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Engineering Properties of Unburnt Bricks Produced from Sugarcane Bagasse and Thermal Power Plant Ashes

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ABSTRACT: Along with the development of industry and agriculture, a large amount of industrial and agricultural wastes was released, negatively affecting the environment. The production of fired clay bricks also generated a huge amount of CO_2 into the atmosphere, causing the greenhouse effect. In order to mitigate the environmental problems related to excessive exploitation of clay resource in the production of fired bricks and overloading of agricultural and industrial wastes, the sugarcane bagasse and thermal power plant ashes were used to produce unburnt bricks. The brick mixtures were designed with the water-to-binder ratios of 0.30 and 0.35. The fly ash was used to replace 70% cement in total binder weight, while sugarcane bagasse was used to replace 0, 3, 6, and 9% weight of bottom ash. The engineering properties of bricks such as unit weight, compressive strength, ultrasonic pulse velocity, water absorption, thermal conductivity, and microstructure were tested. The Test results indicate that the unit weight, compressive strength, ultrasonic pulse velocity, and thermal conductivity of bricks reduced with increasing sugarcane bagasse or the water-to-binder ratio, whereas the water absorption of bricks increased. Many voids and high porosity of brick samples containing sugar bagasse were detected in scanning electron microscope images, confirming for the findings associated with the properties of these bricks. The advantages of unburnt bricks incorporating sugarcane bagasse are lightweight, low thermal conductivity, and suitable compressive strength of above 3.2 MPa. They are considered using in temporary constructions or heat isolation structures.This study proved the feasibility of using sugarcane bagasse and thermal power plant ashes in the production of green bricks.

Keywords: Unburnt brick, sugarcane bagasse, fly ash, bottom ash, agricultural waste, industrial waste.

Abbreviations: LOI, loss on ignition;UPV, ultrasonic pulse velocity; SEM, scanning electron microscope.

I. INTRODUCTION

Fired clay brick is known as the traditional brick, which is a ceramic material and widely utilized in the masonry construction over the world. However, the production of fired clay bricks is being restricted because of extensive exploitation of clay resources, high energy consumption, and releasing a large amount of CO_2 gas into the atmosphere. That causes many serious impacts on the environment such as land loss and greenhouse effect. On the other hand, a large quantity of industrial and agricultural wastes is liberated daily and still keeping on increasing. They are often dumped in ponds or disposed in landfills, also causing environmental pollution. Turning such wastes into green construction materials and replacement fired clay bricks by unburnt bricks attracted to many researchers in recent years. Many industrial and agricultural wastes such as copper mining tailings, gold mill tailings, and rice husk ash have been studied to use in the production of unfired building bricks [1-3].

Among industrial wastes, fly ash and bottom ash released from coal thermal power plants are accounted for a majority. As estimated by previous studies, 4.0, 8.5, 173.0, and 16.4 million tons of these ashes were respectively released in Thailand, Malaysia, India, and Vietnam annually [4-7]. In Vietnam, several thermal power plants opposite to the risk of stopping due to overloaded dumping of the storages. Therefore, recycling of these ashes into construction materials is an alternative way for sustainable development. The use of fly ash in the production of unburnt bricks received much attention from researchers [8-15], while the use of bottom ash or both fly ash and bottom ash is still limited [7, 16-18]. All prior studies demonstrated the feasibility of using fly ash and bottom ash in the production of unfired bricks. Other studies also indicated the possibility of using bottom ash to partially or fully replace fine aggregate in the production of concrete [19-20].

Recently, the amount of sugarcane bagasse collected from sugar mills in the world is abundant. In India and Pakistan, the sugarcane bagasse was generated about 100 and 11 million tons annually [21-22]. That is a by-product during the sugarcane crushing process for sugar extraction. The amount of sugarcane produced in Vietnam is around 14 million tons/year, and most of them are consumed in sugar production. In the production of sugar, 25% of bagasse is generated. It means that 3.5 million tons of sugarcane bagasse are released each year in Vietnam. Most of them are disposed of by incineration or used as fuel in the rural houses. The bagasse ash was studied to utilize as a partial replacement of clay in the production of fired bricks [23-25]. However, the production of fired bricks relates to environmental problems as aforementioned. The use of sugarcane bagasse as reinforced fiber in the production of cement composite was also investigated in several prior studies [26-28].

