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Properties of higher strength concrete made with crushed brick as coarse aggregate

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Abstract

An investigation was conduced to achieve concrete of higher strength using crushed brick as aggregate and study the mechanical properties. It was found that higher strength concrete (f_c' = 4500 to 6600 psi[1]) with brick aggregate is achievable whose strength is much higher than the parent uncrushed brick. Test results show that the compressive strength of brick aggregate concrete can be increased by decreasing its water-cement ratio and using admixture whenever necessary for workability. The compressive strength as well as the tensile strength and the modulus of elasticity of the concrete were studied. The cylinder strength is found about 90% of the cube strength. The ACI Code relations for determining the modulus of rupture was found to highly underestimate the test values., whereas the code suggested expression for elastic modulus gives much higher values than the experimental ones for brick aggregate concrete. Relations were proposed to estimate the modulus of rupture and the modulus of elasticity of brick aggregate concrete of higher strengths.

Keywords: Brick aggregate, concrete, cylinder and cube strengths, elasticity, water-cement ratio.

1. Introduction

In Bangladesh and parts of West Bengal, India, where natural rock deposits are scarce, burnt clay bricks are used as an alternative source of coarse aggregate. In Bangladesh the use and performance of concrete made with broken brick as coarse aggregate are quite extensive and satisfactory. Clay can be burnt in its natural form as is done in brick-making and the product may be a source of coarse aggregate for concrete. Also in brick-making, a large number of bricks are rejected due to nonconformity with the required specifications. One such major nonconformity is the distorted form of brick produced

[1] 1 MPa = 145.04 psi

due to the uneven temperature control in the kiln. These rejected bricks can also be a potential source of coarse aggregate. This would not only make good use of the otherwise waste material but would also help alleviate disposal problems. In spite of extensive use of brick aggregate concrete in this regions and the apparent satisfactory performance of the structures already built, no systematic investigation was conducted and properly documented. The current designs for brick aggregate concretes are based on intuition and accumulation of experience, rather than on sound experimental evidence.

The practical experiences confidently showed us that the maximum range of compressive strength of concretes made with brick aggregate but without using any admixture is around 3000 psi. However, higher strength concrete (f_c' much greater than 3000 psi) can be used advantageously in compression members such as columns and piles. In columns, the reduction in size will lead to reduced dead load and subsequently to reduced total load on the foundation system. Smaller column size also means more available floor space to use. The relatively higher compressive strength per unit volume will also significantly reduce the dead load of flexural members. In addition, higher strength concrete possessing a highly dense microstructure is likely to enhance long-term durability of the structure.

The mix proportion of the concrete is usually done either by the ACI method (1994) or the BS method (1985). In both methods, the coarse aggregate is the crushed natural stones and the unit weight of this concrete ranges from 140 to 152 pounds per cubic foot (pcf[2]) (Nilson and Darwin, 1997), whereas brick aggregate concrete weighing between 125-130 pcf can be termed as medium weight concrete in comparison with normal weight and light weight concrete (Akhteruzzaman and Hasnat 1983). Besides, the texture and surface roughness of brick aggregates are different from those of stone aggregate. So the properties of brick aggregate concrete may not follow exactly the same trends as those of stone aggregate concrete. Consequently, the present codal specifications, which are based on stone aggregate concrete may not be applicable for brick aggregate concrete.

Some studies are found in the literature. Akhtaruzzaman and Hasnat (1983) investigated the various engineering properties of concrete using crushed brick as coarse aggregate. Khaloo (1994) studied the properties of concrete using crushed clinker brick as coarse aggregate. In both the above-mentioned studies, investigations were also done by comparing the properties of brick aggregate concrete with those for stone aggregate concrete. On the other hand, studies were done by Mansur et al. (1999) comparing the properties of stone aggregate concrete with those of equivalent brick aggregate concrete obtained by replacing stone with an equal volume of crushed brick, everything else remaining the same.

The present study reports primarily at to achieve higher strength concrete using crushed brick as coarse aggregate. Various mechanical properties of brick aggregate concrete are also studied and compared with those determined following the codal specifications for stone aggregate concrete.

