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MECHANICAL BEHAVIOR OF ADOBE BRICKS REINFORCED WITH WATER HYACINTH FIBER

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ABSTRACT: Thailand is facing serious water pollution problems, especially in natural water sources such as rivers and canals. The widespread water hyacinth plant prevents oxygen from penetrating and dissolving into the water. Therefore, the utilization of water hyacinth as construction materials can be an alternative to reduce the volume of water hyacinth. This study focused on the mechanical behavior of adobe bricks by using water hyacinth as fiber reinforcement. The mixture of adobe bricks was a combination of clay and sand in a ratio of 1:1. Cement at 5% is added to the mixture of adobe bricks. Water hyacinth at the length of 3 cm, 5 cm, and 7 cm was mixed with soil samples at 0.5% by weight. The mechanical behavior of adobe bricks consists of compressive strength, flexural strength, durability, and volume change are investigated. The results demonstrated that the adobe bricks reinforced with water hyacinth could reduce the shrinkage by approximately 31-34%. Moreover, the flexural strength of adobe bricks reinforced with water hyacinth can reach 61-74% of the compressive strength. However, the flexural strength of non-reinforced adobe bricks can reach only 17% of the compressive strength. The addition of water hyacinth in the adobe bricks can decrease the unit weight by approximately 20%. Moreover, non-reinforced samples broke down after soaking in the water for 24 hours. In conclusion, water hyacinth fiber can increase flexural strength, durability and reduce the shrinkage of adobe bricks.

Keywords: Water Hyacinth, Fiber Reinforcement, Adobe Bricks, Durability

1. INTRODUCTION

Adobe, earth building is the oldest building material. It is most commonly used in the current. Nearly 30% of the total population of the world still resides in a mud house [1], [2]. Brick is the most commonly used building. Adobe (sun-dried) bricks were used in ancient times during the Sumerian and Harappan civilizations. The utilization of the adobe as a building material in the construction industry is an alternative [3]. Sun-dried adobe bricks are simply made with low energy consumption and locally available materials such as cohesive soil and straw [4]. The properties of bricks depend upon soil selection and the process of brick making to obtain the desired strength. The suitable soil required for making adobe brick should contain adequate clay, silt, and sand. The soil is mixed with the water until plastic consistency is obtained. Mainly the adobe construction is vulnerable to water absorption [5]. Some of the problems of the adobe construction are erosion of earth walls, shrinkage, cracking, and frequent maintenance of the structure [3].

Therefore, this study focused on the improvement of the mixture of adobe bricks by ordinary Portland cement and water hyacinth fiber. Literature reviews demonstrated that brick reinforced with natural fibers are feasible to be used as a building material. The presence of fibers in brick reduces brick density and shrinkage, prevents deformation and crack [6], [7], [8], [9].

Water hyacinth is a free-floating perennial plant, as shown in Fig. 1. The water hyacinth plant is easily spread over the water. It grows over a variety of wetland types from lakes, ponds, streams, ditches, waterways, and black water areas. The plant height may vary from few inches. It may rise above the water surface as much as 1 meter in height. The leaves are 10-20 cm in diameter which float above the water surface. The plant can produce thousands of seeds each year and these seeds can remain viable for more than 28 years. The common water hyacinth is double its population in two weeks [10].

Fig.1 Leaf and stalk of water hyacinth.

Thailand is facing serious water pollution problems, especially in natural water sources such as rivers and canals. One of the main reasons is the widespread water hyacinth plant. Since it can grow and reproduce very fast, it covers the water surface in natural water sources. This prevents oxygen from penetrating and dissolving into the water. A water source can be considered polluted when the dissolved oxygen in the water is lower than a standard limit [11]. Therefore, the utilization of water hyacinth as construction materials can be an alternative to reduce the environmental problem in Thailand. Using water hyacinth may reduce the unit weight of adobe bricks more than the other type of natural fibers. This is because of the high pores in water hyacinths. Therefore, this may result in increased use of adobe brick in house construction. Thus, the objective of this study is to study the mechanical behavior of adobe brick reinforced by water hyacinth fiber. This paper investigated the effect of water hyacinth fiber on the volume change, compressive strength, flexural strength, and durability of adobe bricks.

