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Full Paper

Cement and Clay Bricks Reinforced with Coconut Fiber and Fiber Dust

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Abstract

For generations, Sri Lankans use cement bricks and clay bricks as common building materials in the construction field. This study investigates the feasibility of improving the strength while lowering the mass and thermal conductivity of bricks by adding coconut fiber or coconut fiber dust as a reinforcing material. Each reinforcing material is used in both clay and cement bricks. The mixtures are prepared according to varying volume ratios of the raw materials used. Coconut fibers are combed and cut into 4-5 cm pieces and dry coconut fiber dust is sieved using a 4 mm sieving mesh. The mixture is prepared by hand mixing and the traditional processes are replicated in making the bricks. Tests are carried out to understand the variation of mass, compressive strength, thermal conductivity, and water absorption of the reinforced bricks in comparison to bricks with no reinforced material. The cement brick reinforced with coconut fiber achieves the expected results in the compressive strength test and thermal conductivity test but underperformed when comparing masses and water absorption. Clay bricks reinforced with coconut fiber dust show impressive results in compressive tests and with the addition of dust, the appearance seems to have changed. It is observed that reinforcing cement bricks with coconut fiber could double the compressive strength along with a 5% reduction in mass. Reinforcing clay bricks with coconut fiber dust increases its compressive strength by over 70% while decreasing the mass by over 30 %. The study proves that it is feasible to use reinforced coconut fiber or coconut fiber dust to improve the properties of both clay and cement bricks, while clay bricks reinforced with coconut fiber are an exception.

Keywords: Cement bricks, clay bricks, coconut fiber, coconut fiber dust, reinforcing material

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Introduction

Cement bricks and clay bricks play a major role in the masonry construction field all around the world [1] [2]. In Sri Lanka and other South Asian countries, they are considered the most imperative component in building construction. Although they are vastly used, not many improvements have been done to the traditional bricks.

In Sri Lanka, cement brick is the most economical option compared to clay bricks and they have the disadvantages (compared to clay bricks) of lack of strength [3] and lack of thermal comfort. Clay bricks generally have low resistance against tension and torsion compared to concrete blocks [4]. Also in recent building constructions, the thermal performance in the building is strictly constrained [5]. When considering the clay brick even though it is good with strength and thermal comfort, those properties can

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still be improved. On the other hand, clay bricks are low in quality when considering uniformity, shrinkage and surface finish compared to other commercially available bricks. When it comes to surface finish, both cement and clay bricks can be improved. Also, current bricks have a high structural vulnerability to natural hazards due to their poor mechanical properties such as performance under seismic loads, tensile strength, and density [6]. The seismic effect has become a major governing factor in building construction in countries with a higher vulnerability to severe earthquakes [7]. The above concerns pave the way for studies on brick improvements.

There have been studies carried out on the behavior of cement and clay bricks under the influence of additives. These researches include bricks reinforced with cement, gypsums [5] and other waste materials. Most of the traditional bricks and other construction materials are made from natural resources. But with sustainable building construction becoming more popular many researchers are interested in the utilization of solid waste in construction materials [8]. There are researches on reinforcements done using cigarette butts [9], plastic bottle wastes [10], coal-ash, cassava peels [11], waste phosphogypsum, natural gypsum [12], sawdust [13], etc. Moreover, the performance of rubber-added bricks has also been investigated [14]. When it comes to synthetic fibers, Hanifi et al. reinforced clay bricks with plastic fibers and polystyrene fabric [15]. They were able to obtain better thermal insulation**.** Subramaniaprasad et al. investigated sorption characteristics of stabilized soil blocks with waste plastic fiber reinforcement [16]. There are also other studies on reinforcing with alkali resistant (AR) glass fibers, polypropylene [17] in soil blocks. Moreover, concrete has also been reinforced with glass fibers [18].

