio of the Plasticity Index to the percentage of clay particles smaller than 0.002 mm (Terzaghi, Brazelton, & Gholamreza, 1996). Activities for each type of clay are listed in Table 1.

1.3 Factors influencing compressive strength

In the research by Kumar, Singh and Mohan (2006), the mixture of clays in regard to the different amounts of sand from 0–12% were tested. Higher percentages of sand indicated higher compressive strength; however, when the sand content exceeded 10% by weight compressive strength was reduced. By adding the fibrous materials in the mixture, the amount of fibers and the fiber length affected the shrinkage and compressive strength of clay, thus increases in the proportion of fibers in the clay increased compressive strength, with the highest strength accruing from fibers with a length of 12 mm (Bouhicha, Aouissi, & Kenai 2005).

The interface layers of fibrous materials increased the compressive strength and a certain geometrical shape of these layer materials gave the best results (Binici et al., 2005). Lertwattanaruk and Tungsirisakul (2007) studied the effects of agricultural materials, such as rice husk and coconut husk, in the proportions of 1, 2, 3, 6 and 9% by dry weight of materials on the compressive strength of adobe brick. Their results showed that rice husk and coconut husk improved the compressive strength of adobe bricks. However, they also showed that more than 3% rice husk decreased compressive strength. On the other hand, coconut husk improved compressive strength to a greater extent.

Figure 1. Thermal conductivity of adobe bricks and cement mortar.



1.4 Thermal properties

Thermal conductivity depends on the structure of materials. High-density materials can transfer heat well (Goodhew & Griffiths, 2005). Bouguerra et al. (1998) studied the properties of lightweight concrete made from clay, cement and wood chips. Their results showed that high percentage of wood chips in lightweight concrete results in a high level of porosity. Moreover, porosity is related to heat transfer; that is, the higher the porosity, the lower the heat transfer. In addition, the lightweight concrete with a high percentage of wood chips are better insulators than those with a lower percentage of wood chips, but the compressive strength reduces accordingly. In the study of adobe bricks made from clay and natural fibers, Lertwattanaruk and Tungsirisakul (2007) reported that adobe brick containing rice husk is highly porous and can retard the flow of heat through its pores effectively, thus causing the thermal conductivity to decrease. However, coconut husk which is less porous than rice husk showed an increase in thermal conductivity when mixed in adobe brick.

In Figure 1, a comparison of the thermal conductivity of adobe bricks containing rice husk and coconut husk made from two clay sources (Lertwattanaruk & Tungsirisakul, 2007) and cement mortar containing biomass ash (Lertwattanaruk & Chatveera, 2008) showed that adobe brick has a lower thermal conductivity than does the cement mortar. In addition, a comparison of lightweight concrete containing wood chips (Bouguerra et al., 1998) with adobe bricks showed the thermal conductivity of the former to be higher. The wood chips are more porous than rice husk and coconut husk, which resulted in lower thermal conductivity for the lightweight concrete.

1.5 Humidity

Humidity can damage and corrupt the structure of a building: the temperature changes that humidity causes in materials that contain acid or alkali salt additives results in those materials becoming corroded and cracked. The level and dispersion of moisture in the buildings for this research was typical of water flow or moisture resulting from absorption from wall or floor materials (capillary action) that can occur from the top to the bottom, from the bottom to the top, and horizontally. Porous materials easily absorb water from the ground and pass it to the upper wall. There are two types of moisture distribution: diffusion, which depends on the extent to which the material's walls absorb moisture and exfiltration, whereby moisture penetrates the leakage of the walls (Hall, 1986; Hall & Djerbib, 2003).

2. Experimental Program

2.1 Basic properties of clay

Clay used in this study were obtained from Samutprakarn province, Thailand. Tests for the basic properties of clay included the percentage of clay, sand and silt particles. Other tests included the Atterberg's limit of clay mass according to ASTM D4318 (ASTM, 2006) to determine the liquid limit, plastic limit, plastic index and activity.

2.2 Adobe brick specimens

Mixture proportions of adobe bricks are shown in Table 2. The materials mentioned were added to the mixture with the proportion given in dry state. Water was added and the ingredients were further mixed thoroughly by kneading until the mixture attained a uniform consistency. The experiments were performed to compare the properties of adobe brick containing rice husk and bagasse in the different proportion at the levels of 0, 1, 2, 3 and 6% by weight of dry materials.

