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THERMAL CONDUCTIVITY, COMPRESSIVE STRENGTH AND WATER ABSORPTION OF RECYCLED COCONUT FIBRE AND CRUSHED CLAY BRICK MASONRY

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Graphical abstract

Abstract

This study aims to investigate the thermal conductivity, compressive strength and water absorption analysis of recycled masonry bricks using coconut fiber and crushed clay bricks as a partial sand replacement to create a green building material. The variable ratios of coconut fiber were considered and 10 specimens per sample were manufactured manual process using hand. Four (4) series of brick mix design from the total weight of the sand with different levels of coconut fiber and crushed clay brick replace half of the sand was created as irregular mixes comprises of 0%, 2%, 4% and 6% of coconut fiber. Overall, the use of coconut fiber and crushed clay brick as a partial sand replacement reduce the brick thermal conductivity. Thermal properties were measured based on the transient line heat source method using a KD2 Pro thermal properties analyzer. The suitable percentage of partial sand replacement for sand-cement brick using coconut fiber in this study was 4% and 50% of crushed clay brick after compared to commercial brick. The average sample of 4% coconut fiber was 0.532 W/mk of thermal conductivity and 18.74MPa compressive strength with density of 1716.28 kg/m^3. In short, the thermal insulation potential of coconut fiber and crushed clay brick is highly promising for commercial development in Malaysia.

Keywords: Compressive strength, coconut fiber, crushed clay brick, recycled masonry, partial sand replacement, thermal conductivity, water absorption.

1.0 INTRODUCTION

Green building refers to a structure that use environmentally responsible and resource-efficient process throughout a building's life-cycle from sitting to design, construction, operation, maintenance, renovation and demolition. In order to create a green building, the aspects to be concern are economy, utility, durability and comfort. One of the factors to be considered is the material itself. Green building materials are composed of renewable, rather than non-renewable resources. Green materials are environmentally responsible because impacts are considered over the life of the product (Spiegel and Meadows, 1999). Therefore, to achieve the need for green building, brick is one of the materials that will be considered.

Due to the high cost of materials, it is very important to use innovative materials to reduce the cost for masonry bricks. The high demands in the use of natural materials such as sand and aggregates have caused the amount of pollution to nature increased and affect the natural ecosystems. In addition, excessive mining of river sand can cause soil erosion, affect marine life and public safety. The construction industry uses a lot of natural sources from non-renewable materials such as sand (Brasileiro et al., 2013). Therefore, ample studies have been done to replace natural materials with waste available from various sources such as construction sites, plantations, recycle center and others. A number of studies had been reported to test the potential use of crushed clay brick becoming coarse or fine aggregate alternatives (Aliabdo et al., 2013). On the other hand, in this present time, strong attention must be given to focus on natural fibers to preserve energy and protect the environment because of the simultaneously raising awareness on the environment and energy (Asasutjarit et al., 2007). According to Jabatan Perangkaan Pertanian Malaysia (2011) there are about 110,000 hectare area of Coconut or scientific name cocos nucifera in Malaysia. Coconut is a crop that multi-usable commodity. Literally, the disposal of coconut fiber has showed up in stockpiles around Malaysia (Saifuddin et al., 2010). It leads to a disposal problem. Other than people, environment also affected. Although it can be disposed by the environment since it is carbon compound, but it still will take some time. During the process, it caused negative impact towards the environment. Coconut waste that's not properly managed will create a problem such as bad smell and odour.

Protection and reuse of resources is needed to achieve sustainability globally. Usually, system of heat energy storage was insulated with fiber materials such as fiberglass, cellulose and natural fibers. The cost of insulation depends on the type of material used for thermal storage system. Therefore, ways to minimize these costs should be explored. This might help to conserve natural materials by recycling the crushed clay bricks from construction site waste and coconut fiber as alternative materials to make bricks instead of dumping it as waste in a landfill or burn it somewhere else. However the investigations about the thermal properties of crushed clay brick is limited because does not have many studies on it. Furthermore, it can save and reuse resources to achieve sustainability and develop new green building technology. Even from being environment friendly, they have the potential to find the use of cement bricks as warm protection. The factor that can influence the strength and durability of masonry is the degree which it becomes saturated with water (Khalaf and DeVenny, 2002). The saturation can occur in various types such directly exposed to rainfall and indirectly from moving action of water in foundation. The higher of water absorption cause the brick expose to degradation by freezing and thawing action (Khalaf and DeVenny, 2002). Besides, the increasing of fiber content cause the brick lost more water by absorption, this situation reduce the microstructure bond in the brick.

