

THE EFFECT OF CURING CONDITION ON COMPRESSIVE STRENGTH IN HIGH STRENGTH CONCRETE

Ali H. Hameed

Civil Department ,College Engineering , Diyala University
(Received:25/10/2008 ; Accepted:16/2/2009)

ABSTRACT - The paper shows the effect of curing condition on compressive strength in high strength concrete in three cases (Group A(moist curing in water for 7 days followed by air curing) ,Group B(curing until the age test in water) and Group C(curing at high temperature $60^{\circ}\text{C}\pm 2^{\circ}\text{C}$ for six days) and two types of specimen of cubes (150 x150 and 100 x 100) used in the test age (7,28and 90 day) respectively in four mix proportion (Mix No.1(40 Mpa ,Mix No. 2(fcu 60 Mpa) ,Mix No. 3 (fcu 70 Mpa) and Mix No. 4 (fcu 80 Mpa)). Results demonstrate that, in general, concrete specimens moist cured until testing ages (Group B) give compressive strength greater than specimens moist cured for 7 days in water then followed by air – drying (Group A). The percentage of increase in strength is (5 and12%) for mix No.3 and 6% for mix No.4, as compared with 3% for mix No.1 and (2 and4%) for mix No.2. When the curing temperature (group C) increases, the compressive strength increases at different ratios ,the percentage of increase in compressive strength at 7,28 and 90 days for mix No.1 , mixes No.2 and 3 are (20,15 and 14%), (7,11 and 5%) and (13,12 and 5%) respectively, while mix No4. shows an increase of 4 and 10% in compressive strength at 7 and 28 days where there is a reduction in the strength at 90 days by about 2%. Generally, as the size of specimen decreases, the effect of temperature curing (group C)on the compressive strength increases.

Keywords: curing ,compressive strength, concrete ,high strength.

1. INTRODUCTION

Curing is the name given to procedures used for promoting the cement hydration, and

consists of temperature control and moisture movement from and into the concrete. The effect of curing condition on strength, In order to obtain good concrete, the place of an appropriate mix must be followed by curing in a suitable environment during the early stages of hardening. Klieger (cited by ref. 1) reported that for low water – cement ratio concrete, it is more advantageous to supply additional water during curing than in the case with higher water- cement ratio concrete ⁽¹⁾.

Carrasquillo, Nilson, and Slate ⁽²⁾ studied in their work the effect of two different drying conditions on concrete compressive strength: moist curing for 7 days followed by drying at 50 percent relative humidity until testing at 28 days, and moist curing for 28 days followed by drying at 50 percent relative humidity until testing at 95 days. These specimens were tested compared with the control condition of continuous moist curing until testing. They found that high strength concrete shows a larger reduction in compressive strength than normal strength concrete when allowed drying before completion of curing. HSC showed an average reduction of 10 percent relative to continuous moist curing when moist cured at 7 days and then allowed drying until testing at 28 days, while under similar conditions, normal strength concrete showed 4 percent strength reduction. If moist curing for 28 days is followed by drying at 50 percent relative humidity until testing at 95 days, HSC showed a 4 percent loss in strength, while no appreciable reduction occurs on the normal strength concrete.

While other investigators ⁽³⁾ compared the strengths obtained from concrete specimens subjected to different curing conditions. They concluded that 7 days of moist curing period (including the first 24-h in molds) is sufficient to make the high strength concrete impervious. Further moist curing beyond this period is not needed to substantially enhance the compressive strength and elastic modulus of concrete. They found that the difference in compressive strength between the specimens subjected to 7 days moist curing followed by 21 days air curing and those subjected to 28 days moist curing followed by 28 days air curing is only 6%, which is not significant.

Neville ⁽⁴⁾ reported that moist curing for 28 days thereafter in air is highly beneficial in securing HSC at 90 days.

Aitcin and Riad ⁽⁵⁾ observed that the 28 days compressive strength of specimens cured under standard conditions gives a fair representation of the actual strength when the water / cementitious ratio is below 0.3.

