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Use of brick dust in concrete as mineral admixture and partial replacement of cement

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Abstract

Dumping of brick dust and other waste brick particles, flakes etc., not only occupy land but also create environmental problems. The problems could be reduced to a large extent by using these waste materials in cement concrete. The reasons for using brick dust include economical gain and beneficial modification of certain properties of fresh and hardened concrete elements. This study gives an overview of the physical and chemical properties of brick dust as a mineral admixture (BDMA), which is dumped as waste from brick and tile factories in Bangladesh. Various properties of brick dust have been studied. Experimental results indicate that brick dust could be used for partial replacement of cement in concrete. Concrete cubes prepared with 20% cement replaced by brick dust (BDMA) shows compressive strength comparable to concrete cubes prepared with Portland cement only. Concrete prepared with 20% cement replaced by BDMA also shows good resistance to chemical attack, specially the sulfate attack. They also show better pore refinement after long period. Chemical composition and lime reactivity strength of brick dusts have been found to be within the range given for good pozzolanic material. The pore refinement and relatively low heat of hydration in the presence of BDMA show that certain properties of concrete could be improved by using brick dust in combination with Portland cement.

Keywords: Brick dust, mineral admixtures, replacement of cement.

1. Introduction

Plain and reinforced cement concrete is one of the very popular and essential materials for construction all over the world. Bangladesh is experiencing great boom of construction nowadays and cement concrete is a basic and major material for most of the construction here. Since cement is an essential ingredient for concrete and is very costly, its economical use should be emphasized. Mineral admixtures like silica fume, granulated blast furnace and slag and fly ash are widely used materials in developed as well as developing countries (Cook, 1990). In developing countries, considerable efforts have been also directed towards the utilization of indigenous and waste materials such as palm oil fuel ash, rice husk ash, coal ash, brick dust, stone dust in cement concrete (Awal et al, 1997; Zhang, et al, 1996; Karki, 2002). The purpose of this study is to investigate the behavior of concrete prepared with brick dust as mineral admixture. Brick dust is a waste product in innumerous brick kilns in Bangladesh. This paper discusses the various physical, mechanical and chemical properties of cement concrete where brick dust has been used as the mineral admixture (BDMA). The objective of the study is to observe whether the brick dust can replace cement in concrete and whether its use increases the durability of concrete in aggressive environment.

2. Mineral admixtures in Bangladesh

Various types of waste materials, which could be used as mineral admixtures, are available in Bangladesh. Some of them are brick dust, stone dust, rice husk ash, coal ash, etc. Brick dust is a waste product obtained from different brick kilns and tile factories. There are numerous brick kiln which have grown over the decades in an unplanned way in different part of the country. Tons of waste products like brick dust or broken pieces or flakes of bricks (brickbat) come out from these kilns and factories. So far, such materials have been used just for filling low lying areas or are dumped as waste material. Similarly, paddy being one of the major agricultural products in Bangladesh, rice husk ash could be considered another major source of mineral admixtures. Coal ash is often a by-product from coal burning industries and factories. Similarly tons of stone dust produced as waste product from stone and aggregate industries, can be another source of mineral admixtures.

3. Chemical interaction of brick dust as mineral admixture in cement concrete

Brick dust as mineral admixture has the ability to react with lime in presence of moisture to form hydraulic products. As Portland cement liberates lime during hydration, in course of time, this liberated lime is leached out making the structure porous (Samanta et al., 1997). Due to acidic environment, CO_2 reacts with $Ca(OH)_2$ and forms calcium carbonate and water, then leaches out the whitish substance.

Chemical Reactions

$$\text{Portland cement + water} \longrightarrow \text{C-H-S (Glue)} + Ca(OH)_2 \text{ (Fast Reaction)}$$
$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

In cement, mineral admixture mixes with liberated lime that in turn reacts with mineral admixture forming additional amount of hydraulic compounds, reinforcing the hydraulic properties of cement itself. The reaction is as follows:

$$\text{Pozzolana} + Ca(OH)_2 + \text{water} \longrightarrow \text{C-H-S (Glue) (Slow Reaction)}$$

The slow rate of reaction between mineral admixture and liberated lime coupled with the decrease in the portion of cement affects the hydraulic properties in the early age. But in the course of time, the mineral admixture reaction products contribute their share to improve the rate of hydration and consequently the strength properties of the concrete.