2. MATERIALS PREPARATION

Normally, a combination of clay and sand was used as adobe bricks materials. Clay soils from Pathum Thani Province, Thailand were used in this study. The particle size of clay samples is smaller than 0.075 mm. Particle of sand (2.0-0.05 mm) was 2.7%, silt (0.05-0.002 mm) was 37.8%, and clay (<0.002 mm) was 59.5%. Pathum Thani clay was Brackish water alluvial soil. The clay fraction of Brackish water alluvial soils was composed of mica clay minerals 40%, kaolinite minerals 40%, montmorillonite, a small amount of vermiculite, and chlorite 20% [13]. The consistency limit of clay samples includes a liquid limit, plastic limit, and shrinkage limit was investigated. The liquid limit was 45.0%, the plastic limit was 27.7%, the shrinkage limit was 12.6%, and the plastic index was 17.3%. The soil was classified as low plasticity clay, according to the Unified Soil Classification System (USCS). Fine sand was collected from the river. Dried sand smaller than 2.0 mm was used in this test. The chemical composition of fine sand consists of Cao 0.87%, SiO_2 80.48%, Al_2O_3 11.22%, Fe_2O_3 2.08%, K_2O 5.27%, MnO 0.08%. The soil samples for build up the adobe bricks were a combination of clay and fine sand in a ratio of 1:1 [4]. Atterberg's limit value of the soil samples was reduced from clay. The liquid limit, plastic limit, plastic index, and shrinkage limit of the soil samples was 21.1%, 10.8%, 10.3%, and 8.8%, respectively. The values of shrinkage in mixed clayey soils decrease when granular material content increases [14]. Moreover, Portland cement type 1 used as a cementitious material. Portland cement was mixed with the soil samples at 5% by weight.

This study focused on the use of water hyacinth as fiber reinforcement in the adobe bricks. Water hyacinth fiber was taken from stems that are approximately 1 m in length and diameter approximately 0.5-1.0 cm. The water hyacinth fiber was dried in the air for 14 days before mixed with the soil samples, as shown in Fig. 2. The effect of water hyacinth on the volume change, the compressive strength, the flexural strength, and the durability of adobe bricks have been investigated. Water hyacinth at the length of 3 cm, 5 cm, and 7 cm was mixed with the soil samples at 0.5% by weight. Table 1 shows the mixture of adobe bricks reinforced with water hyacinth in this study.

Fig.2 Water hyacinth fiber dried in the air.

Table 1 Mixture of adobe bricks

Mixture Code	Clay: Sand	Cement (%)	Length of Fiber
S1	1:1	0	-
S1C	1:1	5	-
S1CW3	1:1	5	3
S1CW5	1:1	5	5
S1CW7	1:1	5	7

Note: Water at the liquid limit of the soil was used in the mixing procedure.

3. MECHANICAL PROPERTIES OF ADOBE BRICKS

The compressive strength, flexural strength, and durability of adobe bricks reinforced with water hyacinth have investigated by the unconfined compressive strength tests, flexural strength tests, and capillary rise tests, respectively.

3.1 Compressive Strength Tests

The soil samples mixed with water, cement, and water hyacinth, according to Table 1, were used in the test. The soil samples were compacted in the mold at the moisture content of liquid limits. The soil samples were tamped by rod in three layers and compacted 25 times per layer. The specimens were cast in the mold at 10×10×10 cm^3, as shown in Fig. 3. After the samples dried in the air for 1 day, the samples were extruded from the mold and curing in the dried air for 14 days. Then the samples were conducted on an unconfined compressive strength test (ASTM D 2166). The compressive strength values for each mixture are the average of five specimens.

Fig.3 Samples preparation for unconfined compressive strength tests.

3.2 Flexural Strength Tests

The soil samples mixed with water, cement, and water hyacinth according to Table 1 were used in this test. The samples were compacted in the mold at 4×4×16 cm^3. After the samples dried in the air for 24 hours, the samples were extruded from the mold and curing in the dried air for 14 days. The simple beam with center-point loading was used in the test, as shown in Fig. 4. Turn the test specimen on its side concerning its position as molded and center it on the support blocks. Center the loading system to the applied force. Bring the load-applying block in contact with the surface of the specimen at the center. The load shall be applied at a constant rate to the breaking point (ASTM, C293). The flexural strength values for each mixture are the average of three specimens.

