UTILIZATION OF COAL BOTTOM ASH AS FINE AGGREGATE IN ECO-FRIENDLY CONSTRUCTION BRICKS

TẬN DỤNG TRO ĐÁY NHIỆT ĐIỆN LÀM CỐT LIỆU TRONG CHẾ TẠO GẠCH XÂY DỰNG THÂN THIỆN MÔI TRƯỜNG

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(Received: August 21, 2023; Revised: October 23, 2023; Accepted: October 25, 2023)

Abstract - This study aims to recycle the coal bottom ash (CBA) for making environmentally friendly construction bricks. In the brick proportion, CBA was employed as fine aggregate to replace 0, 30, 50, 70, 85, and 100% of stone powder. The results demonstrate that, the compressive strength, ultrasonic pulse velocity, electrical resistance, and thermal conductivity of the 28-day bricks were in the ranges of 16.1 ÷ 61.3 MPa, 3469 ÷ 4208 m/s, 20.2 ÷ 54.6 kΩ.cm, and 0.75 ÷ 2.2 W/mK, respectively. According to scanning electron microscopy analysis, the rise in CBA content was associated with an increase in the number of voids and pores of bricks, which led to a less dense microstructure and a negative impact on the brick's quality. However, all specimens created for this investigation met the standards of the official Vietnamese standard and were categorized as grade M15.0 or higher according to their qualities.

Key words - Coal bottom ash; eco-friendly construction brick; compressive strength; thermal conductivity; SEM observation.

Tóm tắt - Nghiên cứu này nhằm mục đích tái sử dụng tro đáy từ nhà máy nhiệt điện than trong sản xuất gạch xây dựng không nung thân thiện với môi trường. Trong thành phần gạch, tro đáy được sử dụng như là cốt liệu nhỏ để thay thế 0, 30, 50, 70, 85 và 100% đá mạt. Kết quả nghiên cứu cho thấy, cường độ chịu nén, vận tốc truyền xung siêu âm, điện trở kháng bề mặt và độ truyền nhiệt tại 28 ngày tuổi của các mẫu gạch có giá trị tương ứng trong khoảng 16,1 ÷ 61,3 MPa, 3469 ÷ 4208 m/s, 20,2 ÷ 54,6 kΩ.cm và 0,75 ÷ 2,2 W/mK. Phân tích hình ảnh vi cấu trúc cho thấy số lượng và thể tích các lỗ rỗng trong các mẫu gạch tăng khi tăng hàm lượng tro đáy, làm giảm độ đặc chắc và ảnh hưởng tiêu cực đến chất lượng của các mẫu gạch. Tuy nhiên, tất cả các mẫu gạch được chế tạo đều thỏa mãn các yêu cầu kỹ thuật theo tiêu chuẩn Việt Nam hiện hành và được phân loại từ mác M15 trở lên.

Từ khóa - Tro đáy; gạch thân thiện môi trường; cường độ chịu nén; độ truyền nhiệt; phân tích hình ảnh vi cấu trúc.

1. Introduction

The building business has experienced rapid growth in recent years. Numerous construction projects and works have been carried out at various scales. As a result, both the amount and quality of the demand for fundamental construction materials like mortar, concrete, aggregates, brick, etc., are rising. While this is happening, natural resources for building materials are getting more and more expensive and limited. A common example is river sand, which will run out in Vietnam if its exploitation is not carefully controlled [1]. In order to stop the depletion of natural resources and safeguard the environment, research and the development of new materials to replace existing ones have become more important.

Besides, a significant amount of ashes (fly ash and bottom ash) from coal-fired thermal power stations have been released, seriously polluting the environment. Currently, Vietnam has twenty-five coal-fired thermal power stations, which supply approximately 38% of the nation's total electricity needs and also release approximately 16.4 million tons of ashes [2]. Coal thermoelectricity is expected to meet 53% of the system's total electricity needs by 2030, consuming more than 170 million tons of coal a year and releasing more than 35 million tons of ash into the atmosphere. By then, there would be around 442 million tons of these ashes stored in storage yards [3]. As reported by the Ministry of Construction [4], the Mekong Delta region has three coal-fired thermal power facilities, which release 1.8 million tons of ash annually on average. By 2030, it is predicted that the total amount of ashes in the region will be close to 13.6 million tons. Only about 10% of ashes were reused at the beginning of 2018 while up to 90% of ashes were stored in landfills. Due to only a small amount of ashes being recycled, the need for the storage yard area increases, resulting in a reduction in agricultural land. Additionally, the environment and human health will be severely hampered by this massive volume of ashes. Research must be done immediately to determine the best way to treat and use the above-mentioned ashes as a substance for human life.