4. Experimental program

Experimental studies have been carried out to identify the various properties of brick dust to be used as mineral admixture in concrete.

4.1 Materials

Various materials used for the experimental studies were cement, sand, aggregate and brick dust. Brick dust was collected from a brick kiln at Savar, at the outskirts of Dhaka. Physical properties of brick dust in raw state such as grain size distribution, moisture content, specific gravity and bulk density were determined. In order to prepare the brick dust to be used as mineral admixture, it was processed by grinding it in a rotating drum with specific sizes and numbers of iron balls. The speed of rotation of the drum was kept constant at 25 rpm. The time required for grinding for a given weight of raw material with a given weight of iron balls was determined by sieving the grinded material through No. 80 U.S. sieve after a specific number of rotations. The ground brick dust, referred to here as BDMA (mineral admixture prepared form brick dust), retaining about 2 percent in No. 80 U.S sieve was used in the laboratory experiments. This figure was adopted in order to make the fineness of brick dust near to that of cement, which is retained about 2.3 percent in No. 80 U.S. Ordinary Portland cement from Holcim Cement Factory and sand, passing No. 10 (2 mm) U.S. sieve and retaining on No. 200 (0.075 mm) U.S. sieve, from Dhaleswari river and irregular coarse aggregates of size 20 mm were used in this study. Physical and chemical properties of materials used in this study are presented in Table 1 and Table 2.

Table 1
Physical properties of brick, dust, sand & aggregate

Properties	Brick Dust (Raw)	BDMA	Sand	River Bed Aggregate
Moisture content (%)	4.2	0.5	0.00	1.15
Specific gravity (unit)	2.6	2.64	2.63	2.69
Fineness modulus	2.11	2%*	2.79	6.89
Bulk density (kg/m^3)				
Loose	1181.8	717	1360.04	1572.89
Compacted	1370.8	1062	1661.82	1769.08

* Percentage retained on 90 μm sieve.

Table 2
Chemical composition of cement and brick dust (in percentage)

	SiO_2	LOI	R_2O_3	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Other
Cement	17.9-19.9	2.9-4.4	-	4.4-4.9	5.5-7.1	56-59	1.8-2.4	1.7-2.7	-	-	1.4-2.0
BDMA	67.43	1.10	-	7.99	1.99	2.12	2.46	0.39	0.08	0.25	7.90

4.2 Preparation of specimens and testing

Properties of brick dust as mineral admixture were studied at three different structural levels - paste level, mortar level and concrete level. The sizes of specimen used at paste level were cylinders of 15.7 mm in diameter and 10.0 mm in height. The percentage of brick dust (by weight) calculated with respect to the total cementing material that was 0, 10, 20, 30, 40, 50 and 60. At this level, accelerated method of curing was carried out by putting the specimen in a chamber at 60°C temperature and maintaining a humidity of 90 percent. Seven specimen were tested for each condition at this structural level. Compressive strength tests were carried out after 1 day, 3 days and 10 days. In order to identify the properties of brick dust at mortar level, mortar cubes of 50 x 50 x 50 mm were prepared. The ratio of cementing material to sand was 1:3. The cementing material was the sum of cement and brick dust. The percentages of brick dust (by weight) used in place of cement at this structural level were 0, 20, 30 and 50. These ranges were selected on the basis of results obtained from paste level experiments. Accelerated curing test was carried out at this structural level. Compressive strength tests were carried out after 1 day, 2 days, 5 days and 10 days.

Concrete cubes of 100 x 100 x 100 mm were prepared in the ratio of 1:2:4 (cementing material : sand : aggregate). The replacement of cement was 0, 20 and 30 percent by weight of total cementing material. These percentages were selected on the basis of results obtained from the tests at paste and mortar levels. Compressive strength tests were carried out after normal curing for periods of 7, 14, 28, 45 and 90 days. Three specimen were prepared and tested for each condition.

