ENVIRONMENTALLY FRIENDLY UNBURNT BRICKS USING RAW RICE HUSK AND BOTTOM ASH AS FINE AGGREGATES: PHYSICAL AND MECHANICAL PROPERTIES

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Abstract

In order to reduce the serious impacts of industrial and agricultural wastes on the environment, raw rice husk and bottom ash were used as fine aggregates, while fly ash was utilized as a binder material in the production of unburnt building bricks. Two group mixtures were designed with water-to-binder (W/B) ratios of 0.30 and 0.35. The rice husk was used to replace 0%, 3%, 6%, and 9% of bottom ash content by mass. An experimental program was carried out on the brick samples at different ages from 3-day to 28-day to determine the main physical and mechanical properties of brick, such as unit weight, compressive strength, water absorption, ultrasonic pulse velocity and thermal conductivity. The microstructure of brick material was captured using scanning electron microscope technique. The experimental results allow to identify the effects of rice husk, bottom ash content as well as W/B ratio on the properties of bricks. Brick samples produced in this study had a proper compressive strength meeting the practice requirement and were classified as Grade M3.5 and 5.0 based on TCVN 6477:2016. At the use of 9% rice husk, the unit weight and thermal conductivity of bricks were really low (1.06÷1.08 T/m^3 and 0.201÷0.216 W/m.K), they are conformed to be used in temporary construction and insulation structures.

Keywords: rice husk; bottom ash; fly ash; unburnt brick; ultrasonic pulse velocity; thermal conductivity.

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1. Introduction

From past to present, brick is one of the common construction building materials not only domestically but also worldwide. As estimated in previous studies, 42 billion and 1.391 trillion units of bricks were annually consumed in Vietnam [1] and in the world [2], respectively. However, most of them were fired-clay bricks, referred to as traditional bricks. In order to produce a huge quantity of fired-clay bricks as mentioned above, a lot of fuel and natural resources were demanded. The production process of traditional bricks also released a large amount of toxic gases into the air, especially

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carbon dioxide, causing environmental pollution. Therefore, the Prime Minister of Vietnam has issued the Directive on enhancing the use of unburnt construction materials and limiting the production of fired-clay bricks since 2012. Especially, the reuse of solid wastes from industry to produce unfired building bricks has been encouraging.

In Vietnam, the common unfired building bricks are produced from cement, sand or crushed stone as fine aggregates, and water. Their unit weight and compressive strength are typical around 2.0÷2.2 T/m^3 and 3.5÷7.5 MPa, respectively [3]. It is noticed that the production of cement also causes the depletion of natural resources and put the negative impacts on the environment. Recently, the over extraction of river sand is another issue related to aquatic life, water sources, erosion and land loss. While the crushing of quarried stones also has some problems associated with the noise pollution and damages the natural environment. On the other hand, many types of industrial wastes such as fly ash, bottom ash, copper mining tailings, gold mill tailings, red mud are emitted to the environment due to the growth of population and a higher demand of human. These industrial wastes have seriously impacts on the environment and human life. Turning such wastes into green construction materials is an effective solution not only for the environment but also for the economic benefit.

Among many types of solid industrial wastes, the thermal power plant ashes such as fly ash and bottom ash were widely used in the production of unburnt bricks. While fly ash was used as a binder material [4–10], bottom ash was utilized as fine aggregate [3, 11–14]. Although the test results were different among these studies, but most of them showed the high possible using both fly ash and bottom ash in the manufacturing of unfired bricks. Besides fly ash and bottom ash, other industrial wastes such as copper mining tailings [15], gold mill tailings [16], and red mud [9] have been also recycled in the production of unburnt bricks. The recycling of industrial and agricultural wastes in the production of unburnt bricks is a trend in the 4.0 revolution of the construction industry that is attracted to many researchers.