This purpose of this research is to determine whether the bricks can or cannot be used as warm protection with optimum strength. The application for the founding is to create masonry that helps reduce energy consumption in buildings and facilities. This research investigated the effect of coconut fiber and crushed clay brick as partial sand replacement in brick focus on the thermal conductivity, compressive strength and water absorption. Coconut fiber and crushed clay brick were chosen because easy to be obtained. In addition, recycling those materials makes an important contribution to overall sustainability and significantly will reduce the demand on the natural resources for construction materials.

2.0 EXPERIMENTAL PREPARATION

The thermal apparatus is designed to measure thermal properties. It consists of a handheld controller and sensors that can be inserted into the medium wish to measure. The single-needle sensors measure thermal conductivity. The KD2 Pro complies with ASTM D5334-08 which is a significantly updated version of the Standard Test Method for Determination of Thermal Conductivity of Soils and Rock by Thermal Needle Probe Procedure. The range of measurements for the thermal conductivity is 0.02 to 2.00 W/(mK). It represents the best practices in accordance with current research in heat and mass transfer.

Specific Elements of KD2 Pro that compliance to ASTM D5334-08 were All needles have sufficient length to diameter ratio to simulate conditions for an infinitely long, infinitely thin heating source and the device includes linear heat source and temperature measuring element. Moreover, it produces constant current, reads voltage and current to nearest 0.01 V and ampere, measures time to the nearest 0.1 seconds and the device is calibrated to ensure accurate measurements. Accuracy verification standard material is included. Figure 1 shows the thermal conductivity tester machine which a production of Decagon Devices, Inc, 2365 NE Hopkins, CT Pullman, WA 99163, United States.

ATM 3000 compressive machines were used to test compressive strength of the brick. The reading in digital form was showed when performing compressive testing on the brick. It is used for the maximum measured value of force which may apply to a brick sample.

Figure 1 Thermal properties analyzer KD2 pro instrument

Figure 2 ATM 3000 Machine

3.0 Materials

3.1 Cement

Concrete Laboratory of UiTM Shah Alam also provides the Ordinary Portland Cement which Type 1 to use in this research. The reason of using type 1 OPC in this research is because it is suitable for common or general purposes.

3.2 Fine Aggregate

Local natural sand being used as fine aggregates provided by civil engineering faculty that passes ASTM C33-01 or BS 882:1992. For cement bricks, sand was used in the experiment by passing No. 4 sieve to get smaller size than 4.75mm as the class size of coarse aggregate is more than 5mm.

3.3 Crushed Clay Brick

Crushed clay brick wastes were taken from nearby Hospital Shah Alam construction site. Then, it crushed using a jaw crusher machine to turn its small size to get smaller aggregates equivalent to sand size. After crushed, it was separated by using mesh sieve No.4 that is below than 5mm manually. The crushed clay brick was used as to replace partial sand in a sand-cement brick mixture. The small size of crushed clay bricks will be in a fixed 50% of the sand portion ratio. According to Aliabdo et al. (2014), the percentage replacement of aggregate should not be more than 50% to manufacture load bearing concrete masonry units which have low content of cement to follow related standard.

3.4 Coconut Fiber

Coconut fibers were taken from the coconut plantation in near local village at Sabak Bernam. The fibers were ripped from the exsocarp of coconut and separated using hand. Then the fibers were cut using scissors 2 cm- 6 cm length. The fiber length cannot be too long to avoid balling effect. It was used as partial replacement mixture to reduce the usage of sand with a portion ratio of weight coconut fibers corresponding to 2%, 4%, and 6% of sand volume in kg. According to Alida et al. (2011), the composites of the coconut fiber that contained more than 9% cannot produce good workability due to lack of water and the absorbent characteristic of natural fiber.