Klieger ⁽⁶⁾ concluded that temperature increases strength during the first few days after casting, but after one to four weeks, the strength reduces.

Eliverly and Evans ⁽⁷⁾ confirmed that specimens mixed in normal temperature (17°C) and cured under high temperature (40°C) have a higher crushing strength than those mixed and cured under normal temperature by about 19% and 16% at 7 and 49 days, respectively.

Hester ⁽⁸⁾ reported that sealed specimens tested at 43°C have measure strength up to 10% lower than 21°C specimens, and specimens at 71°C have lower strength up to 20%.

Cebeci ⁽⁹⁾ concluded that concrete cured in water within (37°C), has higher compressive strength up to age of 90 days and lower ultimate compressive strength (360 days) compared with concrete cured within (17°C).

Selman ⁽¹⁰⁾ found, that the compressive strength of concrete mixed and cast at temperature not exceeding (29°C) and moist cured under hot weather for 7 days, increases as the curing temperature is increased (up to 90 days). The increase ranges between (4-22%) with respect to mixes cured at normal weather conditions.

Konstantin, and Isaak ⁽¹¹⁾ concluded that the compressive strength at 30 C⁰ increases with time much faster (compared to 20 C⁰ curing) developing mostly during the first week of curing .

2. MATERIALS AND EXPERIMENTAL WORK

2.1. Material

The materials used in this study are locally available and widely distributed over large areas in Iraq .These materials include crushed gravel and natural silica sand, in addition to the drinking water and Lebanon cement .

2.1.1. Aggregate

Aggregate were used in this study include fine aggregate. The grading and particle shapes of fine aggregate are significant factors in the production of HSC. Fine aggregate with rounded particle shape and smooth textures requires less mixing water in concrete and for this reason is preferable in HSC ^(1,4). Sand with fineness modulus of about 3.0 or more is preferable to obtain a workable concrete mix with limited amount of water, and for enough fine material (cement) in the mix to obtain the required consistency

Natural Sand from Al-sadoor region with fineness modulus, specific gravity and absorption 3.18, 2.7% and 1.5% respectively is used in this work. In Table (1) shows its grading and the limits of BS882-92.

Al-hassani ⁽¹²⁾ have shown that the smaller size aggregate produces higher strength values. Therefore, the maximum coarse aggregate size is chosen to be 14mm.

Crushed gravel from Al-sadoor region with specific gravity and absorption 2.64 and 0.57%, respectively is used. In Table (2) shows the grading of this aggregate .This table also gives the limits specified by BS 882-92.

2.1.2. Admixtures

For HSC production, the water content of the mix is needed to be reduced, which can be achieved by using superplasticizers and to compensate for the associated reduction in water content and workability of the concrete mix. A superplasticizer (SP) of melamine formaldehyde condensate, known as (Melment L-10) is used in this work, its properties are listed in In Table (3). According to ASTM-C 494, this superplasticizer is classified as type (F), because it has the capability of more than 12% water reduction for a given consistency. The optimum dosage is found to be 4 % by weight of cement and the reduction in water for this dosage is about 25%, Superplasticizer is used as a white powder by dissolving 1 part solid (SP) in 4 parts of water, a liquid of 20 % concentration (SP) is prepared, five minutes well-stirred in water by small glass rod and left in laboratory for at least (2 hours) before added to the wet concrete mixes⁽¹³⁾.

Table (1): Grading of Fine aggregate.

Sieve size (mm)	% passing by weight	BS 882-92 limits
10.0	100	100
5.00	92.0	89 – 100
2.36	79.5	65 – 100
1.180	62.8	45 – 100
0.600	41.4	25 – 80
0.300	6.2	5 – 48
0.15	0.1	0 -15

Table (2): Grading of Coarse Aggregate.