Natural fiber reinforcements have an edge over synthetic fiber reinforcements as recent building constructions support sustainability. Natural fibers such as coconut fiber, oil palms, bamboo, and coca have been used as reinforcements in cement-based materials [7]. There are also studies on clay bricks reinforced with sisal-fibers, earth building blocks reinforced with jute and banana fiber, adobe bricks reinforced with straw fibers, and clay bricks reinforced with chicken feathers and sugarcane bagasse. Coconut fiber has been used as a reinforcement material in both concrete composites [19] and cement blocks [7]. Most of these natural fibers are available, renewable, cost-effective, and easily extractable with the existing technology. The present study is based on the reinforcement of cement and clay bricks with coconut fiber and fiber dust. These reinforcements were aimed to increase the strength, decrease thermal conduction, reduce mass, and study the water absorption properties of coconut fiber or dust reinforced bricks when compared to normal bricks Coconut fiber consists of unique qualities. It has a high tensile capacity and it is one of the strongest fibers under twist. Generally, they are durable, moth-proof, and show resistance against fungi, moisture, and dampness. Also, they provide better thermal and sound insulation [7]. There are two types of coconut fiber called black and white. In this study, we used white fiber which is extracted before coconuts are ripe. Dry fiber dust was also used as another reinforced material. Although coconut fiber dust has a high-water holding capacity, it is light and slow in decomposition [20]. The carbon percentage (in wt. %) in coconut fiber is 37% to 49% [21] which makes it the major chemical element.

Materials and Methods

Raw Material

- **Coconut fiber:** Coconut fibers were acquired from Madampe city in North Western province of Sri Lanka. The fibers were white coconut fibers which were extracted from unripe coconuts through a fiber extraction machine.
- **Coconut fiber dust:** The coconut fiber dust was also acquired from the same place. After processing they have been dried for approximately two months.
- **Clay:** The unprocessed clay is extracted from Hanwella city in Western province of Sri Lanka.
- **Cement:** Cement was purchased from INSEE Sanstha.
- **Crushed stones:** Crushed stones was used with the binder as a filler material and to provide strength in cement blocks.

Figure 1. Coconut Fiber

Figure 2. Coconut Fiber Dust

The research was conducted as four parallel experiments as cement bricks reinforced with coconut fiber, cement bricks reinforced with coconut fiber dust, clay bricks reinforced with coconut fiber and clay bricks reinforced with coconut fiber dust. These experiments had similar methodologies; however, it is possible to identify some distinguishable differences in the approach too.

Specimen Preparation

The coconut fibers were combed and cut into approximately 5 cm length using a scissor. Dry coconut fiber dust was sieved using a sand sieving mesh of sieve size 4 mm.

Cement Bricks

Here two types of specimens were prepared, one reinforced with coconut fiber and the other with coconut fiber dust. The traditional brick-making process was used, the only difference was adding coconut fiber or coconut fiber dust in the respective brick-making processes. Apart from the reinforced material, only cement, crushed stones, and water were used to prepare the samples. The raw materials were mixed according to the volume ratios shown in Tables 1 and 2. In each case, the volume ratio of cement to crushed stones was kept at 1 to 12. The mixture was manually prepared, and the bricks were pressed in a hydraulic brick pressing machine. The brick size was 12×4×6 inches. Standard cement bricks (Brick ID - CES00), to be used as controls, were also made without reinforced materials to compare results.

Table 1. Cement Bricks Reinforced with Coconut Fiber

Brick ID	**Ratios by volume** (Cement: coconut fiber: crushed stones)	**Number of samples made**
CEF01	1:0.5:12	3
CEF02	1:1:12	3

Table 2. Cement Bricks Reinforced with Coconut Fiber Dust

Brick ID	**Ratios by volume** (Cement: coconut fiber dust: crushed stones)	**Number of samples made**
CED01	1:2:12	3
CED02	1:3:12	3
CED03	1:4:12	3

Figure 3. Cement Bricks Reinforced with Coconut Fiber

Figure 4. Cement Bricks Reinforced with Coconut Fiber Dust

Clay Bricks

When considering the coconut fiber reinforced clay brick, the same process of making a normal clay brick was used. The only change in the process was that coconut fiber was added while seasoning wet clay. The mixing was done according to volume ratios as shown in Table 3 and 4. A wooden mold was used to make the samples with a dimension of 8.75×4×2.5 inches. Then the bricks were left to dry for a week. The same method was conducted when making coconut fiber dust reinforced clay brick. The dried clay bricks were burnt at 900°C in a temperature-controlled furnace rather than using a traditional furnace. Standard clay bricks (Brick ID – CLS00) were also made without reinforced materials for comparison (the control bricks).