3.5 Specimen Preparation and Mix Proportions

The materials will be weighed as much as 10 bricks for each sample. According to Morel et al. (2007), usually bricks were tested in the range of 5 and 10 bricks. Based on Claybricks and Tiles Sdn. Bhd. (2007), the concrete material ratio can use 1:4 for building materials. The designs of brick mix will be used in this study as the experiment was 1:4 where 1 portion for OPC and 4 proportions of sand. Proportions of sand then will be divided into 2 for the replacement. A mixture containing OPC, sand and crushed clay brick will be 1:2:2 in ratios. To study the effects of coconut fiber and crushed clay brick percentage on thermal conductivity, compressive strength, and water absorption, 50 various mixtures (fiber:crushed clay brick:sand:cement) were designed as shown in Table 1. The brick mixture will be casting into the provided steel mould with dimension of 65 × 216 × 102.5 mm complying Malaysia Standard MS 76: 1972.

The mixtures were named with percentage of coconut fiber and type of bricks such as CFB6 means that the coconut fiber brick with 6% of coconut fiber with 50% of crushed clay brick, SCB for sand cement brick and CCB for crushed clay brick. The control mix was only used cement, sand and water to manufacture brick. The cement, water/cement ratio of 0.5 and the dosage of the crushed clay brick used 50% of sand replacement were kept constant for each various ratio to show the effect of percentage of the coconut fiber on the thermal conductivity of recycled masonry.

In this study, the sand (fine aggregate) will be replaced by certain percentage of coconut fiber and fixed percentage of crushed clay brick. The percentage will be 0%, 2%, 4% to 6% of coconut fiber and one sample is normal mixed brick (100% of sand) which will be used as a control sample. The replacement is depending on the mix proportion of sand. After cast in steel mould, tamp the mixture 25 times every three layers for manually. Then, the specimen will keep dry for 24 hours before curing. The mould was removed from test specimens at the age of 1 day. All the specimens were cover by wet fabric until the time of the test which is 14 days after casting. According to Rigassi (1995), the suitable curing process for bricks was 14 days and should not shorter than 7 days.

Table 1 Brick mixture ratio with water cement ratio 0.5

Samples	Coconut Fiber (%)	Crushed Clay Brick (%)	Sand (%)	Coconut Fiber (Kg)	Crushed Clay Brick (Kg)	Sand (Kg)	Cement (Kg)	Water (Kg)
SCB	0	0	100	-	-	2.48	0.62	0.31
CCB	0	50	50	-	1.24	1.24	0.62	0.31
CFB2	2	50	48	0.03	1.24	1.19	0.62	0.31
CFB4	4	50	46	0.05	1.24	1.11	0.62	0.31
CFB6	6	50	44	0.07	1.24	1.04	0.62	0.31

3.6 Test Method

Transient line heat source method is one of the transient method which is used by KD2 Pro Thermal Properties analyzer. According to Decagon Devices, Inc. (2014), transient method use applied heat source to give reaction to temperature change rate. The apparatus uses a fixed initial temperature. During measurement, the line-source produced an amount of heat which causes heat wave to spread into the specimen.

$$k = q(\ln t_2 - \ln t_1)/4\pi(\Delta T_2 - \Delta T_1) \qquad \text{(Eq. 1)}$$

Where

- k = Material thermal conductivity (W/m.K)
- q = Heat transfer rate (W, J/s, Btu/s)
- t = Times (s)
- ΔT = Temperature (°C)

Based on Khedari et al. (2005) experiment, they produce five samples for each ratio for testing. Before using the instrument to do experiments, the brick must be drilled two holes about 3cm to 4 cm depth using 3mm drill bit diameter size and 5mm to 6 mm spacing between the two holes for inserting the dual needle SH-1 sensor type shown on figure 2. The SH-1 was compatible with most solid and granular materials. After drilling the holes, be sure to clean the dust and drill cuttings from the rotary hammer hole using a swab or compressed air before inserting the SH-1 sensor. For experiment set up, placed the sensor in the hole is as tight as possible, but do not bend the needles to get accurate results. Then turn on KD2 Pro and press 'Enter' to read the thermal conductivity value of the brick and wait about 2 minutes to show the result on the instrument.

Figure 3 SH-1 sensor

According to Sanders and Brosnan (2007), the increase void area will not give a major impact to compressive strength. For the compressive strength testing of the brick that follow standardized in BS EN 772-1:2011. After thermal conductivity test, the compressive strength testing will be conducted using ATM 3000 machine. The brick was tested transversely in the ATM 3000 machine which has 3000 kN load. According to Morel et al. (2007), normally bricks were tested in the position where they being pressed in the direction the way they were usually placed. The reading of compressive strength results was recorded when the brick break or crack. For the water absorption, the brick was fully immersed in the clean water so that the water fill the void and the mass of brick was taken after 1hour, 3hour, 12hour and 24hour after being immersed in the water.