The 10x10x10 cm. adobe bricks with 5 samples for each proportion were prepared to determine the average compressive strength according to ASTM C109 (ASTM, 2006) and the TIS 102-2517 standard (TIS, 1981). The samples were measured and weighed and subjected to heat for 24 hours, after which they were measured and weighed again. After the samples had been measured to determine shrinkage, then compressive strength and thermal properties were tested.

2.3 Moisture absorption of adobe brick

Samples of adobe brick concrete each of the size of 60 x 60 cm, one containing rice husk at 3% and one containing bagasse at 3% by dry weight of materials were made. Each sample was placed in a separate sample box made of polystyrene foam 10 cm thick on 5 sides of box and coated with a cement base coat. A relative humidity meter installed within each box near the wall compared with lightweight concrete. The experiment was tested and collected data under actual rain conditions.

Table 2. Mix proportions of adobe bricks.

Type of Fiber	Mix	Dry Clay (kg)	Fiber (kg)	Sand (kg)	Water (kg)
Rice Husk	C	10.00	0.00	1.00	4.00
	R1	9.89	0.11		
	R2	9.78	0.22		
	R3	9.67	0.33		
	R6	9.33	0.67		
Bagasse	C	10.00	0.00	1.00	4.00
	B1	9.89	0.11		
	B2	9.78	0.22		
	B3	9.67	0.33		
	B6	9.33	0.67		

Properties of Clay	Clay in Samutprakarn
Clay (%)	60
Sand (%)	20
Silt (%)	20
Liquid limit	145.0
Plastic limit	56.4
Plasticity index	88.6
Activity	0.45

Table 3. Elements and properties of clay in Samutprakarn Province of Thailand.

3. Results and discussion

3.1 Properties of clay

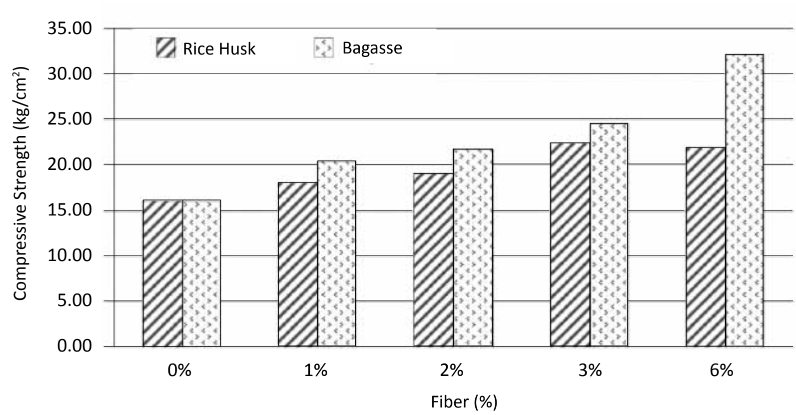
Elements and properties of clay used in this study are shown in Table 3. The clay properties included liquid limit, plastic limit, plastic index and activity. The activity less than 0.75 indicated that clay has relatively small volume changed, which is suitable for adobe brick production. If the clay contains clay mineral particles that are much smaller than 0.02 mm, the clay will be highly porous, a quality that lowers compressive strength. But, if the sand particles are between 0.02 and 2 mm, the clay will have a low level of porosity, a quality that increases compressive strength (Terzaghi, Brazelton, & Gholamreza, 1996).

3.2 Compressive strength of adobe brick

The compressive strengths of adobe brick samples containing rice husk and bagasse are presented in Figure 2. The results show that these agricultural materials improve the compressive strength of adobe brick in the replacement proportions of 1, 2, 3 and 6% by weight as compared with adobe brick with non-agricultural materials, of which the compressive strength is 16.08 kg/cm^2, the compressive strength of adobe brick containing rice husk is 18.07, 19.05, 22.35 and 21.95 kg/cm^2, respectively; for adobe brick containing bagasse, the compressive strength is 20.44, 21.65, 24.52 and 32.17 kg/cm^2, respectively.

The compressive strength of adobe brick containing bagasse was found to be higher than that of rice husk in any mix proportion. For adobe brick containing rice husk, compressive strength was highest at 3% replacement by weight, but the strength decreased at higher percentages of rice husk. For bagasse, compressive strength increased progressively up to 6% replacement by weight. The structure of bagasse which is longer in fiber length and less porous than rice husk provides a stronger fiber-soil bond results in higher compressive strength (Bougerra et al., 1998; Kumar, Singh, & Mohan, 2006).

