Journal of Engineering Sciences
Assiut University
Faculty of Engineering
Vol. 44
No. 3
May 2016
PP. 259 – 271

IMPROVING OF LIGHTWEIGHT SELF- CURING CONCRETE PROPERTIES

Mohammed M. M. Rashwan [1], Hesham M. A. Diab [2] and Yahia M. S. Abd El-Fattah [*, 3]

Civil Eng. Dept., Assuit University, 71516 Assuit.

Received 5 April 2016; Accepted 18 May 2016

ABSTRACT

This study investigates the effect of self-curing agents on the mechanical properties of concrete. The self-curing agent is prewetted lightweight aggregate crushed over burnt clay bricks (COBCB). The COBCB has been used for replacement coarse aggregates in a ratios of 20%, 50% and 100 %. The mechanical properties were evaluated while the concrete specimens were subjected to different curing methods; conventional water curing, air curing regime (in the laboratory environment with 25°C) and chemical curing. The results show that, the use of self-curing agents COBCB in concrete with replacement ratio 20% by volume of coarse aggregates is effectively improved the mechanical properties in all cases of curing.

Keywords: Self curing, Lightweight aggregates, mechanical properties.

1. Introduction

In practice, the conventional type of curing needs a large amount of water, which is lost due to evaporation and runoff. Internal curing refers to the use of prewetted lightweight aggregate (LWA) to provide sufficient moisture which is required for hydrating of cement paste. In this case, the concrete will achieve excellent properties. Internal curing is done by replacing a percentage of coarse aggregate with LWA such as COBCB. The water in COBCB is typically stored in pores that are larger than those in a hydrating cement paste. As a result, the water moves from the LWA to the surrounding cement particles keeping the small pores saturated until the time when moisture equilibrium is reached between the reservoirs and the surrounding cement paste which reducing dry shrinkage of cement paste. Also, it utilizes cement more efficiently during the hydration process. Furthermore, internal curing improves the workability of the concrete and reduces the cracks due to plastic, drying and thermal shrinkage. Moreover, the concrete strength is increased because the bond between the LWA and the hydrated cement increases due to decrease in the permeability of the concrete.

2. Literature survey

Holm.T.A. [1] stated that, shale's, clays, and slates have been expanded in rotary kilns to produce structural grade LWA for use in concrete and masonry units for more than 80 years.

* Corresponding author.
E- mail address: *yahia_samir91@yahoo.com*

Millions of tons of structural grade LWA produced annually are used in structural concrete applications [1]. Khokrin, N.K discussed the unique physical characteristics of rotary kiln expanded slate LWA for producing high performance and high strength lightweight concrete. The compressive strength, elastic modulus, splitting tensile strength, specific creep and other properties of lightweight concrete are significantly affected by the structural properties of the lightweight aggregate used. Concrete production, transportation, pumping and placing are also affected [2]. Hoff. G.C. described the use of saturated LWA as a replacement for a portion of the normal weight aggregate (NWA) in high-strength/high-performance concrete in order to mitigate or eliminate the self-desiccation and autogenous shrinkage that can occur which can further lead to early age cracking and long-term durability problems. The amount of LWA used to achieve beneficial internal curing is a function of the type of LWA, its size and amount, the degree of moisture preconditioning the LWA receives, the amount and type of binder(s) in the mixture, the water-binder ratio at mixing, as well as the amount and duration of external moist curing provided to the concrete element [3]. ArnonBentura et.al. studied the concrete with saturated LWA exhibited no autogenous shrinkage, whereas the normal-weight concrete with the same matrix exhibited large shrinkage. The study shows that; the partial replacement of NWA with 25% by volume of saturated LWA was very effective in eliminating the autogenous shrinkage and restrained stresses of the normal-weight concrete. It is noted that; the internal supply of water from the saturated LWA to the high-strength cement matrix causes continuous expansion, which may be related to continuous hydration [4]. Ryan Henkensiefkenet. al indicated that, while internal curing may have been originally developed to reduce autogenous shrinkage and mitigate early-age cracking in high performance concrete, its application has far-reaching consequences for the performance of concrete throughout its lifetime. By providing an on-demand source of extra water, internal curing can improve the slump retention, workability and finishability of fresh concrete and reduce deformations and cracking due to plastic, autogenous and drying shrinkage [5]. J. Schlitter noted that, the compressive strength of internally cured mixtures with LWA 11% to 24% was reduced in the range of 2% to 8% as compared with plain mixtures without LWA. The split tensile capacity of internally cured mixtures using LWA was slightly less than the control mixture, but no general trend could be found. Internally cured mixtures with LWA were up to 13% softer than the plain mixture [6]. Dayalan J found that, the internally cured concrete resulted in an increment of compressive strength with 20% higher than plain concrete up to 20% replacement. The improved hydration also reduces micro cracking as a result of the lower shrinkage tendency of concrete with LWA (Expanded Shale) used for internal curing [7]. Magda I. Mousa showed that, 15% saturated leca represent the optimum doses as self-curing agents in concrete. This investigation stated that, the indirect tensile strength was in the range of 6.4% to 8.5% of the compressive strength. The test results of flexural strength represented 10–14.5% of the compressive strength [8].