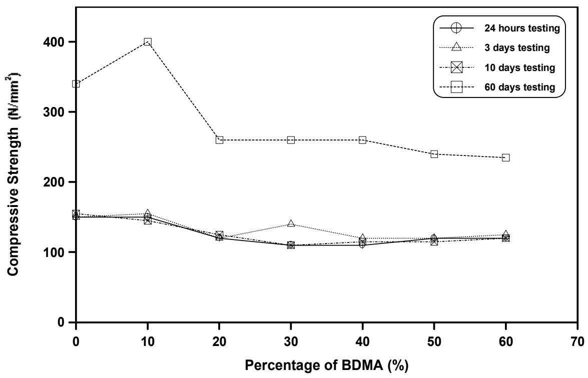

Fig. 1. Compressive strength of cement stone (Fcu) vs. percentage of cement replaced by BDMA

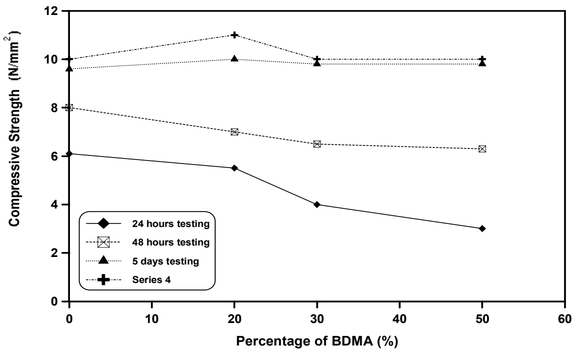

Fig. 2. Compressive strength of cement mortar vs. percentage of cement replaced by BDMA

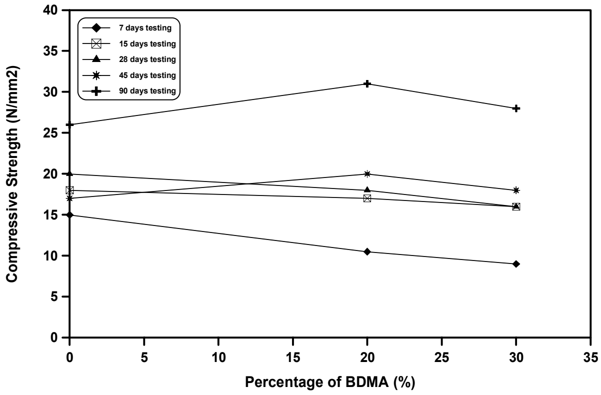

Fig. 3. Compressive strength of cement concrete vs. percentage of cement replaced by BDMA

4.3 Tests for other engineering properties

Various other tests were also carried out to identify the properties of paste, mortar and concrete with brick dust. These properties were lime reactivity, normal consistency, microscopic studies, pore structure by water absorption, durability and heat of hydration.

4.3.1 Normal consistency and setting times

For the determination of normal consistency, the standard test procedures outlined in ASTM 1979(b) were followed. The consistency of paste and mortar was determined with the help of Vicat apparatus and flow table. Setting times were also determined following standard procedures.

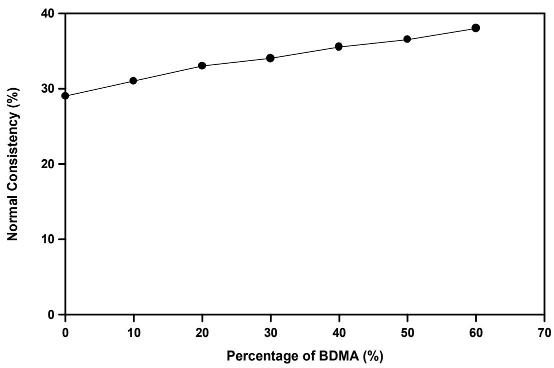

Fig. 4. Normal consistency vs. percentage of BDMA

4.3.2 Lime reactivity

Lime reactivity test was performed as per Indian Standard (IS 1769-67). The lime reactivity of the brick dust was determined by lime reactivity test according to the standard. It was measured in terms of compressive strength of 50 x 50 x 50 mm cubes prepared with lime, mineral admixture and standard sand. The lime used was laboratory reagent grade hydrated lime. The lime reactivity of brick dust has been found to be 2.03 MPa.

