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Performance of bricks made using fly ash and bottom ash

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HIGHLIGHTS

- This paper presents the results of investigation done on performance of bricks made using industrial wastes.
- A novel self compacting technique has been used to develop bricks in this investigation.

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ABSTRACT

This paper presents the findings of investigation carried out on bricks made using fly ash and bottom ash using a non-conventional method. Bricks were cast using self-compacting mixtures of bottom ash, fly ash and cement eliminating both pressing and firing. Bricks were then tested for compressive strength, modulus of rupture, ultrasonic pulse velocity (UPV), water absorption, initial rate of suction, fire resistance and durability. The results showed better performance compared to conventional clay bricks in the properties investigated. Compressive strength was between 7.13 and 17.36 MPa, while UPV ranged from 2.2 to 2.96 km/s. Increase in fly ash reduced the water absorption. Tests for fire resistance indicated that the bricks did not show any spalling, and, there was increase in strength of up to 30% after heating. The optimum ratio of bottom ash, fly ash and cement was found to be 1:1:0.45 for better performance of bricks. It is concluded that bricks developed in this study can be used as an alternative to conventional bricks and hence can contribute to sustainable development.

1. Introduction

Use of bricks in the building construction is inevitable. Bricks are mainly produced from clay and shale since decades. The continuous extraction of clay and the removal of the topsoil for brick manufacturing cause substantial depletion of virgin resources. On the other hand, industrial waste disposal particularly coal combustion wastes have always been a concern in power plants. Statistics show that coal combustion waste, which is mainly fly ash and bottom ash, was 367 million tons in 1992, increased to 459 million in 1996 tones, 480 million tons in 2001 and keep increasing rapidly until the present time [1]. In 2012, coal supplied around 30% of primary energy and 41% of global electricity generation. The worldwide production of coal ashes is estimated to more than 800 million tonnes in 2012. Coal use is forecast to rise over 50% to 2030, with developing countries responsible for 97% of this increase, primarily to meet improved electrification rates [2]. Given this production trend, the estimated worldwide production of coal ashes is around 13.33 billion tonnes in 2030. The reuse rate for fly ash is around 47% whereas the reuse of bottom ash is only around 5.28% [3]. Hence, civil engineers are obliged to find sustainable solution for saving the virgin resources by reusing coal ashes. Researchers went through manufacturing bricks from various wastes such as, bottom ash, fly ash and rice husk ash to overcome the problems associated with the industrial wastes. One of the ways in using such wastes in large quantities is by utilizing them in brick manufacture [4].

This paper reports the results of an investigation done on the performance of bricks made using coal ashes and silica fume. The ingredients were mixed at predefined ratios and made to be flowable. This flowable mixture was then poured into brick moulds to manufacture bricks. Fly ash and bottom ash when used in bricks, will lead to bulk consumption and hence contribute to sustainable development.

2. Experimental methods

2.1. Materials

Ordinary Portland cement (OPC) from Lafarge cement Sdn Bhd, Malaysia confirming to MS522 Part1: 1989 as mentioned in [5] was used for all mixtures. The specific gravity of cement was 3.15 and specific surface area was 2910 $cm^2 g^{-1}$.

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Class F fly ash and Bottom ash were obtained from Kapar Energy Ventures Sdn Bhd, Kapar Thermal Power Station, Selangor, Malaysia. Properties of fly ash and bottom ash are given in Table 1. Bottom ash was dried in an oven at a temperature of 110 °C for three hours before use to ensure it is in dry state. The bottom ash was sieved through a 10 mm sieve and the contents passing through the sieve was used in the investigation.

2.2. Manufacture of bricks

The mix proportions of content materials are shown in Table 2. Total of 12 mix proportions were produced. The Bottom ash and cement were firstly mixed in the mixer in dry state for 2 min. Then, fly ash was added and mixing continued for another 2 min. Mixer was well covered during the mixing process to avoid the volatility of fly ash due to its light weight. Then, water was added and mixing continued for another 2 min. The mixture was then tested for flowability following the procedure specified in ASTM D6103 [6]. The mixture is considered flowable when the spread diameter coming from the 200 mm high tube is 200 ± 20 mm on a horizontal surface [7]. Water content was adjusted until the required flowability was achieved. The fresh mixture was then poured into brick moulds of size (200 mm × 90 mm × 60 mm), its top surface was leveled and kept covered with a wet cloth for two days in the laboratory condition after which the specimens were removed from the moulds and transferred to curing condition of 95% relative humidity at 22 °C. The curing condition was achieved by keeping the bricks in partially water filled closed storage boxes and keeping the boxes in an air conditioned room as mentioned in [8].

2.3. Testing

Bricks were tested for strength, modulus of rupture, UPV, water absorption, sorption, initial rate of suction (IRS) and fire behaviour. Total of 144 specimens were tested for compressive strength. Compressive strength test was done using universal testing machine of 1000 kN capacity at 7, 14, 28 and 56 days in accordance with ASTM C 67-03 [9]. Test for modulus of rupture was made using a universal testing machine following the procedure of ASTM C 67-03 [9]. The length of the span was kept at 167 mm. UPV test is a function of elastic modulus and density of material. Pulse velocity can therefore be used to assess the quality and uniformity of material. The UPV test was conducted according to BS1881-203 [10] at 7, 14, 28 and 56 days.