Fig.4 Flexural strength test of the specimen.

3.3 Capillary rise and durability tests

The soil samples mixed with water, cement, and water hyacinth according to Table 1 were used in this test. Capillary rise and durability cube specimens, 10×10×10 cm^3 was compacted in the mold and cured in the dried air for 14 days in the same condition as unconfined compressive strength specimens. Three specimens were prepared for each mixture. After the curing process, the specimens were placed in a tray with a water level maintained at 10 mm and room temperature of 25±2 °C [12], as shown in Fig. 5. The average level of rising water was measured from the base of the specimens.

Fig.5 The specimens conducted on capillary rise tests.

In order to investigate the durability of adobe bricks reinforced by water hyacinth, the specimens through the capillary rise tests at 7 days were conducted on unconfined compressive strength tests. The results can demonstrate the reduction in the compressive strength of adobe bricks due to the increased moisture.

4. RESULTS AND DISCUSSION

4.1 Volume Change and Density

The soil samples mixed with water, cement, and water hyacinth according to Table 1 were used in this test. Cube specimens at 10×10×10 cm^3 were compacted in the mold and cured in the dried air for 14 days. The volume change was investigated by measuring the width, length, and height of specimens by Vernier Caliper at the curing time of 1, 3, 7, 14, and 21 days, as shown in Fig. 6.

The volume change of adobe bricks for each mixture is shown in Fig. 7. The initial volume of the specimens was 1,000 cm^3. The results demonstrated that the volume of specimens tends to decrease with rising time. The results showed the volume of the sample S1 rapidly decreased in 3 days, followed by a slight decrease. The remaining volume of S1 was 721 cm^3 at 21 days. The reduction in the volume of S1 was approximately 28%. However, the addition of cement at 5% in the mixture can reduce the shrinkage of the specimens, as shown in the results of S1C. The volume of S1C decreased by only 13%, by the remaining volume of S1C was 872 cm^3. Moreover, the volume of the samples mixed with cement and reinforced by water hyacinth decreased by approximately 5-7%. The volume of S1CW3, S1CW5, and S1CW7 was 934 cm^3, 951 cm^3, and 926 cm^3, respectively, at the curing time of 21 days. Therefore, the results demonstrated that the water hyacinth reinforced in the bricks could reduce the shrinkage of adobe bricks. Moreover, the results illustrated that the length of water hyacinth slightly affected the shrinkage of adobe bricks.

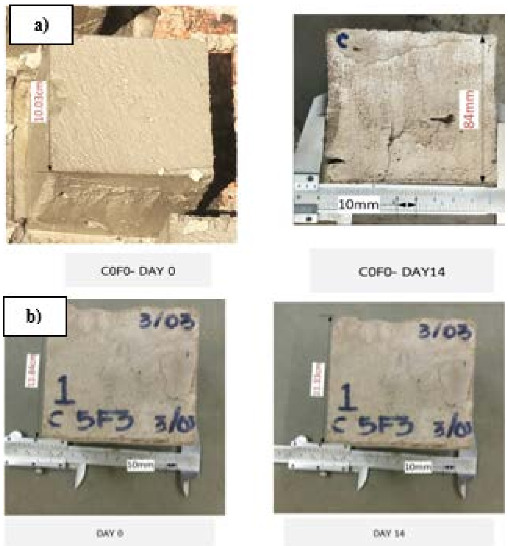

Fig.6 The length change of non-improvement adobe bricks (a) and adobe bricks reinforced by water hyacinth (b).

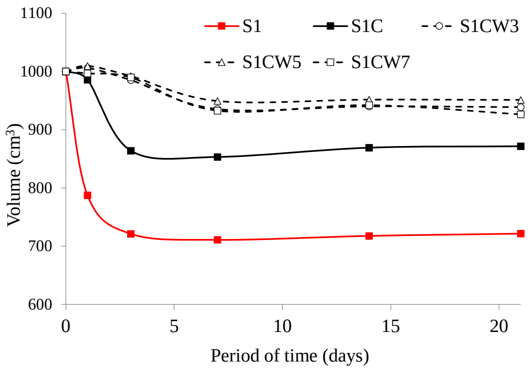

Fig.7 Relation between volume change and period of time.