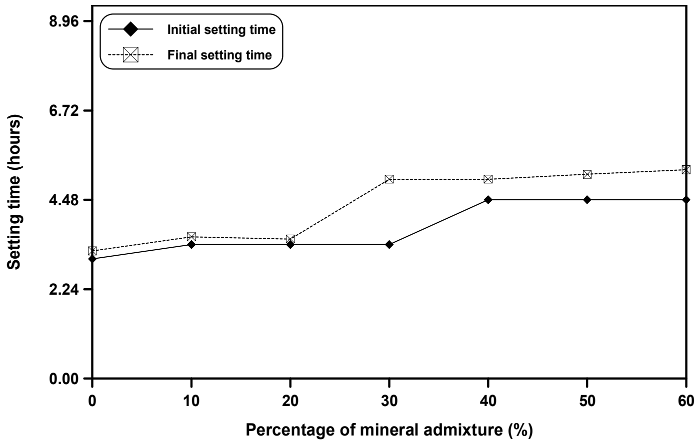

Fig. 5. Initial and final setting time vs. percentage of BDMA

Table 3
Number of pores in cement concrete

S. N.	Number of pores per area of 16 mm^2 in different magnification	
	6 time	12 time
Control		
1	8	9
2	5	7
3	6	8
B-20		
1	5	5
2	3	5
3	6	7

4.3.3 Microscopic study

The microscopic study was carried out on cement stone with 20 percent replacement of cement by BDMA (specimen referred to as B-20) and on control specimen prepared without BDMA. After 28 days of normal curing, the specimen were cut into two pieces by a diamond cutter. The cut surface was smoothen by carborendum stone and cleaned with acetone. The number of visible pores at different magnification was counted in 2 mm^2 area.

4.3.4 Water absorption test

The test was carried out following standard procedure of ASTM D558-57 (1976). Concrete cubes of 75 x 75 x 75 mm were prepared for water absorption test with 0 and

20 percent BDMA. The mix ratio of cementing material: sand: aggregate was 1:2:4 and w/c = 0.55. At the age of 28 days, specimens were placed in chamber at 100 ± 5^0 C. After 48 hours, oven-dried specimens were cooled in silica gel and test was carried out with tap water at 24^0 C.

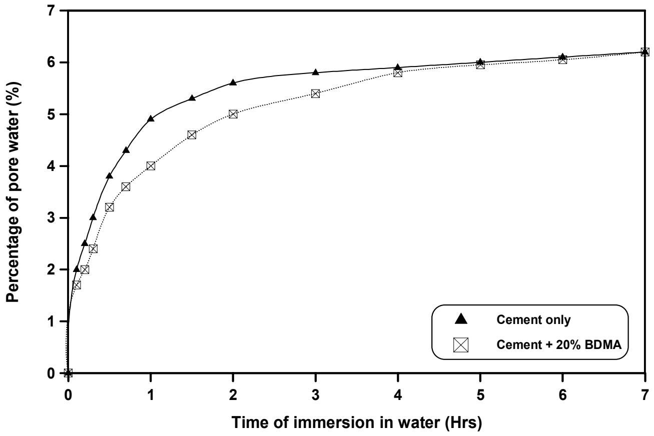

Fig. 6. Graph of water absorbed vs. time of immersion in water at age of 28 days

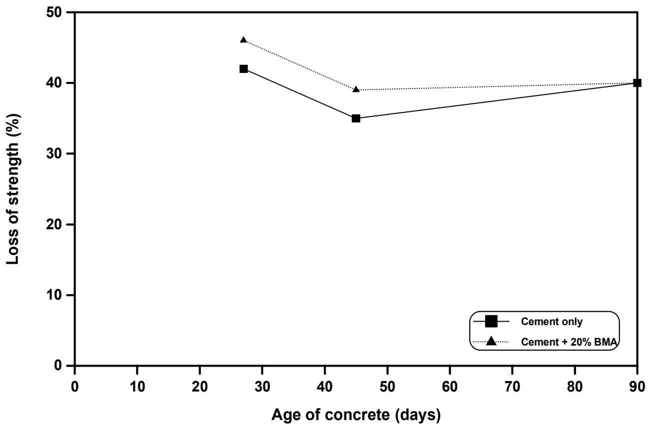

Fig. 7. Percentage loss in compressive strength of cement concrete vs. age of concrete (when concrete is immersed in HCl solution)