4.0 RESULTS AND DISCUSSION

4.1 Determination of Bricks' Dimensions Size

Determination of brick dimension for all samples was done before the compressive strength tests were conducted. The results in the determination of each brick dimensions satisfied with the standard stated in BS EN 772-16:2011. Table 2 shows the results founded from the measurement of the bricks using ruler.

Table 2 The average dimensions of individual brick measured

Dimensions	Measurement of sample (mm)
Length, L	215
Width, W	102
Height, H	65

4.2 Density

According to BS EN 771-1:2011 the density of most masonry construction divided by two category which is below than 1000 kg/m3 for light gross dry density group and more than 1000 kg/m3 for high gross dry density group such as solid unit, frogged unit and vertically perforated unit. Before the compressive strength tests were conducted, the weight and volume of the samples were taken to find the density. The table 3 shows the average results of the density test for 5 from 10 brick samples. The sample density was calculated by dividing weight (kg) with volume (m3) of the brick. From the results, it shows the reduction on density value of the bricks have along with the increase amount of coconut fibers with a constant amount of crushed clay brick. The density of Malaysian commercial brick had been tested in laboratory was 2091.9 kg/m3 with weight of 2.845 kg and 0.0014 m3 volume.

Table 3 Density of bricks

Samples	Average (kg/m3)
SCB	2290.71
CCB	2160.57
CFB2	1907.57
CFB4	1716.28
CFB6	1589.71

4.3 Effect on Thermal Conductivity Tests

It can be seen from Figure 3 and Table 4, the thermal conductivity decreased proportionally when the amount of coconut fiber increased as a sand partial replacement. From the results, it proved that the use of coconut fiber and crushed clay brick as a replacement can bring down the thermal conductivity of a brick. The control brick got thermal conductivity of 0.995 W/mK compared to 0.722, 0.712, 0.532 and 0.448 W/mK for 0%, 2%, 4%, and 6% of coconut fiber with 50% of crushed clay brick. As a result, the lowest thermal conductivity bricks was 0.448 W/mk consist of 6% coconut fiber and 50% crushed clay brick replacement and the highest thermal conductivity bricks was 0.772 W/mK which contains 50% of crushed clay brick replacement.

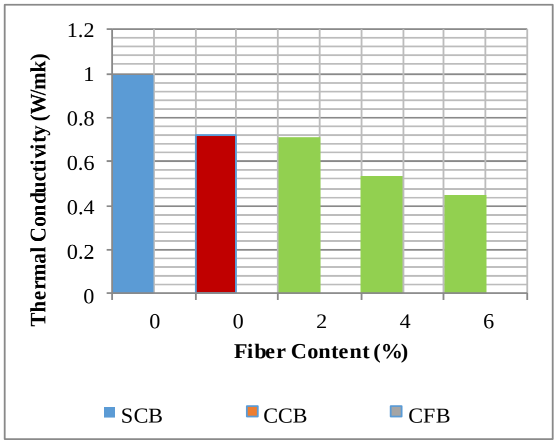

Figure 4 Thermal conductivity of different coconut fiber ratio with fixed percentage crushed clay brick

If compared to tested common commercial cement brick by considering its strength and thermal conductivity (0.696 W/mk), the optimum low thermal conductivity can be proposed for CFB was 0.532 W/mK which has 4% coconut fiber as partial sand replacement.The normal thermal conductivity of concrete brick in range of 0.77 W/mK (Claybricks & Tiles Sdn. Bhd., 2007). The thermal conductivity result obtained in this research was similar to the previous findings, which reported the thermal conductivity reduced along with the increasing amount of coconut fiber (Khedari et al., 2005; Asasutjarit et al., 2007).

In addition, from the result, crushed clay brick also contributes to reduce the thermal conductivity value of the brick as the presence of 50% crushed clay brick which shown by Aliabdo et al. (2013). The thermal conductivity of the brick decreases due to the presence of coconut fiber, which has low thermal conductivity. In the long run, it can attract the potentials for development most tropical country where desirable of low thermal conductivity construction materials to optimize the load of cooling or heating within the space of the building.

