Using Local Materials Wastes For Development Of High Strength Lightweight Concrete

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Abstract

The use of mineral admixtures and super plasticizers, has led to the development of high strength of normal weight concrete. The best use of these materials has resulted in concrete compressive strength exceeding 70 MPa.
This investigation or research reports results of a study undertaken to develop high strength light weight concretes using a waste of local clay brick as a lightweight coarse aggregate, super plasticizer and mineral admixtures.
A series of seven concrete mixtures were made. The cement or cement with mineral admixtures (hydrated lime as an additive) content of the mixtures ranged from 300 to 600 kg/m^3. A large number of test cubes and cylinders and prisms were cast for the determination of the mechanical properties of concrete(density, compressive strength, modulus of elasticity, flexural strength and splitting tensile strength).
From the results of this work. It is concluded that high strength concretes with densities of less than 2000 kg/m^3 can be made with the use of minerals admixtures and super plasticizers and light weight coarse aggregate(waste of local brick) as coarse aggregate .The highest compressive strength achieved was 56.4 MPa at 90 days (3 months) for (cement + mineral admixture) content of 600 kg/m^3.

الخلاصة

من خلال الدراسات السابقة, حيث تم استخدام المضافات الناعمة غير العضوية و المواد الملدنة لتطوير و إنتاج خرسانة (عادية) عالية المقاومة. و الاستخدام الأمثل و المدروس لهذه المواد يمكن أن يعطينا خرسانة ذات مقاومة انضغاط أكثر من 70 ميكاباسكال.
في هذا البحث تم استخدام كسر الطابوق الطيني من مخلفات معامل الطابوق الطيني العراقي كركام خشن (خفيف الوزن) في الخرسانة مع مواد ملدنة و مواد ناعمة(النورة المطفأة) كمواد مضافة لإنتاج و تطوير خرسانة خفيفة الوزن عالية المقاومة.
تم إعداد و عمل سبع أنواع من الخلطات الخرسانية. و كان محتوى الأسمنت و المواد الناعمة (النورة المطفأة) المضافة مع الأسمنت للخلطات الخرسانية بين 300 الى 600 كغم/م^3 . تم استخدام و صب عدد من المكعبات و الأسطوانات و المواشير لدراسة و معرفة خواص الخرسانة (الكثافة , مقاومة الانضغاط, معامل المرونة, مقاومة الشد و مقاومة شد الانفلاق).
يمكن الاستنتاج من نتائج هذه الدراسة التي تم التوصل لها, بإمكانية إنتاج خرسانة عالية المقاومة(نوعا ما) بكثافات أقل من 2000 كغم/م^3 (خرسانة خفيفة الوزن) باستخدام مواد مضافة غير عضوية (النورة المطفأة) و مواد ملدنة و كسر طابوق من مخلفات معامل الطابوق العراقي كركام خشن. و كانت أعلى مقاومة انضغاط تم الحصول عليها هي (56.4 ميكا باسكال) بعمر (90 يوم) لمحتوى (سمنت + مواد ناعمة غير عضوية) 600 كغم/م^3.

1.Introduction

The engineering property that makes lightweight concrete a viable alternative to normal weight concrete is its lower density. The density of lightweight concrete is approximately 80 percent that of normal weight concrete. This lower density creates opportunities for cost savings in both the design and construction phases. The lower dead loads may allow larger beam spacing and smaller loads being transmitted to the substructure and the foundation with resultant saving in support costs. Also construction, the lower density may result in cost saving due to easier handling and the potential for a reduction in shipping costs. Another advantage during construction is that the lower density may allow lifting of members that would otherwise be too heavy for the crane capacity. Hence, lightweight concrete offers more than cost savings, it offers opportunities to overcome constructability issues as well.[Sylva, *et al.,* 2003].

Lightweight aggregates have been used in structural concrete for many years. One of the earliest applications in North America was in the construction of concrete ships during(World War I). The concrete had a density of 1905 kg/m^3 and a 28-day compressive strength of 38.5MPa [Wdison, 1954]. Through the years, by judicious selection of the lightweight aggregate and careful proportioning, semi-lightweight concretes having compressive strengths of 55 to 60MPa have been made[Spratt 1974].