3. Experimental program

3.1. Material properties

The used materials to conduct this work are:

A. Cement: Ordinary Portland cement CEM I 42.5 was used for all concrete mixes. The properties of the used cement agreed with ECP 203 [9] (Assiut cement) and is listed in Table (1).

B. Coarse Aggregate: Local gravel and crushed over burnt clay bricks (COBCB) were used as coarse aggregate. Fig. (1) shows COBCB aggregate samples. COBCB size was reduced by using Morse Jaw Crusher its photo shown in Fig. (2).

C. Fine aggregate: Local sand was used as fine aggregate. The used sand is a medium type.

The percentage passing of aggregates given in Table (2). The physical and chemical properties of aggregates are given in Tables (3 & 4) respectively.

D. Water: Potable water was used.

Table 1.
Physical properties of the used O.P.C.

Physical test		Average values	Specification limits
Water Required for Standard Consistency		0.27	Not exceeded than 0.5
Initial setting time (minutes)		165	Not less than 45 min.
Final setting time (minutes)		370	Not exceeded than 10 hours
Specific surface area (cm^2/gm)		3320	Not less than 2500
Compressive strength (kg/cm^2)	3-day	195	Not less than 183
	7-day	290	Not less than 275

Table 2.
% passing of used aggregates.

Sieve size (mm.)	40	20	10	5	2.5	1.25	0.63	0.31	0.16
(%) of Passing (sand)	100	100	100	100	92	76	50	17	0
(%) of Passing (Gravel)	100	75	25	5	--	--	--	--	--
(%) of Passing (COBCB)	100	94	38	2	--	--	--	--	--

Table 3.
Physical properties of aggregates.

Property		Sand	Gravel	COBCB
Specific gravity		2.5	2.5	1.35
Unite weight (t/m^3)	Loose	1.44	1.56	0.98
	Compact	1.6	1.67	1.03
Shape Factor		1.18	1.13	1.16
Maximum nominal size (mm)		---	40	40
Fineness modulus		2.45	7.11	7.7
Specific surface area (cm^2/gm)		56.24	2.06	2.03
% Water Absorption (By Weight)		1.2	0.64	13.25

Table 4.
Chemical properties of aggregate

Property	Sand	Gravel	COBCB
% of Chloride ions	0.04	0.008	0.018
% of Sulphates ions	0.129	0.012	0.04
Power of Hydrogen (PH)	8.5	8	10.5
% of Clay and Other Fine Materials Content	2.5	0.7	0.8

Fig. 1. The used COBCB aggregate samples.

Fig. 2. Morse Jaw Crusher.

3.2. Proposed mix design

The concrete mix was designed to produce normal strength concrete having 28-days cubic compressive strength of 250 kg/cm^2. The required free water to cement ratio is 0.48. COBCB is mixed in proportions of 20%, 50% and 100% by replacing the coarse aggregates (by volume). In case of neglecting the water absorption of COBCB, the slump was 2 cm. To keep the slump of the concrete mixtures between 7 to 8 cm, COBCB water absorption must be taken into consideration and added to water-cement ratio. The mix proportions are given in the Table (5). Deign Equations used as follows:

- Determination of combined specific surface area.

$$A_{CC} = \left[\frac{B}{B+G}\right] * A_B + \left[\frac{G}{B+G}\right] * A_G \quad (1)$$

Where:

- A_{CC} specific surface area of combined coarse aggregate.
- A_B specific surface area of COBCB. - A_G specific surface area of Gravel.
- Determination of combined specific weight.

$$\gamma_{CC} = \left[\frac{B}{B+G}\right] * \gamma_B + \left[\frac{G}{B+G}\right] * \gamma_G \quad (2)$$

Where:

- γ_{CC} specific weight of combined coarse aggregate.
- γ_B specific weight of COBCB. - γ_G specific weight of Gravel.
- Determination of water – cement ratio (W/C).

$$W/C = \frac{A * Fc\ cement}{Fc\ mean + 0.5 * A * Fc\ cement} \quad (3)$$

Where:

- $F_{C\ Cement}$ Compressive strength of cement. - $F_{C\ mean}$ The mean compressive strength.
- A Constant value.
- Determination of materials amount.
- Determination the amount of materials to cast 1 m³.

$$\frac{C}{\gamma c}+\frac{G}{\gamma g}+\frac{S}{\gamma s}+\frac{W}{\gamma w}=1\ m^3 \tag{4}$$

Table 5.
Amount of constitute materials for 1m^3 of the used concrete

Group No.	Mix component, Kg/m^3						
	Cement	Sand	Gravel	COBCB	Water	W/C	Slump (cm)
M0	350	822	1141	--	168	0.48	7.10
M20	350	713	792	198	168+26.24*	0.55	7.40
M50	350	650	445	445	168+58.96*	0.65	7.80
M100	350	505	--	700	168+92.75*	0.75	8.20

* Amount of water absorbed by COBCB.

3.3. Mixing preparation

The used LWA should be fully saturated; accordingly, it was submerged in water for 24 hours right before casting. A stationary mixer was used to blend the raw materials together. As the dry raw materials are mixed well, water was added to the mixer. The constituents were mixed homogeneously. The test specimens were cast in cast-iron molds. The inside of the molds were coated with oil to facilitate the removal of specimens.

3.4. Preparation after mixing

After the molds are filled with concrete, it is compacted and the surface is leveled. The specimens were kept in the laboratory conditions for 24 hours. Then, they were demolded and divided into three different cases of curing as follows:

i) Conventional curing (CC): specimens were submerged in water (as a reference).
ii) No curing (NC): air curing regime (in the laboratory environment with 25°C)
iii) Chemical curing (Ch.C): specimens were painted by keroseel.

3.5. Fresh concrete properties

Slump test was carried out according to Egyptian Standard Specification No. 1658/1988, Part 1, and the Egyptian Code of Practice (203).

3.6. Hardened concrete properties

3.6.1. Compressive strength test

This test is carried out on 15 x 15 x 15 cm size cubes. A 150 Ton capacity Compression Testing Machine (CTM) is used to conduct the test.

3.6.2. Indirect tensile strength test

The Splitting tensile strength of concrete cylinder was determined. The test was carried out on a cylinder of 15 cm diameter and a 30 cm height3.

3.6.3. Flexural strength test

The test is carried out on 10 x 10 x 50 cm size prisms.

The above tests were measured the average of three specimens at 3, 7, 28 and 56 days.

4. Results and discussions

4.1. Fresh concrete properties

4.1.1. Workability test

The workability of concrete was tested by slump cone test for all concrete mixes. The results are given in table (4).

Table 6.
Slump Cone Test Values

Mix design	M0	M20	M50	M100
Slump value (cm)	7.10	7.40	7.80	8.20

The above results are consistent with those noted by previous researchers. For instance**,** Dayalan J [7] reported that, the slump of mixtures is increased as the replacement ratio increased compared with conventional concrete without COBCB. This is due to the additional water in COBCB.

4.2.Hardened concrete properties

- **The effect of lightweight aggregate replacement ratio on the hardened concrete properties (0%COBCB as reference):**

A. Unit Weight: Fig. (3) shows the relationship between the replacement percentage and the unit weight of concrete. It is apparent that, increasing replacement proportions results in a reduction in the unit weight of the concrete. The results also show that, the specimens with 100% replacement ratio exhibit the highest percentage of reduction in the unit weight. For concrete without COBCB, the unit weight was 2.55 t/m^3 but when 100% (COBCB) replacement ratio the unit weight was 1.98 t/m^3 this means that the reduction in unit weight is 22.35% compared with concrete without COBCB. This result is almost certainly due to the higher amount of cement mortar attached to the 100% COBCB replacement concrete compared with other samples. Increment of air content can be attributed to the higher porosity of the lightweight aggregate. The net effect is that concretes mixed with lightweight aggregate have lower masses due to the higher air void content.