Sieve size (mm)	% passing by weight	BS 882-92 limits
20	100	100
14	100	90 -100
10	70	50 – 85
5.00	6	0 – 10
2.36	0	-----

Table (3): Properties of Super plasticizer #

Main action	Concrete superplasticizer
Subsidiary effect	Hardening accelerator
Appearance	Clear to slightly milky
Solid in aqueous solution	Approx. 20%
Density	1.1 g/cm ³
pH value	7-9
Chloride content	less than 0.005 %
Storage life	At least two years
sugar content	none

(#) Properties obtained from product catalogue

2.2. Concrete Mixes

Four concrete strength levels are investigated in this work, namely 40, 60, 70 and, 80 MPa which are expressed as Mix No.1, 2,3 and 4, respectively. British Standard BS 5328: part 2:1991 mix design method is used because it yields mixes with strength range higher than the compressive strength ACI 211 method. The details of four groups mix proportions are shown in Table (4).

Table (4): Mix Proportions of Concrete

Mix No.	W/c ratio	Water kg/m ³	Cement kg/m ³	Sand kg/m ³	Gravel kg/m ³	SP %	fcu (MPa)
1	0.50	200	400	728	1092	-----	40
2	0.38	160	446	762	1050	4%	60
3	0.30	160	540	687	1030	4%	70
4	0.27	160	600	664	996	4%	80

2.3. Testing Hardened Concret

2.3.1. Compressive Strength Measurement

Compressive strength is carried out by 2000 KN capacity compression machine. Each result of compressive strength obtained is the average of three specimens -

2.3.2. Two types of moulds are used

1-150mm cubes which are prepared according to BS 1881:Part 108:1983 and tested according to BS 1881:Part 116:1983.

2-100mm cubes which are prepared and tested according to the same specifications.

2.3.3. Curing and Testing Age

Water curing of high- strength concrete is very essential due to the low water- cement ratios employed.

Three types of curing are simulated: -

Group A-Moist curing in water for 7 days followed by air curing inside the laboratory at (26-30°C) until testing age.

Group B-Moist curing in water until testing age.

Group C-High temperature curing: by placing the specimens in a water-curing tank placed in a controlled- temperature room. The curing temperature is $60^{\circ}\text{C}\pm 2^{\circ}\text{C}$ for six days then these specimens are air cured in the laboratory at temperature range between (26-30°C) until testing age. The test ages are 7,28 and 90 days.

3. THE RESULTS AND DISSCUSION

4.1. Effect of Curing Condition on Strengths

The results of compressive strength for the concrete mixes are shown in Table (°) for the different ages, various specimen sizes and various curing conditions. The mentioned results are plotted against age in the Figs. (¹) to (°). Results demonstrate that, in general, concrete specimens moist cured until testing ages (Group B) give compressive strength greater than specimens moist cured for 7 days in water then followed by air – drying (Group A).

It can be seen from the same table and its accompanying figures that the rate of increase in 28 and 90 days compressive strength for HSC is greater than those of NSC. The rate of increase in strength is (5 and12%) for mix No.3 and 6% for mix No.4, as compared with 3% for mix No.1 and (2 and4%) for mix No.2. That means HSC concrete shows a higher reduction in compressive strength than normal strength concrete. This behavior is in agreement with Carrasquillo et al (¹). These Figures also show that the small specimens are more affected by drying than large ones. Since the difference in the compressive strength

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between the two groups of concrete is slight, so a 7-day initial moist curing period is sufficient for the development of potential strength. This result is in agreement with Aitcin et al⁽⁵⁾.

The relations between compressive strength of 150X150mm cube versus the compressive strength of 100X100mm cube (four Mix. No. 1,2,3,and 4 respectively)are shown in Figs. (1) to (4). The mathematical expression may be expressed⁽¹³⁾, as follows:

- for mix No.1

$$f_{cu150} = 0.92 f_{cu100} \quad \text{-----(1)} \quad (r=0.983)$$

- for mix No. 2

$$f_{cu150} = 0.880 f_{cu100} \quad \text{-----(2)} \quad (r=0.967)$$

- for mix No. 3

$$f_{cu150} = 0.910 f_{cu100} \quad \text{-----(3)} \quad (r=0.944)$$

- for mix No. 4

$$f_{cu150} = 0.927 f_{cu100} \quad \text{-----(4)} \quad (r=0.976)$$

This result agrees with the general tendency pointed by other researchers ⁽²⁾ who obtained values ranging from 0.95-0.87 percent for 10-131MPa concrete strength, Table (5). For cubes, the average ratio of compressive strength of 150mm to 100mm cubes for the same mixes is:

$$f_{cu150} = 0.92 f_{cu100} \quad \text{-----(5)} \quad (r=0.989)$$

regardless of strength and test age, Fig. (5).