Although sugarcane bagasse has been already studied to use in the production of construction material; however, its application in the production of unburnt bricks is still limited. In this study, sugarcane bagasse and thermal power plant ashes are utilized in the production of unburnt bricks. The effect of sugarcane bagasse content on the engineering properties of unburnt brick is also investigated.

II. MATERIALS AND EXPERIMENTAL PROGRAMS

A. Materials

Sugarcane bagasse was sourced from a local sugar factory in Thanhhoa province of Vietnam. It was dried in the sun and removed too long fibers. Then, it was submerged in a calcium hydroxide solution for improving its durability. Finally, it was dried again before using. The natural appearance of sugarcane bagasse is shown in Fig. 1a. The specific gravity and dry rodded weight of sugarcane bagasse in this study are only 239 kg/m^3 and 63 kg/m^3, respectively. Fly ash and bottom ash were obtained from the Nghi Son coal power plant, which is also a local plant in Thanh Hoa province. The bottom ash was used as a fine aggregate, while the fly ash was used as a binder material. The natural appearance of bottom ash is shown in Fig. 1b, and its characteristics are given in Table 1. Along with fly ash, type PC40 cement acquired from Nghi Son company, a local cement company in Thanh Hoa province, was used as a binder material in unburnt brick mixtures. The density and chemical components of both fly ash and cement are tabulated in Table 2.

Table 1: Characteristics of bottom ash.

Density	Dry rodded weight (T/m^3)	Maximum particle size (mm)	Fineness modulus	Water absorption (%)
2.00	1.08	5.00	2.09	23.15

Table 2: Chemical components and density of fly ash and cement.

Composition (wt.%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Others	LOI	Density
Fly ash	51.5	20.2	7.07	1.99	1.23	2.16	15.9	2.16
Cement	21.2	5.5	4.9	61.0	3.0	4.0	0.4	3.12

(a) Sugarcane bagasse

(b) Bottom ash

Fig. 1. The natural appearance of (a) sugarcane bagasse and (b) bottom ash.

B. Brick mixtures

Unburnt bricks in this study were produced from cement, fly ash, bottom ash, sugarcane bagasse, and water. Eight brick mixtures were designed with two water-to-binder ratios of 0.30 and 0.35. Binder materials were cement and fly ash, in which cement and fly ash contents were respective 30% and 70% in the total weight of the binder. The mixture proportions of all brick samples are given in Table 3. Two control mixtures were designed without sugarcane bagasse, whereas others were designed with sugarcane bagasse. The sugarcane bagasse was used to replace 3, 6, and 9% by weight of bottom ash. It is noticed that the replacement volume of bottom ash by sugarcane bagasse is much higher than that of the weight replacement level. Nomenclature as seen in Table 3 are described as follows: WB30 and WB35 denote the brick samples with water-to-binder ratios of 0.30 and 0.35, respectively; whereas the number 0, 3, 6, and 9 after them represent the sugarcane bagasse content.

Table 3: Mix proportions of unburnt bricks.

Mixture	W/B	Ingredient proportions (kg)				
		Cement	Fly ash	Bottom ash	Bagasse	Water
WB30-0	0.30	180	420	1128	0	180
WB30-3				1094	34	
WB30-6				1061	68	
WB30-9				1027	102	
WB35-0	0.35	154	360	1200	0	180
WB35-3				1164	36	
WB35-6				1128	72	
WB35-9				1092	108	

C. Samples preparation and test programs

Cement and fly ash were mixed in dry first for two minutes. Then, bottom ash and sugarcane bagasse were added together with two-thirds of water and mixed for an additional three minutes.

Finally, the remain of water was added and continuously mixed for at least one minute, until the homogeneous paste was obtained. Brick samples with dimension of 160 × 85 × 40 mm were fabricated by using the steel mold. The forming pressure of around 0.5 MPa was applied in the production of samples. After casting, the brick sample was immediately de-molded and stored in natural room conditions until testing days.

The engineering properties of unburnt bricks consisting of unit weight, compressive strength, ultrasonic pulse velocity (UPV), water absorption, and thermal conductivity were investigated. The microstructure of brick was also investigated by the use of a scanning electron microscope (SEM). The unit weight, compressive strength, and water absorption tests were conducted conforming to the Vietnamese standard for concrete brick [29]. The UPV and thermal conductivity tests were conducted by using modern equipment, Matest C369, and Isomet-2014, respectively.

