PROPERTIES OF HARDENED CONCRETE USING CRUSHED CLAY BRICK AS AGGREGATES

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ABSTRACT

This paper provides the result of an investigation to use of crushed clay brick as aggregates in producing concrete. Eight different crushed clay brick aggregate concretes were used in this investigation. Compressive strength, splitting tensile strength and pulse velocity of crushed clay brick aggregates concrete were determined and compare to natural aggregate concrete. The compressive strength of crushed clay brick aggregates concretes were always lower than the compressive strength of natural aggregates concrete regardless the age of concrete, but the crushed clay brick aggregates concrete showed better performance as the age of concrete increases and average reduction in compressive strength were 33.5% at the age of 7 days but it becomes only 20% at the age of 56 days compared to natural aggregates concrete. The splitting tensile strength of crushed clay brick aggregates concrete were always lower than natural aggregate concrete, the reduction in splitting tensile strength of crushed clay brick aggregates concrete is ranging between 11 and 26% with an average reduction of about 18.5% compared to natural aggregates concrete. The pulse velocity of crushed clay brick aggregates concrete were also lower than natural aggregates concrete, the reduction in pulse velocity of crashed clay brick aggregates concrete is ranging between 6 and 22% with an average reduction of about 14% compared to natural aggregates concrete.

KEY WORDS
Concrete, Hardened concrete, crushed clay brick aggregate concretes

خصائص الخرسانة المتصلبة باستخدام مكسر الطابوق الطيني

الخلاصة :

يبين هذا البحث نتائج استخدام مكسر الطابوق الطيني كركام في إنتاج الخرسانة ثمانية نسب من مكسر الطابوق الطيني استخدمت في إنتاج الخرسانة . تم فحص مقاومة الانضغاط باعمار (56,28,7) مقاومة الشد غير المباشر بعمر 28 يوم وفحص سرعة الذبذبات فوق الصوتية بعمر 28 يوم ايضاً لخرسانة مكسر الطابوق الطيني ومقارنتها مع خرسانة الركام الاعتيادي ووجد إن مقاومة الانضغاط لخرسانة مكسر الطابوق الطيني كانت دائماً أقل من مقاومة الانضغاط لخرسانة الركام الطبيعي بغض النظر عن عمر الخرسانة لكن وجد ايضاً أن مقاومة الانضغاط لخرسانة مكسر الطابوق الطيني تزداد مع تقدم عمر الخرسانة ، حيث وجد أن معدل انخفاض مقاومة الانضغاط هي 33.5% بعمر 7 أيام ولكنها تصبح 20% بعمر 56 يوم مقارنة بخرسانة الركام الطبيعي . أما مقاومة الشد غير المباشر لخرسانة مكسر الطابوق الطيني كانت هي الاخرى أقل بنسبة تتراوح ما بين (26% - 11) أي بمعدل 18.5 % مقارنة بخرسانة الركام الاعتيادي . في حين كان فحص سرعة الذبذبات

فوق الصوتية لخرسانة مكسر الطابوق الطيني أقل من سرعة الذبذبات لخرسانة الركام الطبيعي و كانت نسبة الانخفاض تتراوح ما بين (6-22%)أي بمعدل 14% .

1- INTRODUCTION

The aggregate element in concrete comprises some 60-75% of the total volume (Neville 2005). Aggregate inclusion in concrete reduces its drying shrinkage and improves many other properties. Aggregate is also the least expensive per weight unit. It is costly to trans-port so local sources are needed, but due to the extensive use of aggregate in the construction of building and roads, local sources are no longer available in urban centuries. This necessitates finding other sources and alternatives. Sustainability and reuse to overcome the increasing demands.

Many countries throughout the world have to find other sources of aggregate to use in construction. One of the alternative sources of aggregate is to recycle demolished building rubble(De Varies 1993,Collins et.al. 1995,Tavakoli et.aI.1996).

Most of the recycled aggregate produced has mainly been used for low level application such as pipe bedding, site fill, sub-base, or as a capping layer.

Systematic investigations have been carried out on the use of crushed brick aggregate in high level applications, but most of these investigations were carried out in the 1940s and 1950s using the type of bricks available at that time(Hansen 1992). A review on the subject by Khalaf et.al.(2004)showed that there was more information on the use of crushed recycled concrete aggregate in producing concrete than crushed unused or recycled brick aggregate. Brick aggregate is different than crushed concrete aggregate as its more porous and problems arise when used in concrete.