Around the world, research has been done on the use of coal ashes as additives in the manufacturing of cement and concrete. With an annual consumption of up to 10 million tons, coal ashes are also successfully used to make plaster walls, lightweight materials, ceramics, ceiling panels, and other products [5, 6]. In developed countries, the use of coal ashes in road construction is generally supported and occasionally subject to tight control. For instance, up to 99% of coal ashes are recycled in France; 80% in Japan; and 85% in Korea. These ashes are primarily utilized in many other nations to manufacture unfired bricks. The production of traditional fired clay bricks is more expensive and uses more energy than the production of unfired bricks made from coal-fired thermal power stations' ashes [7]. Numerous studies have been conducted in Vietnam on the use of these ashes as cement additives and in the manufacture of tunnel bricks, etc.

Despite the fact that several studies have been done on employing these ashes as raw materials, which are mainly employed to create unburned bricks and concrete. It has been observed that the qualities of the ashes from various thermal power stations will vary based on the type of coal used and coal-burning technology. Each study has its focus on using local materials. Additionally, the majority of earlier studies tended to pay less attention to the material's durability properties and instead concentrated on examining the mechanical capabilities of the resulting materials. To produce eco-friendly construction bricks in Vietnam, research is being done to utilize coal bottom ash (CBA). Regarding the CBA replacement level, the bricks' tenacity, engineering qualities, and microstructure were assessed.

2. Materials and experimental methods

2.1. Materials

In this study, Nghi Son cement type PCB40 (PCB) was used as the binder material, while coal bottom ash (CBA) sourced from Nghi Son coal-fired thermal power plant was used to replace stone powder (SP) at 0, 30, 50, 70, 85, and 100% by weight. Both CBA and SP were used as fine aggregates in the brick proportion mixtures. The SP was acquired from a local stone mine in Thanh Hoa province. The main chemical compositions of both PCB and CBA are given in Table 1.

Table 1. *Chemical compositions of PCB and CBA*

Chemical elements	**Compositions (wt.%)**	
	PCB	***CBA***
SiO_2	21.2	52.2
Al_2O_3	5.5	20.0
CaO	61.0	2.4
Fe_2O_3	4.9	7.2
MgO	3.0	1.2
LOI	0.4	15.0
Others	4.0	2.0

The scanning electron microscopy (SEM) observation of CBA with a magnification of 500 times is shown in Figure 1. It should be noted that the CBA used in this study has a high loss on ignition (LOI), indicating that a significant amount of unburned impurities is present in CBA. Additionally, Figure 1 shows that CBA is primarily made up of porous particles, and the irregularly shaped particles seen in this figure may be unburned impurities, which are linked to CBA's relatively high LOI. In addition, Table 2 and Figure 2 present the physical properties and the particle size distribution of SP and CBA, respectively. When compared to SP, CBA's water absorption was significantly higher and its density was relatively lower. These traits are primarily due to the CBA particles' highly porous structure, which can be seen in Figure 1.

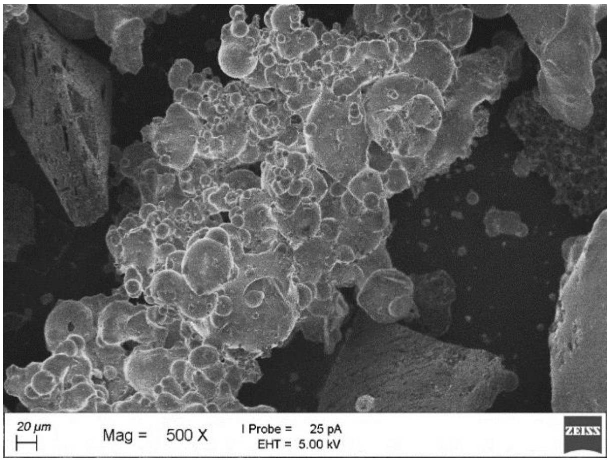


Figure 1. *SEM image of CBA particles*

Table 2. *Characteristics of SP and CBA*

Material name	**Properties**			
	Density (T/m³)	***Dry rodded weight (T/m³)***	***WA* (%)***	***FM*****
SP	2.69	1.62	1.08	3.39
CBA	1.99	1.08	23.15	2.09