High strength concrete is a relatively recent development in concrete technology made possible by the introduction of efficient water-reducing admixtures and cementitious materials. So, when considering high strength concrete(HSC) one must first define what the mean of high strength. A simple definition would be "concrete with a compressive strength greater than that covered by current codes and standards". In UK this include concrete with a compressive strength of 60 MPa or more.[Newman and Seng Choo 2003].

In recent times, with the advent of the use of fly ash and super plasticizers (also known as high range water reducers), lightweight concretes having compressive strengths of greater than 70MPa are possible.[Takeshi 2006].

The use of high strength lightweight concrete in Texas concrete bridges has potential advantages and disadvantages. Advantages include reduced dead load, crane capacity, and shipping costs. Disadvantages include higher deflections, camber, and material costs. Lightweight concrete material costs are higher than normal weight concrete. However, the higher costs are somewhat offset by reduced shipping costs.[Sylva, *et al.,* 2003].

[Yasar *et al.,* 2004] showed that a structural lightweight high strength concrete (SLWHSC) made with and without ternary mixtures of cement-fly ash-silica fume (20% fly ash and 10% silica fume as a cement replacement) and lightweight basaltic-pumice (scoria) aggregate led to 28 day compressive strength and air dry unit weight of structural lightweight concrete (SLWC) varied from 28 to 47 MPa and 1800 to 1860 kg/m^3, respectively. Laboratory test results showed that structural lightweight concrete SLWC of 30 MPa at 28 days can be produced by the use of scoria. However, the use of mineral additives seems to be mandatory for the production of SLWHSC of 35 MPa or higher grade.

A new generation high strength, structural, insulative, light weight concrete building product developed under collaborative research agreements involving[Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and private industry group 2008]with densities ranging from 1000kg/m^3 to 1500kg/m^3 (compared to traditional concrete of 2500kg/m^3) combined with compressive strengths of 10MPa to 25MPa ensures the HySSIL is a suitable alternative to traditional concrete.

2. Experimental Methods

2.1 MATERIALS:

Sulphate Resisting Portland cement(Tassluga trade mark) was used, Its conformed to Iraqi specification [IQS 5-1984] type V [ASTM C150-05]. The physical properties and chemical analysis are shown in Table 1. Testing of cement was conducted in the Laboratories of the consultant Engineering Bureau in Babylon University.

Coarse aggregate was crushed clay brick(waste of local brick manufactory as lightweight coarse aggregate) with a maximum size of 20mm, physical and chemical properties are listed in Table 2. It was separated by sieve analysis and recombined it to

satisfying the grading according to Iraqi specification [IQS 45-1984],as shown in Figure 1. The crushed brick as lightweight coarse aggregate are shown in Figure 2.
Fine aggregate was a natural sand from Al-Akaidur region. The specific gravity and absorption values and other properties are listed in Table 3.The grading is conformed to the Iraqi specification [IQS 45-1984].
The super plasticizer used was a sulphonated naphthalene formaldehyde condensate. The aqueous solution contained 42% solids and had a density of 1200 kg/m^3. The chloride content was negligible. It is conformed to [ASTM C494-05].
The hydrated lime was used as an additive to the cement. Its physical properties and chemical analysis are shown in Table 4. It is conformed to[ASTM C 110 – 05a]

Table 1 Chemical Compositions and physical properties of (type V) Sulphate Resisting Portland Cement (Tassluga**).**

CHEMICAL ANALYSIS

Chemical Analysis	Test Result	Limits According to IQS
I.R	0.82	<=1.5 %
SiO2	22.15	********
Al2O3	4.09	********
Fe2O3	4.95	********
CaO	63.16	********
MgO	1.93	<=5 %
SO3	2.47	<=2.5 % ifC3A<3.5/<=2.8 % if C3A>3.5
Loss	0.93	<=4 %
Total	99.68	********
F.CaO	1.56	********
L.S.F	0.88	0.66-1.02
S.M.	2.45	********
A.M.	0.83	********
C3S	40.77	********
C2S	32.93	********
C4AF	15.05	********
C3A	2.46	********

PHYSICAL TEST

Setting Time	Initial	2:20	>=45 min
	Final	4:00	<=600 min
Blaine		2844	>=2500
Res. 180		0.43	<= 1
Res. 90		3.11	<= 10
Autoclave		0.04	<=0.8
3Days		23.2	>=15
7Days		32.1	>=23

Table 2 Physical Properties of lightweight Coarse Aggregate(crushed brick).

