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Engineering properties of unfired building bricks incorporating various industrial wastes

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ABSTRACT

This paper is aimed to study the feasibility of using a mixture of fly ash and residual rice husk ash for producing unfired building bricks. The brick mixtures were designed using densified mixture design algorithm concept. A small amount of ordinary Portland cement (5–10%) was added into the mixtures as binder substitution. Especially, unground rice husk ash was used to replace natural aggregate in the mixtures by 10–20%. The brick samples with dimensions of 220×105×60 mm were prepared in accordance with TCVN 1451:1998 using a forming pressure of 35 MPa. These samples were subjected to the tests of compressive strength, flexural strength, water absorption, and bulk density. The experimental results revealed that all of the brick samples achieved good mechanical properties that well-conformed to the requirements of the related Vietnamese standards. The compressive strength and water absorption of the brick samples were respectively in the range of 13.8-19.7 MPa and 9.7-14.8%. The results of the present study further demonstrated a great potential to produce the unfired building bricks from fly ash and residual rice husk ash.

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1 INTRODUCTION

Brick has been one of the most common materials that widely used in construction industry for a long time. In the world, an approximately 1.4 trillion bricks are produced each year and the demand for bricks is expected to be continuously rising (Hwang and Huynh, 2015). Recently, the conventional bricks including fired clay bricks and ordinary Portland cement (OPC) bricks still remain a large quantity beside a minority of unfired building bricks (UBB) that are produced from different solid waste materials (Malhotra and Tehri, 1996; Lin, 2006; Chen *et al*., 2011; Chen *et al*., 2012; Turgut, 2012). It is well-known that the production of OPC has generated a noticeable amount of carbon dioxide (CO_2) to the environment, accounting for an approximate 5% of total man-made CO_2 emissions all over the world (Hwang and Huynh, 2015). Therefore, using various sources of supplementary cementitious materials such as fly ash (FA), rice husk ash (RHA), ground granulated blast furnace slag, bottom ash, etc. as a partial or full substitution of OPC is considered as one of the effective ways of reducing the negative effects to the environment. In recent years, there are many studies on the use of only FA or RHA in the production of bricks by different methods (Zhang, 2013). However, studies on the use of blended FA and RHA, which are available in Vietnam with a plentiful amount, in the production of UBB are still limited in the literature. Moreover, utilization of UBB to replace conventional bricks is found to have many advantages such as saving natural resources, reducing environmental pollution, and cost effectiveness. Therefore, the primary aim of the present study is to evaluate the feasibility application of binder materials that were made from FA-RHA-OPC blends in the production of UBB. The effect of replacing natural aggregate in the brick mixtures by unground rice husk ash (URHA) on properties of the UBB was also studied in this investigation.

2 EXPERIMENTAL PROGRAMME

2.1 Material properties

A mixture of FA and RHA with different amounts of OPC addition as a binder material was used to prepare the UBB samples. The characteristics of these materials are shown in Table 1. Natural sand sourced from Taiwan (density 2.6 and water absorption 1.4%) and URHA sourced from Vietnam (density 2.1 and water absorption 27.5%) were used as aggregates in the brick mixtures. It is noted that the aggregates used were in saturated surface-dry condition and that the presented properties of all of the materials used were checked at the Construction Material Research Laboratory (CMRL) of the National Taiwan University of Science and Technology (NTUST), Taiwan. Mixing water was local tap water.

Table 1: Characteristics of raw materials

Materials		OPC	FA	RHA
Physical properties	Specific gravity	3.15	2.08	2.18
Chemical compositions (wt. %)	SiO_2	22.0	63.9	95.6
	Al_2O_3	5.5	20.0	-
	Fe_2O_3	3.4	3.4	0.2
	CaO	62.8	3.8	0.7
	MgO	2.6	1.3	-
	Others	0.8	2.8	3.3

2.2 Experimental methods

The UBB samples were prepared using FA and RHA as binder materials with 5–10% (by total weight of binders) OPC substitution and 10–20% URHA as a natural sand replacement. Densified mixture design algorithm was used to design the mixture proportions for making UBB samples as shown in Table 2. The UBB samples with a standard dimension of 220×105×60 mm were prepared using a constant water-to-binder (W/B) ratio of 0.35 and a forming pressure of 35 MPa. All of the casted UBB samples were cured at ambient temperature until the time of testing. Then, the tests of compressive strength, flexural strength, water absorption, and bulk density of the UBB samples were conducted at the CMRL, NTUST, Taiwan. The preparation and test of the UBB samples followed the TCVN 1451:1998 (MOC, 1998) and TCVN 6355:2009 (MOC, 2009), respectively. In this study, the designed compressive and flexural strengths for the UBB samples were at least 10 MPa and 2.2 MPa at 28 days, respectively. Table 3 shows the requirements for strengths that used for evaluation of brick quality, as well as for classification of solid bricks, under TCVN 1451:1998 (MOC, 1998).