2. Experimental investigation

In this study, manually crushed well burnt (gas burnt) clay bricks were used as ¾ in. (19

[2] 1 pcf = 16.01 kg/m^3

mm) down-graded coarse aggregate. The bricks used were well shaped and reddish in color. The average compressive strength of the bricks was 4476.3 psi (30.9 MPa). A mixture of coarse sand (Sylhet sand) and locally available fine sand in the ratio of 1:1 was used as fine aggregate. The fineness modulus of the mixed sand and the brick aggregate were 1.86 and 6.97 respectively and their absorption capacities were 2.6% and 15.8% respectively. The physical properties of brick aggregate and sand are given in Table 1. Type-I ordinary Portland cement was used in all cases.

In the experimental program, four basic mixes designated by A, B, C, and D were chosen to attain target strengths (28 day cylinder compressive strength) of 4500, 5000, 5500, and 6000 psi respectively. The corresponding mix ratios were selected following the ACI specifications (1994) for concrete mix design. The details of the various mixes are presented in Table 2.

Table 1
Properties of aggregates used

Type of aggregate	Bulk specific gravity (SSD*)	Dry rodded unit weight (lb/ft^3)	Absorption capacity (%)	Fineness modulus
Coarse Aggregate	2.10	68.0	15.80	6.97
Fine Aggregate	2.50	---	2.60	1.86

*Saturated surface dry

Table 2
Details of concrete mix proportions

Mix	Target cylinder strength (psi)	Mix ratio by weight (cement : sand : brick aggregate)	w/c ratio by weight	% of admixture by weight of cement
A	4500	1 : 1.50 : 2.40	0.44	---
B	5000	1 : 1.30 : 2.17	0.40	---
C	5500	1 : 1.20 : 2.06	0.35	0.6
D	6000	1 : 1.06 : 1.95	0.30	0.8

2.1 Casting of specimens

The graded aggregates (both fine and coarse aggregates) were soaked in water for 24 hours and then air-dried to saturated surface dry (SSD) condition before mixing with other ingredients. To improve the workability of the two mixes: C and D, a superplasticizer "SIKAMENT-280(M) [modified melamine and naphthalene formaldehyde sulphonate type] was added in the proportions as mentioned in Table 2. For each mix, all of the ingredients with appropriate proportions were added in the mixture machine, then mixing was done for about 2 minutes. The workability of the fresh concrete was measured with a standard slump cone immediately after mixing. A slump of 1" to 2" was measured for concretes without an admixture, whereas the slump value for concretes with admixture was recorded from 3" to 4". The test specimens were cast in steel molds and compacted with a vibrator nozzle. They were demolded 24 hours after casting and were cured under water until 24 hours before the test. Each of the mixes comprised of five $6'' \times 12''$-cylinders, four $6''$-cubes and three $4'' \times 4'' \times 18''$-prisms.

2.2. Testing of specimens

For each mix of concrete, three $6'' \times 12''$-cylinders and four $6''$-cubes were tested to determine the compressive strengths. The remaining two $6'' \times 12''$-cylinders were tested to determine the modulus of elasticity. Whereas three $4'' \times 4'' \times 18''$-prisms were tested under single point loading to determine the modulus of rupture. A 1000-kN capacity universal testing machine was used to test all of the above mentioned specimens. Typical failure patterns of cylinder and cube are shown in Fig. 1.

3. Test results and discussions

Test results are presented in figures and tables and discussed categorically. The results include cylinder compressive strength f_c', cube compressive strength f_{cu}, modulus of rupture f_r, and modulus of elasticity E_c. The means of the test values for each of the properties are presented in Table 3. In this table, the ratios of the actual to the targeted cylinder strengths indicate that the desired concrete strengths have successfully been achieved in this study. The ratios of the values of various properties of concrete with the corresponding compressive strength values (either f_c' or, $\sqrt{f_c'}$) are presented in Table 4.