Rice husk is an agricultural waste, which is a major by-product of the rice milling process. As estimated in 2010, an approximation of 149 million tons of rice husk was generated in over the world [17]. In recent decades, Vietnam is known as one of the largest rice exporter in the world. Consequently, a huge amount of rice husk is emitted. A part of it is used as fuel by famers, another part is used in agricultural land reclamation. However, most of them are dumped into the rivers, causing some serious problems related to environmental pollution [1]. Therefore, turning such waste into the construction materials has received many attentions from researchers. While some studies investigated the use of rice husk as a component in fired – clay bricks [18–21], others used rice husk ash in the production of unburnt bricks [1, 22]. It is noticed that ground rice husk ash can be used as binder materials [1, 22–24], whereas unground rice husk ash can be used as fine aggregate [1, 22]. Most of test results indicated that both the unit weight and compressive strength of bricks reduced, but the water absorption of bricks increased with the increase in rice husk content. With the use of 10% rice husk by weight, the unit weight and compressive strength of bricks could decline to around 1.15 T/m^3 and 0.5 MPa, respectively, and water absorption increased to 37.8% [18–20]. Similarly, Görhan and Şimşek [21] investigated the use of rice husk as 5%, 10%, and 15% by volume of fired-clay brick. Test result showed that the unit weight, compressive strength, water absorption, and thermal conductivity of bricks ranged 1.28÷1.67 T/m^3, 2.0÷9.0 MPa, 21.9÷37.8%, and 0.173÷0494 W/m.K, respectively. The utilization of rice husk in the production of cement brick has been investigated by Abdullah and Lee [25]. The cement bricks were made with 10%, 20%, and 30% rice husk by weight of the brick. The compressive strength and water absorption of bricks were respective 2.0÷6.0 MPa and 10÷50%.

Most of the previous studies proved that rice husk and rice husk ash can be used in the production of fired-clay bricks and unfired bricks. Although the compressive strength decreased, water absorption increased, but the unit weight of bricks significantly declined to incorporate rice husk. Therefore, rice husk shows a great potential in the manufacture of lightweight bricks. However, the use of raw rice husk in the production of unfired building bricks is still limited. In this study, raw rice husk and bottom ash are used as fine aggregates, while fly ash is used as a binder material in the production of environmentally friendly unfired building bricks. The effect of raw rice husk content on the properties of green building bricks is investigated.

2. Experimental program

2.1. Materials

In this study, the main compositions used to produce the unburnt brick samples includes cement, fly ash, bottom ash, and rice husk. The type-PC40 cement was taken from the Nghi Son factory with a specific gravity of 3.12. Both fly ash and bottom ash were sourced from Nghi Son thermal power plant in Thanh Hoa province with their respective densities of 2.16 T/m^3 and 1.99 T/m^3. The density, fineness modulus, moisture content, and water absorption of bottom ash were 1.08 T/m^3, 1.97, 17.06% and 23.15%, respectively. Rice husk was taken from a rice mill in Thanh Hoa city with its characteristics as the density of 1.068 T/m^3, the bulk density of 0.098 T/m^3, the fineness modulus of 3.38, and the water absorption of 3.7%. The low value of rice husk's bulk density was proved by Mansaray and Ghaly's study (from 0.086 to 0.114 T/m^3) [26]. Table 1 shows the physical and chemical properties of cement and fly ash. Table 2 shows the sieve analysis and fineness modulus of bottom ash and rice husk.

Table 1. Physical and chemical properties of raw materials

Materials	Density (g/cm^3)	LOI* (%)	Chemical compositions (% by weight)						
			SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Others
Cement	3.12	0.41	21.23	5.50	4.90	61.02	2.97	1.47	2.50
Fly ash	2.16	15.85	51.50	20.20	7.07	1.99	1.23	-	2.16

LOI* = Loss on ignition.

Table 2. Sieve analysis and fineness modulus of bottom ash and rice husk

Sieve size (mm)		5.0	2.5	1.25	0.63	0.315	0.14	FM*
Percentage of passing (%)	Bottom ash	80.6	75.8	71.6	65.8	59.7	50	1.97
	Rice husk	69.6	34.4	34	31.6	31.2	30.8	3.38

FM* = Fineness modulus

2.2. Mixture proportions

Table 3 shows the mix proportions used for preparing various unfired building brick samples. The brick mixtures were designed with two water-to-binder (W/B) ratios of 0.30 and 0.35, denoted as M30 and M35, respectively. For each W/B ratio, the rice husk was used to replace 3%, 6%, and 9% of bottom ash content by mass. RH denotes rice husk, and the numbers 0, 3, 6, and 9 after it denote the percentage of rice husk to replace bottom ash in brick mixtures. Two control mixtures were designed