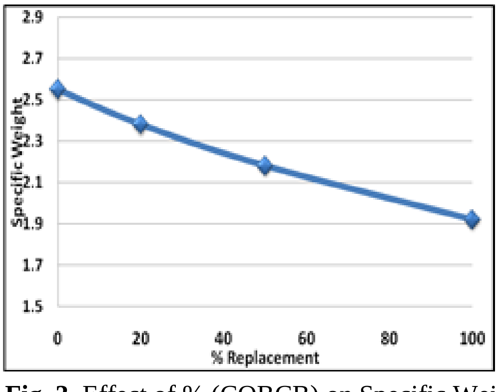
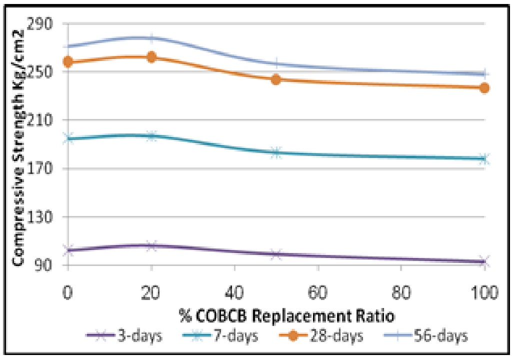
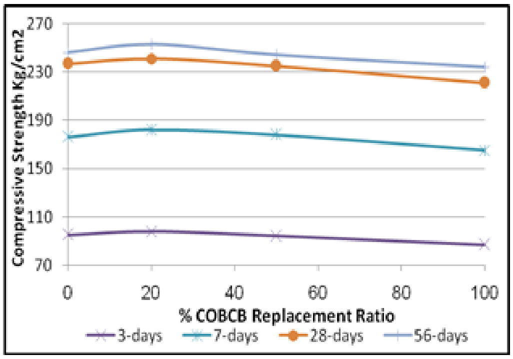


Fig. 3. Effect of % (COBCB) on Specific Weight

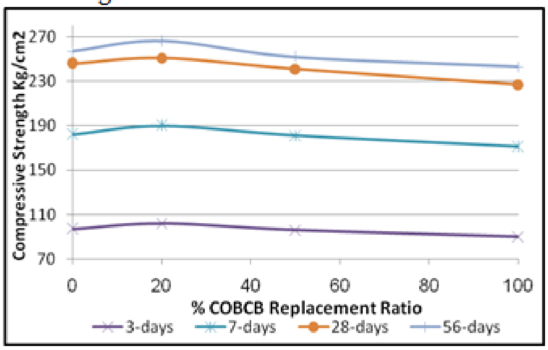
B. Compressive Strength: Fig. (4) shows the compressive strength of all studied concrete mixes either conventional curing, no-curing or chemical curing concretes, which increase gradually with time in different rates. At 28 days concrete with 20% COBCB gives higher compressive strength by about 1.7% for the conventional curing and no-curing concrete and by about 2% for the chemical curing concrete compared with the conventional concrete 0% COBCB. This increment may be attributed to the continuation of the hydration process as a result of providing the cement paste by store water in the saturated COBCB particles. This causes greater bond force between the cement paste and aggregate. After 20% COBCB replacement compressive strength begins to decrease tile the concretes containing 100% COBCB give lower compressive strength compared with conventional concrete for all types of curing. At 28 days concrete with 100% COBCB give lower compressive strength by about 8.1% for conventional curing concrete, by about 6.8% for no-curing concrete and by about 7.7% for chemical curing concrete compared with conventional concrete 0% COBCB.



Conventional Curing



No-Curing



Chemical Curing

Fig. 4. Effect of % (COBCB) on compressive strength**.**

C. Indirect Tensile Strength: Fig. (5) shows the indirect tensile strength of all the concretes studied either self-curing, chemical curing or conventional curing concretes. The indirect tensile strength of concretes with or without COBCB (reference concrete) is increased with time. at 28 days a 20% COBCB gave the highest increase in tensile strength by about 4.3% for conventional curing concrete, by about 2.1% for self-curing concrete and by about 3% for chemical curing concrete when compared with conventional concrete without COBCB.

D. Flexural strength: Fig. (6) shows that, the flexural strength for all the concrete mixes studied either self-curing, chemical curing or conventional concretes, which increase gradually with time in different rates. The concrete containing 20% (COBCB) gave a higher 28 days strength by about 5% for all cases of curing relative to conventional concrete (0.0% COBCB).