Table 3. Clay Bricks Reinforced with Coconut Fiber

Brick ID	Ratios by volume (Clay: coconut fiber)	Number of samples made
CLF01	1:0.5	3
CLF02	1:1	3

Table 4. Clay Bricks Reinforced with Coconut Fiber Dust

Brick ID	Ratios by volume (Clay: coconut fiber dust)	Number of samples made
CLD01	1:0.5	3
CLD02	1:1	3

Figure 5. Wet Clay Bricks Reinforced with Coconut Fiber

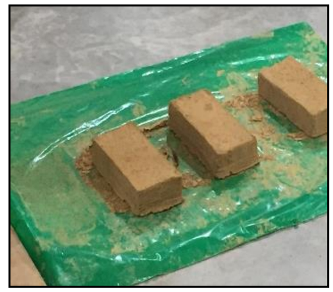

Figure 6. Wet Clay Bricks Reinforced with Coconut Fiber Dust

Figure 7. Burnt Clay Bricks Reinforced with Coconut Fiber Dust

Testing Procedures

Once the experimental specimens were ready, the experiments were conducted based on the research requirements. Research requirements are listed below with the method that was used to measure the related parameters.

Thermal Comfort of the Experimental Bricks Compared to the Control Bricks

In order to measure this, it was required to develop a custom experimental model as there were no pre – existing method for that. The developed experiment did not measure the thermal conductivity of each brick, but it compared each brick with other bricks for its thermal conductivity. This was based on measuring surface temperature of each brick by using an IR thermometer while heating the other surface of the brick using a hot plate for a predefined time. The larger surfaces were selected to heat and measure surface temperature as they are the surfaces that are exposed to heat absorption and release. The ambient conditions were kept constant throughout the whole experiment by conducting the experiment in a closed temperature-controlled room.

The hot plate setting was kept at the same setting for all experiments. For clay bricks, the top surface temperature readings were taken with 5 min intervals up to 15 min. For Cement bricks, the surface temperatures were measured with 10 min intervals up to 30 min. Here the top surface temperatures measured after 30 min were used for the calculations. By those values we were able to compare the thermal conductivity of each experimental specimen.

Compressive strength of the experimental bricks compared to existing bricks

Strength was a key factor that was assessed in this study as these bricks has potential to be used for building construction. To compare strengths of the experimental bricks, a compressive strength test was conducted. The test was carried out using IMPACT 2000kN cube and cylinder compression machine. From the machine, breaking load of all the reinforced and control bricks were obtained for comparison.

Figure 8. Compressive Test on Cement Bricks

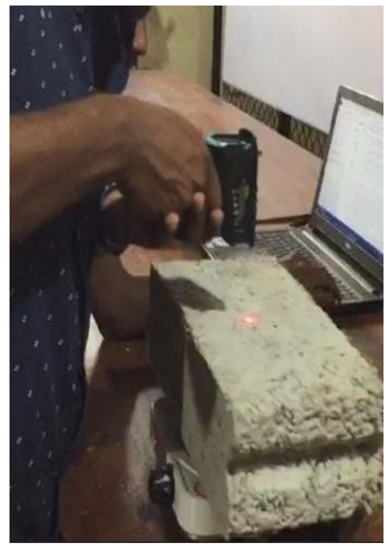

Figure 9. Setup to Determine Thermal Comfort

Water Absorption of the Experimental Bricks Compared to the Control Bricks

Water absorption was another main interest of the research as it contributes to strength deformations in bricks. Before conducting the experiment, mass of each brick was measured and noted down. Then each brick was fully submerged in a water container which was kept at constant room temperature throughout the experiment. The bricks were submerged in water for 12 hours. Then the bricks were taken out from the water containers and their masses were measured again.

Mass of the Experimental Bricks Compared to the Control Bricks

Mass reduction was one of the major concerns in this study. Here the masses of reinforced bricks were compared with the control bricks with no reinforcements. Masses were measured by using an electronic mass measuring scale.

Once all the experiments were conducted, the values obtained were used to make conclusions about the research. Here reinforced bricks were compared with each other and also with standard bricks without reinforcements.