Table 3. Mix proportions

Mix notation	W/B	Mix proportions (kg/m^3)				
		Cement	Fly ash	Bottom ash	Rice husk	Water
M30RH0	0.30	180.0	420.0	1128.3	0.0	180.0
M30RH3		177.4	413.9	1078.7	33.4	177.4
M30RH6		174.9	408.0	1030.4	65.8	174.9
M30RH9		172.4	402.3	983.5	97.3	172.4
M35RH0	0.35	154.3	360.0	1199.9	0.0	180.0
M35RH3		151.9	354.5	1146.1	35.4	177.2
M35RH6		149.6	349.1	1093.8	69.8	174.6
M35RH9		147.4	343.9	1043.1	103.2	172.0

without rice husk, referred to as M30RH0 and M35RH0. The content of cement and fly ash were respective 30% and 70% by weight of the total binder. Except cement was used with low content, other ingredients were industrial and agricultural wastes. In which, rice husk was utilized to reduce brick's weight. The purpose of these designed mixtures is to investigate the effect of rice husk content on the properties of unfired building bricks.

2.3. *Sample preparation*

The content of all the brick ingredients was precisely prepared based on Table 3. Cement and fly ash were firstly mixed by the use of the laboratory mixing pan in two minutes. After that, bottom ash and rice husk were added and mixed for another two minutes. Then, water was gradually poured, and

(a) Rice husk

(b) Bottom ash

(c) Test samples

Figure 1. Manufacturation of brick samples in the laboratory

the mixer continuously ran at moderate speed until a homogeneous mixture was obtained. Finally, the mixture was poured into a steel mold with dimensions of 160×85×40 mm and produced under forming pressure of around 0.5 MPa. The brick samples were immediately removed from the mold after casting and stored in in-door condition until testing as shown in Fig. 1.

2.4. Test program

In compliance with TCVN 6477:2016 [27], the properties of unfired building bricks including compressive strength, unit weight, and water absorption were tested. Other properties consisting of ultrasonic pulse velocity and thermal conductivity were also tested. It is noticed that the compressive strength and ultrasonic pulse velocity of brick samples were tested at 3, 7, 14, and 28 days of age, while other testes were conducted at 28 days of age. The reported values in this study are average of three measurements. The compressive strength, unit weight and water absorption were conducted in accordance with TCVN 6477:2016. Ultrasonic pulse velocity and thermal conductivity values of brick samples were directly measured by testing equipments such as MATEST C369 and ISOMET-2014, respectively. The ultrasonic pulse velocity was conducted on natural-dry samples according to ASTM 597 [28], while thermal conductivity was measured on saturated-surface-dry samples. The microstructure of bricks was also observed by using the scanning electron microscope provided by SEISS producer. All the compressive strength values presented herein were multiplied with 0.73, which is a coefficient factor reflecting the shape effect of the brick sample as stipulated in TCVN 6477:2016.

3. Results and discussion

3.1. Unit weight

The correlation between rice husk content and unit weight of bricks is shown in Fig. 2. As observed, when rice husk content changed from 0% to 6%, the unit weight of bricks slightly reduced from 1.56 T/m^3 to 1.49 T/m^3 and from 1.49 T/m^3 to 1.31 T/m^3 corresponding to W/B ratios of 0.30 and 0.35. Since rice husk content increased up to 9%, the unit weight of bricks significantly dropped to 1.06÷1.08 T/m^3. These values are notably smaller than that of current cement bricks used in practice (around 2.0÷2.2 T/m^3) [3]. It is noticed that the bulk density of rice husk (0.098 T/m^3) is really low due to the existence of gaps and voids among them. When the rice husk content is low, these gaps and voids were easily filled with cementitious paste. However, when its content increased, it is very difficult to compact and fulfill these gaps and voids by paste. This phenomenon is proved during the casting process of brick samples, and explained for the significant reduction in unit weight of brick samples with high rice husk content. This result shows a potential to apply rice husk in the production of lightweight bricks.