4.4 Effect on Compressive Strength Tests

Since the coconut fibers are natural fibers, from figure 6, the authors concluded that the average strength brick containing coconut fiber decline as fiber content increase after 14 days of curing. It owed because of the increasing amount of fiber that enhances the ability of brick to absorb water due to its absorbent characteristics (Alida et al., 2011). For this condition, it affects the cement which requires large amounts of water for hydration process to bind the bricks by generating gel acts as glue. Another researcher, Salla et al. (2013), have found that 0.5% jute and banana fiber which is natural fiber use as replacement in fly ash brick shows the can only produced maximum strength of 6.813 MPa and 6.812 MPa after 14 days. Hence, during compression, the natural fiber elastic, flexible and soft properties created 'creeping' effect (Chee-Ming, 2011).

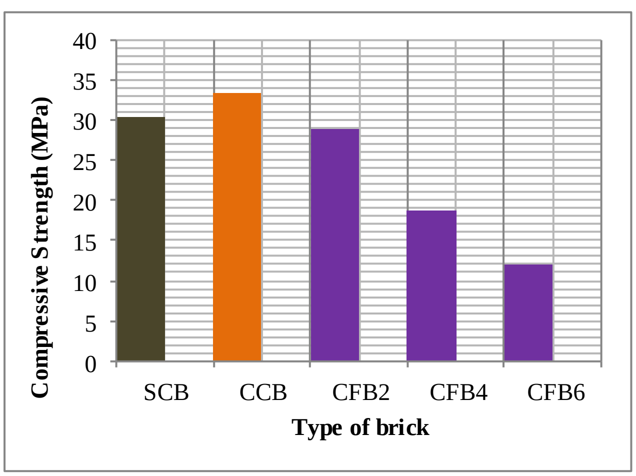

Figure 5 The average compressive strength of bricks samples

Again on the graph, the brick with 50% replacement of crushed clay bricks generated the highest compressive strength about 33.55 MPa while the brick with 6% of coconut fiber and 50% of crushed clay brick as replacement produce the lowest compressive strength about 12.11 MPa. Figure 4 shows the CFB4 which have the 4% replacement of coconut fiber and 50% crushed clay bricks from sand gives 18.74 MPa averages compressive strength and has reduced about 38.5% of the control value.

The results of this study indicate that the coconut fiber were not relevant to enhance the compressive strength of the bricks. The achieved results of compressive strength of this study were also similar to previous investigations which concluded the decrease of compressive strength because of the increasing amount of fiber (Khedari et al., 2005; Asasutjarit et al., 2007). Meanwhile, for the compressive strength result for sample which contains 50% of crushed clay brick also proved Aliabdo et al. (2013) study that at 50% of replacement of crushed clay brick can raise the compressive strength. The issue defined when the non-baked specimens have fibers, it can conclude the main reason for the stiffness and strength of the brick becomes less.

Other than that, the optimum strength of the brick to relate with low thermal conductivity was 18.74 MPa where the content of coconut fiber was 4% if compared with the compressive strength of commercial cement brick which in range from 12.40 MPa to 16.16 MPa. Additionally, extra amounts of the coconut fiber more than 6% will lead to a reduction of compressive strength. This was because of difficult to blend homogeneously and make the mixture become not workable mixing. In this case, the larger quantity of coconut fiber in the sample mixture will minimize the compressive strength of the sample.

4.5 Workability of The Brick Samples

Slump value of all the bricks with water cement ratio 0.5 is 0 respectively. One of the factors that usually contribute to the different reading of slump is a changes value of water cement content. Since there is no change in water cement ratio, the slump also has no change. However, the brick mixture that contains replacement components is dryer compare to control mixture for the brick. For those concrete which have slumped values nearer to zero it's known as no slump and in this state the fresh concrete can retain their quality and concrete mixes in a consistent state (Neville and Brook, 2010). As a result, the mixture of fresh brick from this research that was a concrete based was in suitable condition to be cast as a brick since the quality and the mix was in the consistent state.

4.6 Effect Water Absorption Test

Figure 5 shows the result of water absorption in the brick, where the highest rate absorption of water represented by the brick containing 6% of fiber and the lowest rate of water absorption was the control brick. It is happened due to the increase the amount of fiber will increase the capability of brick to absorb the water because the fibers have absorbent characteristics (Alida et al., 2011).