Table 3
Various properties of concretes

Mix	Target cylinder comp. strength $f'_{c,tgt}$ (psi)	Actual compressive strength (psi)		Tensile strength f_r (psi)	Modulus of elasticity E_c (psi)	Ratio $\left(f_c' / f'_{c,tgt} \right)$
		Cylinder, f_c'	Cube, f_{cu}			
A	4500	4515.3	5019.2	849.0	2530000	1.00
B	5000	5051.4	5555.8	919.7	2630000	1.01
C	5500	5343.5	5793.4	937.4	2800000	0.97
D	6000	6600.6	---*	1043.4	3050000	1.10
				Mean		1.02
				SD**		0.0552

*The test specimens could not be failed due to the limitation of the capacity of testing machine
**Standard deviation

Table 4
Relations between the various properties of concretes

Mix	Cylinder strength f_c' (psi)	Ratio $\left(f_c' / f_{cu} \right)$	Ratio $\left(f_r / f_c' \right)$	Ratio $\left(f_r / \sqrt{f_c'} \right)$	Ratio $\left(E_c / \sqrt{f_c'} \right)$
A	4515.3	0.90	0.19	12.63	37651
B	5051.4	0.91	0.18	12.94	37004
C	5343.5	0.92	0.18	12.82	38304
D	6600.6	---	0.16	12.84	37541
	Mean	0.91	0.18	12.81	37625
	SD*	0.0114	0.0129	0.1277	534

*Standard deviation

(a) Cylinder (b) Cube

Fig. 1. Typical failure patterns of cylinder and cube specımens

3.1 Effect of water-cement ratio on compressive strength

The effect of water-cement (w/c) ratio on the compressive strength of concrete measured at 28-days on standard cylinder is shown in Fig 2. From this figure it is seen that concrete strength is reduced drastically with the increase of w/c ratio. Also the rate of reduction of concrete compressive strength appears to be higher for lower w/c ratio. A regression analysis shows the following relationship between the concrete compressive strength and the w/c ratio (Fig. 2).

$$f_c' = 73517\left(\frac{w}{c}\right)^2 - 68347\left(\frac{w}{c}\right) + 20432 \tag{1}$$

in which the strength value is in pound per square inch (psi) and the w/c ratio is by weight.

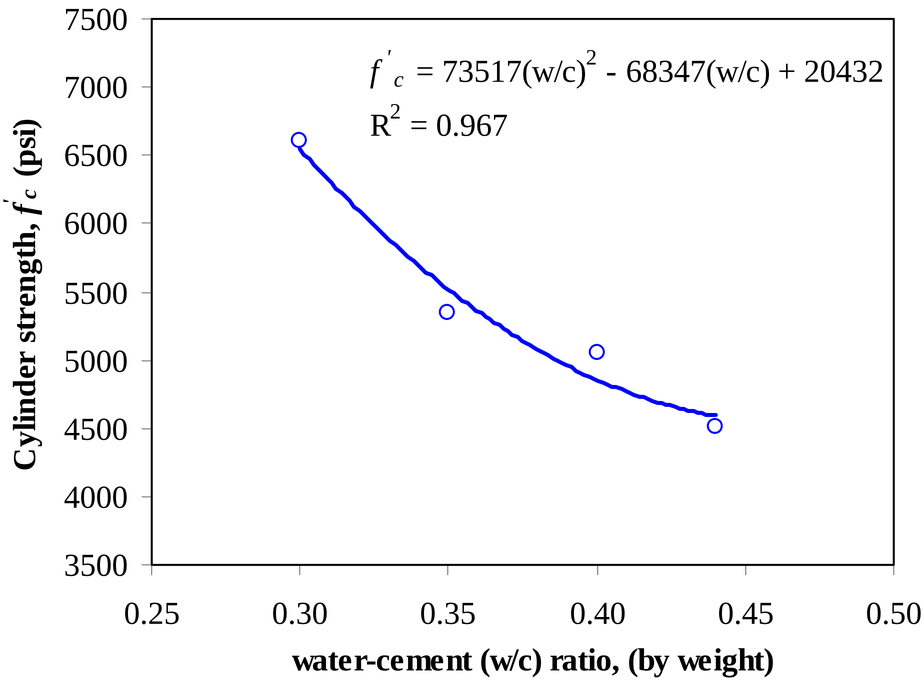

Fig. 2. Variation of concrete compressive strength with the variation of w/c ratio