Where : r is the correlation factor

Table (5): The result of Compressive Strength with Different Specimens, Curing Types and Mix No.

Age day	Curing type	Mix No. 1		Mix No. 2		Mix No. 3		Mix No. 4	
		f _{cu150} (MPa)	f _{cu100} (Mpa)	f _{cu150} (Mpa)	f _{cu100} (Mpa)	f _{cu150} (Mpa)	f _{cu100} (Mpa)	f _{cu150} (Mpa)	f _{cu100} (Mpa)
7	A	35.60	37.00	44.2	53.3	50.44	61.00	66.00	70.4
	B	35.60	37.00	44.5	53.5	50.45	61.00	66.00	70.4
	C	39.30	44.40	43.15	57.4	62.0	68.9	70.00	73.2
28	A	49.73	51.80	63.3	71.25	67.77	73.87	78.00	85.2
	B	52.54	56.50	64.4	78.57	68.2	77.77	82.00	88.00
	C	56.53	59.50	71.00	79.00	75.56	82.7	85.00	93.65
90	A	54.80	59.60	77.3	85.8	73.00	78.00	82.2	88.00
	B	57.70	64.83	78.6	85.57	84.4	85.00	84.3	92.2
	C	59.00	64.70	80.5	86.6	74.3	81.35	71.6	80.42

- A= 7day moist cured specimens
- B= moist cured continuously specimens
- C= hot weather cured specimens

4.2. Effect of Curing Temperature on Strengths

Figures (1) to (5) show the relationships between compressive strength and age of concrete specimens cured at 60 °C (group C) and those cured at 25 °C (group A). It is clear from these figures that as the curing temperature increases, the compressive strength increases at different ratios.

These results show that there is a significant increase in compressive strength for concrete specimens cured at 60 °C with respect to those cured at 25 °C, for mixes No.1 and No.2. The rates of increase in compressive strength of ages 7,28, and 90 days are 12,26, and 14% for mix No.1 and 18, 19, and 8% for mix No.2 respectively.

Similar observations were reported by Cebeci ⁽⁹⁾ who stated that concrete cured in water within (37 °C) has higher compressive strength than that cured in water with (17 °C). Selman ⁽¹⁰⁾ also showed that the specimens cured at temperature of (60 °C) have an increase in their 7,28, and 90 days compressive strength of about 22,18 and 9% respectively in comparison with those cured at normal temperature (25 °C).

Mixes No.3 and No. 4 show slighter increase in compressive strength than mixes No.1 and No. 2. The rates of increase in their 7 and 28 days compressive strength are 10 and 8 % for mix No.3, and 6 and 11% for mix No. 4 respectively, but at 90 days they give 0 and 9% reduction in their strength.

The rise in curing temperature speeds up the chemical reaction of hydration and, thus, affects the early strength of concrete. The rapid initial rate of hydration at higher temperature retards the subsequent hydration and produces a non- uniform distribution of the products of hydration within the paste. This is due to the fact that at the high initial rate of hydration, there is insufficient time available for the products of hydration away from the cement particle and for a uniform precipitation of the products of hydration space. As a result, a high concentration of the products of hydration is built in the vicinity of the hydration particles, and this retards the subsequent hydration and adversely affects long- term strength⁽¹³⁾.

This behavior is in agreement with the result of Al- Kafaji⁽¹⁴⁾ who reported that the percentage of increases in compressive strength slightly decreases at the age of 56 days. The strength ratio increases about (2-5)% when the compressive strength is in the range of (45-65) Mpa, but there are considerable reductions ranging between (7-13)% for 75 Mpa concrete

compressive strength.