Properties	Results	Limits(IQS 45:84)
Apparent specific gravity	1.66	-
Absorption	25.4%	-
Bulk Density	1100 Kg/m^3	-
Percentage passing sieve size 75 micron	0.62%	Max. 3%

Gradation of Gravel for Maximum Size 20mm.

Sieve Size	% Passing Acc. Max. Size 20 mm	Limits IQS45-84	Limits ASTM (C33-03)
75mm	100	-	-
37.5mm	100	100	-
20mm	95	95-100	90-100
14mm	-	-	-
10mm	35	30-60	20-55
5mm	5	0-10	0-10

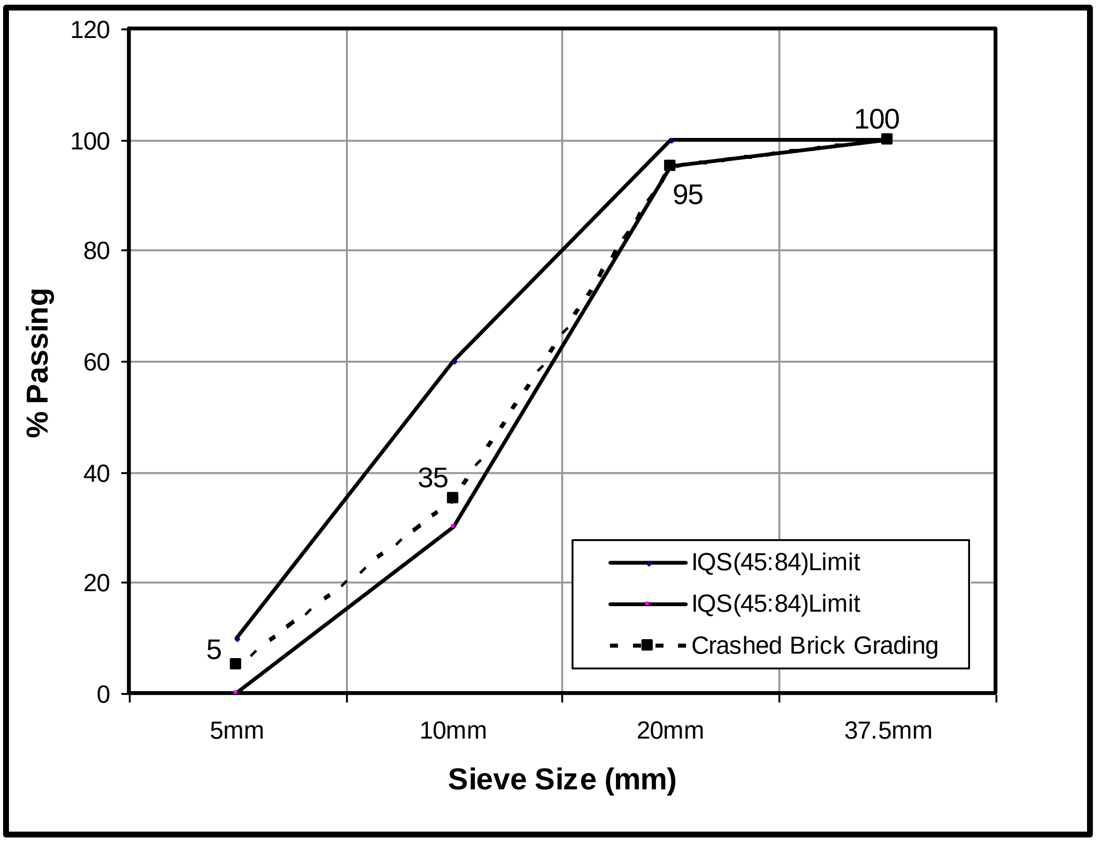

Figure 1 Grading of Crashed Brick of Max. Size 20mm According with IQS45:84

Figure 2. crushed brick as lightweight coarse aggregate

Table 3 Physical Properties of Fine Aggregate from Al-Akaidur region

Properties	Results	Limits(IQS 45:84)
Apparent specific gravity	2.56	-
Absorption	11.0%	-
Moisture content	0.15%	-
% passing S. Size 0.075mm	0.32%	Max. 5%
SO_3	0.23%	Max. 0.5%
Shape	Rounded	
Surface Texture	Smooth	
Fineness Modulus	2.77	

Gradation of Sand According .

% Passing Acc.