Akhtaruzzaman et.al (1983) carried out some research using well burnt brick as coarse aggregate in concrete. They found that it was possible to achieve concrete of high strength using crushed brick as course aggregate. Their research primarily concentrated on determining the mechanical properties of brick aggregate concrete, rather than the properties of brick aggregate itself.

Khaioo(1994) used crushed clinker bricks as the course aggregate in concrete. He reported only a 7% loss in concrete compressive strength compared to concrete made with natural aggregates. In addition to this decrease in strength, there is a decrease in the unit weight of crushed brick concrete of 9.5%.

2- Materials used

2.1 Cement

Ordinary Portland Cement manufactured by Lebanese cement factory was used. Chemical analyses of representative samples are shown in Tables 1 and 2, respectively. The cement satisfies ASTM C 150-02a specification for Ordinary Portland Cement(Type I).

Table 1: Physical properties of cement

physical properties	Test results	Limit required by ASTM standard C150-02a
Fineness, m^2/kg : (Blaine)	366	280 (minimum)
Compressive strength. MPa : 3 days 7days	 22.3 28.4	12.4 (minimum) 19.3 (minimum)
Time of setting, min.: (Vicat test) Initial set Final set	 105 231	45 (minimum) 375 (maximum)

Table 2: Chemical analysis of cement

Chemical Composition	Percent by weight	Limit required by ASTM standard C150-02a.
Silicon dioxide ($Si0_2$).	21.62	
Calcium oxide (CaO),	60.66	
Aluminum oxide (Al_2O).	5.72	
." Ferric oxide (Fe_2O_3)	2.29	
Magnesium oxide (MgO)	1.75	6.0 (maximum)
Sulfur trioxide (SO_3),	3.5	3.5 (maximum)
Loss on ignition	0.61	3.0 (maximum)
Insoluble residue	0.75	0.75 (maximum)
Tri Calcium Silicate(C_3S)	28.2	
Di Calcium Silicate(C_2S)	40.9	
Tri Calcium Aluminates (C_3A)	10.09	
Tetra Calcium Alumino Ferrite (C_4AF)	6.96	

2.2 Natural aggregates

2.2.1 Fine aggregate

Fine aggregate from Al-Akhaider region was used. It is a yellowish-brown colored sand with sub-angular to sub-rounded shaped particles and sulphate content of less than 0.08%. The grading of this sand satisfies ASTM C33-03 specification as illustrated in Table 3.

Table 3: Grading of natural and crushed brick fine aggregates

Sieve size (mm)	Percent passing	Limit required by ASTM Standard C33-03.
4.75	100	95-100
2.36	92.62	80-100
1.18	75.5	50-85
0.600	49.5	25-60
0.300	17.0	10-30
0.150	5.0	2-10

2.2.2 Coarse aggregate

River crushed gravel of Al- Nibaaie region was used as natural coarse aggregate in concrete mixes. The particle shape of the crushed gravel is angular and the surface texture is generally rough. The crushed gravel has a nominal maximum size of 19mm and with a grading satisfying ASTM C33-03 specification as shown in Table 4.

Table 4: Grading of natural and crushed brick coarse aggregates

Sieve size (mm)	Percent Passing	Limit required by ASTM Standard C33-03
25	100	100
19	98	90-100
9.5	38	20-55
4.75	2	0-10
2.36	0	0-5

2.3 Crushed clay brick aggregates

Crushed clay brick aggregates were prepared by crushing the clay bricks manually.

Crushing products were screened into four size fractions (25 to 19mm, 19 to 9.5mm, 9.5 to 4.75mm and 4.75 to 2.36mm) by using a sieve shaker. In order to produce the crushed clay brick coarse aggregate, the various size fractions were re-combined to give a grading similar to that of the natural coarse aggregate (Table 4). Crushing products passing the 2.36mm sieve were also screened into five sizes fraction (2.36 to 1.18mm. 1.18 to 0.6mm. 0.6 to 0.3mm, 0.3 to 0.15mm and fraction passing the 0.15mm sieve) by using a sieve shaker. In order to produce the crushed clay brick fine aggregate, the various size fractions were re-combined to give a grading similar to that of the natural fine aggregate (Table 3).

2.4 Water

Ordinary tap water was used throughout this work for washing aggregates, mixing and curing of concrete.

3. Experimental Work

3.1 Mix Proportions

Nine different mixes were made according to ACI 211.1-91 with different proportions of natural and crushed clay brick aggregates using water to cement ratio of 0.45 for all mixes to examine the influence of replacing nature aggregates with crushed clay brick aggregates on characteristics of concrete.
Table 5 summarizes the composition used for production of normal and crushed clay brick aggregate concretes.

