EFFECT OF HIGH TEMPERATURE ON SOME PROPERTIES OF LIGHT WEIGHT CONCRETE

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ABSTRACT

In this study, effect of high temperature on the compressive and flexural strength of concrete used crushed clay brick as coarse aggregate were studied and compared the results with concrete containing normal coarse aggregate as a control mix. The replacement of normal coarse aggregates in concrete mixes was done at 0%, 50% and 100% by volume for concrete mixes with crushed clay brick as coarse aggregate. Concrete specimens were heated up to temperatures20^{o}C, 100^{o}C, 200^{o}C, 300^{o}C, 400^{o}C and 500^{o}C. Samples were allowed to cool down naturally to room temperature. After that, the maximum compressive and flexural strength were evaluated for each temperature above. Three samples were tested for each temperature. The compressive and flexural strength of concrete containing 100% of crushed clay brick as vcoarse aggregate gradually decreased (small loss) for all temperature increments compared with other two concrete mixes used (0% and 50%) by volume of crushed clay brick as coarse aggregate. However replacing 50% of normal aggregates with lightweight aggregates (crushed clay brick) by volume did not have a significant effect on the compressive and flexural residual strengths.

Keywords: crushed clay brick, compressive, flexural strength, lightweight aggregates, temperature.

تأثير درجات الحرارة العالية على بعض خواص الخرسانة الخفيفة

الخلاصة:

في هذا البحث تم دراسة خواص الخرسانة الخفيفة (مقاومة الأنضغاط و مقاومة الكسر) التي تستخدم مخلفات معامل الطابوق (كسر الطابوق الطيني) كركام خشن تحت تأثير درجات الحرارة العالية و مقارنتها مع خواص الخرسانة (خلطة مرجعية) التي تستعمل الركام الخشن العادي. حيث تم استبدال الركام الخشن العادي بكسر الطابوق الطيني بنسب حجمية 50% و 100% . تم تعريض النماذج الخرسانية إلى درجات حرارة بمقدار (100,20 , 200, 300, 400 و 500) درجة سيليزية و تم تبريد النماذج بصورة طبيعية إلى درجة حرارة الغرفة. بعد ذلك تم فحص مقاومة الانضغاط و مقاومة الكسر للنماذج لكل درجة حرارة كما في ذكر أعلاه, حيث تم فحص ثلاث نماذج خرسانية لكل درجة حرارة. حيث تم ملاحظة بوجود انخفاض تدريجي قليل في مقاومة الأنضغاط و مقاومة الكسر لخرسانة تستعمل ركام خشن(كسر الطابوق) بنسبة 100% مقارنة مع الخرسانة التي تستعمل الركام الخفيف (كسر الطابوق الطيني) بنسب (0% و 50%) في جميع درجات الحرارة المقترحة في هذا البحث.

1. INTRODUCTION

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**.[A. M. Neville, 2000]**
Under high temperature effect, chemical composition, physical structure and moisture content of concrete changes. These changes are primarily observed at the cement paste and then at the aggregates as well. Heating to high temperatures causes the dehydration of hardened cement paste and conversion of calcium hydroxide into calcium oxide in which chemically bound water is gradually released to become free water. Aggregates also lose their evaporable water and hydrous aggregates dehydrate at high temperatures, and undergo crystalline transformation accompanied by a significant volume expansion temperature **[Ahmet B. Kizilkanat, Nabi Y., Nihat K., 2013].**

It was observed that light weight concrete properties were deteriorated at 150 C˚ and the specimens began to lose some of their initial strengths at this temperature. Though a considerable strength lose was not seen between 150-300˚ C, all types of concrete mixture continued to lose their compressive strength after 300˚C, and it was found that the heating duration does not affect the strength loss significantly**.[A Ferhat Bingol & Rustem Gul, 2004].** But the **[Bazant 1996]** observed that the duration of the exposure affects the loss of the strength considerably as well. When the duration of the exposure is more than 1 hour, the concrete loses its strength significantly and the most significant strength loss happens when the exposure is between 1 and 2 hours.