III. RESULTS AND DISCUSSION

A. Unit weight

As seen in Table 4, the unit weight of brick decreased with increasing sugarcane bagasse content. This finding is related to much lower specific gravity and dry rodded weight of sugarcane bagasse in comparison with those of bottom ash. It is noticed that although the sugarcane bagasse only replaced 3, 6, and 9% of bottom ash by weight; however, its real corresponding replacement volume is much larger. That explains the significant decrease in a unit weight of brick samples with the presence of sugarcane bagasse.

The unit weight of unburnt brick reduced from 1.56 T/m^3 to 1.16 T/m^3 and from 1.49 T/m^3 to 1.03 T/m^3 when the sugarcane bagasse content increased from 0% to 9%, corresponding to the water-to-binder ratios of 0.30 and 0.35. In Vietnam, unburnt bricks are often produced from cement and stone powder or sand in practice, referred to as concrete bricks with their unit weight of around 2.0-2.5 T/m^3.

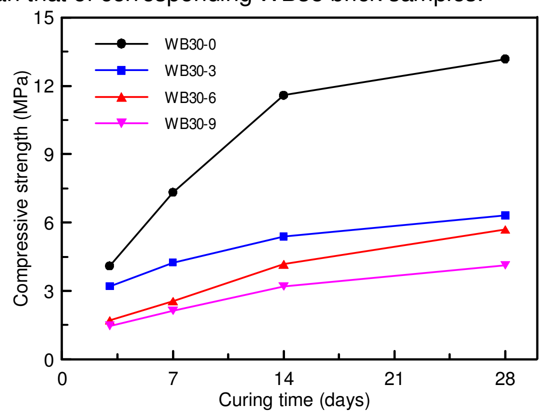
The much lower unit weight of unburnt bricks in the present study compared with that of concrete bricks is also attributable to the low density of fly ash and bottom ash. The density of fly ash and bottom ash are respective 2.16 and 2.00, while the densities of cement and stone powder are about 3.12 and 2.69, respectively [20].

Table 4: Unit weight of unburnt bricks.

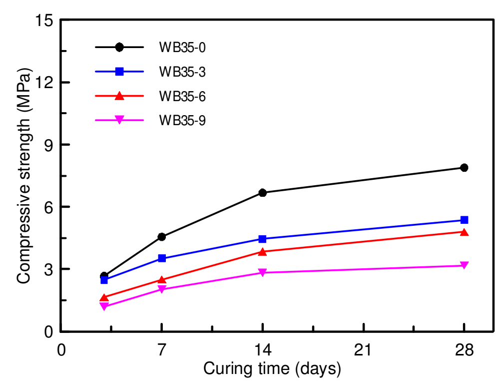
Samples	Unit weight (T/m^3)	Samples	Unit weight (T/m^3)
WB30-0	1.56	WB35-0	1.49
WB30-3	1.41	WB35-3	1.39
WB30-6	1.20	WB35-6	1.19
WB30-9	1.16	WB35-9	1.03

B. Compressive strenght

Compressive strength is a vital characteristic because it reflects the quality of brick. The Vietnamese standard classified the brick grade based on its compressive strength. The common bricks used in practice often have compressive strength from 3.5 MPa to 7.5 MPa, corresponding to grades M3.5 and M7.5 [7]. Fig. 2a and b show the compressive strength development of WB30 and WB35 brick samples, respectively. The compressive strength of WB30 brick samples is higher than that of corresponding WB35 brick samples.



(a) WB30



(b) WB35

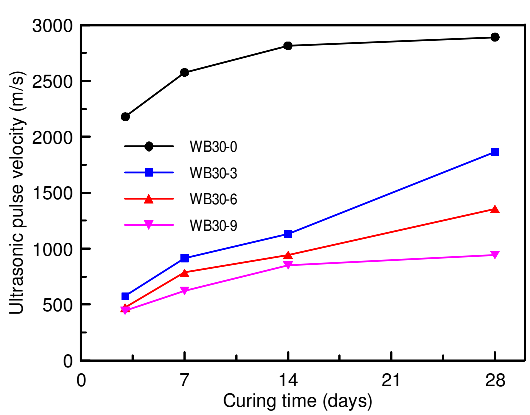
Fig. 2. Compressive strength of (a) WB30 and (b) WB35 brick samples.