3.2 Relationship between cylinder and cube compressive strengths

Figure 3 shows the relationship between the ratio of cylinder to cube compressive strengths with the cube compressive strength. Generally for normal weight and normal strength concretes the cylinder compressive strength is approximately 0.80 of the cube compressive strength (Neville and Brooks 2002). However from Table 4 it is seen that the mean of cylinder to cube compressive strengths is 0.91 with a standard deviation (SD) of 0.0114 for the concrete strength-range studied. It can be seen from Fig. 3 that higher the compressive strength, the higher is the value of the ratio of cylinder to cube compressive strengths. Akhtaruzzaman and Hasnat (1983) and Mansur et al. (1999) also reported similar findings.

A linear regression analysis shows the following relationship between the ratio of cylinder to cube compressive strengths and the cube compressive strength (Fig. 3).

$$\left(\frac{f'_c}{f_{cu}}\right) = 3\times10^{-5}\left(f_{cu}\right) + 0.761 \qquad (2)$$

in which all strength values are in psi.

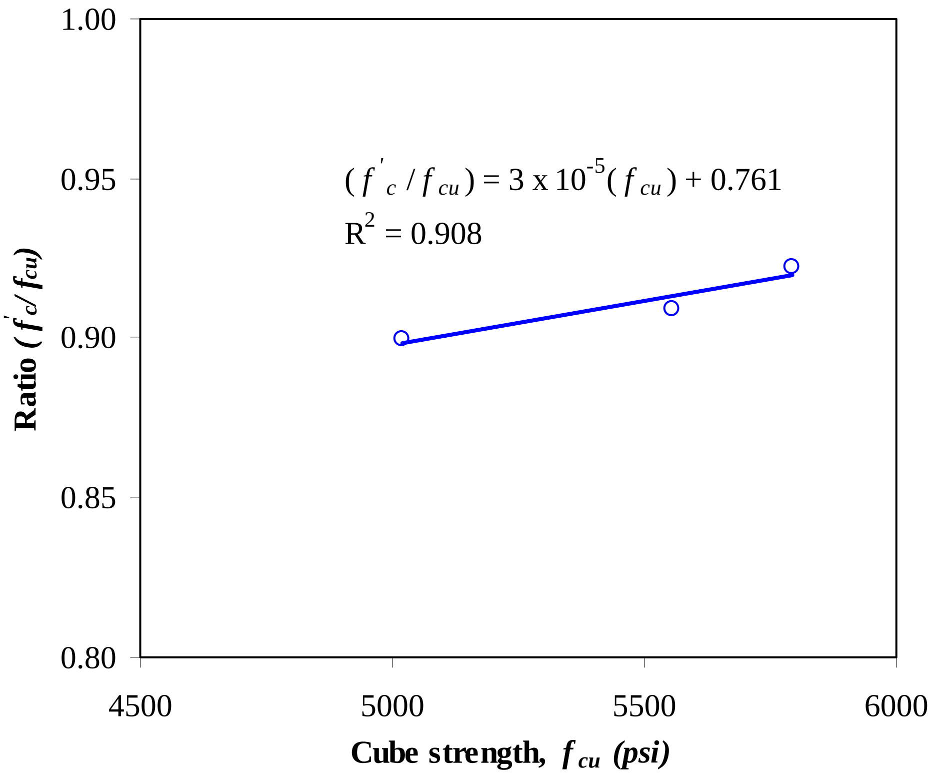

Fig. 3. Relation between cylinder and cube compressive strengths

3.3 Relationship between tensile and compressive strengths

Using the test data, a relationship between the modulus of rupture and the cylinder compressive strength is presented in Fig 4. As expected, the tensile strength (f_r) increases with increase in compressive strength (f'_c) of concrete. Akhtaruzzaman and Hasnat (1983) and Mansur et al. (1999) also reported similar trends. The more angular shape and rougher surface texture of brick aggregate possibly enhanced the interfacial bond, thus resulting in a higher tensile strength. It can also be seen that the modulus of rupture