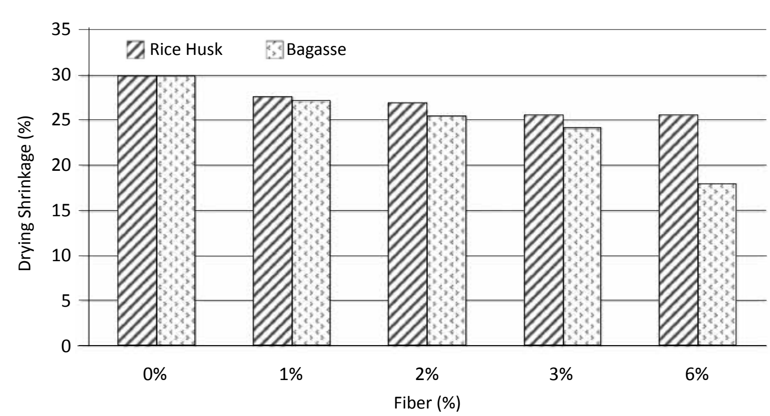
Figure 2. Compressive strength of adobe brick containing rice husk and bagasse.



3.3 Shrinkage of adobe brick

The volumetric shrinkage of the adobe bricks containing rice husk and bagasse are shown in Figure 3. When the percentage of agricultural materials increased, the percentage of shrinkage decreased: the percentage of shrinkage of the adobe brick containing rice husk at 0, 1, 2, 3 and 6% by weight is 29.99, 27.58, 26.94, 25.63 and 25.63%, respectively; the values for bagasse

Figure 3. Percentage of drying shrinkage of adobe brick containing rise husk and bagasse.



are 29.99, 27.12, 25.47, 24.19 and 17.95%, respectively. Incorporating rice husk and bagasse tends to reduce the shrinkgage. A decrease of shrinkage is observed with the increase of fiber proportion, but the positive effect seems to be more noticeable with bagasse. This could be attributed to a sufficient length of bagasse fiber for improving the bond at the fiber-soil interface to oppose the deformation and soil contraction. (Bougerra, et al., 1998; Bouhicha, Aouissi, & Kenai, 2005).

% Replacement	Before Tested	After Tested
0%		
1% Rice husk		
2% Rice husk		
3% Rice husk		
6% Rice husk		
1% Bagasse		
2% Bagasse		
3% Bagasse		
6% Bagasse		

Figure 4. Physical shapes of clay before and after compressive strength test.

3.4 Physical properties of clay

A survey of the physical shape of adobe brick containing rice husk and of that containing bagasse before and after compressive strength testing offers a guideline for selecting materials for construction purposes (Figure 4). The survey found that the surface of adobe brick containing rice husk is smooth, but adobe brick containing bagasse has a rough surface that clearly shows the bagasse fiber, especially at the edges. Consider the shape of the adobe brick samples after compressive strength testing: the brick containing rice husk is fractured, showing that the clay and rice husk are separated from each such that the brick is broken. On the other hand, no such fractures are present in the brick containing bagasse. In the latter case, shrinkage slowly occurred in the brick because the long bagasse fibers helped to hold the clay together; this resulted in an increase in compressive strength after deforming.

3.5 Thermal properties of adobe brick

The results in Figure 5 indicate that the highest thermal conductivity of adobe brick containing non-agricultural materials is 0.71 W/m-K. For adobe brick containing rice husk at 1, 2, 3 and 6% by weight, the thermal conductivity decreases to 0.65, 0.64, 0.57 and 0.54 W/m-K, respectively; for bagasse added at the same percentages, the thermal conductivity is 0.65, 0.62, 0.54 and 0.45 W/m-K, respectively. Compare the thermal conductivity of adobe brick containing rice