The first mix indicated as "REF" was consisting of natural fine and coarse aggregates only and work as a reference mix.

The second mix indicated as "BRI" was consisting of crushed clay brick fine and coarse aggregates only.

The third mix indicated as "NB1" was consisting of 50% natural fine aggregate, 50% crushed clay brick fine aggregate and 100% natural coarse aggregate.

The fourth mix indicated as "NB2" was consisting of 100% natural fine aggregate. 50% natural coarse aggregate and 50% crushed clay brick coarse aggregate.

The fifth mix indicated as "NB3" was consisting of 100% natural fine aggregate and 100% crushed clay brick coarse aggregate.

The sixth mix indicated as "NB4" was consisting of 50% natural fine aggregate, 50% crushed clay brick fine aggregate, 50% natural coarse aggregate and 50% crushed clay brick coarse aggregate.

The seventh mix indicated as "NB5" was consisting of 100% crushed clay brick fine aggregate and 100% natural coarse aggregate.

The eighth mix indicated as "NB6" was consisting of 50% natural fine aggregate, 50% crushed clay brick fine aggregate and 100% crushed clay brick coarse aggregate.

The Ninth mix indicated as "NB7" was consisting of 100% crushed clay brick fine aggregate, 50% natural coarse aggregate and 50% crushed clay brick coarse aggregate.

Table 5: Composition of natural and crushed clay brick aggregate concretes.

Mix designation	Mix composition (kg)					
	Water	Cement	Natural Fine Brick	Crushed Clay Brick Aggregate Fine Aggregate	Natural Coarse Aggregate	Crushed Clay Brick Coarse Aggregate
REF	11.7	26	39	-	52	-
BRI	11.7	26	-	39	-	52
NBl	11.7	26	19.5	19.5	52	-
NB2	11.7	26	39	–	26	26
NB3	11.7	26	39	-	-	52
NB4	11.7	26	19.5	19.5	26	26
NB5	11.7	26	-	39	52	-
NB6	11.7	26	19.5	19.5	-	52
NB7	11.7	26	-	39	26	26

3.2 Making and curing concrete test specimens

Mixing concrete materials. casting and curing concrete test specimens were carried out in
accordance with ASTM C 192 .
Natural and crushed clay brick aggregate concretes were mixed in a 0.056m^3 capacity pan-mixer. The following specimens were cast for various tests: three 150x300mm cylinders for compressive strength and pulse velocity tests. and three 150x300mm cylinders for splitting tensile strength tests. A vibrating table was used to compact the molded specimens.

All specimens were demoded after 24 ± 8h and cured in water at 23 ± 20 ^{0}C for required age.

3.3 Testing hardened concrete

3.3.1 Compressive strength test

Compressive strength test was conducted according to ASTM C39.Test cylinders of (l50x300mm) were prepared according to ASTM C192. A computerized testing machine of 1000 kN capacity was used for testing cylinders with a loading rate of 4.4 kN/sec. Three cylinders were tested for each batch at the age of 7, 28 and 56 days, and an average value of the compressive strength was obtained.

3.3.2 Splitting tensile strength test

Splitting tensile strength test was conducted according to ASTM C496.Test cylinders of (l50x300mm) were prepared according to ASTM Cl92. A computerized testing machine of 1000 kN capacity was used for testing cylinders with a loading rate of 1.4 kN/sec.

Three cylinders were tested for each batch at the age of 28 days, and an average value of the splitting tensile strength was obtained. The splitting tensile strength of the specimens was calculated to the nearest 35 kPa as follows:

$$T = \frac{2p}{\pi \ell d}$$

where:-

T = splitting tensile strength, MPa,

P = maximum applied load indicated by the testing machine. N,

. ℓ. = length, mm, and

d = diameter, mm.

3.3.3 Pulse Velocity test

Before each compressive strength test, pulse velocity through concrete was also measured by pulse velocity apparatus according to ASTM C597-02. The pulse velocity was calculated to the nearest 10 m/s as follows:

$$V = \frac{L}{T}$$

where:-

v = pulse velocity, m/s,

L = distance between centers of transducers faces, m, and

T= transit time, s.

4. Results and discussion

4.1 Compressive strength

The results of the compression tests are summarized in Table (6) and Figures (1 & 2).