increases linearly with the increase in compressive strength. The ACI Code (1999) proposed relation ($f_r = 7.5\sqrt{f'_c}$) for normal weight concrete is also plotted to make a comparison (Fig. 4). However, the ACI code expression underestimates (about 40%) the values of modulus of rupture of brick aggregate concrete (Fig. 4 and Table 4). From Table 4, it can be seen that the mean of the ratios of modulus of rupture to cylinder compressive strength is 0.18 with a SD of 0.0129. A linear regression analysis shows the following relationship between the modulus of rupture and the square-root of cylinder compressive strength (Fig. 4 and Table 4).

$$f_r = 12.8\sqrt{f'_c} \tag{3}$$

in which all strength values are in psi.

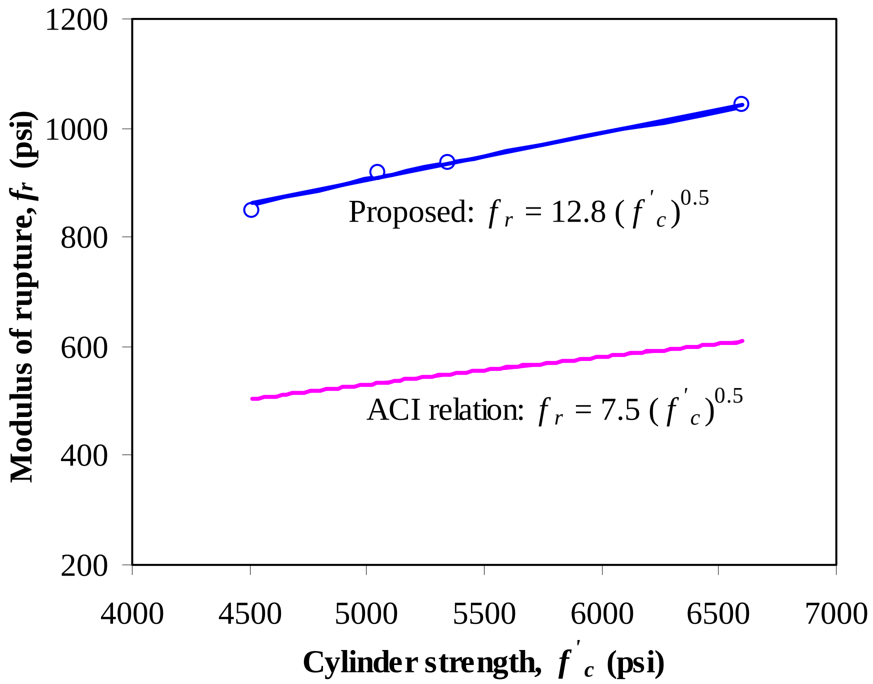

Fig. 4. Relation between modulus of rupture and compressive strength

3.4 Relationship between modulus of elasticity and compressive strength

Fig. 5 shows the plot of the secant modulus of elasticity against the corresponding cylinder strength. As expected, an increase in concrete strength increases the elastic modulus of brick aggregate concrete. For comparison purpose, the ACI Code (1999) suggested relationship $E_c = 33(w_c)^{1.5}\sqrt{f_c'}$ is also plotted in the same figure. The unit weight of brick aggregate concrete $w_c = 130$ pcf has been considered in this relation. From the Fig. 5 and Table 4, it is obvious that the ACI Code (1999) relationship overestimates (about 30%) the elastic modulus of brick aggregate concrete. For the unit weights of brick aggregate concrete used in this study and the range of cylinder strength tested, the elastic modulus (E_c) can be expressed empirically by –

$$E_c = 37500\sqrt{f_c'} \tag{4}$$

in which both strength and elastic modulus are in psi.