Light weight 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. The highest splitting tensile strength achieved was 4.0MPa at 28 days **[H.M.Albaghdadi 2010].**

Different types of aggregates have various processes happening under high temperature. The common of aggregates have a tendency to be more or less stable until the temperature is about 500^{o}C. For the non- siliceous aggregates, the temperature when reactions like transformation and decomposition will start is at about 600^{o}C **[Harmathy & Aleen 1973].**

At temperatures between 600^{o}C and 900^{o}C, the chemical and physical changes happen not only to aggregates, but to hardened cement paste as well. When dehydration of hardened cement paste takes place, it changes porosity and water evaporates from aggregates **[Bazant 1996].**

The duration of the exposure affects the loss of the strength considerably as well. When the duration of the exposure is more than 1 hour, the concrete loses its strength significantly and the most significant strength loss happens when the exposure is between 1 and 2 hours. After the first hour of expo-sure, residual strengths of the concrete are approximately 80, 70, 60 and 30% at heating correspondingly to 200, 400, 600, 800^{o}C. After two hours or more, residual strengths decrease to 70, 60, 45 and 25 % at 200, 400, 600, 800^{o}C **[Bazant 1996].**

[Peng et al. 2006] was concluded that when the concrete cools down with a rapid change of temperature under cooling in water or spraying water for more than 30 min, it experiences ‘thermal shock’ and severe damage. When concrete is exposed to a temperature of 200^{o}C and cooled down under natural conditions, its compressive strength can be higher than when kept at room temperature. The activation of additional hydration of residual cement in concrete happens at elevated temperatures, it happens to a lesser degree when there are rapid cooling regimes like water spraying.

At high temperatures, the color of the concrete changes to red/pink for the concrete containing most types of siliceous aggregates. However, the discoloration may not happen with all types of aggregates and concrete with aggregates containing ferrous salts is more likely to develop a pink hue color. The color of the concrete remains normal up to 300^{o}C, and then it changes to pink. When the temperature in the concrete is above 600^{o}C it becomes whitish grey. **[Soutsos, 2010].**

It is considered that if the concrete's temperature is not more than 300^{o}C, the residual strength after cooling is not considerably changed. When the concrete's temperature exceeds 300^{o}C, it is assumed that concrete losses of strength are significant**. [Arpacıoglu, U., Tanacan, L. & Ersoy, H.Y, 2008]**

Lightweight concrete containing periwinkle shells is only suitable for structures that will be subjected to temperature less than 300^{o}C. **[F. FALADE, E. E. IKPONMWOSA, N. I. OJEDIRAN, 2010]**. Lightweight concrete with vermiculite shows a good performance at elevated temperatures. Expanded vermiculite is a significant lightweight aggregate for cementitious materials which are used for fire resistance applications**.[F. Koksal1, O. Gencel, W. Brostow and H. E. Hagg Lobland, 2012].**

2. EXPERIMENTAL METHOD

2.1 Materials

Ordinary Portland cement (Tassluga trade mark) was used; it's conformed to Iraqi specification **[IQS 5-1984]** type II **[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 course 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].** The crushed brick as lightweight coarse aggregate are shown in **Figure 1**. Rounded normal coarse aggregate from AL- Nibaee quarry is used. The coarse aggregate was washed, and then stored in air to dry. **Table 2** shows the physical and chemical properties.

Fine aggregate was 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 44% solids and had a density of 1210 kg/m^3. The chloride content was negligible. It is conformed to **[ASTM C494-05].**

2.2. Mix Proportions

Three main groups of concrete mixes were cast containing normal coarse aggregate and lightweight aggregate as coarse aggregate (crushed clay brick).

The replacement of normal coarse aggregate with crushed clay brick in concrete mixes A, B and C was done correspondingly at 0%, 50% and 100% by volume, that mean the mix A was the control group.

The cement content and the slump value were kept constant. Table 3 shows the mix design **[Le Larrard 1999]** for three different concrete mixes containing normal coarse aggregate and light weight aggregate as coarse aggregate (crushed clay brick). The strength of the mixes was designed to be approximately 40 N/mm^2 for the control mix with slump values between 50 and 100 mm. The amount of water was adjusted to test fresh properties of concrete and get the required slump value.

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.

2.3. Casting And Curing Of Test Specimens

From each batch, specimens for specific tests were cast; the following test specimens were prepared.
Cubs, 150x150x150 mm in size
Prisms, 100 x 100 x 500 mm in size

The moulded specimens were covered by thick wet polyethylene sheets to maintain a relative humidity of not less than 90%. 24 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 28 days.