It can be seen that the relationship between compressive strength and age were the same for both natural and crushed clay brick aggregate concretes and that the compressive strength of concrete increases as the age of concrete increases. In general the compressive strength of crushed clay brick aggregate concretes were always lower than the compressive strength of natural aggregate concretes regardless the age of concrete, but the crushed clay brick aggregate concretes showed better performance as the age of concrete increases and the average reduction in compressive strength were 33.5% at the age of 7days but it becomes only 20% at the age of 56 days compared to natural aggregates concrete. The comparison in compressive strength between the different mixes at each age is as follows:

- at the age of 7 days the reduction in compressive strength of crushed clay brick aggregate concretes is ranging between 29 and 38% with an average reduction of 33.5% compared to that of natural aggregate concrete (mix REF), but compared to the crushed clay brick fine and coarse aggregate concrete (mix BRI), some of concrete mixes that contains combination of natural and crushed clay brick aggregates (mixes NBl, NB2, NB3, NB4, NB5, NB6 and NB7) showed better performance and the compressive strength can be as high as 8% (mix NB2) or as low as 10% (mix NB6) compared to (mix BRI).

- At the age of 28 days the reduction in compressive strength of crushed clay brick aggregate concretes is ranging between 16 and 43% with an average reduction of 29.5% compared to that of natural aggregates concrete (mix REF), but compared to the crushed clay brick fine and coarse aggregate concrete (mix BRI), all concrete mixes that contains combination of natural and crushed clay brick aggregates (mixes NB1, NB2, NB3, NB4, NB5, NB6 and NB7) showed better perforJT1ance and the compressive strength were between 15% (mix NB3) and 48% (mix NB4) higher than that of (mix BRI).
- At the age of 56 days the reduction in compressive strength of crushed clay brick aggregate concretes is ranging between 5 and 35% with an average reduction of 20% compared to that of natural aggregates concrete (mix REF), but compared to the crushed clay brick fine and coarse aggregate concrete (mix BRI), all concrete mixes that contains combination of natural and crushed clay brick aggregates (mixes NB1, NB2, NB3, NB4, NB5, NB6 and NB7) showed better performance and the compressive strength were between 6% (mix NB3) and 45% (mix NB4) higher than that of (mix BRI).

It seems that in terms of strength, concrete made with crushed clay brick aggregate can be regarded as a composite system consisting of four components: mortar, mortar-aggregate bonds, natural aggregates and crushed clay brick aggregates. The overall physical properties of such a composite system will depend on the properties of the aforesaid constituents, mechanism of their interaction and their volume fractions.

Efficiency of crushed clay brick aggregate concrete can be expected to be less, in terms of strength. than the natural aggregate concrete due to a number of causes. Firstly. the total porosity of crushed clay brick aggregate concrete is more than that for the natural aggregate concrete due to the higher porosity of crushed clay brick aggregate. Secondly, the resistance of crushed clay brick aggregates to mechanical actions is lower than that of natural aggregates. Finally, crushed clay brick aggregates contain higher micro-cracks which are incurred during crushing of the bricks from which crushed clay brick aggregate are derived.

The best performance for the crushed clay brick aggregate concrete were mix NB2 and mix NB4 in which only 50%

replacement are made for coarse or both fine and coarse natural aggregates. The worse performance for crushed clay brick aggregate concrete were mixes NB3, NB6 and NB7 respectively in which 100% replacement are rnade for fine or coarse natural aggregates.

Table 6: Compressive strength of natural and crushed clay brick aggregate concretes at different ages.

Mix Designation	Compressive Strength (MPa)		
	Age of concrete in days		
	7 days	28 days	56 days
REF	29.92	35.53	37.57
BRI	19.89	20.15	24.42
NB1	19.55	28.48	29.75
NB2	21.42	29.16	35.08
NB3	20.83	23.23	25.93
NB4	19.81	29.92	35.53
NB5	18.53	25.84	28.62
NB6	17.85	23.46	26.52
NB7	19.13	24.23	27.71