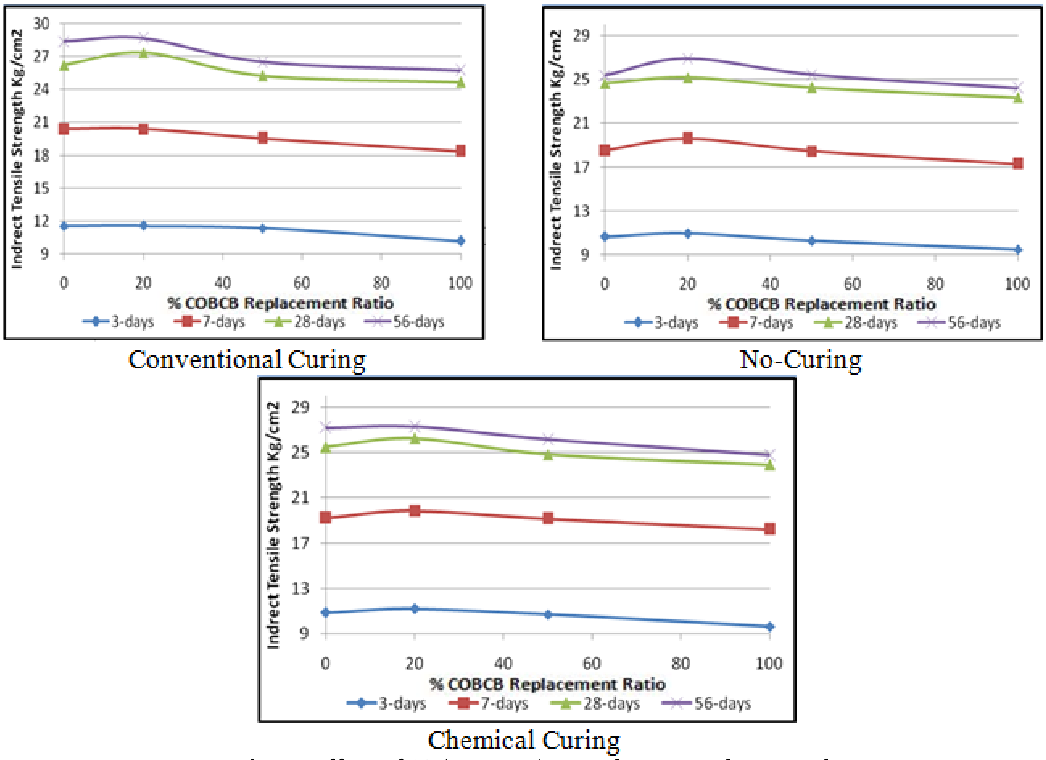


Fig. 5. Effect of % (COBCB) on indirect tensile strength.

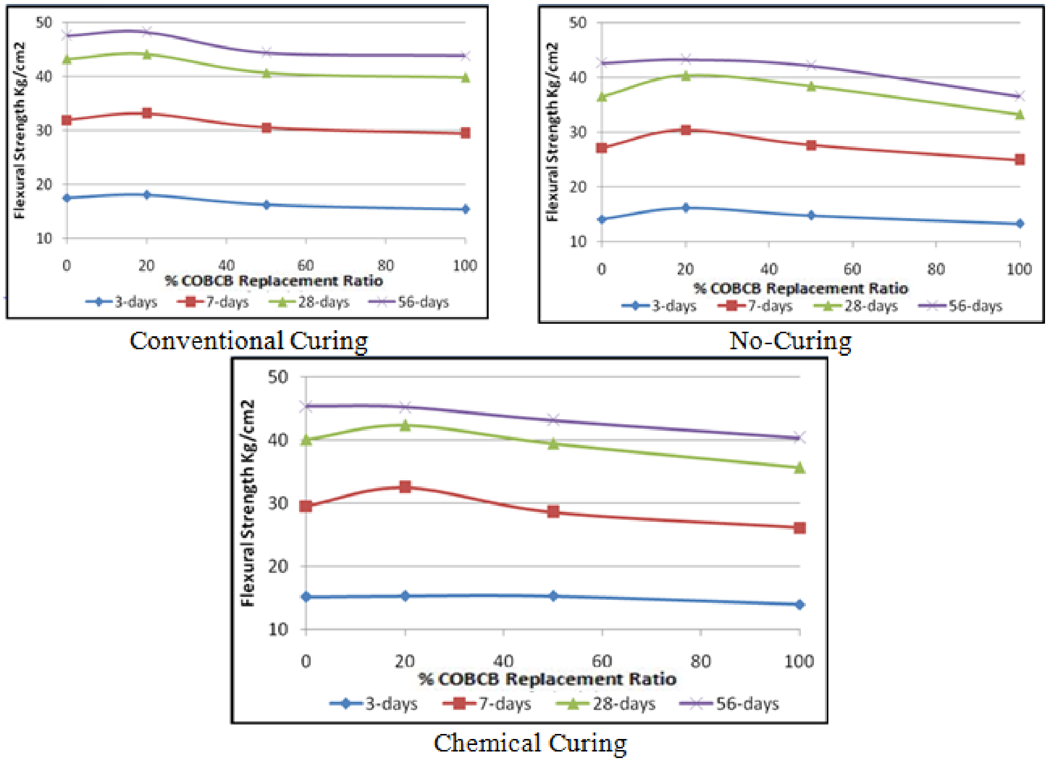
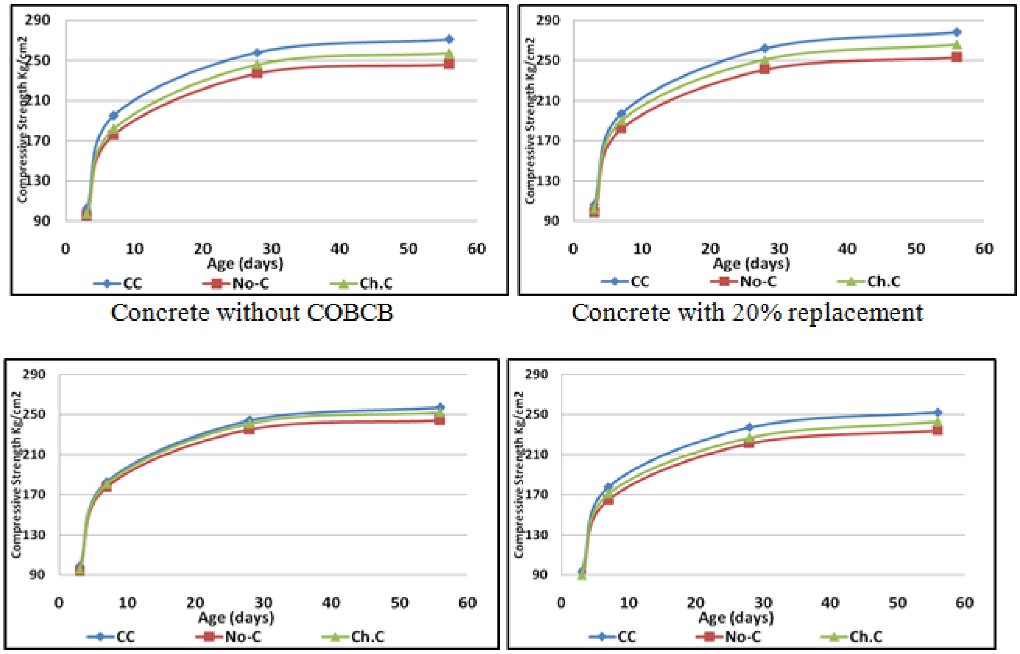