*WA = Water absorption; FM**=Fineness modulus

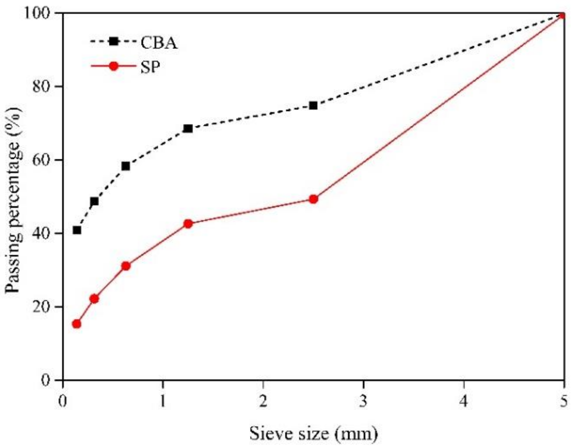


Figure 2. *The particle size distribution of SP and CBA*

2.2. Mix design and proportions

Table 3. *Brick's mix proportions*

Mixture	**CBA content (%)**	**Materials (kg/m³)**			
		PCB	***SP***	***CBA***	***Water***
CBA00	0	457.2	1865.4	0.0	160.0
CBA30	30	431.4	1232.2	528.1	151.0
CBA50	50	415.8	848.3	848.3	145.5
CBA70	70	401.2	491.2	1146.1	140.4
CBA85	85	391.0	239.3	1356.1	136.8
CBA100	100	381.3	0.0	1555.7	133.4

Table 3 shows the mixed proportions of all bricks with a constant water-to-binder ratio of 0.35. First, the reference mixture (CBA00) was designed with a blend of PCB, SP, and water. The amount of water was selected equal to 160 kg/m^3. After that, the CBA was used to replace SP at different levels of 30, 50, 70, 85, and 100% by weight (respectively denoted as CBA30, CBA50, CBA70, CBA85, and CBA100), whereas other materials' weight was kept constant. It should be noticed that the amount of all materials tabulated in Table 3 was re-calculated for exactly 1 m^3. The purpose of this mix design is to investigate the effect of CBA contents on the performance of eco-friendly bricks.

2.3. Samples preparation and test methods

Figure 3 illustrates the mixing procedure and sample preparation. The brick specimens were fabricated in a steel mold with dimensions of 160×80×40 mm. Table 4 shows the experimental program, in which compressive strength (CS) was conducted based on TCVN 6477:2016 [8], and other tests were performed based on the procedure described in a previous study [9]. While CS and ultrasonic pulse velocity (UPV) were conducted at 3, 7, 14, and 28 days, electrical resistivity (ER) and thermal conductivity (TC) were conducted at only 28 days. The SEM observation was performed based on broken pieces in the compression test at 28 days. It is noted that all the CS values presented herein were modified with a factor of 0.7 due to the effect of brick dimension as stipulated by TCVN 6477:2016 [8].

Preparation of raw materials

Dry mix for 2 min then mix with water for another 3 min

Demold and cure the samples in laboratory

Make the brick samples (under 0.5 MPa pressure)

Figure 3. *Sample preparation*

Table 4. *Test methods*

No.	Test name	Test day	References
1	CS	3, 7, 14, 28	TCVN 6477:2016 [8]
2	UPV	3, 7, 14, 28	Ngo et al. [9]
3	ER	28	
4	TC	28	
5	SEM	28	

3. Results and discussion

3.1. Compressive strength

Figure 4 shows the CS development for all brick specimens. All brick specimens' CS values can be seen to have increased with curing time. The 28-day-old strength values obtained, especially for the CBA bricks, were smaller in comparison to the 3-day CS. For instance, the 3-day-old strength values for the CBA50, CBA70, CBA85, and CBA100 combinations are 17.9, 14.5, 12.7, and 11.8 MPa. After 28 days, these mixtures generated equivalent CS values of 25.9, 22.9, 20.9, and 16.1 MPa. At 3 and 28 days, the CS values for the no-CBA specimens were 36.6 and 61.3 MPa, respectively.