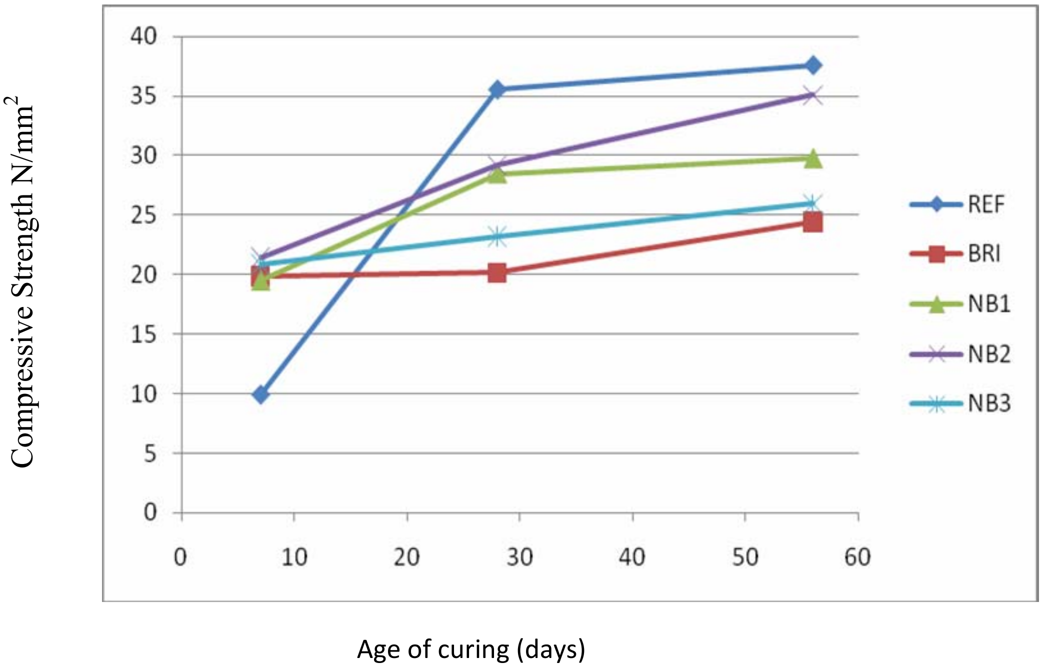


Fig (1) Relation between REF, BRI, NB1, NB2and NB3

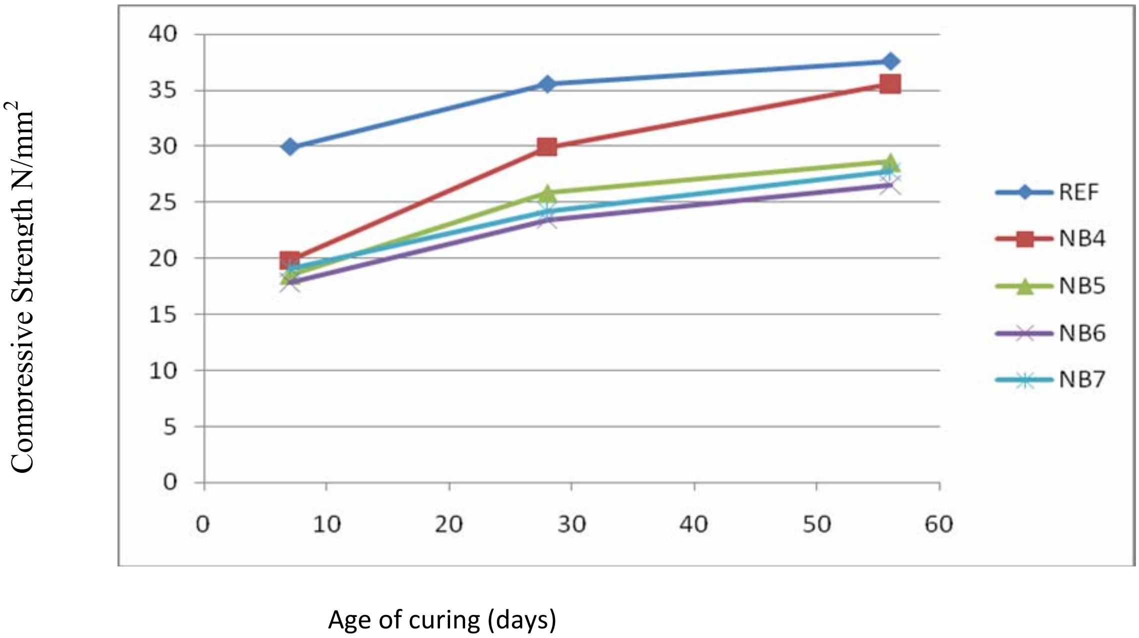


Fig (2) Relation between REF, NB4, NB5, NB6 and NB7

4.2 Splitting tensile strength

The results of the splitting tests for natural and crushed clay brick aggregate concretes are summarized in Table 7 and Figure 3.In general the splitting tensile strength of crushed clay brick aggregate concretes were always lower than natural aggregate concrete, the reduction in splitting tensile strength of crushed clay brick aggregate concretes is ranging between 11 and 26% with an average reduction of about 18.5% compared to natural aggregate concrete. It seems that crushed clay brick aggregate, in general, reduces the splitting tensile strength of crushed clay brick aggregate concretes. Visual observation at the failure surfaces of the concrete cylinders for crushed clay brick aggregate concretes shows that the failure occurs at the brick particles, thereby making the crushed clay brick aggregate the weaker and therefore, the strength-controlling links of the composite system of concrete (see Photos 1 through 9).