Fig. 6. Effect of % (COBCB) on flexural strength.

- **The effect of curing type on the hardened concrete properties (Conventional curing (CC) as a reference):**

A. **Compressive Strength:** Fig. (7) shows the compressive strength of all the concretes studied either without COBCB, 20%, 50% or 100% replacement ratio, which increase gradually with time in different rates. As usual conventional curing concrete gives higher compressive strength compared with the other curing. The compressive strength systematically decreased in case of no-curing larger than the chemical curing. At 28 days concrete without COBCB, the reduction in the compressive strength was 8.1% for no-curing concrete and by about 4.7% for chemical cuing concrete when compared with conventional curing concrete. This reduction in the compressive strength disappears up to the replacement ratio was 50% COBCB, there is no significant difference between the different type of curing which may be because of the large amount of store water in the saturated COBCB particles. After the replacement ratio exceeded than 50%, the reduction in the compressive strength appears again. At 28 days concrete with replacement ratio 100% COBCB, the reduction was 6.8% for self-curing concrete and by about 4.2% of chemical curing concrete when compared with conventional concrete.



Concrete without COBCB

Concrete with 20% replacement

Concrete with 50% COBCB

Concrete with 100% replacement

Fig. 7. Effect of curing type on compressive strength.

B. **Indirect Tensile Strength:** Fig. (8) shows the indirect tensile strength of all the concretes studied either without COBCB, 20%, 50% or 100% replacement ratio, which increase gradually with time in different rates. As usual conventional curing concrete gives higher indirect tensile strength compared with the other curing. The indirect tensile strength systematically decreased in case of no-curing larger than the chemical curing. At 28 days concrete without COBCB, the reduction in the indirect tensile strength was 6% for no-curing concrete and by about 2.8% of chemical cuing concrete when compared with conventional curing concrete. This reduction in the indirect tensile strength disappears up to the replacement ratio was 50% COBCB, there is no significant difference between the different type of curing which may be because of the large amount of store water in the saturated COBCB particles. After the replacement ratio exceeded than 50%, the reduction in the indirect tensile strength appears again. At 28 days concrete with replacement ratio 100% COBCB, the reduction was 6.2% for self-curing concrete and by about 2.9% of chemical curing concrete when compared with conventional concrete.