4.3.5 Heat of hydration

Heat of hydration was estimated indirectly by measuring the temperature of mixing water as a function of time for specimen prepared with cement only and those prepared with 20 percent cement replaced by BDMA.

4.3.6 Durability

The durability of concrete was determined in terms of loss of weight and strength due to exposure in acid and sulfate solutions in comparison with the control specimen. For this test, concrete cubes of 100 x 100 x 100 mm were prepared with 0 and 20 percent replacement of cement by BDMA. The w/c was 0.55. All the samples were cured in normal water for 14 days, and then 3 specimen of each type were placed in 5% HCl solution, 5% Na_2SO_4 solution and normal water (control specimen). pH value and salt concentration of the solutions were measured periodically, at an interval of 10 days, and maintained constant by adding the acid and sulfate solutions, as required. After 28, 45 and 90 days, specimen were removed from the solutions, cleaned and surface dried. Then they were tested on universal compression testing machine. The percentage loss and gain in strength compared to the control specimens were determined.

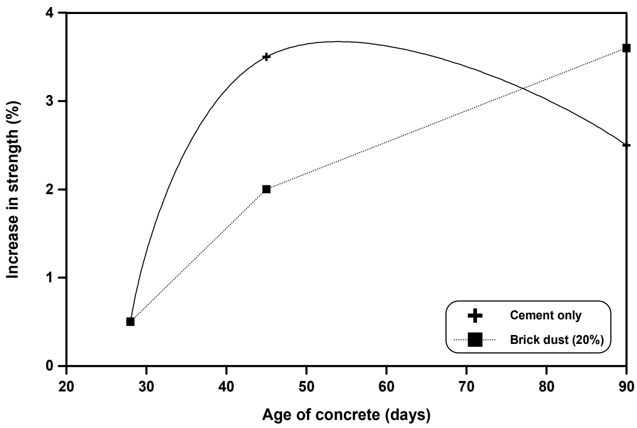

Fig. 8. Percentage increase in compressive strength vs. age of concrete (when immersed in Na_2SO_4 solution)

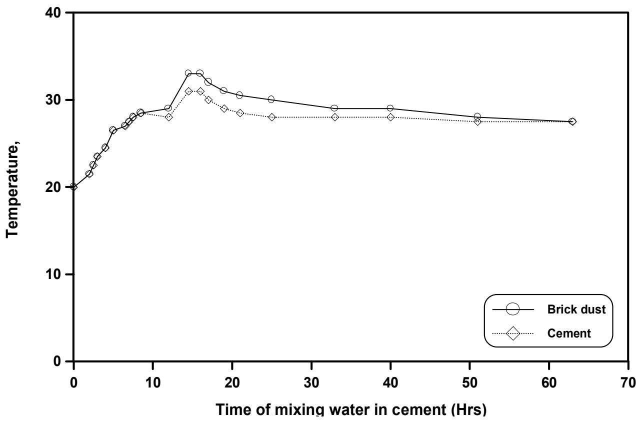

Fig. 9. Temperature variation with time of mixing water in cement

Table 4
Chemical attack tests

Age of concrete (days)	Acid attack				Sulfate attack			
	Loss of strength (%)		Loss of weight (%)		Gain of strength (%)		Increase in weight (%)	
	Control	B-20	Control	B-20	Control	B-20	Control	B-20
28	41.46	46.19	4.26	4.71	0.61	0.68	0.07	0.07
45	33.12	38.16	3.92	3.06	3.47	2.43	0.00	0.02
90	40.01	39.63	4.89	3.05	2.55	3.87	0.24	0.39