Sieve Size	Max. Size 20 mm	Limits Zone 2 IQS45-84	Limits ASTM (C33-03)
9.5mm	100	100	100
4.75mm	98	100-90	100 -95
2.36mm	85	100-75	100-80
1.18mm	70	90-55	80-50
600μm	50	59-35	60-25
300μm	18	30-8	30-10
150μm	2	10-0	10-2

Table 4. physical properties and chemical analysis of Hydrated Lime

Hydrated Lime	Standarad Specificatuon No. 1989 (807)	Properties
68.97		Activity
1.82	Not more Than % 5	CO_2%
72.30	Not Smaller Than % 64	MgO%+CaO%
0.34	Not more Than % 5	MgO %
0.20	Sum of Oxide Not More Than % 5	Fe_2O_3%
		Al_2O_3 %
3.0		SiO_2 %
0.24		SO_3 %
23.90		(L.O.I)
	--	Slacking time
	Not Smaller Than 70 C	Slacking temp
3.3	Not More Than % 10	% Retain on Sieve (90M)
87.32		Ca (OH)2 %

2.2. Mix Proportions

Whilst a number of studies have considered the development of rational or standardized method of concrete mix design for HSC [Le Larrard 1999]. A series of six concrete mixtures were made, with cement contents of 500,400, and 300 kg/m^3 of concrete. Three of the mixtures contained only the cement (Mix.500, Mix.400, Mix.300) and three incorporated 20% hydrated lime in addition to the cement(Mix.A.500, Mix. A.400, Mix.A.300). The seventh mixture contained 600 kg cement/m^3 of concrete(Mix.600), the equivalent of the mixture containing 500kg of cement, plus the hydrated lime. In each of the mixtures, super plasticizer was added to give the fresh concrete a slump of at least 130mm. Table 5 Shows the mixture proportions and measured slump.

The air dried lightweight aggregate(crushed clay brick) was flooded with water, 24h prior to mixing, then this was drained just before mixing. Sufficient water was added to the fine aggregate, 24h prior to mixing, to satisfy the absorption. The mixing water, added subsequently was adjusted according to water absorbed by the fine aggregates.

The total mixing time was 10min.The cement, hydrated lime were added simultaneously.

2.3. Casting and Curing Of Test Specimens

From each batch, specimens for specific tests were cast, the following test specimens were prepared.

cylinders. 100 x 200mm in size

prisms, 100 x 100 x 400 mm in size

cubs, 150x150x150 mm in size

Table 5 Mixture proportions (kg/m3) [Le Larrard 1999]

Mixture No.	W/C+A	Cement Kg/m^3	Additive 20% of cement	Coarse Agg. Kg/m^3	Fine Agg. Kg/m^3	super plasticizers% of cement mass Kg/m^3	Slump mm	Unit Weight Kg/m^3
Mix.500	0.3	500	-	770	510	3.60	140	1925
Mix.A.500	0.29	500	100	650	460	4.32	130	1935
Mix.400	0.36	400	-	750	618	3.60	170	1910
Mix.A.400	0.34	400	80	680	560	3.45	130	1915
Mix.300	0.43	300	-	740	733	3.60	160	1900
Mix.A.300	0.39	300	60	683	681	2.60	130	1905
Mix.600	0.27	600	-	725	450	4.32	160	1960

The moulded specimens were covered by thick wet polyethylene sheets to maintain a relative humidity of not less than 90% . 48 hours after casting specimens were demoulded carefully in a manner to avoid causing any spalling in the specimens, and placed it in a curing tank filled with water until the age of test namely 7,28 and 90 days.

2.4. Concrete Testing

The following tests were carried out ;compressive, flexural and splitting-tensile strengths in addition to static modulus of elasticity. Testing was done in accordance with the appropriate ASTM standard. The densities(oven dry density) were determined at 28 days. Compressive strength was carried out according to[ASTM C 39]by using a hydraulic compression machine of 2000 KN. All specimens (cub 150x150x150mm) were cured in water until testing ages (7, 28 and 90 days). Each result of compressive strength obtained is the average of three specimens.

The splitting tensile strength [ASTM C 496] and static modulus of elasticity [ASTM C 469] were determined(on cylinder 100x200mm) at age of 28 days. Each splitting tensile strength and static modulus of elasticity results are the average of two specimens. Knowing that splitting tensile strength is calculated from the equation $\sigma=2p/\pi LD$ [Nevile 2000].