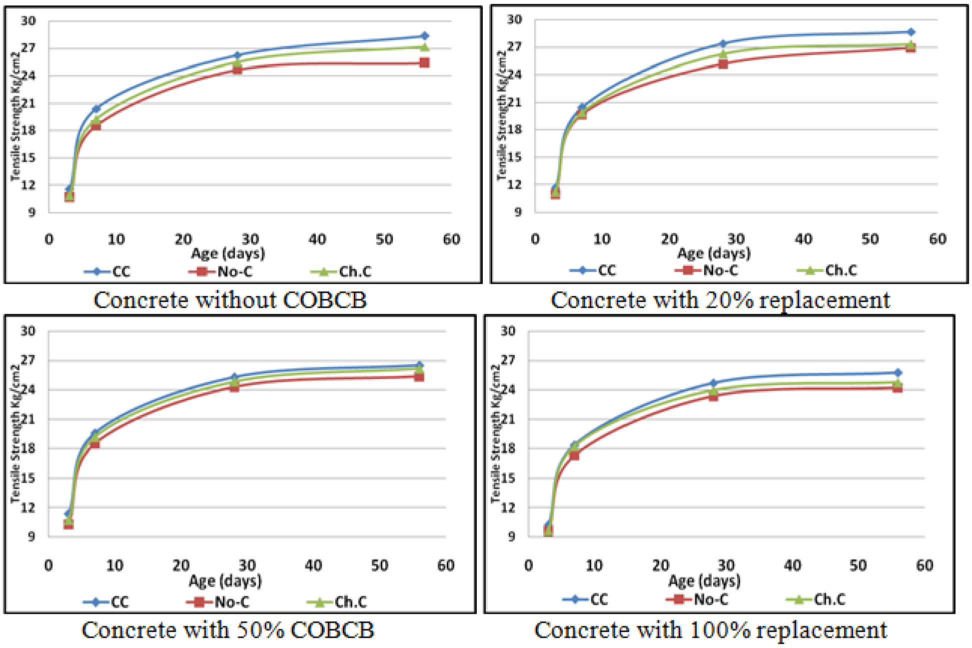


Fig. 8. Effect of curing type on indirect tensile strength.

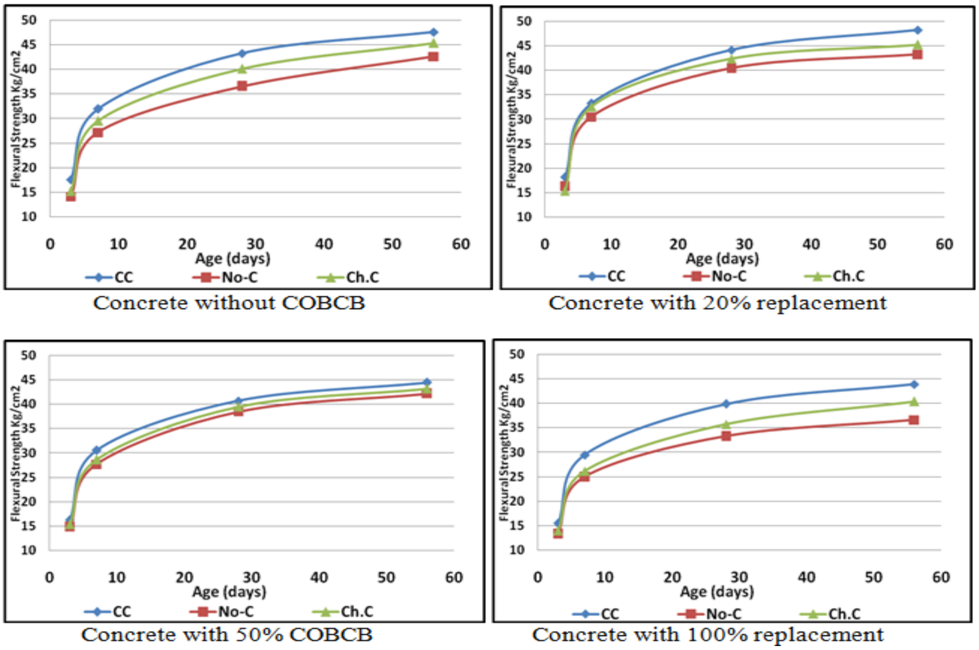


Fig. 9. Effect of curing type on flexural strength.

C. **Flexural Strength:** Fig. (9) shows the flexural strength of all the concretes studied either without COBCB, 20%, 50% or 100% replacement ratio, which increase gradually with time in different rates. As usual conventional curing concrete gives higher flexural strength when compared with the other curing. the flexural strength systematically decreased in case of no-curing larger than the chemical curing. At 28 days concrete without COBCB, the reduction in compressive strength was 15.5% for no-curing concrete and by about 9.1% of chemical cuing concrete when compared with conventional curing concrete. This reduction in the flexural strength disappears up to the replacement ratio was 50% COBCB, there is no significant difference between the different type of curing which may be because of the large amount of store water in the saturated COBCB particles. After the replacement ratio exceeded than 50%, the reduction in the flexural strength appears again. At 28 days concrete with replacement ratio 100% COBCB, the reduction was 16.6% for self-curing concrete and by about 10.5% of chemical curing concrete when compared with conventional concrete.