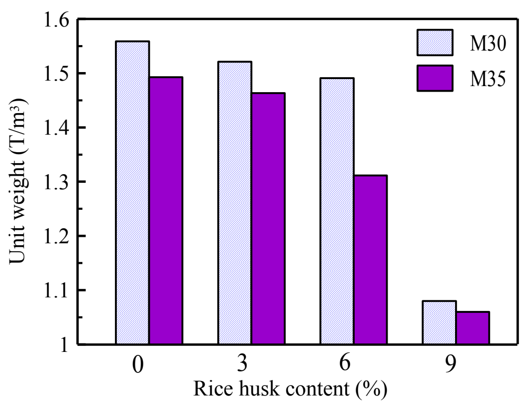


Figure 2. Effect of rice husk content on unit weight of brick samples

On the other hand, the unit weight of bricks was slightly reduced with increasing the W/B ratio. This is explained that when the W/B ratio increased, then the water content increased and the binder content decreased. The density of water (1.0 T/m^3) is smaller than that of cement (3.12 T/m^3) and fly ash (2.16 T/m^3). Another possible reason is due to the water evaporation during the hardening process. They leads to the reduction in unit weight of bricks as increasing W/B ratio.

3.2. Compressive strength

Compressive strength is a basic characteristic of bricks, then the grade of bricks is classified based on this property. The popular bricks used in practice for normal walls have a grade of from M3.5 to M7.5 corresponding to the compressive strength of from 3.5 MPa to 7.5 MPa. For lightweight bricks, the common compressive strength is around 3.5 MPa to 5.0 MPa. The development of compressive strength of all brick samples over time is shown in Fig. 3. Similarly to concrete, the compressive strength of brick samples with a W/B ratio of 0.3 is higher than that of the samples with a W/B ratio of 0.35. This is due to the effect of the W/B ratio on the strength development of cement hydration products. The compressive strength of M30 and M35 bricks felt within the range 4.22÷9.62 MPa and 3.42÷5.75 MPa, respectively. These values are similar to compressive strength results from previous studies conducted by Sutas et al. [18] (0.5÷5.5 MPa), Silva et al. [19] (2.0÷3.55 MPa), Ponphuak et al. [20] (2.5÷16.2 MMPa), Görhan and Şimşek [21] (2.0-9.0 MPa), and Abdullah and Lee [25] (2.0÷6.0 MPa).

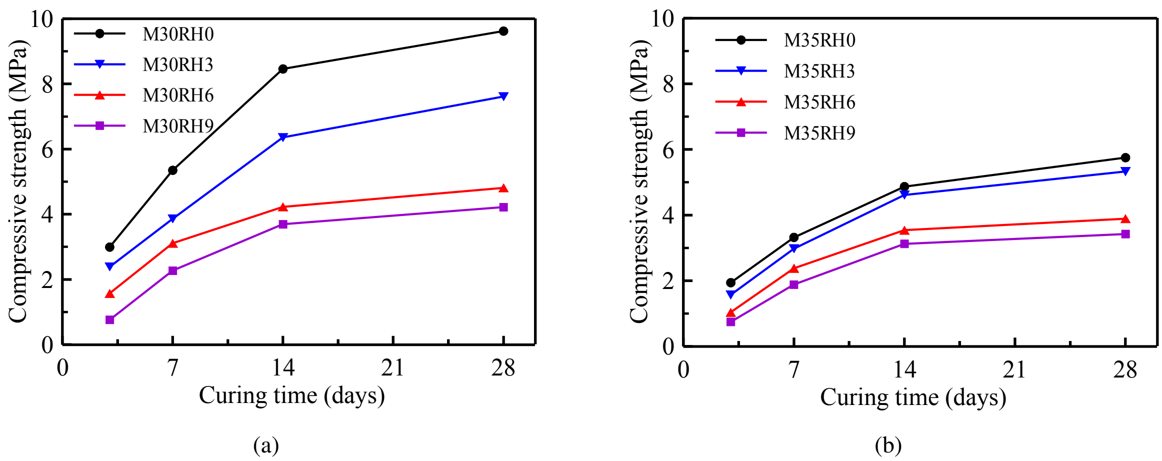


Figure 3. Compressive strength of (a) M30 and (b) M35 brick samples

With an increase in the rice husk content, the compressive strength of bricks reduced. As aforementioned, the bulk density of rice husk is really slight due to the voids among them, leading the less compaction during the manufacturing of brick samples. This is the main cause leading to the reduction in compressive strength of bricks with the presence of rice husk. However, the compressive strength of bricks is still higher than 5.0 MPa (referred to as Grade M5.0) if the replacement of 3% bottom ash by rice husk (M30RH3 and M35RH3). When increasing the rice husk content to 6% and 9%, the compressive strength of bricks is still higher than 3.42 MPa, could be classified as Grade M3.5. It demonstrated that rice husk can be utilized as fine aggregate in the production of unfired building bricks, at least considered as lightweight bricks. These rice husk bricks can be suitably used in temporary construction and non-load bearing walls due to the lightweight.