Table 7 also shows a comparison of measured splitting tensile strength with ACI predictions. The approximate ACI formulation can result in as high as 10% overestimation or 19% underestimation in crushed clay brick aggregate concretes.

Table 7: Splitting tensile strength of natural and crushed clay brick aggregate concretes

Mix Designation	Measured splitting tensile strength (MPa)	Compressive strength(MPa)	Approximate ACl splitting tensile strength•• (MPa)	Over/under estimation (%)
REF	3.73	35.53	3.31	- I 1.26
BRI	2.92 (78%)•	20.15	2.50	- 14.38
NBl	3.18 (85%)	28.48	2.97	- 6.60
NB2	3.32 (89%)	29.16	3.00	- 9.64
NB3	2.80 (75%)	2323	2.68	- 4.28
NB_4	276 (7-1°0)	29.92	3.04	+ 10.14
NB5	2.93 (78%)	25.84	2.83	-3.41
NB6	3.32 (89%)	23.46	2.69	- 18.97
NB7	3.00 (80%)	24.23	2.74	- 8.67

• Value in ( ) shows the ratio to the natural aggregate concrete

•• $f_{ci} = 0.556 (f'_c)^{0.5}$; where f_{ci} is splitting tensile strength and f'_c is the compressive strength

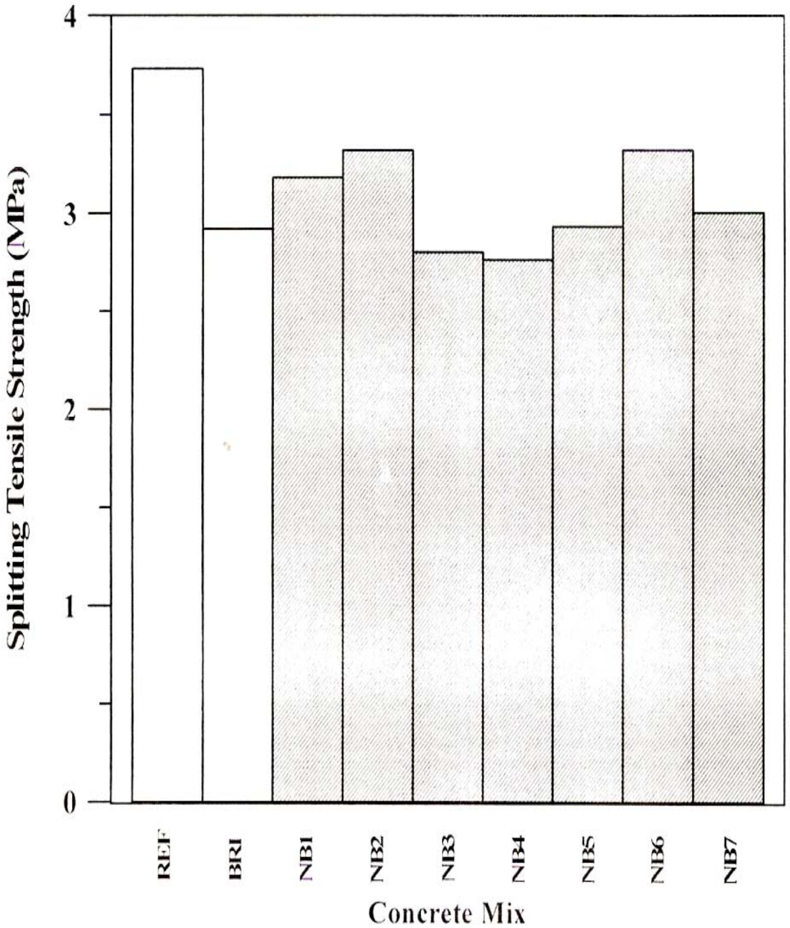


Figure 3 Bar chart for 28 day splitting tensile strength of natural and crushed clay brick aggregate concretes.