This behavior is for large specimens since small specimens show a higher increase in their compressive strength, as compared with large specimens. The rates of increase in compressive strength for mix No.1 at 7,28 and 90 days are 20,15 and 14%, for mixes No.2 and 3 and the rates of increase are 7,11 and 5% and 13,12 and 5% respectively, while mix No.4. shows an increase of 4 and 10% in compressive strength at 7 and 28 days where there is a reduction in the strength at 90 days by about 2%.

Generally, as the volume of specimen decreases, the effect of hot weather on compressive strength increases, and the rate of increase in compressive strength increases.

It seems from the results, that mixing and casting of concrete at temperature ranging between (25-29) °C, and moist curing for 7 days, play a significant role in the reduction of the harmful effect of hot weather on compressive strength especially for high strength concrete.

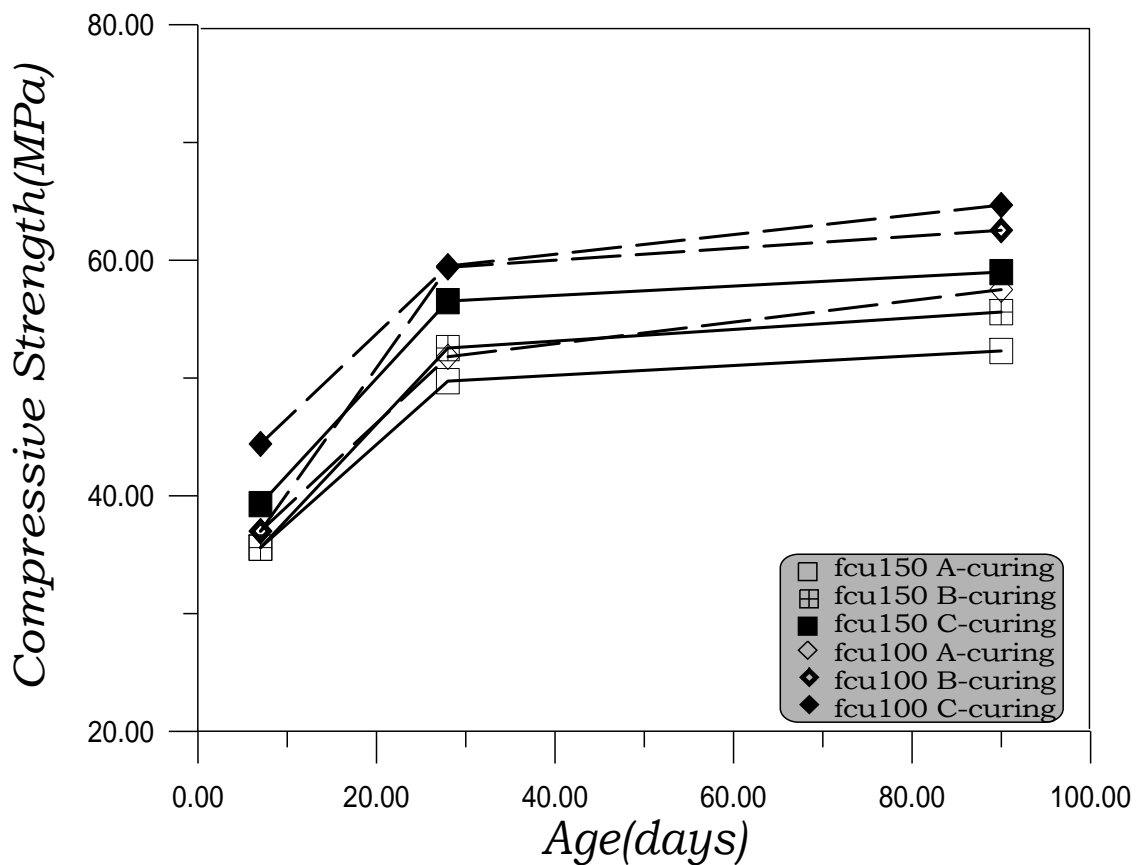


Fig. (1): Compressive Strength Development of 150mm and 100mm Cube with Age for Mixes Cured at Varying Conditions, mix No.1