That is due to the effect of water-to-binder ratio on the compressive strength of cement-based products, which is well-known as the basic knowledge of construction materials. For the same water-to-binder ratio, as an increment in sugarcane bagasse content, the compressive strength of brick significantly reduced. The reduction in compressive strength of brick is associated with the low specific gravity and dry rodded weight of sugarcane bagasse. A material with a low density also means that it is high porosity, resulting in low compressive strength [3].

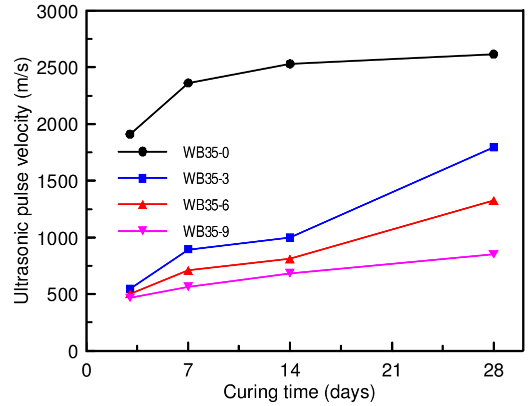
As observed in Fig. 2, the compressive strength of brick suddenly dropped since the appearance of sugarcane bagasse. The compressive strength of WB30 brick samples reduced from 13.2 MPa to 4.1 MPa when sugarcane bagasse content changed from 0% to 9%. For WB35 brick samples, the compressive strength also declined from 7.9 MPa to 3.2 MPa. Most sugarcane bagasse bricks had a compressive strength of above 3.5 MPa, except for WB35-9 mixture. However, the water-to-binder ratio can be adjusted for enhancing the compressive strength of brick. In other words, most of the brick produced in this study can be classified as grade M3.5 and can be used in the real. The lightweight and a suitable compressive strength are advantages of unburnt bricks produced from sugarcane bagasse and thermal power plant ashes.

C. Ultrasonic pulse velocity

Fig. 3 shows the UPV values of WB30 and WB35 brick samples with curing time. A similar trend to compressive strength, the UPV value decreased with increasing the water-to-binder ratio or sugarcane bagasse content. The low UPV value of these brick samples is also attributable to the low density of sugarcane bagasse. At 28-days age, the UPV values of WB30 brick samples with 0, 3, 6, and 9% sugarcane bagasse content were 2891, 1864, 1354, and 944 m/s. They are 2615, 1793, 1324, and 850 m/s for corresponding WB35 brick samples. As reported in a previous study [12], the fired clay brick had the UPV value of 793 m/s, whereas that value of the cement brick was 1501 m/s. All brick samples in this study had UPV values of above 800 m/s, indicating their relative quality is comparable or even higher than the fired clay bricks. The brick samples with 3% sugarcane bagasse content had a comparable UPV value to the cement bricks. This finding proves the feasibility of using sugarcane bagasse and thermal power plant ashes in the manufacture of unburnt bricks.



(a) WB30



(b) WB35

Fig. 3. UPV of (a) WB30 and (b) WB35 brick samples.

D. Water absorption

The water absorption of unburnt bricks with sugarcane bagasse content is illustrated in Fig. 4. It is clearly observed from Figure 4 that the water absorption of unburnt brick samples increased with increasing the water-to-binder ratio or sugarcane bagasse content. As mentioned above, the brick sample with a high amount of sugarcane bagasse resulted in low unit weight due to the low density of sugarcane bagasse. The lower density of brick samples, the higher water absorption is. The water absorption of WB30 brick samples increased from 12.4% to 39.6% corresponding to sugarcane bagasse content increasing from 0% to 9%. Similarly, the water absorption of WB35 brick samples increased from 13.6% to 42.5% with increasing sugarcane bagasse content. These values are as high as reported values from previous studies [14, 16]. In order to reduce water absorption in practice, the forming pressure during sample casting should be increased or reducing the water-to-binder ratio in brick mixture.

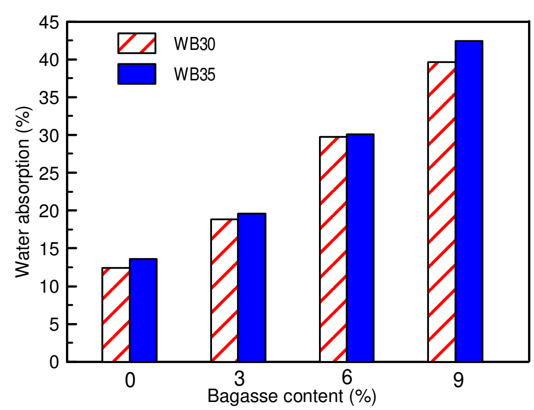


Fig. 4. Effect of sugarcane bagasse content on water absorption of brick samples.