Table 2: Mixture proportions for the preparation of UBB samples

Mixture ID	W/B	Brick ingredients proportions, kg/m^3					
		FA	RHA	OPC	Sand	URHA	Water
C05U00	0.35	341.5	227.7	30.0	1452.8	-	209.7
C10U00		323.6	215.7	59.9	1452.8	-	209.7
C10U10		323.6	215.7	59.9	1307.5	145.3	209.7
C10U20		323.6	215.7	59.9	1162.2	290.6	209.7

Table 3: Classification of brick grade under TCVN 1451:1998

Brick grade	Compressive strength (MPa)		Flexural strength (MPa)	
	Average	Minimum	Average	Minimum
M200	20	15	3.4	1.7
M150	15	12.5	2.8	1.4
M125	12.5	10	2.5	1.2
M100	10	7.5	2.2	1.1
M75	7.5	5	1.8	0.9
M50	5	3.5	1.6	0.8

3 RESULTS AND DISCUSSION

3.1 Compressive strength development

Compressive strength is an important indicator for quality of a building brick. The compressive strength development and the effect of URHA addition on compressive strength of the UBB samples are presented in Figures 1 and 2, respectively. Figure 1 shows that the UBB samples had compressive strength values of greater than the requirement stipulated by TCVN 1451:1998 (MOC, 1998). Generally, all of the brick samples produced for this investigation can be classified as Grade M125 standard in term of compressive strength as shown in Table 3. Particularly, the bricks with 10% cement and up to 10% URHA met the standard requirement for Grade M150. Moreover, the UBB samples obtained a greater strength at higher cement content (Figure 1) due to the increased hydration rate in the samples. Moreover, Figure 2 clearly shows that using URHA to partially replace natural sand in the brick mixtures significant affected the bricks strength. As the results, the compressive strength of the UBB samples reduced significantly with higher URHA content. The compressive strength values of the UBB samples with 10% and 20% URHA were about 18% and 29% lower than those of the URHA-free bricks, respectively. According to TCVN 6477:2011 (MOC, 2011), the UBB samples prepared for this investigation can be classified as the good quality bricks.