It was also discovered that the loss in brick CS was due to the replacement of SP by CBA. The CS values decreased with increasing CBA content. In comparison to the CBA-free bricks, the CS of the ones containing 30, 50, 70, 85, and 100% CBA was approximately 53.5, 42.2, 37.4, 34.1, and 26.2%. Because of the CBA particles' highly porous structure, as depicted in Figure 1, the CS of the CBA bricks was significantly reduced. A further indication that CBA has a higher porosity than SP is its lower density and greater water absorption as compared to SP (Table 2). The Vietnamese national standard, however, classifies all brick specimens as high-strength brick grade (M15 or more) [8].

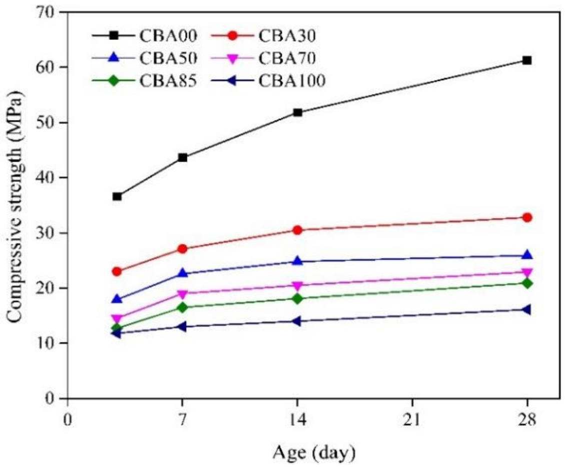


Figure 4. *CS of bricks*

3.2. Ultrasonic pulse velocity

All brick specimens' UPV values were discovered to increase steadily with curing age (see Figure 5), according to the CS development depicted in Figure 4. However, UPV values decreased as a result of the CBA being added to the brick mixtures. Thus, the specimens with 30, 50, 70, 85, and 100% CBA had 28-day UPV values of 3991, 3846, 3778, 3542, and 3469 m/s, respectively, which are roughly 95, 91, 90, 84, and 82% of the UPV value of the no CBA-specimen. The presence of highly porous CBA particles (see Figure 1) is thought to have caused the system to be less compact by adding more voids and pores (which will be detailed in the SEM observation section) within the brick structure, resulting in lower UPV values. The UPV values of all the specimens created for this investigation, however, were much greater than those of the unburnt bricks used in other studies [2, 10]. However, this investigation discovered that the CS of the bricks had a tight relationship with UPV. A high UPV value will be found in the brick sample with a high CS. It is noteworthy that earlier studies [2, 10] produced unburnt bricks using CBA as fine aggregate, but their CS was rather low, resulting in a lower UPV value. In other words, larger UPV values signify higher brick quality. Figure 6 illustrates the correlation between UPV and CS for all specimens, which can be described by the equation $y = 2573 + 63.1x - 0.62x^2$ ($R^2 = 0.928$). As a result, the UPV grew in direct proportion to the bricks' CS.