3.3. Water absorption

The effect of rice husk content on water absorption of brick samples is presented in Fig. 4. The water absorption value is often related to the compactness and density of the brick sample, so it is also related to the compressive strength value. According to Fig. 4, the water absorption of bricks slightly increased since the rice husk content increased from 0% to 6% or the W/B ratio increased. Its value significantly increased when the rice husk content increased to 9%. These findings are associated with the change of brick's unit weight as aforementioned. The higher water absorption of bricks is attributed to the voids among rice husk particles. The water absorption of bricks in this study ranged from 12.4% to 35.3%. Although these values are really high in comparison with that of normal cement bricks. However, these results are similar to those results from previous studies, felt within the range 12.7% ÷ 37.8% [19–21]. It is noticed that the water-resistance of bricks in practice will be enhanced by a layer of mortar.

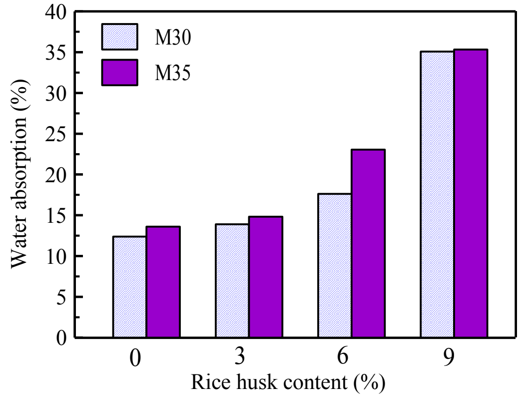


Figure 4. Effect of rice husk content on water absorption of brick samples

3.4. Ultrasonic pulse velocity

Ultrasonic pulse velocity (UPV in km/s) test is a non-destructive method, its result is related to the presence of voids and density of bricks. Figs. 5(a) and 5(b) exhibited the UPV values of tested samples corresponding to W/B ratios of 0.3 and 0.35, which were measured from 3-day to 28-day of bricks. The UPV of the M30 brick sample is higher than that of the corresponding M35 brick sample. This is due to the higher density of the M30 brick sample compared with the M35 brick sample. For the same W/B ratio, the UPV values of bricks declined with increasing rice husk content. At 28-day age, the UPV values of M30 brick samples were 2.89, 2.44, 1.94, and 1.25 km/s corresponding to rice