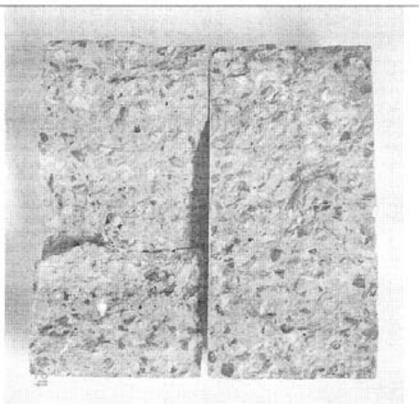


Photo 1: Splitting tensile strength test
Failure surface for mix REF

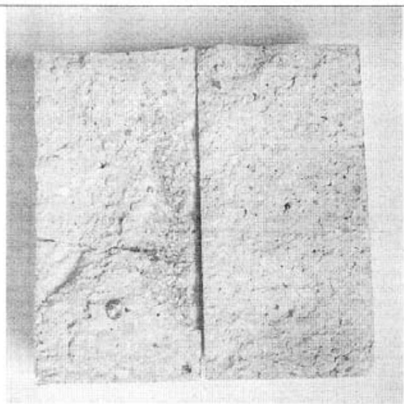


Photo 2: Splitting tensile strength test
Failure surface for mix BR1

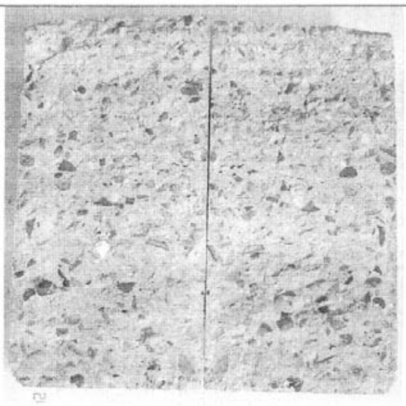


Photo 3: Splitting tensile strength test
Failure surface for mix NB1

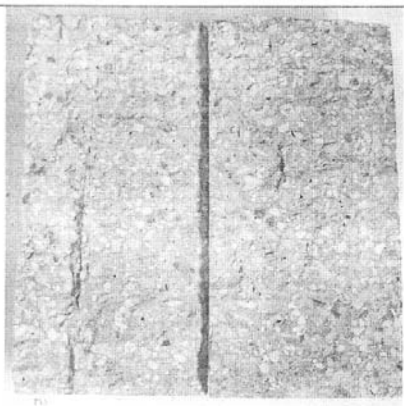


Photo 4: Splitting tensile strength test
Failure surface for mix NB2

Photo 5: Splitting tensile strength test
Failure surface for mix NB3

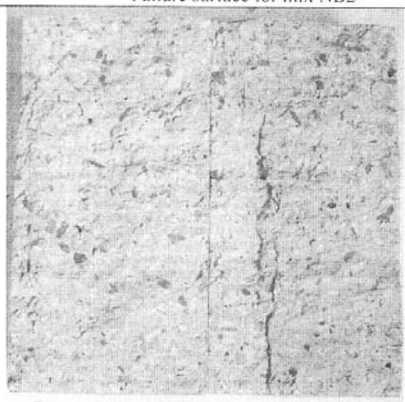
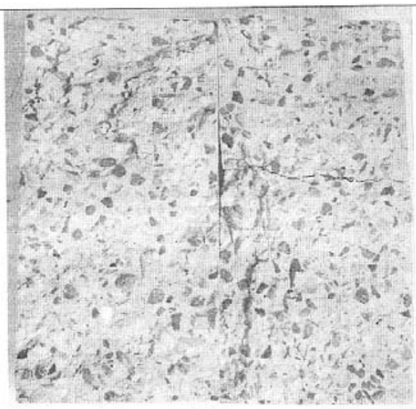
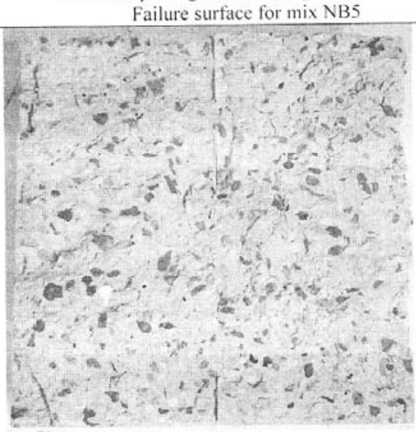


Photo 6: Splitting tensile strength test
Failure surface for mix NB4

 Photo 7: Splitting tensile strength test Failure surface for mix NB5	 Photo 8: Splitting tensile strength test Failure surface for mix NB6
 Photo 9: Splitting tensile strength test Failure surface for mix NB7	

4.3 Pulse velocity

The results of the pulse velocity tests for natural and crushed clay brick aggregate concretes are summarized in Table 8 and Figure 4. In general the pulse velocity of crushed clay brick aggregate concretes were always lower than natural aggregate concrete, the reduction in pulse velocity or crushed clay brick aggregate concretes is ranging between 6 and 22% with an average reduction of about14% compared to natural aggregate concrete. It seems that crushed clay brick aggregate, in general, reduces the pulse velocity of crushed brick aggregate concretes. This is due to the higher amount of voids in crushed clay brick aggregates than in natural aggregates.