Where, p=the applied compressive load(N)

L=the cylinder length(mm), D= the cylinder diameter(mm)

Concrete prisms of dimension (100x100x400mm) were tested to determined the flexural strength at 28 days.[ASTM 78-03]

Figure 3 Show the concrete specimens types (cubs, cylinders, prisms).

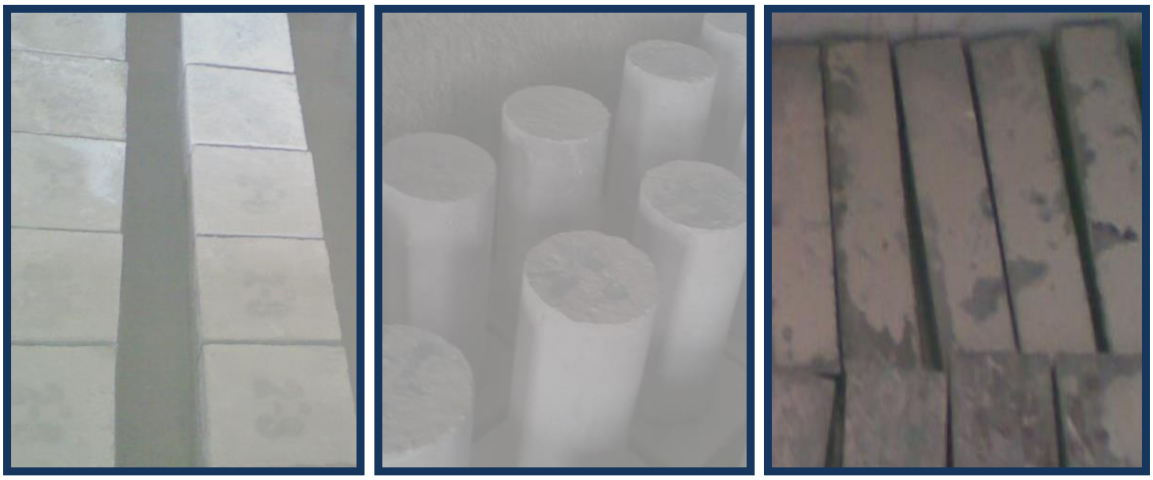

Figure 3 The concrete specimens types (cubs, cylinders, prisms).

3. Discussion Of Test Results

3.1 Slump And Density

The concrete mixtures had been proportioned to have a minimum slump of 130mm and unit weight not exceeding 2000kg/m^3. With minor exceptions, these requirements were met. For each concrete mixture series, cement or cementitious content(as additive materials) and water content were kept constant and the slumps in excess of 130mm were maintained by the use of the super plasticizer. The few instances when the slumps had exceeded 130mm were due to excessive dosage of the super plasticizer.

The highest density of the concrete mixture , 1960 kg/m^3, was for concrete mixture (Mix.600) containing 600 kg/m^3 of cement; the lowest value of 1900 kg/m^3 was obtained for mixture (Mix.300), incorporating nominally 300 kg/m^3 of cement. Data of slump and density for concrete mixtures are given in Table 5

3.2 Compressive Strength

Compressive strength results at age of (7, 28 and 90 days) of concrete mixtures (with cement and cement + additive materials) are shown in Table 6.

The highest 90-day compressive strength, of 56.4 MPa on (150mm x 150mm x 150mm) cubs, was obtained for concrete mixture (Mix.A.500) incorporating 600kg/m^3 of cement + cementitious material. The corresponding reference mixture (Mix.600), incorporating 600kg/m^3 of cement only, had 90-day compressive strength of 53.3MPa, indicating that the mineral admixtures used can satisfactorily compensate for cement similar patterns of strength development follow for concrete mixtures (Mix.A.400)/(Mix.500) and (Mix.A.300)/(Mix.400).

In this investigation mineral admixtures (Hydrated Lime) have been added to cement as an additional cementitious material, due to its high fineness particles, would contribute to the strength increase at early ages and at later ages. Also, the use of hydrated lime would contribute to reduced heat of hydration. Data of compressive strength of concrete mixtures are illustrated in Figure 4 .The analysis of the strength development data (Figure 4) indicates that:

First, the rate of strength development of the concrete incorporating mineral admixtures at age up to 28 days is significantly higher than that of correspond reference mixtures.
Second, There is almost small strength gain between 28 and 90 days for the concrete incorporating the mineral admixtures, whereas the reference concrete made with cement only continues to gain strength up to 90 days. That is clear in Figure 5 and Figure 6 .These show an increase in compressive strength with an increasing (cement and cement + mineral admixtures).
The highest compressive strength of 56.4MPa at 90-days was obtained for concrete with a cementitious material content of 600kg/m^3. Normal-weight concretes mixture with cementitious material of about 600 kg/m^3 produce compressive strength of about 90MPa[Johan Newman 2003]. The limiting factor in attaining very high strength (>70 MPa) in the low density concrete investigation is the strength of the aggregate itself.