Consideration on the density of the specimens for each mixture, the density of the specimens tended to decrease with the rising time, as shown in Fig. 8. The results demonstrated that the density of S1 was higher than S1C, approximately 13-17%. Moreover, the specimens reinforced with water hyacinth can reduce the density of approximately 5-11% from S1C. The density of the specimens reinforced with water hyacinth was between 1,422-1,452 kg/m^3 at the curing time of 21 days. The results illustrated that the changing length of water hyacinth was not affecting the density of adobe bricks. The density of the reinforcement samples reduced approximately 19-23% from S1.

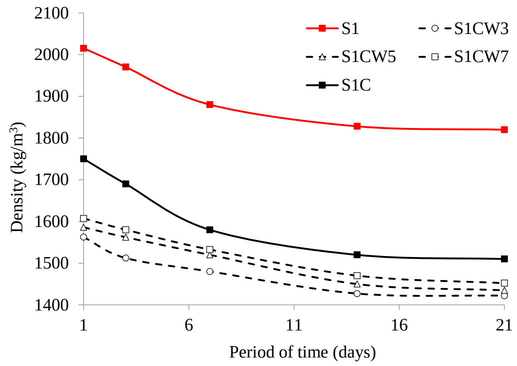

Fig.8 The relation between the density of adobe bricks and period of time.

The low density of the reinforcement samples can be described by the relation between the alteration in volume and weight of the sample for each mixture, as shown in Fig. 9. It shows the results of the samples at the curing time of 21 days. The results illustrated that the weight of the sample for each mixture slightly different; as shown, the weight was between 1.31-1.38 kg. However, the volume of S1and S1C less than S1Cw3, S1CW5, and S1CW7 due to the high shrinkage of the samples. Therefore, this result shows the water hyacinth fiber can assist in maintaining the volume of adobe bricks. This induced the density of the reinforcement specimens to less than the specimens without reinforcement.

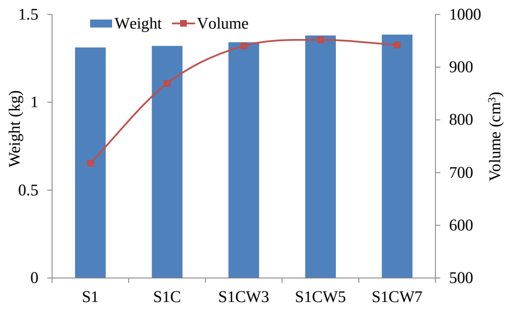

Fig. 9 Relation between the alteration in weight and volume of S1, S1C, S1CW3, S1CW5 and S1CW7.

Moreover, Fig. 10 demonstrated the effect of cement on the volume change of adobe bricks. The results illustrated that the volume change of adobe bricks tends to decrease with the increase of cement content in adobe bricks. The results demonstrated the samples mixed with cement at 5% could reduce the alteration of volume approximately 200 cm^3 from non-improvement soil.

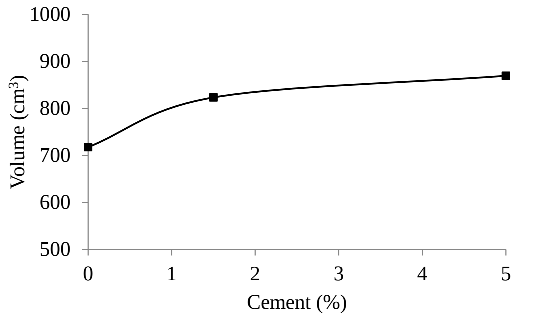

Fig.10 Relation between the cement content and volume of adobe bricks at the curing time of 21 days.

4.2 Compressive Strength

The compressive strength of the specimens for each mixture is shown in Fig. 11. The results demonstrated that S1 gave the highest strength. The compressive strength of S1 was 13.68 ksc (Kilogram-force per Square Centimeter) (1 ksc=98 kPa). However, the addition of cement at 5% in the soil samples decreased the compressive strength by approximately 64% from S1. The compressive strength of S1C was 4.97 ksc. The strength parameter such as cohesion and friction angle of sand with clay mixture increases along with the increase in clay content. The increase in cohesion and internal friction angle is attributed to cementation and particle to particle contact. The mechanical response in kaolinite depends on aggregate to aggregate interactions rather than particle to particle interactions. The aggregates of kaolinite can be considered analogous to sand particles [15].