Table 5
Comparison of chemical composition (in percentage)

Constituents	IS 3812-1981 Standard	ASTM C618-91 Standard Class			BDMA
		N	F	C	
SiO_2+Al_2O_2+Fe_2O_2 (min.%)	69.0	69.0	68.0	49.0	78.45
MgO (max. %)	5.3	4.9	5.2	5.0	2.62
SO_2 (max. %)	2.81	3.5	4.0	5.0	0.39
Na_2O (max. %)	1.4	1.4	1.4	1.4	0.07
Loss on ignition (max. %)	11.0	9.0	11.0	6.0	1.29

5. Results and discussion

Compressive strengths of cement paste, cement mortar and cement concrete as a function of percentage of BDMA used as mineral admixture are presented in Fig. 1, 2 and 3, respectively. These figures show that compressive strengths of specimen prepared with brick dust (BDMA) are comparable to those of the control specimen. For cement concrete specimen, replacement of 20 to 30 percent of cement with BDMA gives almost the same or slightly higher compressive strengths compared to control specimen under normal curing for 45 and 90 days (Fig. 3). Figure 4 shows a plot of normal consistency of cement paste versus percentage of BDMA added to replace cement. It shows that the requirement of water to attain normal consistency increases with increasing percentage of BDMA. Figure 5 shows initial and final setting times as a function of percentage of BDMA. It shows that addition of BDMA in excess of 20 percent increases the setting times.

Table 3 shows results of microscopic study. It shows that the cement-stone specimen with brick dust (B-20) has relatively fewer numbers of bigger as well as smaller pores. Figure 6 shows results of water absorption test. It shows that up to 4 hours of immersion in water, the percentage of pore water in less for specimen prepared with 20% BDMA, compared to the control specimen prepared without any BDMA; beyond four-hour immersion period, percentage pore water in both the specimen was about the same.

Table 4 shows results of tests performed to assess effect of chemical attack on concrete specimen prepared with BDMA. The table shows loss of strength and weight of cement concrete specimen due to acid attack, and gain of strength and increase in weight due to sulfate attack. It shows that in all respects, performance of specimen prepared with BDMA is comparable to that of the control specimen. Figure 7 shows percentage loss of compressive strength due to exposure in HCl solution as a function of time for specimen prepared with 20% BDMA and for the control specimen (no BDMA). It shows that loss of strength for specimen prepared with 20% BDMA (B-20) is slightly higher than that for the control specimen after 28 and 45 days; but after 90 days the losses are almost identical for B-20 and the control specimen. Figure 8 shows increase in strength of cement concrete specimen due to exposure in sulfate solution as a function of time.

Figure 9 shows temperature of mixing water (an indirect measure of heat of hydration) as a function of time for cement only and for the case where 20 percent has been replaced with BDMA. It shows that the temperature of the mixing water is slightly less when 20 percent cement is replaced by BDMA, especially between 10 and 50 hours after mixing. The peak temperature of the mixing water for such specimen was about 2.9°C less than specimen without brick dust.

Table 5 shows a comparison of chemical composition of the BDMA used in this study with Indian fly ash and fly ash conforming to ASTM C618 for pozzolanic material. It shows that the BDMA used in this study conforms well to these standards.

6. Conclusions

The following conclusions could be drawn from the study:

- Brick dust as waste product from brick kilns and tile factories available in Bangladesh could be used as mineral admixtures in concrete. Its use in concrete could save as much as 20 percent of cement as binding material, while providing the same strength.
- Brick dust concrete could be produced with satisfactory slump and setting times with nearly the same water cementing material ratio as in normal concrete without mineral.
- Under certain conditions, replacement of cement by brick dust appears to increase the strength of concrete.
- Under acid and sulfate attack, performance of cement concrete cube specimen prepared with 20 percent cement replaced by BDMA has been found to be comparable to that of the control specimen prepared without BDMA.
- In mass concrete, use of brick dust as mineral admixture would reduce the heat of hydration, which could help to control the development of secondary stresses in the structures.
- The brick dust mineral admixture has a reddish color, which could be aesthetically more pleasant.

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