Control brick shows the highest reading of average weight which is 3.207kg, followed by bricks containing 2% of fiber which is 3.025kg. It is followed by bricks containing 4% of fiber with average of 2.404kg and the lowest average weight is the bricks containing 6% of fiber with average weight 2.226kg. It can be conclude that less dense of composites contained more void spaces compared with the dense composites and result can absorbed more water (Alida et al., 2011).

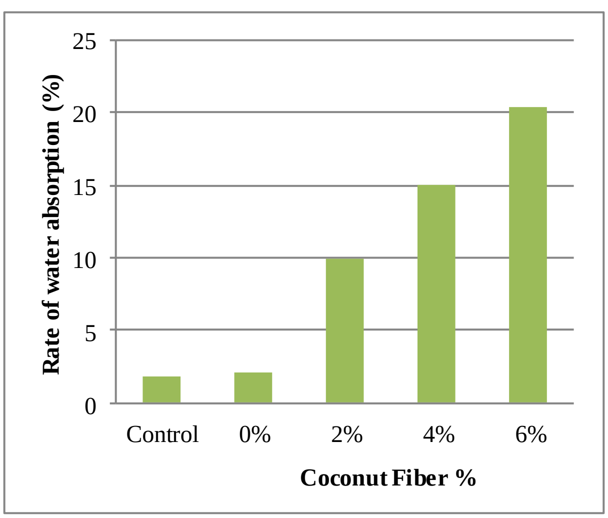

Figure 6 Water absorption of brick

Table 4 Effect of the percentage of coconut fiber with fixed percentage of crushed clay brick

Samples	Coconut fiber (%)	Crushed Clay Brick (%)	Thermal conductivity [W/(m.k)]						Average W/(m.k)
			I	II	III	IV	V	VI	
SCB	0	0	1.331	1.551	0.991	1.199	0.919	0.969	0.995
CCB	0	50	0.865	0.82	0.962	0.799	0.807	0.794	0.722
CFB2	2	50	0.715	0.852	0.356	0.874	0.769	0.706	0.712
CFB4	4	50	0.573	0.517	0.492	0.500	0.525	0.582	0.532
CFB6	6	50	0.565	0.5	0.313	0.521	0.486	0.305	0.448

Table 5 Compressive strength of the brick

Samples	I	II	III	IV	V	VI	VII	VIII	IX	X	Average (MPa)
SCB	30.31	30.60	30.61	31.56	30.00	31.16	30.31	29.36	30.92	29.76	30.46
CCB	35.62	31.48	34.78	34.33	33.95	32.77	33.15	31.15	32.32	35.95	33.55
CFB2	29.38	32.23	28.48	27.73	25.63	30.13	29.43	28.43	29.70	28.16	28.93
CFB4	18.96	18.52	19.97	19.24	17.51	18.24	17.78	19.43	19.70	18.05	18.74
CFB6	10.64	13.57	12.66	13.22	12.89	11.91	11.56	11.00	11.33	12.31	12.11

5.0 SUMMARY AND CONCLUSION

An experimental study was conducted to determine the influencing factors on the thermal conductivity of brick when the coconut fiber and crushed clay brick replaced the sand using Thermal Properties Analyzer KD2 Pro Instrument which the principle of Transient line heat source method was adopted. The following conclusions may be made based upon the systematic investigation of the thermal conductivity, compressive strength, and water absorption of the different tested brick samples:

1) The thermal conductivity and compressive strength of the bricks decreased when the content of coconut fiber as partial replacement of sand increased at the constant replacement level of crushed clay brick.

2) The percentage of water absorption increased when the percentage of coconut fiber content increased in the brick.

3) The authors proposes that the 4% coconut fiber from weight of sand in comparison with other fiber had the optimum thermal conductivity about 0.532 W/mk and compressive strength about 18.74 MPa and also compared with 5 samples of Malaysian commercial cement brick strength in the ranges of 12.40 MPa to 16.16 MPa.

4) The bricks containing coconut fiber and crushed clay bricks have good potential to be used in the construction industry because reduce production cost by recycling the waste resource to produce optimum thermal insulation to achieve sustainability and develop new green building technology.

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