Table 6 Compressive strength of concrete mixtures .

Mixture No.	Compressive Strength MPa		
	7-day	28-day	90-day
Mix.500	32.9	41.2	44.9
Mix.A.500	43.7	53.7	56.4
Mix.400	27.7	33.4	39.7

Mix.A.400	37.8	48.7	52.1
Mix.300	19.2	27.2	31.5
Mix.A.300	29.5	41.3	44.2
Mix.600	42.2	49.6	53.3

3.3 Flexural Strength

In this test, a plain (unreinforced) concrete beam (100x100x400mm) at 28 days is subjected to flexural. Because the load points are spaced at one-third of the span, the test called a third-point loading test[ASTM C78-03]. The lowest value of flexural strength (4.5 MPa) for mixture (Mix 300) and the highest value (7.1 MPa) for mixture (Mix.A 500). The flexural strengths show an increase with increasing cementitious content, for example, the strength values for mix series (Mix.A300, Mix.A400 and Mix.A500) were (5.0, 6.2 and 7.1 MPa) respectively as shown in the Figure 7.
Data of flexural strength for concrete mixtures at 28 days are given in Table 7

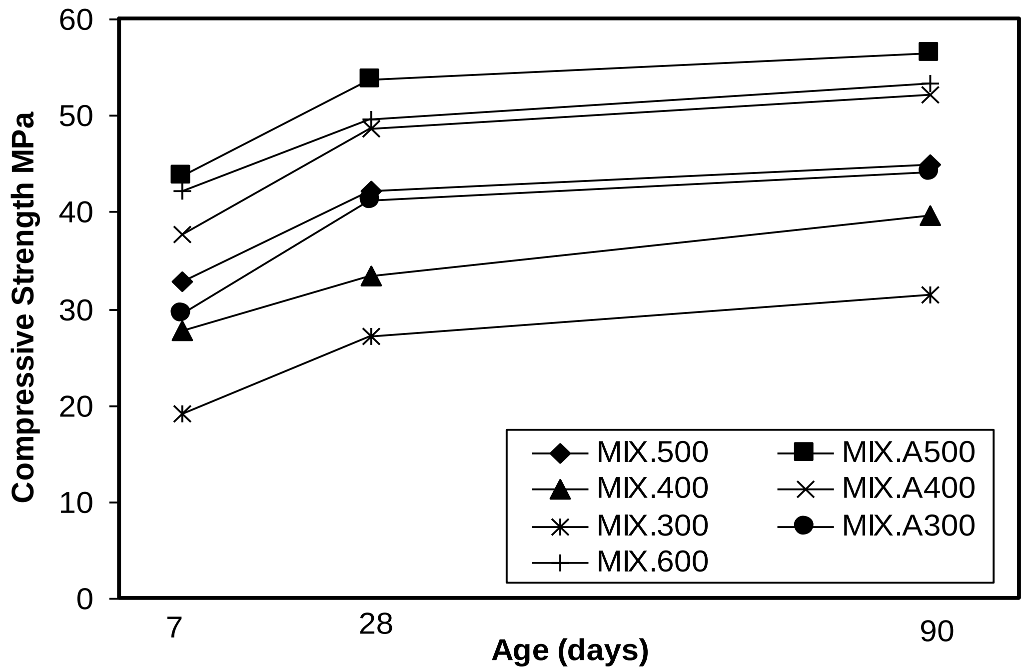

Figure 4 Relation between Age and Compressive Strength

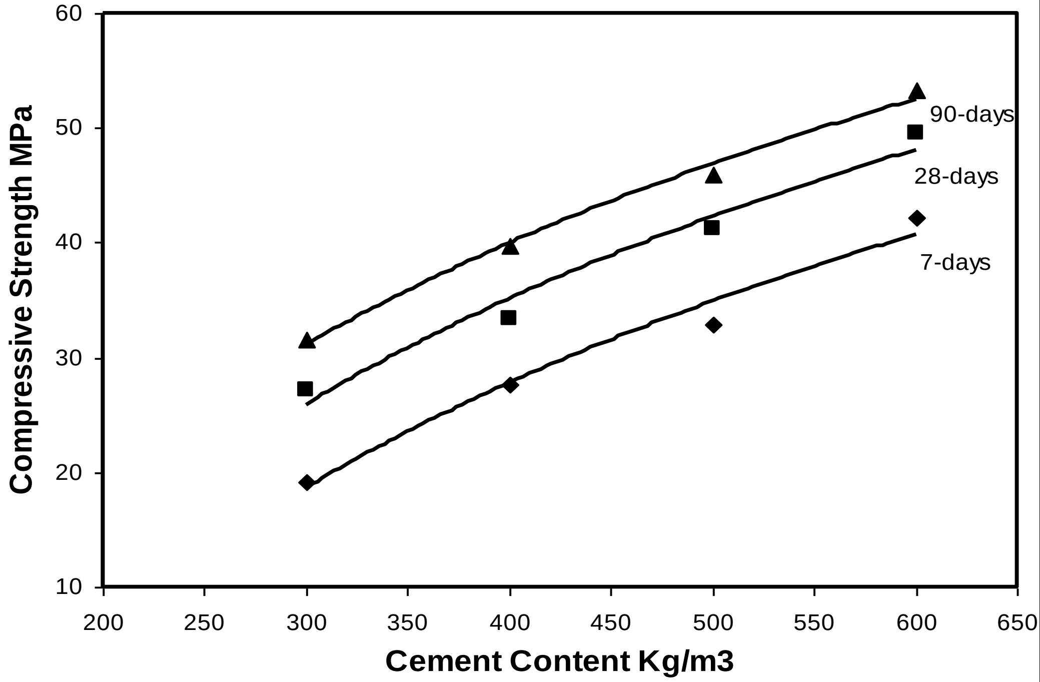

Figure 5 Relation Between Cement Content and Compressive Strength

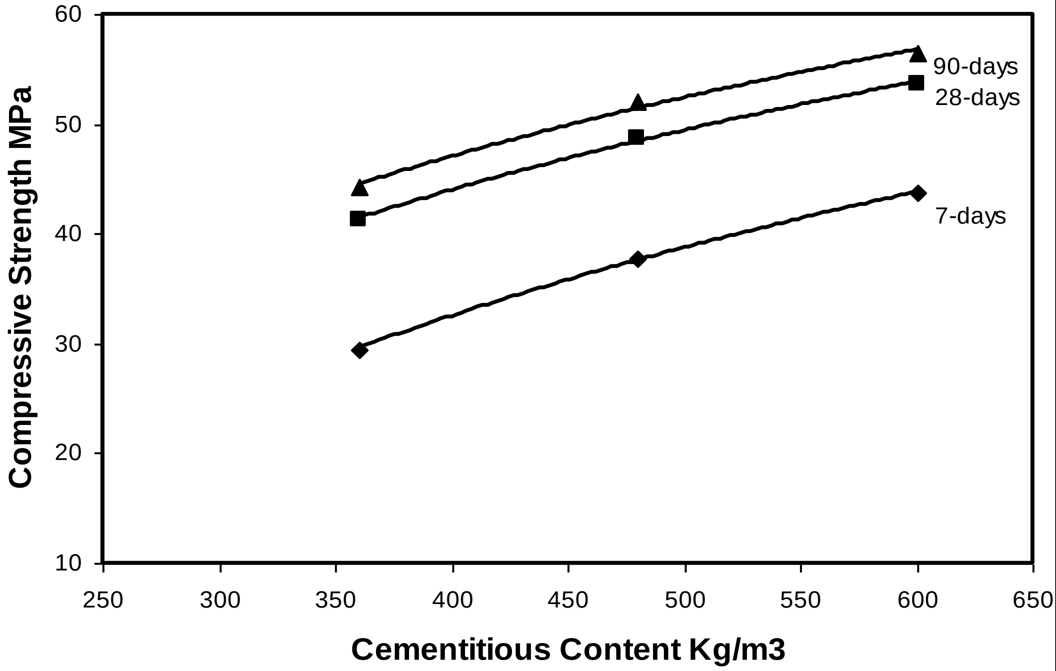

Figure 6 Relation Between Cementitious Content and Compressive Strength