4. Conclusions

The following conclusions may be drawn from the present study:

(1) Crushed bricks may be used satisfactorily as coarse aggregate for making concrete, the strength of which is much higher than that of bricks considered. The unit weight of such concrete is around 130 pounds per cu ft which is about 13% lower than that of normal weight concrete.
(2) Similar to normal weight concrete a drastic reduction in the compressive strength of brick aggregate concrete due to the increase in water-cement ratio has been found. The rate of this strength reduction is higher for lower water-cement ratio.
(3) The cylinder compressive strength has been found about 90% of the corresponding

cube compressive strength for brick aggregate concretes studied. The higher the compressive strength the higher is the ratio of cylinder to cube compressive strengths. Eq.(2) may be used to correlate cylinder and cube compressive strengths of brick aggregate concrete.

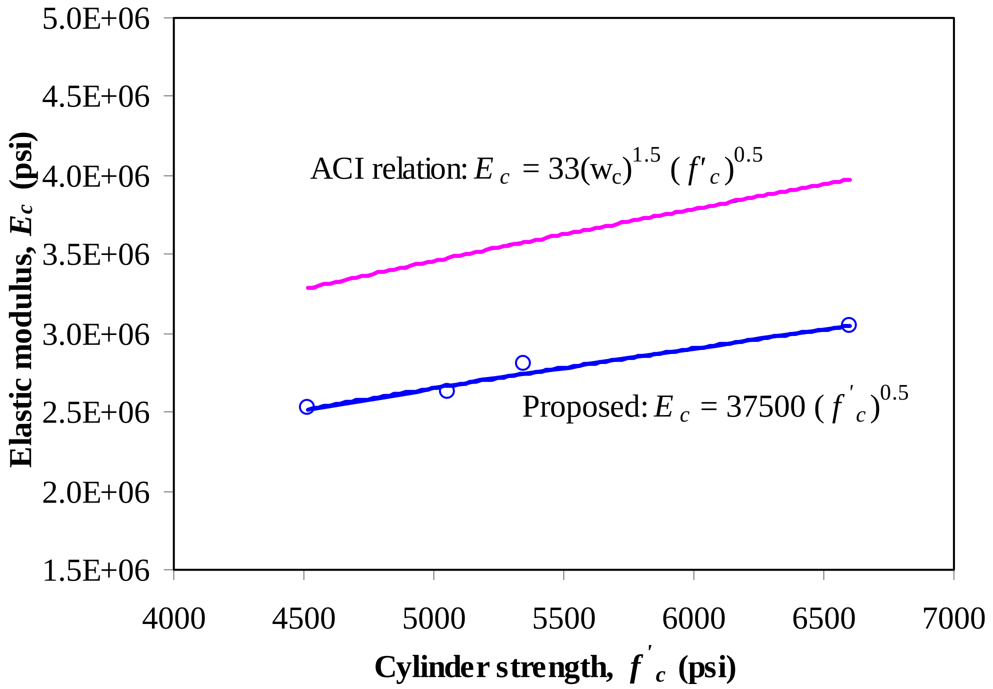

Fig. 5. Relation between concrete compressive strength and modulus of elasticity

(4) The ACI Code (1999) expression underestimates (about 40%) the values of modulus of rupture for brick aggregate concrete. The Eq. (3) may be used to estimate the modulus of rupture of brick aggregate concrete.

(5) The ACI Code (1999) expression overestimates (about 30%) the values of modulus of elasticity for brick aggregate concrete. The Eq. (4) may be used to estimate the elastic modulus of higher strength brick aggregate concrete.

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Notations

The following symbols have been used in this study -

f'_c	=	concrete cylinder compressive strength, psi
$f'_{c,tgt}$	=	targeted cylinder compressive strength, psi
f_{cu}	=	concrete cube compressive strength, psi
f_r	=	modulus of rupture of concrete, psi
E_c	=	secant modulus of elasticity of concrete, psi
w_c	=	dry unit weight of concrete, pcf