Conclusion

Based on the results it has been concluded that,

- The unit weight of lightweight concrete produced with crushed COBCB decreased gradually with the increasing of % replacement ratio. When the % replacement ratio is 100%, the reduction of unit weight is 23% when compared with the control one. By using lightweight structural concrete with COBCB, the dead load and as a result the weight of the building will be considerably decreased. So it is possible to reduce the dimensions of the supporting structure, minimize the earthquake force on the building and economize the project.
- In contrast to this decrease in unit weight, there is a decrease in the compressive strength of COBCB concrete of 8%.
- The use of self-curing agents COBCB in concrete mixes enhances the mechanical properties. The value of 20% saturated COBCB represent the optimum doses as self-curing agents in concrete for all of curing type.
- The increasing of compressive strength of internally cured mixtures with 20% COBCB replacement ratio is 1.7% for conventional curing and no-curing and 2% for chemical curing when compared with control mixtures without COBCB.
- The increasing of indirect tensile strength of internally cured mixtures with 20% COBCB replacement ratio is 4.3% for conventional curing concrete, 2.1% for self-curing concrete and 3% for chemical curing concrete when compared with control mixtures without COBCB.
- The increasing of flexural strength of internally cured mixtures with 20% COBCB replacement ratio is 5% for all cases of curing when compared with control mixtures without COBCB.
- It is clear that, when the replacement ratio is 50% COBCB, there is no significant difference between the different type of curing which may be because of the large amount of store water in the saturated COBCB particles.

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تحسين خواص الخرسانة خفيفة الوزن والمعالجة ذاتيا

الملخص العربى:

تستهلك الطرق التقليدية لعلاج الخرسانة سواء بالرش او الغمر لكميات كبيرة من المياه مما يتسب فى فقد جزء كبير من هذه المياه فى التبخر والجريان السطحى. لذا فإن هذه الدراسة تعتبر محاولة لمعالجة الخرسانة ذاتيا عن طريق إستخدام ركام خفيف الوزن يحتفظ داخله بالمياه المطلوبة للتفاعلات الكيميائية واللازمة لإتمام عملية إماهة الاسمنت والتى بدورها تحقق الخواص الميكانيكية المنشودة من الخرسانة. ويتم هذا عن طريق استبدال نسبة من الركام الكبير بركام خفيف الوزن. يعتبر كسر الطوب الطينى المحروق احد انواع الركام خفيف الوزن وهو المستخدم فى هذه الدراسة. عند استخدام هذا الركام فانه يحيفظ بالمياه داخل مسامه التى تكون اكبر من تلك الموجودة فى المونة الاسمنتية. ونتيجة لذلك فإن المياه تتحرك من الركام الخفيف الى المونة الاسمنتية المحيطة وهذا يؤدى إلى تشبعها بالمياه الى ان يحدث الاتزان بينهم. فى حالة حدوث الاتزان يقل الانكماش الجاف للاسمنت وهذا يجعل الاسمنت اكثر كفاءة خلال عملية الاماهة. وعلاوة على ذلك فإن المعالجة الداخلية تحسن من قابلية الخرسانة للتشغيل وتقلل من حدوث الشروخ والناتجة من الانكماش اللدن والجاف. ونتيجة لكل ما سبق فهذا يزيد من قوة التماسك بين الركام الخفيف والمونة الاسمنتية الذى يؤدى الى تقليل نفاذية الخرسانة.

الخرسانة خفيفة الوزن والمحتوية على ركام خفيف الوزن مثل كسر الطوب أصبحت أكثر انتشاراً على مستوى العالم نظرا للسلوك الجيد لها . ومن ضمن الأسباب أيضاً لاستخدام تلك المواد أنها غير مُكلفة و أقل ضرراً للبيئة مقارنة بالمواد الاخرى.

تشير النتائج الى ان الجرعة المثلى لنسبة استبدال الركام الكبير بالركام الخفيف هى 20% بعد هذه النسبة يبدأ الانخفاض فى مقاومة الضغط للعينات لتصل إلى 92% من المقاومة الاصلية عند نسبة استبدال 100%. فى حالة الخرسانة المعالجة بالطرق التقليدية. ووصلت الى نسبة 93% من المقاومة الاصلية عند نسبة استبدال 100%. فى حالة الخرسانة الغير معالجة. ووصلت الى نسبة 92% من المقاومة الاصلية عند نسبة استبدال 100%. فى حالة الخرسانة المعالجة بالمادة الكيميائية.