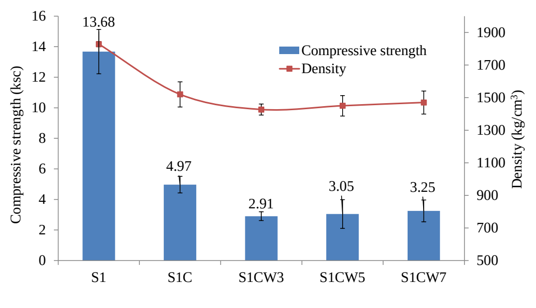

Fig. 11 Compressive strength of S1, S1C, S1CW3, S1CW5 and S1CW7.

Moreover, the specimens reinforced by water hyacinth have the lowest compressive strength. The compressive strength of S1CW3, S1CW5, and S1CW7 was 2.91 ksc, 3.05 ksc, and 3.25 ksc, respectively. The results illustrated that the compressive strength of the samples reinforced by water hyacinth tended to increase with the additional length of the fiber.

The reduction in the compressive strength can describe by the density of the samples for each mixture. The results illustrated that the compressive strength tended to decrease with the reduction of density, as shown in Fig. 12. This phenomenon causes the shrinkage of the samples. The high shrinkage of S1 induced the high density and low porosity of the specimen. However, the samples S1C, S1CW3, S1CW5, and S1CW7 shrink less than S1. This low induced density and high porosity. Therefore, the high porosity is the cause of the compressive strength of S1CW3, S1CW5, and S1CW7 decreased 35-42% from S1C.

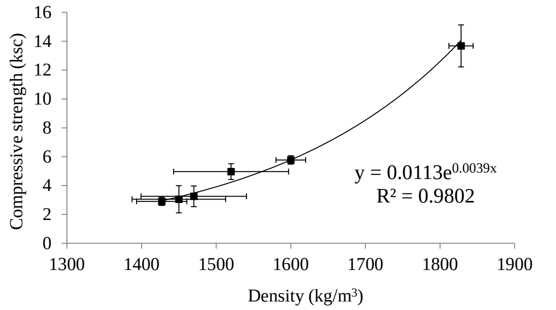

Fig. 12 Relation between compressive strength and density of the samples for each mixture.

4.3 Flexural Strength

The flexural strength of the samples for each mixture is shown in Fig. 13.

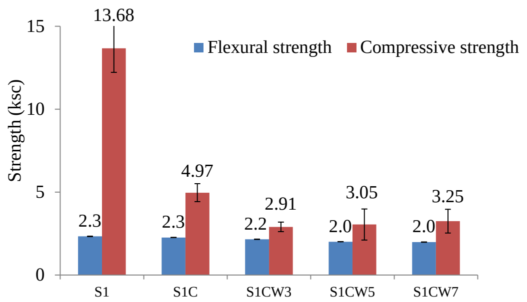

Fig. 13 Relation between the compressive strength and flexural strength of S1, S1C, S1CW3, S1CW5 and S1CW7.

The results demonstrated that the flexural strength of the samples for each mixture slightly different. The flexural strength of S1, S1C, S1CW3, S1CW5, and S1CW7 was 2.3, 2.3, 2.2, 2.0 and 2.0 ksc, respectively. The results illustrated that the flexural strength of S1 extremely decreased from the compressive strength. The flexural strength can reach only 17% of the compressive strength.

However, the addition of cement at 5% can enhance the flexural strength of the samples. The flexural strength of S1C can reach 46% of compressive strength. Moreover, the flexural strength of the samples reinforced with water hyacinth can reach 61-74% of the compressive strength. Therefore, the results illustrated the reinforcement of water hyacinth can enhance the flexural of adobe bricks by approximately 15-28% from the non-reinforced adobe bricks.