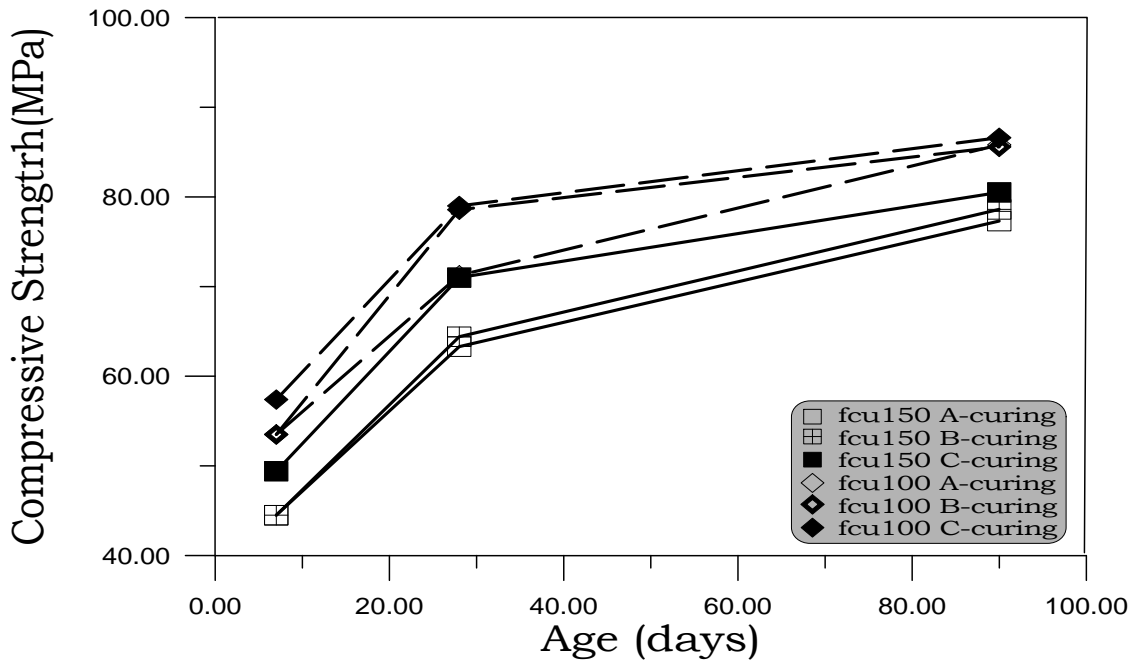


Fig. (2): Compressive Strength Development of 150mm and 100mm Cubes with Age for Mixes Cured at Varying Conditions, Mix No.2