Results and Discussion

Cement Bricks

Thermal Conductivity Test

For this experiment, the standard cement brick, cement bricks reinforced with coconut fiber dust and cement bricks reinforced with coconut fiber were used. From the observations of the thermal conductivity test, average temperatures of surfaces were calculated. The values are shown in Table 5. From the data gathered, the differences between the top surface of the brick and hot plate temperatures were calculated. With those results the thermal conductivities were compared as it can be considered proportional to the calculated temperature difference. The percentages in Table 5 were calculated from average top surface temperatures of cement bricks using Equation (1).

$$PITC = ((T_{DS} - T_{DR}) / T_{DS}) \times 100\% \qquad \text{Equation (1)}$$

PITC - Percentage increase in thermal conductivity

T_{DS} - Temperature difference in standard brick

T_{DR} - Temperature difference in reinforced brick

Table 5. Results of Thermal Conductivity Test – Cement Brick

Brick ID	**Average Top Surface temperature after 30 min (˚C)**	**Estimated reduction in thermal conductivity compared to** CES00
CES00	46.6	
CED01	39.2	1.6%
CED02	38.7	1.7%
CED03	37.0	2.1%
CEF01	40.9	1.2%
CEF02	41.2	1.2%

The results showed that either type of bricks reinforced with coconut fiber or dust have a reduction in thermal conductivity when compared to the standard. That leads to a conclusion that mixing coconut fiber dust or coconut fiber increases thermal comfort of cement bricks. CED12 showed the highest percentage reduction in thermal conductivity compared to the standard, which was by 2.1%.

As illustrated in Figure 10 and Figure 11, the temperature difference between two opposite surfaces of the brick (the surface heated and the surface opposite to it) was increased as coconut fiber dust volume increases. So, it can be concluded that as the dust volume of the brick increases the thermal comfort also increases. On the other hand, the temperature differences between surfaces in bricks reinforced with coconut fiber have almost similar values. However, the coconut fiber dust is more effective in achieving thermal comfort than coconut fiber.

Compression Test

The compression test was carried out on each of the cement bricks with different compositions. The recorded breaking loads and the percentage increase in strength when compared to standard cement brick are shown in Table 6. The percentage increase in strength were calculated using (2). The results show that cement bricks reinforced with coconut fiber dust have a decreased compressive strength whereas when reinforced with coconut fiber the cement bricks have an increased compressive strength compared to the standard cement bricks.

$$PICS = ((B_{LR}-B_{LS}) / B_{LS}) \times 100\% \qquad \text{Equation (2)}$$

PICS -Percentage increase in compressive strength

B_{LR} - Breaking load of reinforced brick

B_{LS} - Breaking load of standard brick

As illustrated in Figure 10 and Figure 11, the compressive strength of the cement bricks decreases as the reinforced dust volume increases. Also, in bricks reinforced with coconut fiber, the compressive strength is inversely proportional to the fiber volume. But in each case, significant increase in compressive strength compared to standard brick has observed. The CEF01 and CLF01 bricks showed twice the strength of the standard brick.

Table 6. Observations And Results of Compression Test - Cement Brick

Brick ID	**Breaking load(kN)**	**Percentage increase in strength when compared to standard**
CES00	95.4	
CED01	90.9	-5%
CED02	68.4	-28%
CED03	50.7	-47%
CEF01	200.1	110%
CEF02	121.6	27%

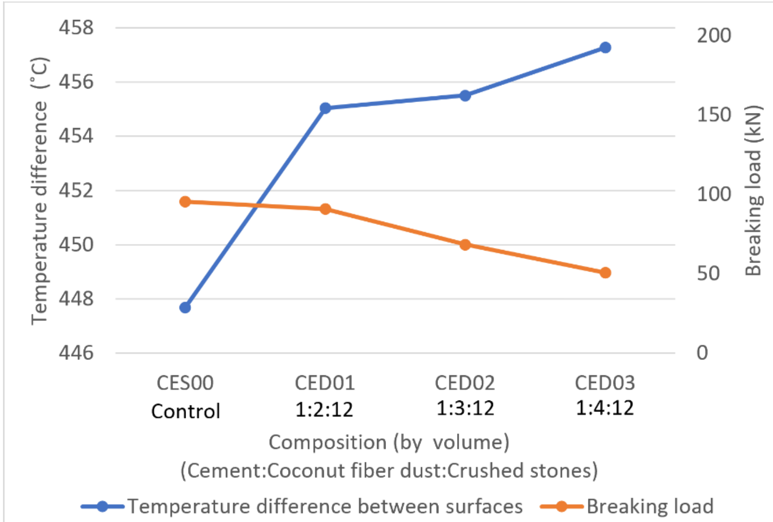

Figure 10: Breaking Load and Temperature Difference (Cement Brick Reinforced with Coconut Fiber Dust)