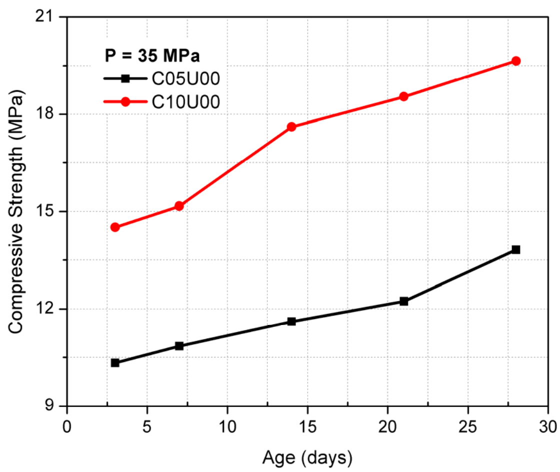

Fig. 1: Compressive strength development of the UBB samples

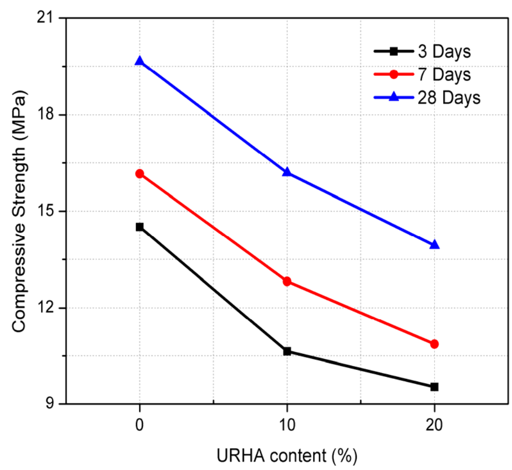

Fig. 2: Effect of URHA on compressive strength of the UBB samples

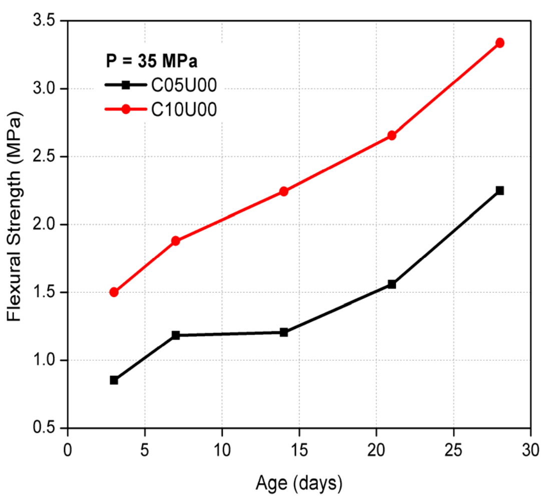

Fig. 3: Flexural strength development of the UBB samples

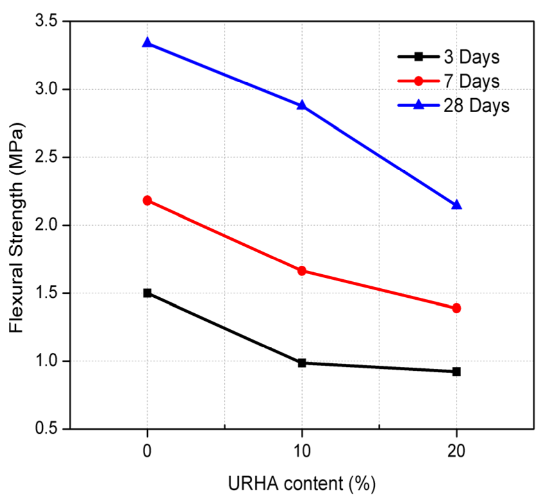

Fig. 4: Effect of URHA on flexural strength of the UBB samples

3.2 Flexural strength development

Test results of flexural strength at various brick ages and with different URHA contents are presented in Figures 3 and 4, respectively. It could be observed that the UBB samples achieved the flexural strength values of above the strength level stipulated by TCVN 1451:1998 (MOC, 1998). As consistency with compressive strength development, the UBB samples incorporating higher amounts of OPC had greater flexural strength values (Figure 3). Figure 4 further reveals that the URHA content also affected the flexural strength of brick significantly. Similar findings were previously reported by the authors (Hwang and Huynh, 2015). As the results, all of the brick samples met the standard requirement for Grade M100, as shown in Table 3, in term of flexural strength. In particular, the brick samples prepared with 10% cement and up to 10% URHA conformed well to the standard requirement for Grade M150.

3.3 Water absorption capacity

Water absorption is considered as an indicator for quality of brick samples as less water infiltration in the bricks is closely associated with more durable of the bricks. Test results for water absorption of the 28-day-old UBB samples are shown in Figures 5 and 6. The UBB samples registered water absorption level of below 16%, which is the maximum limit required by TCVN 1451:1998 (MOC, 1998). Furthermore, this study found that water absorption of bricks increased significantly with URHA content (see Figure 6) because of the highly porous structure of the URHA particles and the greater water absorption capacity of the URHA as compared to that of natural sand. Therefore, the UBB samples containing more URHA had higher water absorption levels. Averagely, the water absorption levels of the UBB samples with 10% and 20% of natural sand replaced by URHA were about 27% and 53% higher than those of the samples without URHA, respectively. This result was in line with the strength development of the bricks as aforementioned.