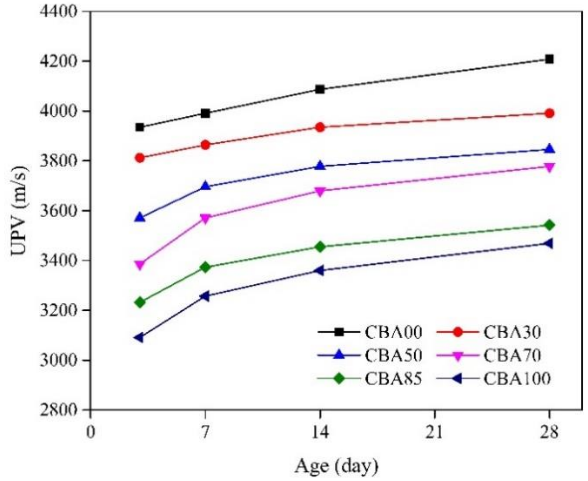


Figure 5. *UPV of bricks*

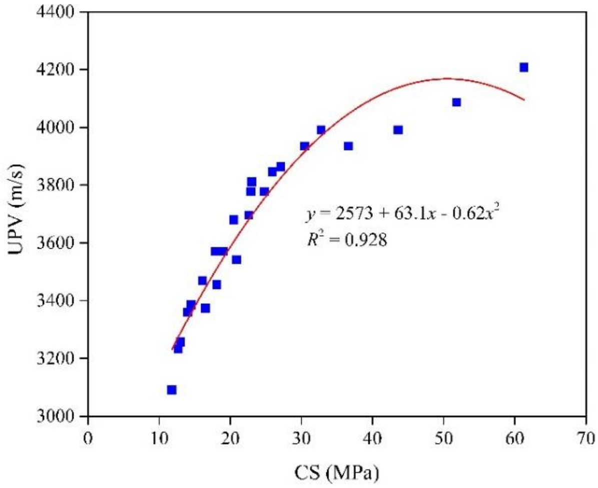


Figure 6. *The relationship between UPV and CS of bricks*

3.3. Surface electrical resistivity

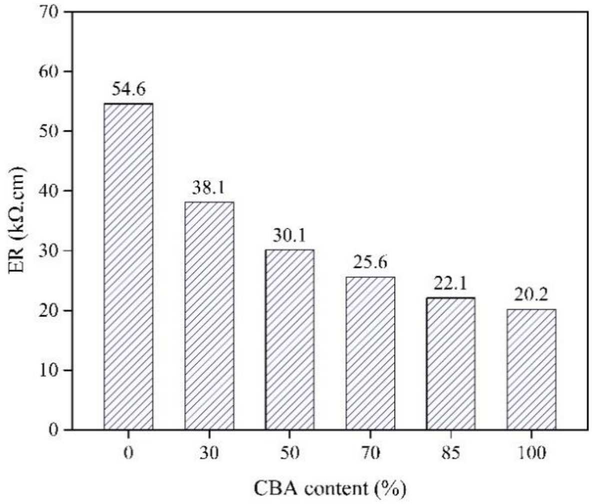


Figure 7. *ER of bricks*

When SP was substituted for CBA in the brick mixtures, it was discovered that all 28-day brick specimens had considerably lower ER measurement values (Figure 7). As a result, the addition of 30, 50, 70, 85, and 100% CBA lowered the ER values of the bricks by approximately 30, 44, 53, 59.5, and 63% when compared to that of the specimens without CBA. The inclusion of a significant number of porous CBA particles in the mixtures, which resulted from the replacement of SP with CBA, is linked to the bricks' lower ER values. All of the brick specimens' ER values, however, were significantly higher than the threshold of 10 kΩ.cm, which is required to categorize a material as having good resistance to chemical attack [11]. Thus, it can be said that every specimen made for the study showed excellent resistance to chemical attack.

3.4. Thermal conductivity

Brick's capacity for heat isolation under real-world conditions is represented by its TC value. According to Figure 8, the TC values for the tested specimens were in the range of 0.75 – 2.21 W/mK. The bricks' TC values were dramatically reduced as a result of the substitution of CBA for SP in the brick mixtures. Consequently, when the levels of CBA replacement increased, the bricks' TC values declined.