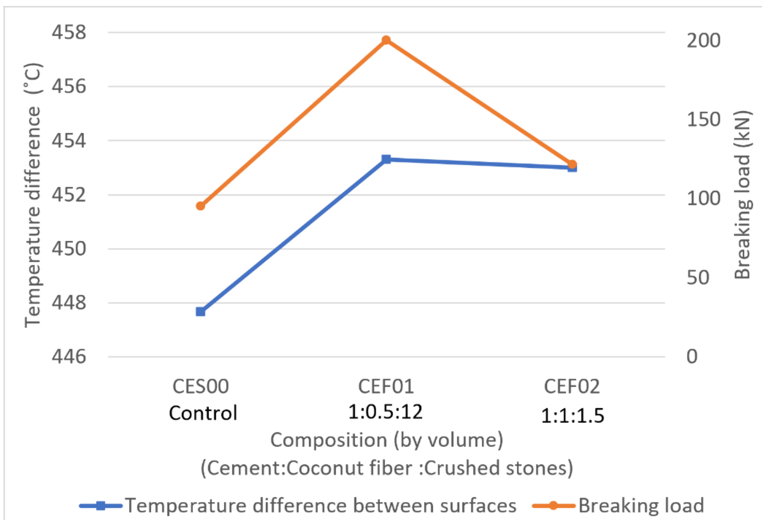

Figure 11: Breaking Load and Temperature Difference Between Surfaces (Cement Brick Reinforced with Coconut Fiber)

Water Absorption Test

The measured masses before submerging the bricks in water and the mass of submerged bricks after 24 hours are recorded and used to calculate the percentage of water absorbed and the percentage increase in water absorption compared to standards were using (3) and (4) respectively. The results are shown in Table 7.

$$WAP = ((M_A - M_B) / M_B) \times 100\% \qquad \text{Equation (3)}$$

WAP - Percentage of water absorbed
M_A - Mass of the brick before putting in to water
M_B - Mass of the brick after taken out of water

$$PIWA = ((WAP_R - WAP_S) / WAP_S) \times 100\% \qquad \text{Equation (4)}$$

$PIWA$ - Percentage increase in water absorption
WAP_R - Percentage of water absorbed of reinforced brick
WAP_S - Percentage of water absorbed of standard brick

As illustrated in Figure 12 and Figure 13, the water absorbed in both types of reinforced bricks are higher than the standard brick. The highest percentage increase in water absorbed when compared to the control brick is of the CED03 which is 128%, more than twice the water absorbed in a standard brick. In bricks reinforced with coconut fiber dust, the percentage of water absorbed increases as the dust volume increases. Also, in bricks reinforced with coconut fiber, the percentage of water absorbed has increased as the fiber volume increases. When considering the water absorption property none of the reinforced bricks performed better than the standard brick.

Table 7. Results of Water Absorption Test - Cement Brick

Brick ID	**Percentage of water absorbed (%)**	**Percentage increases in water absorption when compared to** CES00
CES00	5.6	
CED01	9.5	69%
CED02	10.1	80%
CED03	12.8	128%
CEF01	6.3	12.2%
CEF02	7.7	36.6%

Mass Comparison

The average masses of the bricks were calculated with the recorded data. Then the percentage reduction in mass compared to the control brick was calculated using (5). The results are tabulated in Table 8.

$$PRIM = ((M_S - M_R) / M_S) \times 100\% \qquad \text{Equation (5)}$$

$PRIM$ -Percentage reduction in mass
M_S - Mass of the standard brick
M_R – Mass of reinforced brick

According to the results obtained it is evident that the mass of coconut fiber dust or coconut fiber reinforced bricks have decreased when compared to the control bricks. CED03 shows the highest percentage reduction in mass. As illustrated in Figure 12 and Figure 13, there is an inverse relationship between the dust volume and the mass of the brick. When we consider the cement bricks reinforced with coconut fiber, the lowest percentage is shown by the brick with the lowest fiber percentage.