2.4. Concrete Testing

The following tests were carried out; compressive, flexural. Testing was done in accordance with the appropriate ASTM standard. Compressive strength was carried out according to **[ASTM C 39-03]** by using a hydraulic compression machine of 2000 KN. All specimens (cub 150x150x150mm) were cured in water until testing ages 28 days. Each result of compressive strength obtained is the average of three specimens.

Concrete prisms of dimension (100x100x500mm) were tested to determine the flexural strength at 28 days**. [ASTM 78-03]**

2.5 Heating and Cooling Down Process

The total amount of cubes and prisms used for testing was 54 and 36 respectively. Specimens were exposed to temperature levels of 20^{o}C, 100^{o}C, 200^{o}C, 300^{o}C, 400^{o}C and 500^{o}C. For each set of temperatures, 3 cubes (150x150x150) mm and 2 prisms (100x100x500) mm were used to determine the residual compression and flexural strength.

The period of the heating was for 5 hours at each temperature increase to allow the concrete inside the samples to reach the required temperature. The dimensions of the oven used for heating were 380x350x800mm with a maximum heating capacity of 600°C. Taking into consideration the size and amount of concrete specimens, it was decided to place specimens of each concrete mix in three sets to reach the specified temperature. Specimens were weighed before and after heating to calculate moisture loss. After heating, specimens were left to cool down under natural conditions.

3. DISCUSSION OF TEST RESULTS

3.1 Slump

The concrete mixtures had been proportioned to have a minimum slump of 100mm and unit weight not exceeding 2000kg/m^3.The slump value was recorded as 90 mm for the control Mix A, 70 mm for Mix B and 60 mm for Mix C. Data of slump for concrete mixtures are given in **Table 3**

3.2 Compressive Strength

Compressive strength results at age of (28 days) of concrete mixtures under increment of heating temperature are shown in **Table 4.**

Figure 2. Show a decrease in compressive strength with an increasing in heating temperature for all groups of concrete mixtures.Concrete mixes A and B showed similar approximately compressive strength reduction after heating up to 500°C of about 75% of their initial strength. Significantly lesser loss of compressive strength was observed for mix C, in which was a loss of 52%. The change of the compressive strength is given on **Figure 3.**

3.3 Flexural Strength

Flexural strength results at age of (28 days) of concrete mixtures under increment of heating temperature are shown in **Table 5.**

Figure 4. Show a decrease in flexural strength with an increasing in heating temperature for all groups of concrete mixtures.

The largest flexural strength reduction experienced was for mix A, which had a flexural strength of 4.3 N/mm^2 - a 93% loss of initial concrete flexural strength. Concrete mix B had strength of about 3.6 N/mm^2 corresponding to 83% loss. Mix C containing 100% light weight aggregate as coarse aggregate (crushed clay brick) showed the least flexural strength loss of about 48% of initial strength. The flexural strength change between unheated and heated to 500°C is given in **Figure 5.**

3.4 Residual Strength Against Temperature Increments

Concrete mixes containing normal aggregates and light weight aggregate (crushed clay brick) confirmed similar trends of a decrease in strength with an increase in temperature. A gradual decrease of strength was observed up to 300^{o}C; at higher temperatures concrete specimens practiced a more severe and progressive decrease in strength.

For concrete mixes containing normal aggregates the loss of compressive strength was between 20% and 35% when specimens were heated up to 300^{o}C. It was observed that a considerable loss of compressive strength happens when specimens are heated to the temperature higher than 300^{o}C. For concrete mixes A and B loss in compressive strength was 80% when samples were subjected to a temperature of 500^{o}C which indicates that the major loss of strength (about 45%) happens between 300 and 500^{o}C. When specimens of mix C were exposed to high temperature, the reduction of compressive strength happened gradually compared to other concrete mixes. The more impressive reduction of compressive strength which is observed for mixes A and B is not familiar for mix C.

A similar gradual decrease of the strength is observed for all 3 mixes from the results of flexural strength. The graph for flexural strength to temperatures for each of the mixes is close to linear as shown in (Fig.4). Specimens of concrete mix A had a flexural strength of about 0.3 N/mm^2 when they reached 500^{o}C, which means they lost more than 90% of their initial strength. Mix C containing light weight aggregate (crushed clay brick) had a value of 1.6 N/mm^2 with a 48% reduction of the initial flexural strength. As expected, the lightweight concrete had a better performance in high temperature loading than the concrete with normal aggregates.