Table 8: Pulse velocity of natural and crushed clay brick aggregate concretes.

Mix Designation	Measured length (cm)	Measured time (μs)	Pulse velocity (m/s)
REF	29.85	60.55	4930
BRI	29.75	72.7	4100
NBl	29.90	64.55	4640
NB2	30.00	68.60	4380
NB3	30.00	71.75	4190
NB4	29.85	70.4	4240
NB5	30.00	69.50	4320
NB6	30.00	78.5	3830
NB7	29.90	74.55	4020

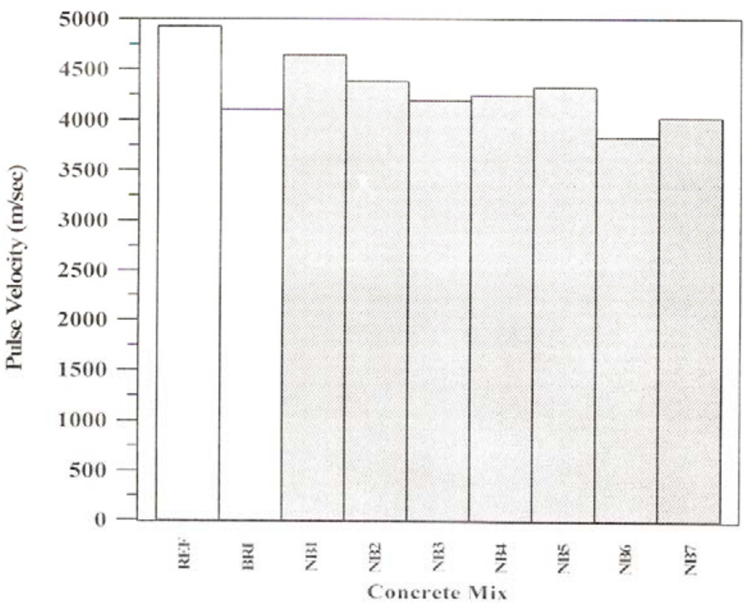


Figure 4 : Bar chart for 28 day pulse velocity of natural and crushed clay brick aggregate concretes.

5. Conclusions

The following conclusions can be made from the work presented in this paper:-

1- The compressive strength of natural aggregate concretes were always higher than the compressive strength of crushed clay brick concretes.

2- The compressive strength increase with the increases of the age for crushed clay brick and natural aggregates concretes.

3-AII mixes of crushed clay brick concretes showed better performance in compressive strength than the mix BRI(which contain crushed clay brick as fine and coarse aggregates).

4- The best performance for crushed clay brick concretes in compressive strength were in mixes NB2 (100% natural fine aggregate,50% natural coarse aggregate and 50% crushed clay brick coarse aggregate)&NB4(50% natural fine aggregate, 50% crushed clay brick fine aggregate,50% natural coarse aggregate,50% crushed clay brick coarse aggregate).

5-AII the mixes of crushed clay brick concretes showed better performance in splitting tensile strength except mixes NB3(100% natural fine aggregate,100% crushed clay brick coarse aggregate)&NB4(50% natural fine aggregate, 50% crushed clay brick fine aggregate,50% natural coarse aggregate,50% crushed clay brick coarse aggregate) compared with the mix BRI(which contain crushed clay brick as fine and coarse aggregates).

6-the best splitting tensile strength were in mixes NB2(100% natural fine aggregate,50% natural coarse aggregate and 50% crushed clay brick coarse aggregate) &NB6(50% natural fine aggregate,50% crushed clay brick fine aggregate,100% crushed clay brick coarse aggregate).

7 -AII the mixes of crushed clay brick concretes showed better performance in pulse velocity except mixes NB6(50% natural fine aggregate,50% crushed clay brick fine aggregate,100% crushed clay brick coarse aggregate)&NB7(100% crushed clay brick fine aggregate, 50% natural coarse aggregate,50% crushed clay brick coarse aggregate) compared with the mix BRI(which contain crushed clay brick as fine and coarse aggregates).

8-The best mixes in pulse velocity were NB1(50% natural fine aggregate, 50% crushed clay brick fine aggregate,100%natural coarse aggregate)&NB2(100% natural fine aggregate,50% natural coarse aggregate and 50% crushed clay brick coarse aggregate).

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