Table 8. Masses - Cement Bricks

Brick ID	Average mass (kg)	Percentage reduction in mass when compared to CES00
CES00	12.622	
CED01	11.372	10%
CED02	11.028	13%
CED03	10.331	18%
CEF01	12.476	1.2%
CEF02	11.699	7.3%

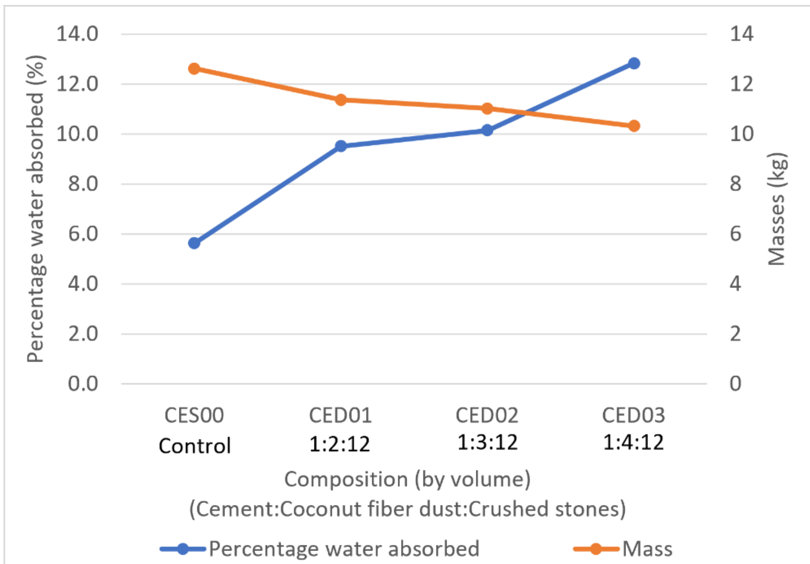

Figure 12: Percentage Water Absorption and Masses (Cement Brick Reinforced with Coconut Fiber Dust)

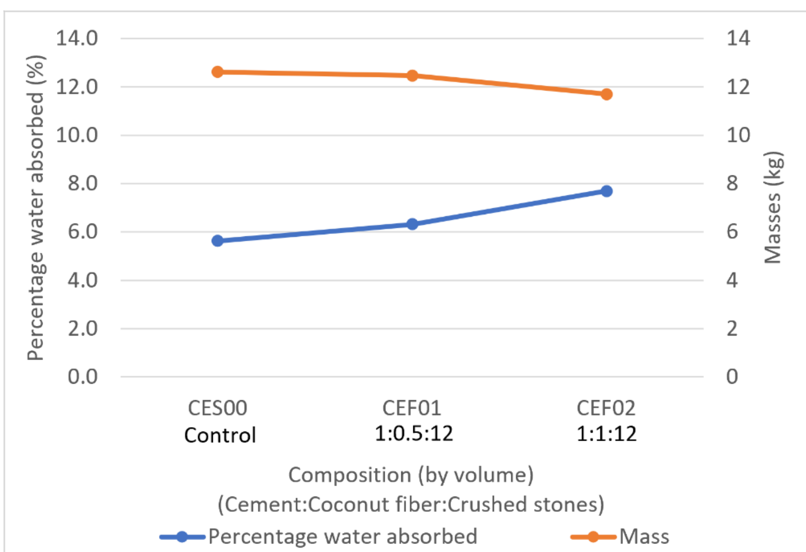

Figure 13: Percentage Water Absorption and Masses (Cement Brick Reinforced with Coconut Fiber)

Clay Bricks

Although reinforced cement bricks gave better results in different aspects, all the clay bricks reinforced with coconut fiber were a failure. Most of the clay bricks reinforced with coconut fiber were destroyed in the burning process inside the furnace and others collapsed when handling. This was due to the fibers that had burnt and left many voids inside the brick. Therefore, only the results of clay bricks reinforced with coconut fiber dust are discussed.

Thermal Conductivity Test

The percentage increase in thermal conductivity was calculated from difference of temperatures between two opposite surfaces of the bricks (the surface which was heated and the surface opposite to it) using (1) as in cement bricks. The temperatures are shown in Table 9. Here also the hot plate was kept at the same setting for all bricks and the temperature on the hot plate was measured as 494.2˚C.