E. Thermal conductivity

Fig. 5 shows the relationship between the thermal conductivity of brick samples and sugarcane bagasse content. The thermal conductivity of brick samples decreased when the water-to-binder ratio or sugarcane bagasse content increased. As demonstrated by Uysal *et al.* [30], the thermal conductivity is related to the density of samples.

The sample with a lower density resulted in the lower thermal conductivity. In the present study, the unit weight of brick samples declined since the water-to-binder ratio or sugarcane bagasse content increased, thus their thermal conductivity reduced. The thermal conductivity value of brick samples in this study felt within the range of 0.2-0.60 W/mK. Those values are much lower than the reported values from Turgut's study [8] and similar to the values from Cicek and Tanrverdi's study [14]. It is worth noting that the thermal conductivity of sugarcane bagasse bricks in the present study is comparable to that of foam lightweight bricks from Pahroraji's study [31]. The really low density of sugarcane bagasse bricks explains for the low thermal conductivity of these brick samples.

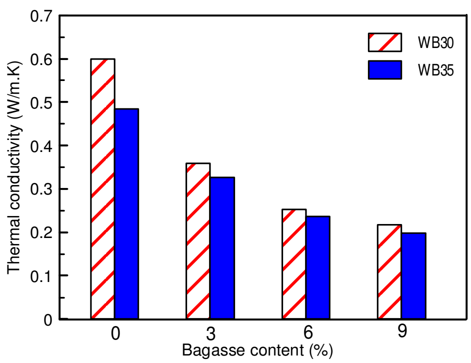
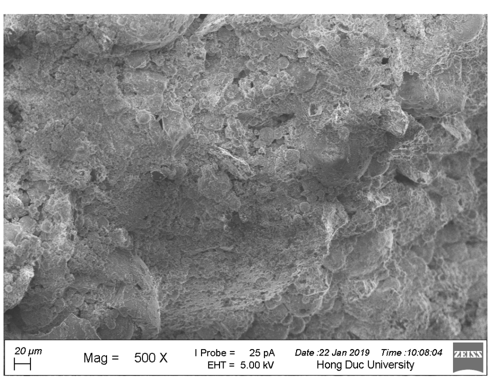


Fig. 5. Effect of sugarcane bagasse content on thermal conductivity of brick samples.

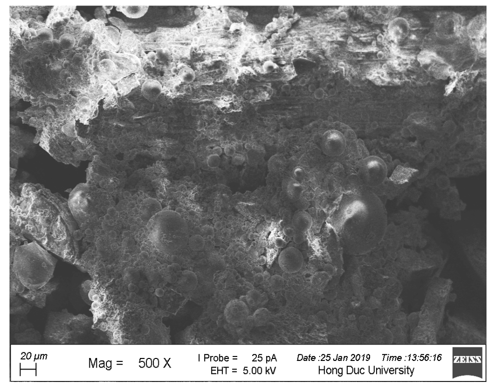
F. SEM observation

The microstructure images of all brick samples are shown in Fig. 6. The SEM images focused on the connection between sugarcane bagasse fibers and pastes. As seen from Figs. 6b, c, d, f, g, and h, the interconnection between sugarcane bagasse fibers and paste is not good, many voids between them were observed, leading to the high porosity of brick sample. This finding explains for the reduction in unit weight, compressive strength, UPV, thermal conductivity values, and increasing water absorption of brick samples incorporating sugarcane bagasse as aforementioned. However, with the lightweight, low thermal conductivity, and a suitable compressive strength, these bricks are suitably applied in the temporary constructions and insulation structures. The use of sugarcane bagasse and thermal power plant ashes in the production of unburnt bricks is proved to be positive in this study.