3.5 Color Change

A change in color with temperature was an indication of physical and chemical changes of aggregates used for concrete mixes. The samples heated to 200°C maintained their original color, while specimens heated to 500°C changed to pink. At this level of heating, the samples with light weight aggregate (crushed clay brick) aggregate obtained a rather more concentrated coloring than the specimens with normal aggregates. The change of the color is related with chemical transformations of the aggregates at elevated temperatures.

3.6 Cracking And Spalling

When specimens are exposed to high temperatures, they experience moisture loss due to increased pore pressure from evaporating water inside the concrete. This process results in an increase in internal stresses and therefore appearance of cracks.

During the experiments, visible micro cracks on specimens appeared when temperatures of exposure were 400^{o}C and 500^{o}C. As the increase in moisture loss results in appearance of more excessive cracking, cubes heated to 500^{o}C had a significant increase in number and size of cracks, compared to cubes exposed to 400^{o}C.

When specimens are exposed to high temperatures, and due to the difference in modulus of thermal expanding of cement past with normal aggregate that lead to increase in internal stresses and therefore appearance of significant cracks as shown in Mix A. While in Mix C that containing light weight aggregate (crushed clay brick), they observed a visible micro cracks on specimens due to the modulus of thermal expanding of light weight aggregate (crushed clay brick) was lesser than normal aggregate.

4. CONCLUSIONS

1. The chemical composition, physical structure and water content of concrete were changed when exposed to high temperatures. These changes occur both in the hardened cement paste and in aggregates. It results in reduction of residual strength.
2. All types of concrete mixes containing natural aggregates and lightweight aggregates (crushed clay brick) confirmed reduction of their compressive and flexural strengths.
3. For specimens tested at temperatures between 20°C and 300°C, the reduction of the compressive strength was relatively small. However, when samples were exposed to temperatures higher than 300°C, a severe decrease in residual strength was measured.
4. Adding of 50% lightweight aggregates (crushed clay brick) did not improve the residual strength of the samples heated at 500˚C significantly in comparison with samples from normal aggregates.
5. For both mixes A and B and after heating to 500°C the reduction of the flexural strength was more significant than the reduction of the compressive strength (Fig.6). For samples from mix C (100% lightweight aggregates (crushed clay brick)) the reduction in compressive and flexural strength was approximately the same.
6. In conclusion, investigations that were carried out showed that concrete with lightweight aggregates (crushed clay brick) had much better performance at higher temperatures than other concrete aggregates.

REFERNESES

[1] A Ferhat Bingol & Rustem Gul,(Compressive Strength of Light weight Aggregate Concrete Exposed to High Temperatures), Indian Journal of Engineering and Materials Science, Vol. 11, February 2004, PP.68-72.

[2] A. M. Neville, **2000**, (Properties of Concrete), Fourth and Final Edition , England.

[3] Ahmet B. Kizilkanat, Nabi Yuzer, Nihat Kabay, (Thermo-physical properties of concrete exposed to high temperature), Construction and Building Materials45, 2013, 157-161.

[4] American Society for Testing and Materials, **2003**, C33-03 (Specification of Concrete Aggregate, Annual Book of ASTM Standard , Vol.04.01.2003.

[5] American Society for Testing and Materials, **2005**, C150-05 (Specification of Portland Cement),

[6] Annual Book of ASTM Standard , Vol.04.02.2005.

[7]American Society for Testing and Materials, **2005**, C494-05 (Specification of For Chemical Admixtures For Concrete), Annual Book of ASTM Standard , Vol.04.01.2005.

[8] American Society for Testing and Materials,**2003**, C 78,(Standard Test for Flexural Strength of Concrete using simple beam with third-point loading), Annual Book of ASTM Standard,2003

[9] American Society for Testing and Materials,**2003**, C-39,(Standard Test for Compressive Strength of Concrete), Annual Book of ASTM Standard,2003

[10] Arpacıoglu, U., Tanacan, L. & Ersoy, H.Y.(Effect of high temperature and cooling conditions on aerated concrete properties.) Construction and Building Materials. (2008)

[11] Bazant, Z.P., Kaplan, M.F. (Concrete at High Temperatures. Material Properties and Mathematical Models). Har-low: Longman Group Limited, (1996).