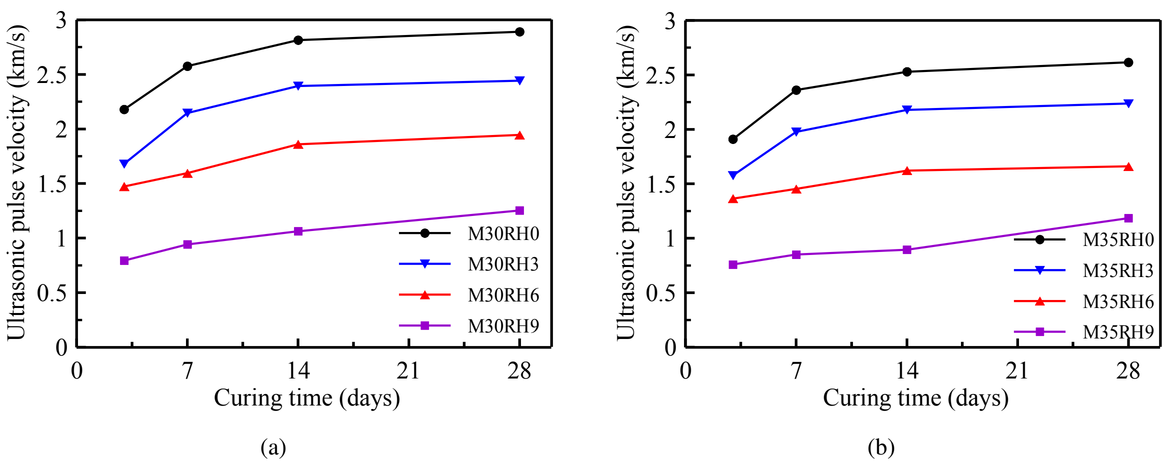


Figure 5. Ultrasonic pulse velocity of (a) M30 and (b) M35 brick samples

husk content of 0%, 3%, 6%, and 9%, respectively. Those were 2.61, 2.24, 1.66, and 1.18 km/s for the corresponding M35 brick samples. As mentioned above, the density of bricks reduced when rice husk content increased, resulting in reduction in UPV values. The low UPV value of brick samples is attributed to the voids among rice husk particles. It is demonstrated in previous studies [3, 29] that the UPV values and the compressive strength has a relationship. The bricks produced by the use of thermal power plant ashes had UPV values of 1.10÷1.77 km/s coressponding to compressive strength of 1.18÷7.7 MPa [3]. While the bricks used 5% rice husk ash and 5% surgarcane bagasse ash had UPV values of 1.16÷1.64 km/s [30]. In present study, at the rice husk content of 6% or higher, the UPV values of bricks ranged from 1.18 km/s to 1.94 km/s, similar to those values from previous studies [3, 30]. It is noticed that the compressive strength and unit weight of these bricks were around 3.42÷4.81 MPa and 1.06÷1.49 T/m^3, considered as lightweight bricks. While other brick samples with rice husk content of 0% and 3% had compressive strength of 5.33÷9.62 MPa, unit weight of 1.46÷1.56 T/m^3, resulting in UPV values of above 2.2 km/s. They may be considered as normal unfired building bricks. Depending on the actual requirements, the rice husk content is properly selected.

3.5. Thermal conductivity

The lightweight bricks are usualy used in heat isolation structures, then the thermal conductivity test was conducted to assess the insulation capacity of these bricks in this study. The effect of rice husk content on the thermal conductivity of bricks is illustrated in Fig. 6. It can be seen in Fig. 6, the thermal conductivity of bricks decreased with increasing rice husk content and W/B ratio. It was stated that the thermal conductivity of a brick sample is related to its unit weight and porosity [3, 31]. When the rice husk content increased, the unit weight of bricks declined. Consequently, their thermal conductivity values reduced. The similar trend is observed when W/B ratio increased. Incorporating rice husk, the thermal conductivity of bricks felt within the range of 0.201÷0.454 W/m.K. This range is similar to the result from Görhan and Şimşek's study [21]. It is noticed that Görhan and Şimşek used rice husk in the production of fired-clay lightweight bricks. Their thermal conductivity ranged from 0.173 to 0.494 W/m.K. It is worth noting that the brick samples with 9% rice husk had a very low thermal conductivity values (0.201÷0.216 W/m.K). As the results, with low unit weight and low thermal conductivity, these rice husk bricks in this study is also suitably used in isolation structures.

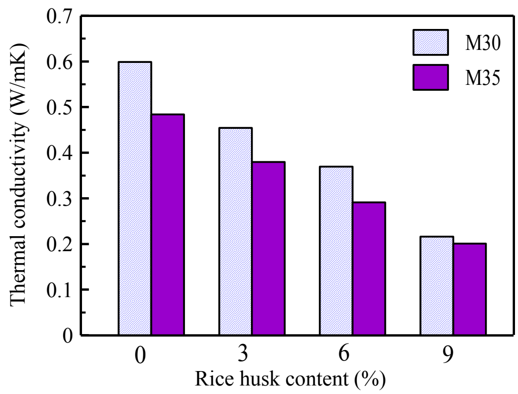
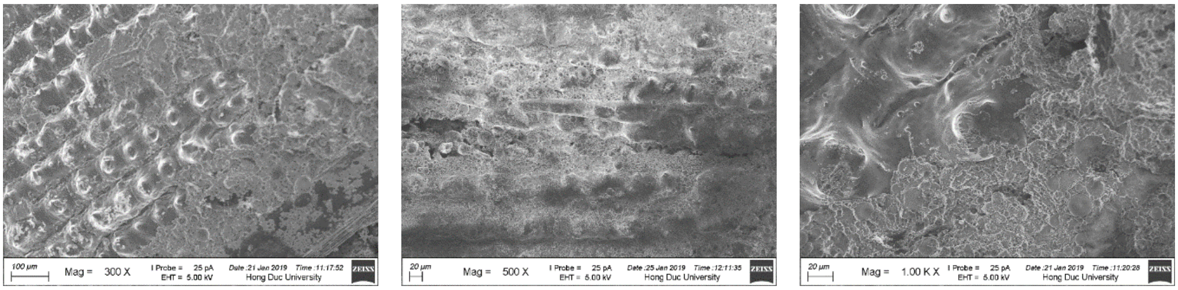