As illustrated in the Figure 14, the temperature difference decreased in clay bricks reinforced with coconut fiber dust compared to the standard brick which means higher thermal conductivity. That leads to a conclusion that mixing coconut fiber dust decreases thermal comfort slightly.

Table 9. Results of Thermal Conductivity Test - Clay Bricks

Brick ID	**Average top surface temperature after 30 min (˚C)**	**Percentage increase in thermal conductivity when compared to standard**
CLS00	70.7	
CLD01	79.5	2 %
CLD02	86.7	0.5%

Compression Test

The breaking loads of compression test which were directly obtained by the compression testing machine are shown in Table 10. This table also shows the percentage increase in strength compared to the standard clay brick which was calculated using (2). The reinforced clay bricks showed increased compressive strength compared to the control clay brick. CLD02 shows the highest percentage increase in compressive strength of 73%.

Figure 14 shows the graphical representation of breaking loads of the reinforced bricks and the control brick. Here the breaking load is proportional to the coconut fiber dust volume. The broken bricks after compression test shows different break patterns and black dots were visible inside the reinforced clay bricks which are likely the burnt coconut fiber dust.

Table 10. Percentage Increase in Strength -Clay Bricks

Brick ID	Breaking load (kN)	Percentage increase in strength when compared to standard
CLS00	117	
CLD01	162.9	39%
CLD02	202	73%

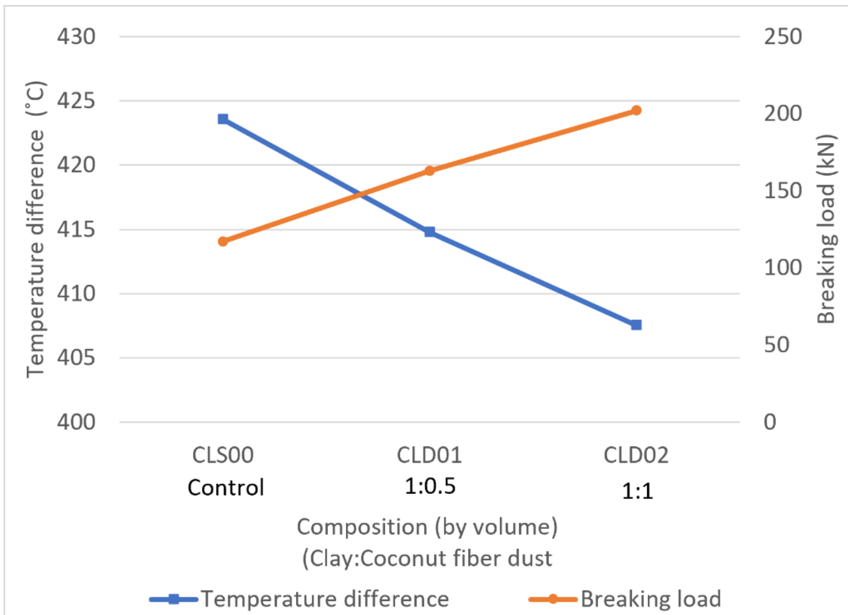

Figure 14: Breaking Load and Temperature Difference (Clay Brick Reinforced with Coconut Fiber)

Water Absorption Test

The calculated water absorption percentage and the percentage increase in water absorption compared to the control bricks are shown in Table 11. The results show that each reinforced brick shows increased water absorption property. The maximum percentage increase in water absorption compared to standard is shown by the brick CLD02. Here the percentage water absorbed increases as the reinforced fiber volume increases as illustrated in Figure 15.