[12] F. FALADE, E. E. IKPONMWOSA, N. I. OJEDIRAN (Behavior of Lightweight Concrete Containing Periwinkle Shells at Elevated Temperature), Department of Civil and Environmental Engineering, University of Lagos, Lagos, Nigeria, Journal of Engineering Science and Technology, Vol. 5, No. 4 (2010) 379 – 390 School of Engineering, Taylor's University

[13] F. Koksal1, O. Gencel, W. Brostow and H. E. Hagg Lobland (Effect of high temperature on mechanical and physical properties of lightweight cement based refractory including expanded vermiculite), Materials Research Innovations 2012 VOL 16 NO 1

[14] H.M.Albaghdadi,(Using Local Materials Wastes For Development Of High Strength Lightweight Concrete), Babylon Journal , Vol. (2010).

[15] Harmathy, T.Z. and Allen, L.W. Thermal properties of selected masonry unit concretes. Journal American Con-crete Institution 70(2) , (1973)

[16] Iraqi Organization of Standard, IQS 45-**1984** , for Natural Aggregate Resources .

[17] Iraqi Organization of Standard, IQS 5-**1984** , for Portland Cement .

[18] Le Larrard, F, (Concrete mixture proportioning) , A Scientific approach, London, 1999.

[19] Peng, G.F., Bian, S.B., Guo, Z.Q., Zhao, J., Peng, X.L. and Jiang, Y.C. (Effect of thermal shock due to rapid cooling on residual mechanical properties of fiber concrete exposed to high temperature). (2006)

[20] Soutsos, M. (Concrete durability. A practical guide to the design of durable concrete structures). London: Thomas Telford Limited. (2010)

[21] Wdison, C. (Concrete ship resists sea water thirty four years), Concrete. Vol. 62, No.1, 1954, pp 5-8.

Table 1: Chemical Compositions And Physical Properties Of (Type Ii) Ordinary Portland Cement (Tassluga).

Compound Composition	Chemical Composition	Percentage by weight	Limits of IOS 5:1984
Lime	CaO	62.41	-
Silica	SiO_2	21.78	-
Alumina	Al_2O_3	4.85	-
Iron Oxide	Fe_2O_3	3.96	-
Magnesia	MgO	1.98	<5
Sulfate	SO_3	2.55	<2.8
Loss on Ignition	L.O.I	3.11	<4
Insoluble residue	I.R	1.28	<1.5
Lime saturation factor	L.S.F	0.95	0.66-1.02
Physical Properties		Test result	Limits of IOS5:1984
Fineness using Blain air permeability apparatus (m^2/kg)		315	>230
Soundness using Autoclave method		0.19%	<0.8%
Setting time using Vicat's instruments Initial (hrs: min) Final (hrs: min)		2: 50 4 : 44	0:45 ≥ ≤ 10:00
Compressive strength for cement mortar 3 days (MPa) 7 days (MPa)		22.3 31.5	>15 >23

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

Properties	Test Results lightweight	Test Results normal	Limits of Iraqi specification No.45/1984
specific gravity	1.65	2.66	-
Absorption	25.4%		-
Bulk Density	1105 Kg/m^3	1660 Kg/m^3	-
Percentage passing sieve size 75 micron	0.60%	0.1%	Max. 3%
Gradation of Gravel for Maximum Size 20mm			
Sieve size(mm)	Passing % lightweight	Passing % normal	Limits of Iraqi specification No. 45/1984
75mm	100	100	-
37.5mm	100	100	100
20mm	95	97	95-100
14mm	-	-	-
10mm	36	42	30-60
5mm	4	6	0-10

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

Properties	Test Results	Limits of Iraqi specification No.45/1984
specific gravity	2.56	-
Absorption	11%	-
Moisture content	0.15%	-
SO_3	0.21%	Max. 0.5%
Percentage passing sieve size 75 micron	0.32%	Max. 5%
Gradation of Gravel for Maximum Size 20mm		
Sieve size(mm)	Passing %	Limits of Iraqi (Zone 2) specification No. 45/1984
9.5 mm	100	100
4.75 mm	98	100-90
2.36 mm	85	100-75
1.18 mm	70	90-55
0.6 mm	50	59-35
0.3 mm	18	30-8
0.15 mm	3	10-0

Table 4: Concrete Mix Design **[Le Larrard 1999]**

	Mix A Control Mix	Mix B	Mix C
Cement (Kg)	64.3	64.3	64.3
Water letter	29.20	21.2	24.7
Sand (Kg)	75.5	75.5	75.5
Normal Coarse Aggregate (Kg)	160.4	80.2	0
Light Weight Aggregate (crushed clay brick) Kg	0	30.8	61.6
Slump mm	90	70	60