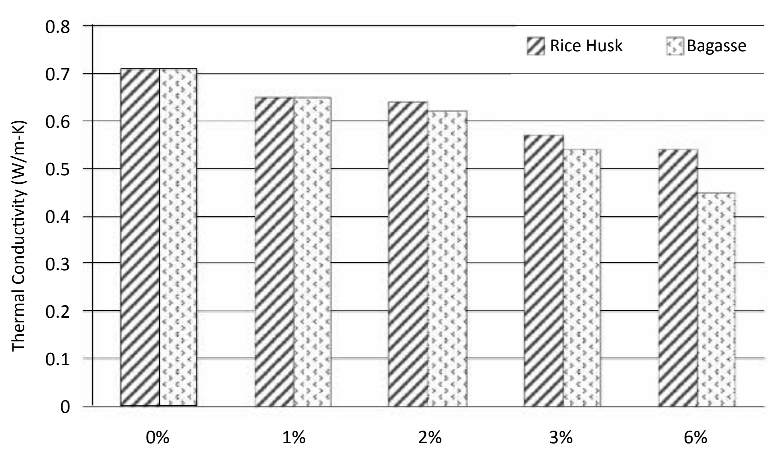


Figure 5. Thermal conductivity of adobe brick containing rice husk and bagasse.

husk and adobe brick containing bagasse, the values are the same at 1% by weight: 0.65 W/m-K. However, in comparison with adobe brick containing rice husk, the sample containing bagasse shows lower thermal conductivity especially at the percentage replacement of 2, 3 and 6% by weight of materials. The incorporation of bagasse caused the positive effects in binding ability and reduction of soil contraction leading to better refinement of the pore distribution, and resulting in an increase in porosity and lowering the thermal conductivity (Binici et al., 2007; Bouguerra et al., 1998)

From the specific heat-capacity results of adobe brick containing rice husk and that containing bagasse (shown in Figure 6), the increased percentage of agricultural fibers results in decreased specific heat capacity. The highest value of non-agricultural fibers is 1.09 MJ/m³K. Adobe brick containing rice husk at 1, 2, 3 and 6% by weigth has values of 0.95, 0.74, 0.66 and 0.54 MJ/m³K, respectively, whereas adobe brick with bagasse has values of 0.95, 0.85, 0.79 and 0.71 MJ/m³K, respectively. Comparing the specific heat capacity of adobe brick containing rice husk with that containing bagasse, the adobe brick containing rice husk shows lower values at 2, 3 and 6% by weight. Increasing the bagasse percentage replacement yielded the positive effects in binding ability and reduction of soil contraction leading to better refinement of the pore distribution, and resulting in an increase in porosity and a higher specific heat capacity (Binici et al., 2007; Bouguerra et al., 1998)

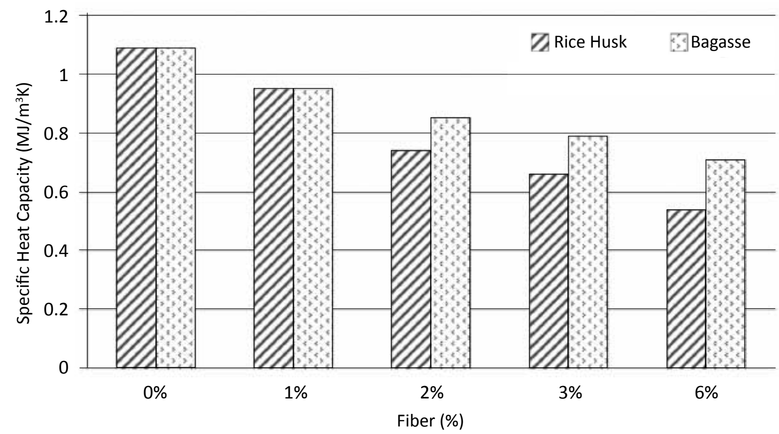


Figure 6. Specific heat capacity of adobe brick containing rice husk and bagasse.

3.6 Moisture absorption of adobe brick as compared with lightweight concrete

The moisture absorption of the adobe brick containing rice husk and that containing bagasse at 3% by weight was tested by placing the samples in a sample box in order to measure their relative humidity for 24 hours compared with lightweight concrete. The testing took place on a rainy day (before and after rain): the relative humidity outside was around 80%, and the relative humidity inside the sample box was around 62%.