Table 11. Observations of Water Absorption Test - Clay Bricks

Brick ID	Percentage water absorbed	Percentage increase in water absorption when compared to standard
CLS00	11.6%	
CLD01	12.2%	5%
CLD02	13%	12%

Mass Comparison

As three samples were prepared for each composition, the average mass of bricks were calculated. The calculated average masses and the percentage reduction in mass compared to the standard are shown in Table 12. Here each reinforced bricks shows reduction in mass. As the reinforced coconut fiber dust volume increases masses of the reinforced bricks also increase as illustrated in Figure 15. The highest reduction in mass is shown by the brick CLD02. In this case 33% mass reduction was achieved

Table 12. Masses-Clay Bricks

Brick ID	Mass	Percentage reduction in mass when compared to standard
CLS00	1.363	
CLD01	1.082	21%
CLD02	0.92	33%

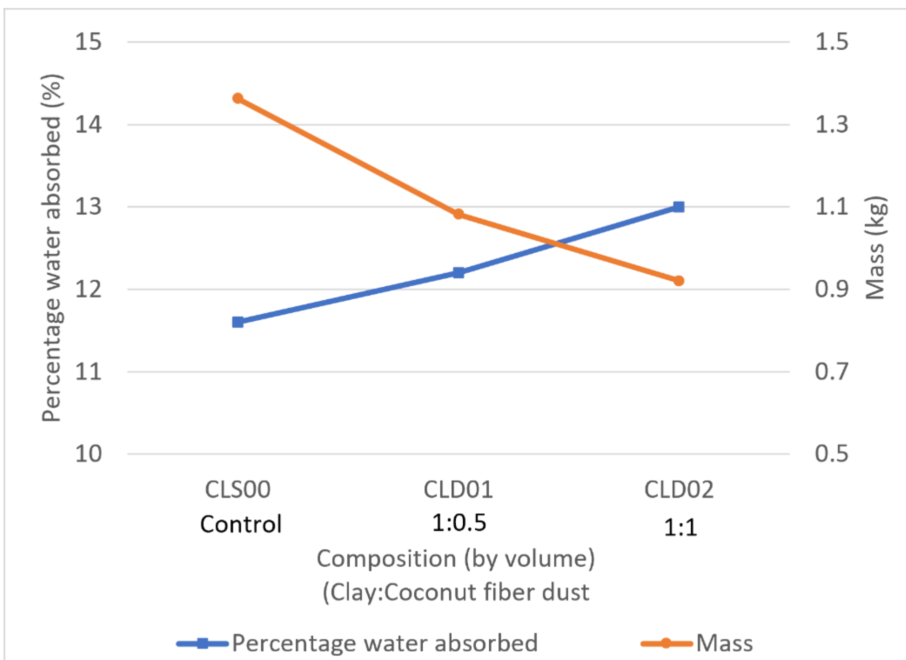

Figure 15: Percentage Water Absorption and Masses (Cement Brick Reinforced with Coconut Fiber Dust)

Conclusion

Main goal of the research was to find the effect of mixing coconut fiber or coconut fiber dust to traditionally made cement and clay bricks and explore the effects of that based on thermal comfort, compression strength, water absorption & mass. When considering reinforced cement bricks, significant improvement and deviations compared to the control bricks were shown from the test results. Coconut fiber dust reinforced cement bricks were able to give more thermal comfort where coconut fiber reinforced cement bricks provided an in-between thermal comfort compared to normal and coconut fiber dust reinforced cement

bricks. Although the cement bricks reinforced with coconut fiber dust shows less compressive strength compared to the standard, fiber reinforced bricks showed significant improvement in compressive strength where the brick CEF02 and CEF01 has displayed the compression strength which is more than twice compared to the normal cement brick. Also cement brick reinforced with coconut fiber dust showed significant reduction in mass and better surface finish. When considering clay bricks, none of the clay bricks reinforced with coconut fiber showed any improvements. But clay bricks reinforced with coconut fiber dust showed better results in the compressive strength test and significant reduction in mass. Here CLD02 shows the highest percentage increase in compressive strength of 73% compared to the standard.
In the majority of the tests such as compression test, thermal conductivity test and water absorption test, cement bricks reinforced with coconut fiber dust did not achieve the expected results. On the other hand, the cement brick reinforced with coconut fiber achieved the expected results in the compressive strength test and thermal conductivity test but under performed when comparing masses and water absorption. Clay bricks reinforced with coconut fiber dust showed impressive test results in compressive test and with the addition of dust, the chemical composition seems to have changed significantly. The study proves that it is feasible to reinforce cement and clay bricks with coconut fiber or coconut fiber dust and improve their properties except for clay bricks reinforced with coconut fiber. It is recommended that the study should be continued to identify the durability of the reinforced bricks.

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