Table 5:. Compressive Strength Results

Temperature	**MIX A**	**MIX B**	**MIX C**
	Compressive Strength Mpa		
20^{o}C	40.4	37.0	26.7
100^{o}C	37.6	34.4	23.1
200^{o}C	35.4	30.8	20.1
300^{o}C	31.3	23.3	18.8
400^{o}C	25.4	15.6	13.8
500^{o}C	10.0	8.6	12.7

Table 6: Flexural Strength Results

Temperature	**MIX A**	**MIX B**	**MIX C**
	Flexural strength Mpa		
20^{o}C	4.3	3.6	3.1
100^{o}C	3.7	3.2	2.5
200^{o}C	2.9	2.6	2.2
300^{o}C	1.8	1.8	2.1
400^{o}C	1.2	1.0	1.8
500^{o}C	0.3	0.6	1.6

Figure (1): Crushed brick as lightweight coarse aggregate

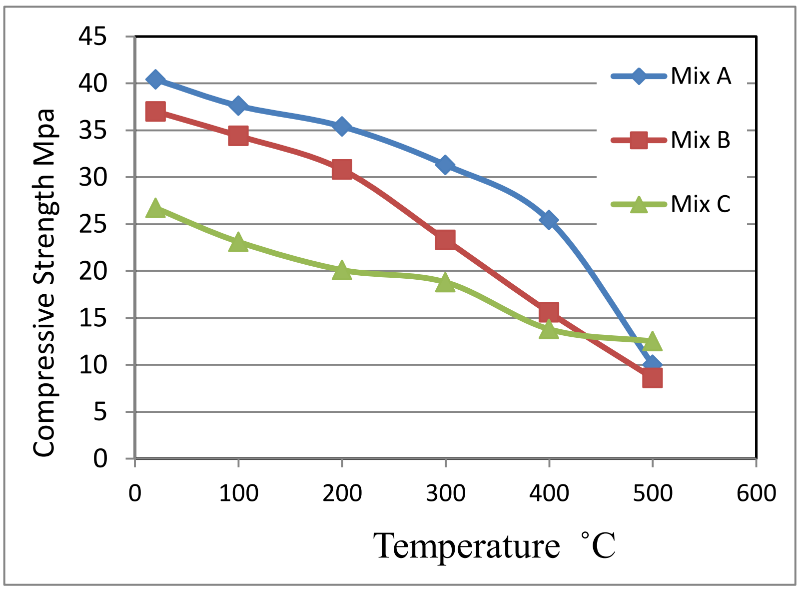

Figure (2): Relation of compressive Strength with increment Temperature

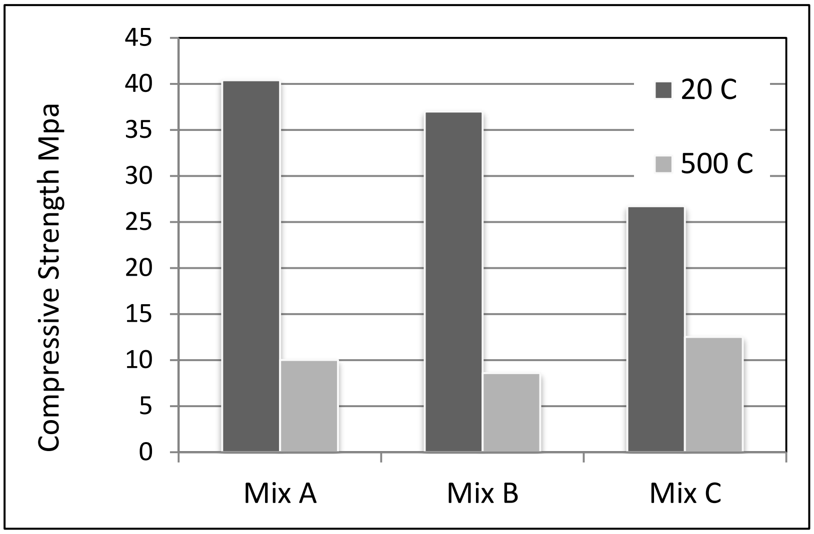

Figure (3): Change of the compressive strength.