The results in Figure 7 show that as the relative humidity of the air increases the humidity of the adobe brick containing rice

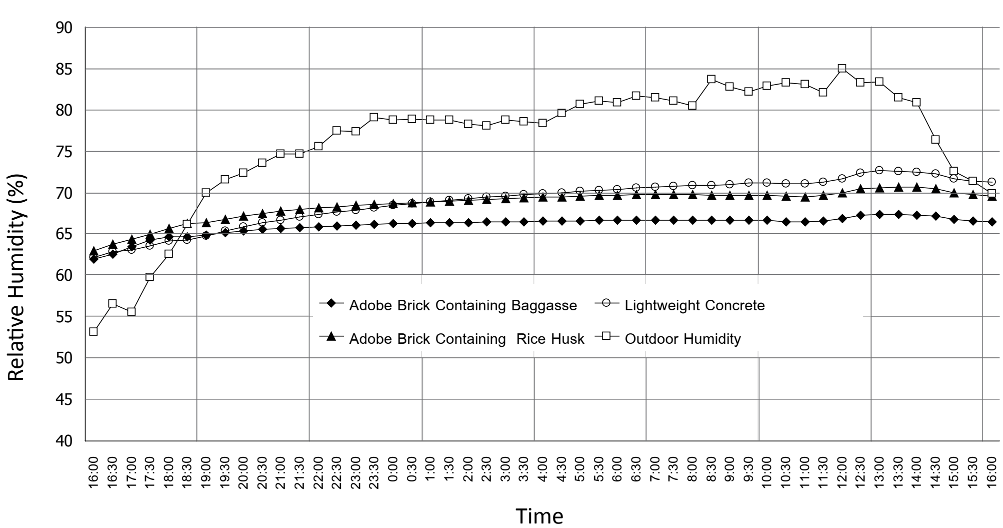


Figure 7. Comparison of moisture absorption between adobe brick and lightweight concrete walls.

husk, the adobe brick containing bagasse, and the lightweight concrete grew accordingly. During the first 8 hours of testing, the moisture content of the box with the adobe brick containing rice husk wall showed its highest value. During this same period, the lightweight concrete wall and the adobe brick containing bagasse wall boxes both showed moisture content of approximately 65%. After 10 hours, the moisture content in the sample box with the lightweight concrete was higher than that of the boxes with the adobe brick containing rice husk and that containing bagasse and likely increasing over time. While the relative humidity inside the sample box housing the adobe brick containing bagasse increased and constant at 66–67% and 69–70% for rice husk, approximately. It can, therefore, be inferred that the lightweight concrete continuous absorbed the moisture and have more moisture accumulation. But, the adobe brick containing rice husk and that containing bagasse absorbed more moisture initially than did the lightweight concrete, and the moisture was constant or slightly decreased over the period. Due to the fact that porous materials are permeable by air and moisture through pore networks, the lightweight concrete contains a network of micropore which is smaller than that in the abode bricks, and results in lower water absorption at the beginning and also less evaporative loss later on (Hall 1986; Hall & Djerbib, 2004).

4. Conclusions

Based on the results of the adobe bricks containing agricultural by-products studied, the following conclusions can be drawn.

1. Bagasse and rice husk can each improve the compressive strength of adobe brick. Bagasse is more effective than rice husk in all mix proportions.

2. The appropriate proportions for adobe brick containing rice husk are clay 87%, sand 10% and rice husk 3%. For bagasse, appropriate proportions are clay 84%, sand 10% and bagasse 6%

3. The compressive strength of adobe brick containing 6% bagasse by weight was similar to the value of hollow brick in ISO 102-2517.

4. The shrinkage of adobe brick containing bagasse was lower than that of rice husk, but the value of the former still depended on the type of clay used.

5. Adobe brick containing bagasse shows better binding ability than does rice husk. When subject to loadings, the structure of the adobe brick with bagasse erodes less than that with rice husk.

6. Adobe brick containing bagasse more than 1% is more capable of preventing the heat from the outside than is adobe brick with rice husk. On the other hand, the brick with bagasse accumulates more heat. Therefore, the selection of adobe brick mix proportion must be appropriately determined.

7. Adobe brick containing rice husk and that containing bagasse both have less moisture accumulation in comparison with lightweight concrete. In fact, the adobe brick with bagasse shows the least moisture accumulation of the three. It is likely that structures built with adobe brick with bagasse would have absorb less moisture than would structures built with the other two materials considered here. The use of bagasse then would mean that less energy would be expended through the use of air-conditioning units.

8. Future research shall include the comparison of moisture ingress and energy usage of air-conditioning of the model house built with adobe bricks containing other natural fibers at various percentage replacements. The higher replacement of natural fibers in adobe brick more than 6% by weight shall be further investigated to study effects on properties of adobe brick.

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