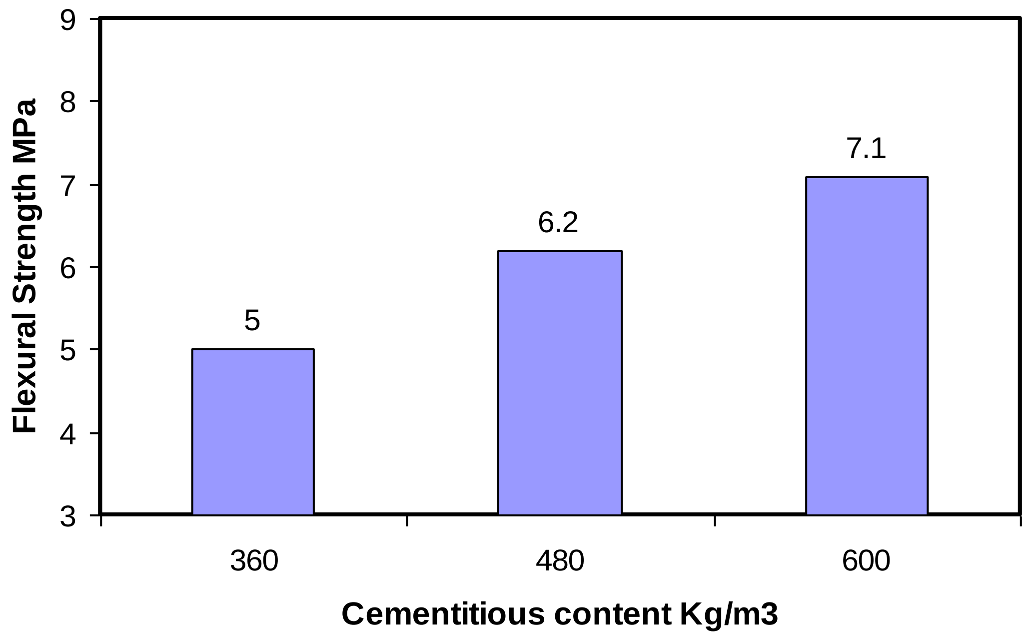

Figure 7 Relation between Cementitious content of mixtures and Flexural Strength

Table 7 Flexural Strength, Splitting Tensile Strength Modulus of Elasticity and of concrete mixtures .

3.4 Splitting-Tensile Strength

The splitting-tensile strength results are summarized in Table 7. Concrete cylinders of 100x200mm were tested for splitting-tensile strength at age 28 days.
The results range from 3.1 to 4.0 MPa, and also the results are not consistent with compressive strength; for example, the concrete with the highest compressive strength shows the lowest splitting-tensile strength. The inherent variability of the test may explain this inconsistent pattern.

3.5 Modulus Of Elasticity

The modulus of elasticity results are summarized in Table 7. Concrete cylinders of 150x300mm were tested for splitting-tensile strength at age 28 days. The results range from 22.8 to 26.0 GPa. The concretes incorporating mineral admixtures show slightly higher values of the modulus than the reference concrete mixtures(modulus of elasticity increases with the increase in the density[Johan Newman 2003]), but the difference is of little practical consequence. Modulus of elasticity does not increase at the same rate as strength[A.M.Neville 1990].

4. Conclusions

1. High strength concretes with densities of less than 2000kg/m^3 can be made with an crushed clay brick (waste of local clay brick manufactory) as light weight aggregate. The highest compressive strength obtained was 56.4MPa at 90 days at a cementitious content of 600kg/m^3(Mix.A.500) . The highest splitting tensile strength achieved was 4.0MPa at 28 days at a cementitious content of 360 kg/m^3(Mix.A.300)

2. The compressive strength, of the concretes increases with increasing cement or cementitious content, on the other hand, it is unconvinced if compressive strengths beyond 70MPa can be achieved by further increases in the cementitious content because of the strength limitations of the crushed brick aggregate and the type of cement used.

3. High strengths can be achieved with or without the use of the mineral admixtures, but the use of a super plasticizer is binding to obtain reasonable slumps.

4. The study would be more useful and significant if testing extend to (drying shrinkage, moist-cured expansion and freezing and thawing). And also, it could be carried out on other types of light weight aggregate and mineral admixtures.

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