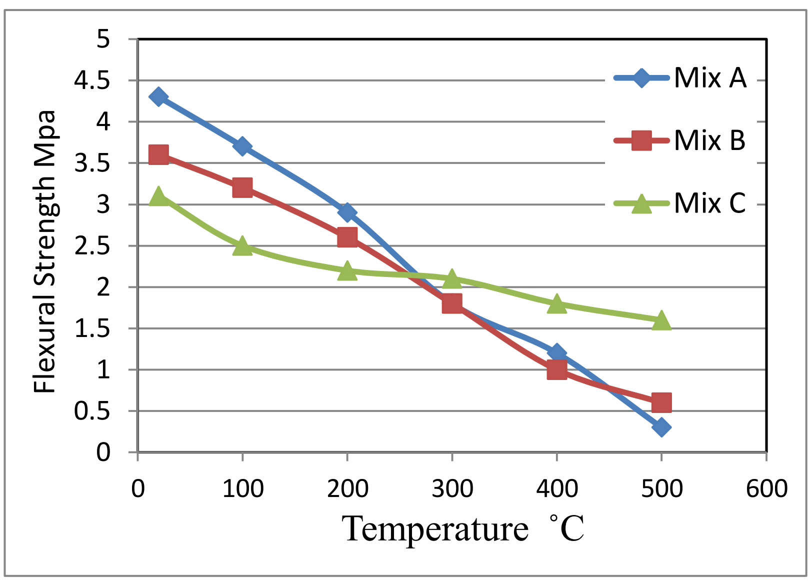

Figure (4): Relation of Flexural Strength with increment Temperature

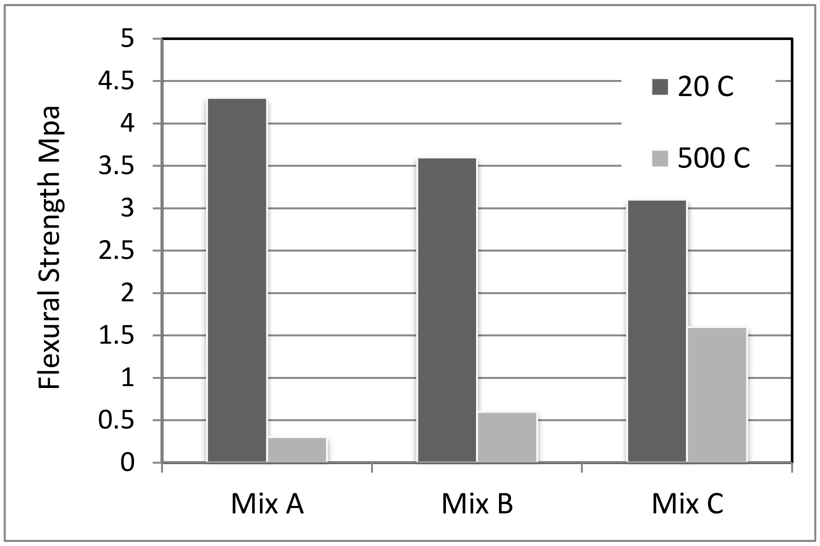

Figure (5): Change of the Flexural Strength.

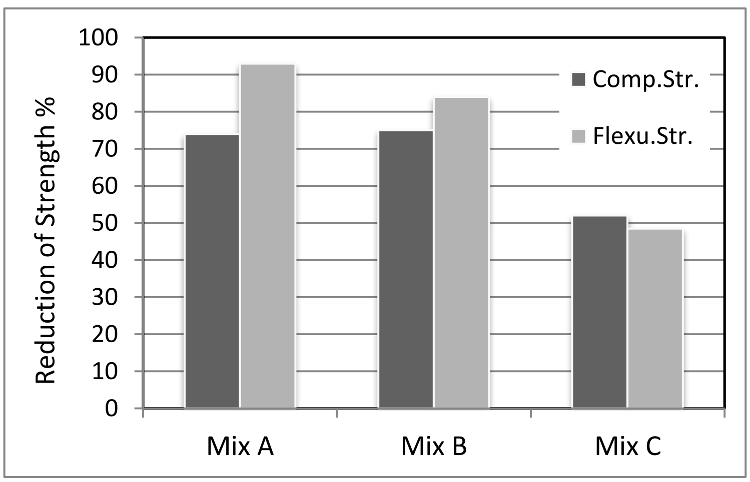

Figure (6): Reduction in strength of concrete mixes after heating to 500°C