Water absorption is an important factor affecting the durability of brick. The lesser the water infiltrates into brick, the higher will be the durability of bricks. The determination of water absorption was done at the age of 28 days according to BS3921 [11]. Initial rate of suction (IRS) denotes the amount of water absorbed by the brick upon contact with mortar during laying. IRS, resulting from the presence of capillary mechanism of small pores in the brick, is an important property in masonry construction since it affects the bond strength between the brick and mortar; thus affecting water tightness and durability of masonry. Test for IRS was done as per BS3921 [11].

Test for fire resistance of bricks was made by placing the bricks in an oven at 28 days of curing at a temperature of 200 °C for 20 days. The bricks were then tested for compressive strength. This test was conducted as per ASTM C67 as mentioned in [9].

Durability test examines the performance of bricks in severe environments resulting from acidic rain as well as sodium chloride that happens to be present in coast areas. The durability of bricks have been assessed in terms of corrosion resistance and increase of weight after immersion in acidic and alkaline medium. Bricks were immersed in 1% Sulphuric acid (H_2SO_4) solution to emulate acidic condition [12], and in 3.5% concentration of Sodium chloride (NaCl) solution for alkaline condition. The specimens were kept in these curing conditions for 28 days as mentioned in [4]. The following equation was used to derive the percentage of weight increase [4]:

Table 1
Chemicals composition of constituent Materials.

Chemical components	Materials		
	Cement	Fly ash	Bottom ash
SiO_2	21.54	56.58	56.0
Al_2O_3	5.32	27.83	26.7
Fe_2O_3	3.6	4.0	5.80
K_2O	63.6	–	2.60
CaO	–	4.3	0.80
TiO_2	–	–	1.30
SO_3	2.1	–	0.10
Na_2O	–	–	0.20
MgO	1.0	1.40	0.60
Loss in ignition	2.48	2.53	4.60
Espacific gravity	3.15	2.323	2.1–2.7

Table 2
Mixture proportions.

No.	Mix ID	Bottom ash	Fly ash	Cement
1	M1A	1	1	0.25
2	M1B	1	1	0.35
3	M1C	1	1	0.45
4	M2A	1	0.75	0.25
5	M2B	1	0.75	0.35
6	M2C	1	0.75	0.45
7	M3A	1	0.5	0.25
8	M3B	1	0.5	0.35
9	M3C	1	0.5	0.45
10	M4A	1	1.25	0.25
11	M4B	1	1.25	0.35
12	M4C	1	1.25	0.45

$$\text{I.W.} = \frac{\text{M2} - \text{M1}}{\text{M1}} \times 100\% \quad (1)$$

I.W.: The weight increase in percent (%).
M1: The weight of brick before immersion in acidic or alkaline medium (g).
M2: The weight of brick after immersion in acidic or alkaline medium (g).

The corrosion resistance was measured using the following equation [13]:

$$C.R. = \frac{S_a}{S_n} \times 100\% \quad (2)$$

$$\text{C.R} = \frac{S_s}{S_n} \times 100\% \quad (3)$$

C.R.: The corrosion resistance (%).
S_a: The compressive strength of brick submerged in acid (MPa).
S_s: The compressive strength of brick submerged in salt (MPa).
S_n: The compressive strength of bricks cured normally (MPa).

3. Results and discussion

Results of various tests are reported in Table 3 and the results are discussed below.

3.1. Compressive strength

Compressive strength of the bricks ranged between 7.13 and 17.36 MPa. The compressive strength for conventional clay bricks and cement bricks are 15 MPa and 12 MPa respectively [4] and the minimum compressive strength of clay bricks is 70 kgf/cm^2 (6.8 MPa) [14]. This indicates that the bricks produced in the investigation have satisfactory compressive strength. The relationship between strength and bottom ash to cement ratio (BA/C) is shown in Fig. 1. It can be observed that increase in fly ash and cement increases the strength for all mixtures. This is because of the reaction of fly ash with cement during hydration. The increase of fly ash content in the mix resulted in increased chemical reaction and hence increase in strength [15]. It is also observed from Fig. 1 that the strength in maximum when BA to FA ratio is 1:1.25 and this is because the fly ash content is highest in this mix ratio. Hence it is concluded that enhanced strength can be achieved by increase the fly ash in the mix.

3.2. Ultrasonic pulse velocity

UPV was conducted at 28 days of curing. Results ranged between 2.2 and 2.96 km/s. The UPV of clay brick is 0.793 km/s and for cement brick is 1.501 km/s [4]. The bricks developed in this investigation exhibited higher values of UPV compared with conventional bricks. As noticed in Fig. 2, UPV increases with the increase in fly ash in all mixtures. It is also observed in Fig. 2 that the maximum value of UPV is gained when BA to FA ratio is 1:1.25. This is because the finer particles of fly ash fills the pores and