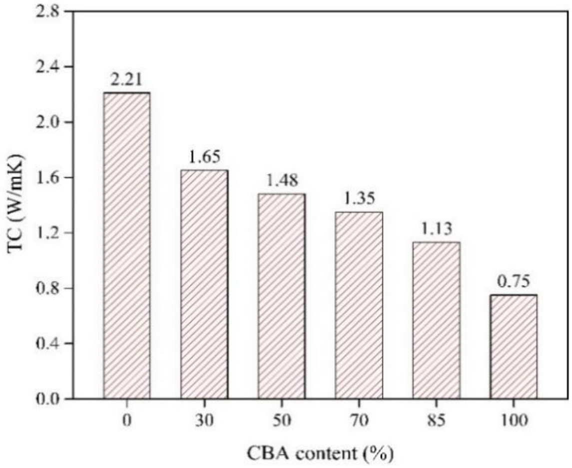
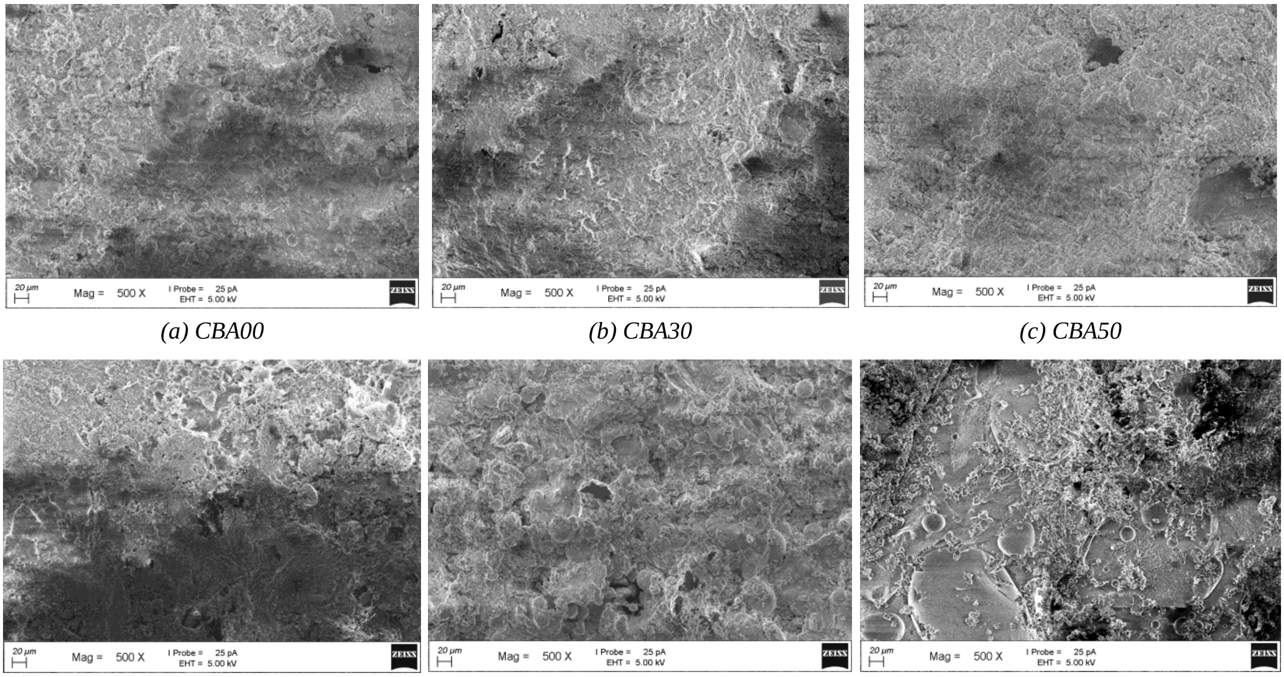


Figure 8. *TC of bricks*

The presence of larger voids and pores as a result of the less-active and unreacted CBA particles, as described above, was the main cause of the CBA bricks' lower TC values when compared to the CBA-free brick. In the following part, the microstructure observation will be used to better explain this phenomenon.

3.5. SEM observation

SEM was used to study the microstructure of all brick specimens (Figure 9). The surface of the CBA00 brick mixture (Figure 9a) was largely smooth with a few tiny pores/voids. Figures 9(b – f) show the SEM micrographs of bricks with CBA contents of 30 – 100%. In general, the addition of more voids and pores generated by the inclusion of porous CBA particles resulted in a less compact brick structure when CBA was substituted for SP. There was increased porosity and larger CBA particles in the 28-day brick specimen. As a result, the conclusions from the previously discussed CS, UPV, ER, and TC measures were further supported by the less compactness of the brick structure.



(a) CBA00 *(b) CBA30* *(c) CBA50*

(d) CBA70 *(e) CBA85* *(f) CBA100*

Figure 9. *SEM images of bricks*

4. Conclusions

The main goal of this study is to assess the Vietnam CBA's potential for recycling in environmentally friendly brick production. The following outcomes can be given in light of the experimental findings:

(1) The characteristics and microstructure of the brick specimens were adversely impacted by the addition of CBA to the brick mixtures in place of SP, except for TC. However, the study's brick specimens can all be categorized as being of the high-strength brick grade.

(2) The SEM observation revealed that as the CBA content increased, the quantity of voids/pores of various sizes increased as well. This resulted in a less compact microstructure, which had an adverse effect on the quality of the brick specimens.

(3) According to the regular use, every brick produced for this study met the requirements of the Vietnam national standard for construction bricks. For instance, because of its low TC, low price, and strong strength, the CBA100 will be recommended for regular application.

Acknowledgment: The authors would especially like to thank Ms. Trinh Thi Ha Phuong from Hong Duc University (Vietnam) for her invaluable help with the experimental work.

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