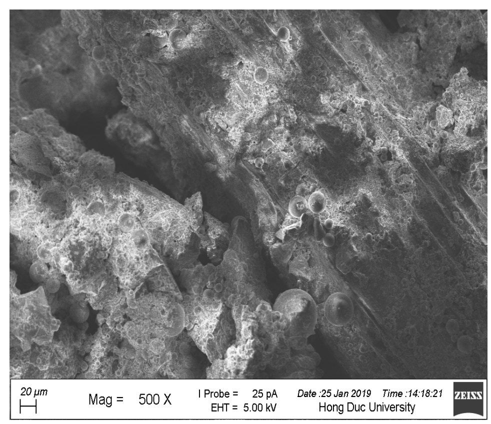


(a) WB30-0

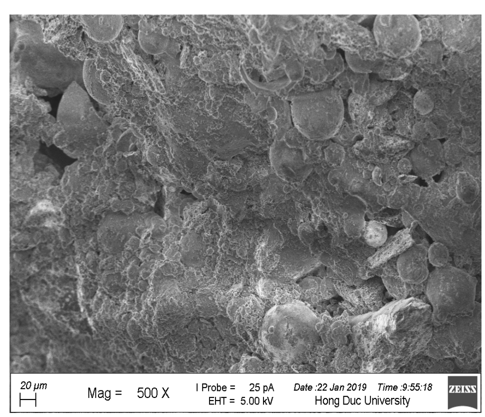
(b) WB30-3



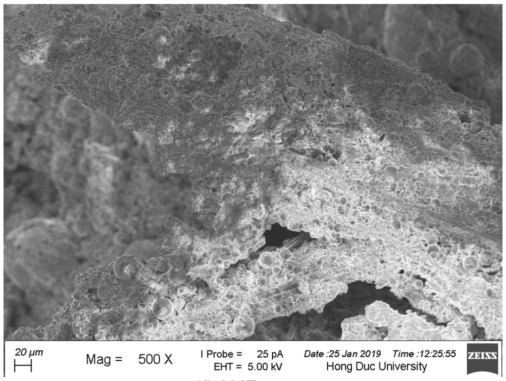
(c) WB30-6



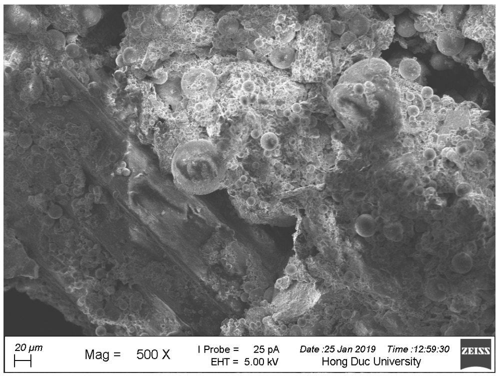
(d) WB30-9



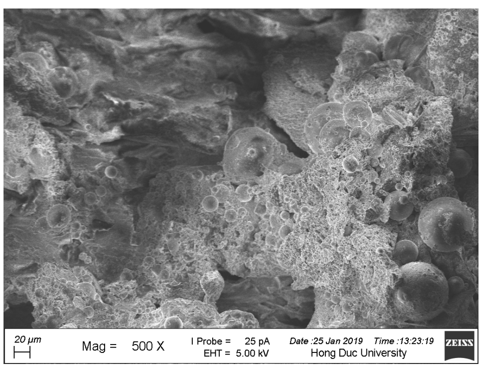
(e) WB35-0



(f) WB35-3



(g) WB35-6



(h) WB35-9

Fig. 6. SEM micrographs of unburnt brick samples.

IV. CONCLUSION

In this study, the unburnt bricks were made from sugarcane bagasse and thermal power plant ashes. The engineering properties of these bricks were also investigated. Some main conclusions may be drawn based on the experimental work conducted above, as follows:

— The unit weight, compressive strength, UPV, and thermal conductivity of bricks decreased with increasing sugarcane bagasse content or the water-to-binder ratio, while the water absorption of brick increased.

— The brick sample incorporating sugarcane bagasse had a lightweight, low thermal conductivity, and compressive strength of above 3.2 MPa. They are properly used for temporary constructions and heat insulation structures.

— Many voids and high porosity were observed in the SEM images of the brick sample containing sugarcane bagasse. This finding is related to the declining in unit weight, compressive strength, UPV, thermal conductivity, and increasing water absorption of these bricks.

V. FUTURE SCOPE

The effect of forming pressure on the engineering properties of sugarcane bagasse bricks should be investigated in the near future.

Conflict of Interest. The authors declare that there is no conflict of interest regarding the publication of this paper.

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