4.4 Capillary Rise and Durability

The results of capillary rise tests demonstrated that the samples S1 heavily of capillary rise after 24 hours. S1 samples broke down, as shown in Fig. 14. This is due to the high amount of clay in the soil samples. Therefore, it induced high water pressure in the samples and broke down the samples. However, the samples mixed with cement at 5% and reinforced by water hyacinth can maintain the characteristics of the specimens during soaked in the water for 7 days, as shown in Fig. 15.

Fig. 14 The samples without reinforcement after soaked in the water for 24 hours.

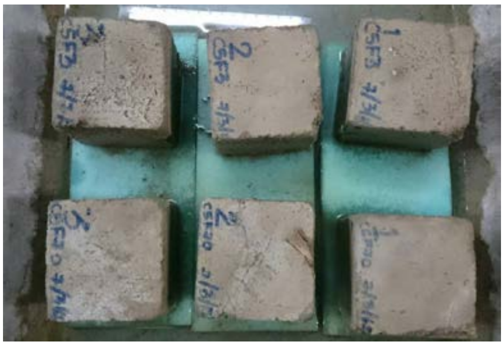

Fig. 15 The samples reinforced by water hyacinth fiber soaked in the water for 7 days.

Moreover, the results illustrated that the density of S1CW3, S1CW5, and S1CW7 tended to increase after soaked in the water for 7 days, as shown in Fig. 16. The density of S1CW3, S1CW5, S1CW7 after soaked in the water for 7 days increased approximately 20-25%. The samples S1C3, S1CW5, and S1CW7 after the capillary rise tests were conducted on the unconfined compressive tests to investigate the durability of adobe bricks. The results of the durability test are shown in Fig. 17.

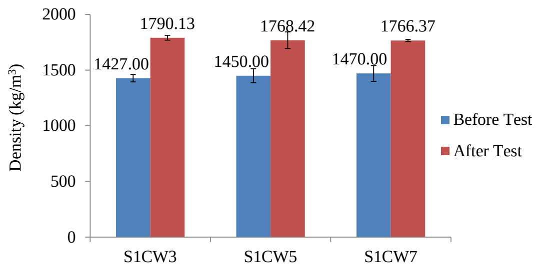

Fig. 16 Density of the reinforced samples (S1CW3, S1CW5, and S1CW7) after 7 days immersion in water.

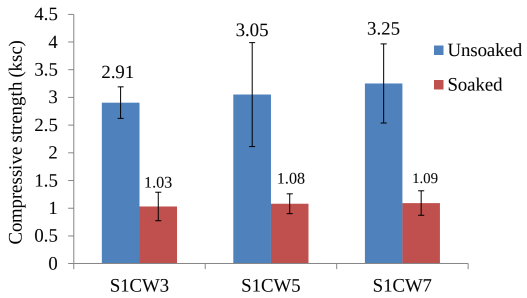

Fig. 17 Compressive strength of the reinforced specimens (S1CW3, S1CW5, and S1CW7) after soaked in the water.

The compressive strength of S1CW3, S1CW5, and S1CW7 after soaked in the water for 7 days was 1.03, 1.08 and 1.09 ksc, respectively. The compressive strength decreased approximately 65% from the dry samples. However, the samples S1 cannot conduct on the unconfined compressive strength tests due to the samples broke down after soaking in the water for 24 hours. Therefore, the results of capillary rise tests and unconfined compressive strength tests demonstrated the water hyacinth fiber could increase the durability of adobe bricks.

5. CONCLUSION

Based on the results obtained from this study, the following conclusion was made:

1. Water hyacinth can reduce the shrinkage of adobe bricks by approximately 31-34% and decrease the density of adobe bricks by approximately 20%.
2. The compressive strength of adobe bricks reinforced with water hyacinth decreased by approximately 35-42% from the non-reinforced bricks.
3. The flexural strength of adobe bricks reinforced with water hyacinth can reach 61-74% of the compressive strength. However, the flexural

strength of non-reinforced adobe bricks can reach only 17% of the compressive strength.

4. Non-reinforced adobe bricks broke down after soaking in the water for 24 hours. However, water hyacinth fiber can maintain the characteristic of adobe bricks.

5. Water hyacinth fiber can increase the flexural strength, durability and reduce the shrinkage of adobe bricks.

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