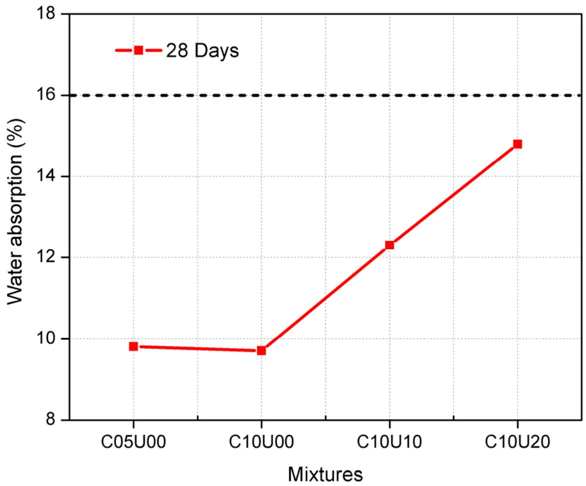

Fig. 5: Water absorption capacity of the UBB samples

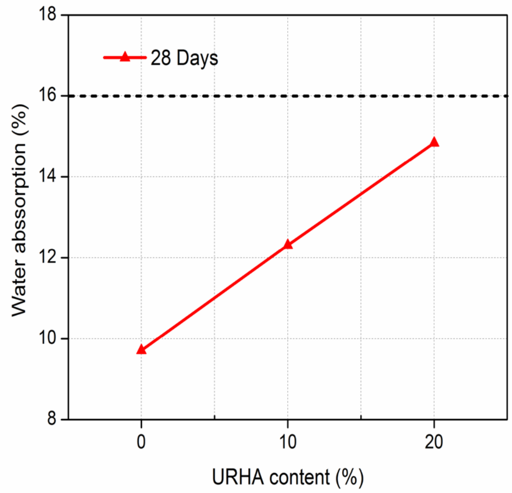

Fig. 6: Effect of URHA on water absorption of the UBB samples

3.4 Bulk density

Bulk density is an indicator used to classify a solid brick. The lower bulk density value is associated with the lighter weight of bricks. Test results for bulk density of the UBB samples are shown in Figures 7 and 8. As the results, all the brick samples prepared for this investigation had bulk density values of above 1600 kg/m^3, which is a minimum level for a solid building brick (MOC, 1998). Figure 7 clearly shows that bulk density of the UBB samples slightly increased with OPC content because of the higher specific gravity of the OPC in comparison with that of the FA and RHA (see Table 1). On the other hand, Figure 8 shows that replacement of natural sand by URHA caused a remarkable reduction in brick density as lower bulk density values were associated with higher URHA content in the brick mixtures. This phenomenon was mainly due to the much lower specific gravity of the URHA as compared to that of natural sand. In fact, the UBB samples containing 10% and 20% URHA as a natural sand replacement had a respective bulk density about 6% and 12% higher than those of the no URHA samples.

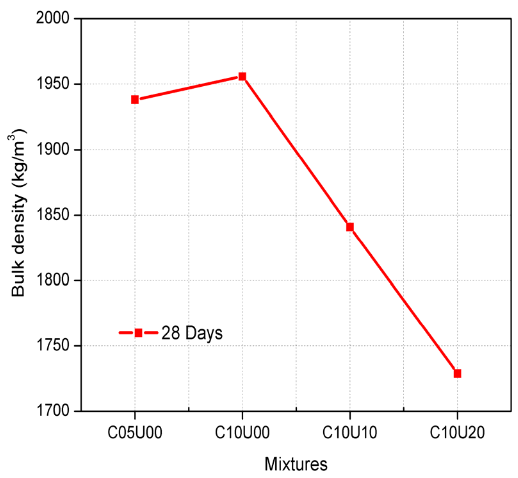

Fig. 7: Bulk density of the UBB samples at 28 days

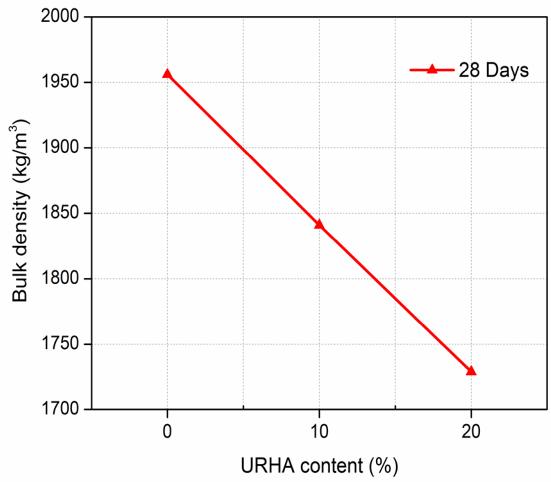

Fig. 8: Effect of URHA on bulk density of the UBB samples

4 CONCLUSIONS

The above experimental results lead to the following conclusions. The strength of the UBB samples increased with the amount of OPC content in the mixtures. In addition, the URHA content affected all of the engineering properties of the UBB samples significantly. The brick samples incorporating higher levels of URHA replacement exhibited a lower strength, greater water absorption, and much lower density in comparison to the bricks without URHA. All of the properties of the UBB samples met the requirements of the related Vietnamese Standard as the good quality of solid building bricks. The results of the present study demonstrated a high feasibility of producing UBB using FA and RHA.

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