Figure 6. Effect of rice husk content on thermal conductivity of brick samples

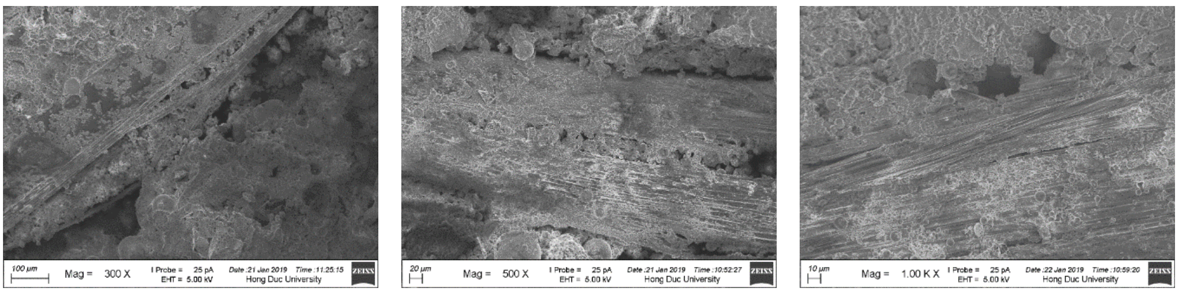
3.6. SEM observation

The scanning electron microscope (SEM) was used to observe the microstructure of bricks, especially the connection between rice husk and paste. The SEM micrographs of unfired building bricks incorporating rice husk are shown in Figs. 7 and 8. These micrographs were taken on different samples with magnifications (denoted Mag) of 300, 500, and 1000 times. It is interesting that the connection between the back of rice husk and cementitious paste is greatly good as shown in Fig. 7, while many voids were detected around the connection between the belly of rice husk and paste as shown in Fig. 8. The spikes on the back of rice husk help them bond well with the cementitious paste. Therefore, when the rice husk content level is low (around 3%), the compressive strength of bricks is still good (higher than 5.0 MPa). Whereas, the gaps in the belly of rice husk are responsible for the low unit weight, UPV, thermal conductivity, compressive strength, and high water absorption. Consequently, if the rice husk content is high (6% and 9%), the quality of brick is significantly reduced. These findings are related to all test results presented above.



(a) Mag = 300 X (b) Mag = 500 X (c) Mag = 1000 X

Figure 7. The connection between back of rice husk and paste



(a) Mag = 300 X (b) Mag = 500 X (c) Mag = 1000 X

Figure 8. The connection between belly of rice husk and paste

4. Conclusions

In this study, raw rice husk and bottom ash were used as fine aggregates in the production of environmentally friendly unburnt bricks. In which, rice husk was used to substitute 0%, 3%, 6%, and 9% of bottom ash content by weight. The brief conclusions can be drawn based on the experimental results as follows:

- As the increase in rice husk content, the unit weight, compressive strength, UPV, the thermal conductivity of bricks decreased, while water absorption of bricks increased. However, all bricks produced in this study can be classified as Grade M3.5 or M5.0.

- The unit weight and thermal conductivity of bricks are significantly dropped (1.06÷1.08 T/m^3 and 0.201÷0.216 W/m.K), when the rice husk content increased up to 9%. The tested bricks are suitably used in temporary construction and isolation structures. Depending on the actual requirement, the amount of rice husk is properly selected.

- The back of the rice husk showed a good connection with cementitious paste, while the belly of the rice husk exhibited a poor connection. Many voids around the connection between belly of rice husk and cementitious paste were detected under the SEM image. This finding explained the poor properties of bricks containing high amount of rice husk.

- This study showed that industrial wastes from thermal power plants (fly ash and bottom ash) and agricultural wastes (rice husk) located in Vietnam can potentially be used in the production of unfired bricks, especially the use of rice husk for lightweight bricks.

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