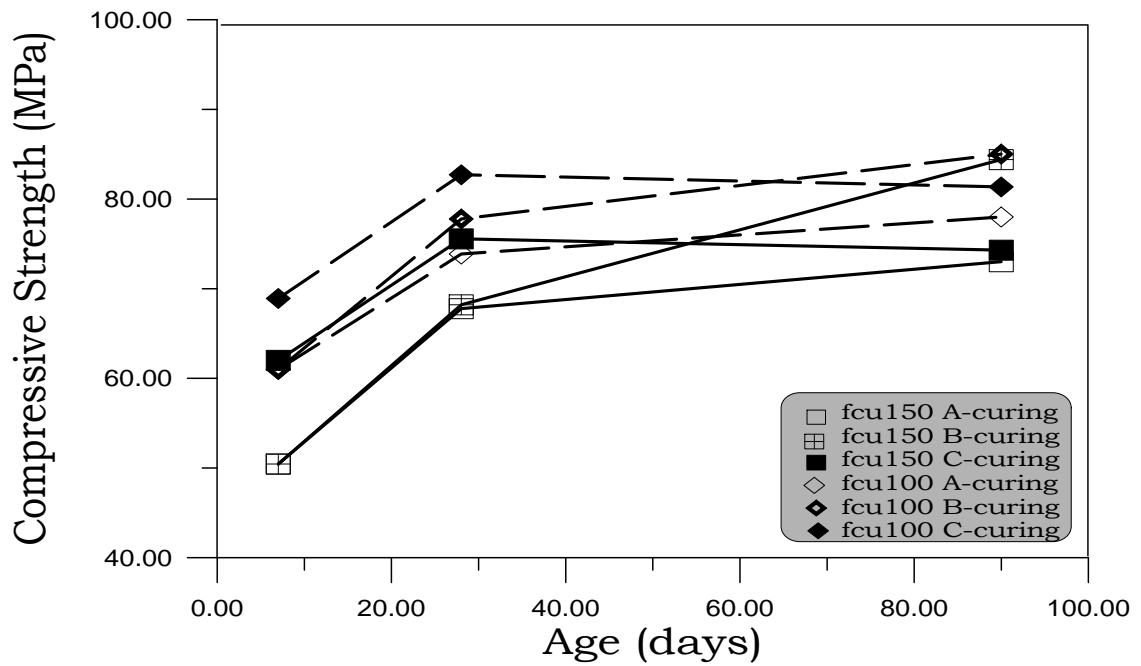


Fig. (3): Compressive Strength Development of 150mm and 100mm Cubes with Age for Mixes Cured at Varying Conditions, Mix No.3

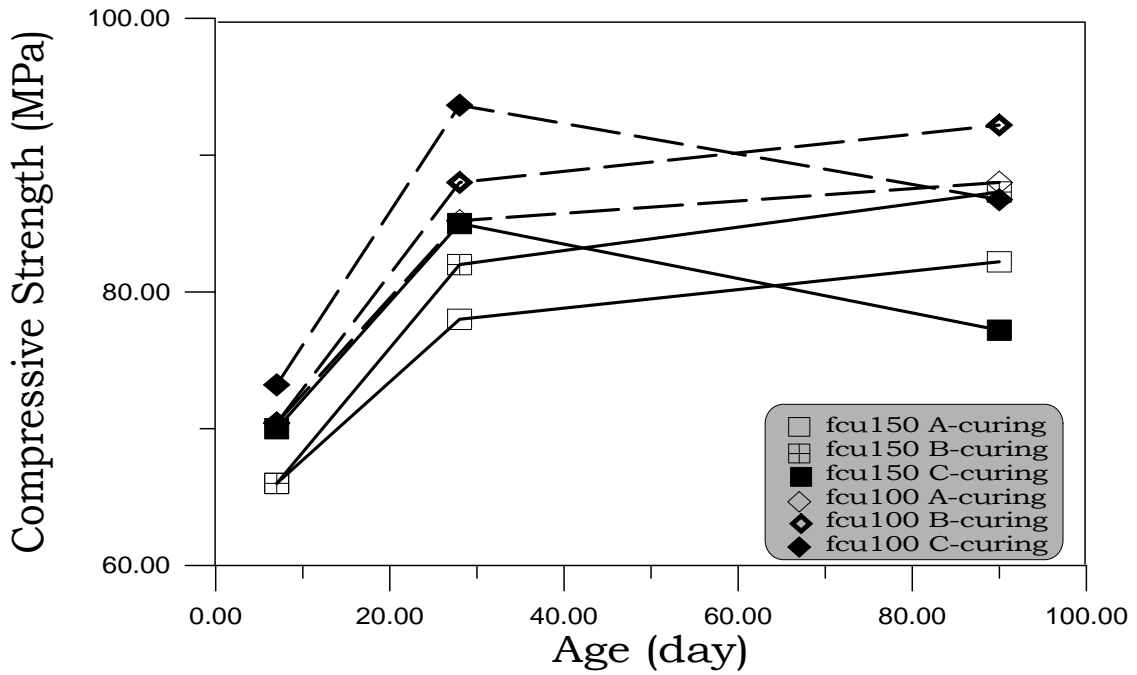


Fig. (4): Compressive Strength Development for 150mm and 100mm Cubes with Age for Mixes Cured at Varying Conditions, Mix No.4

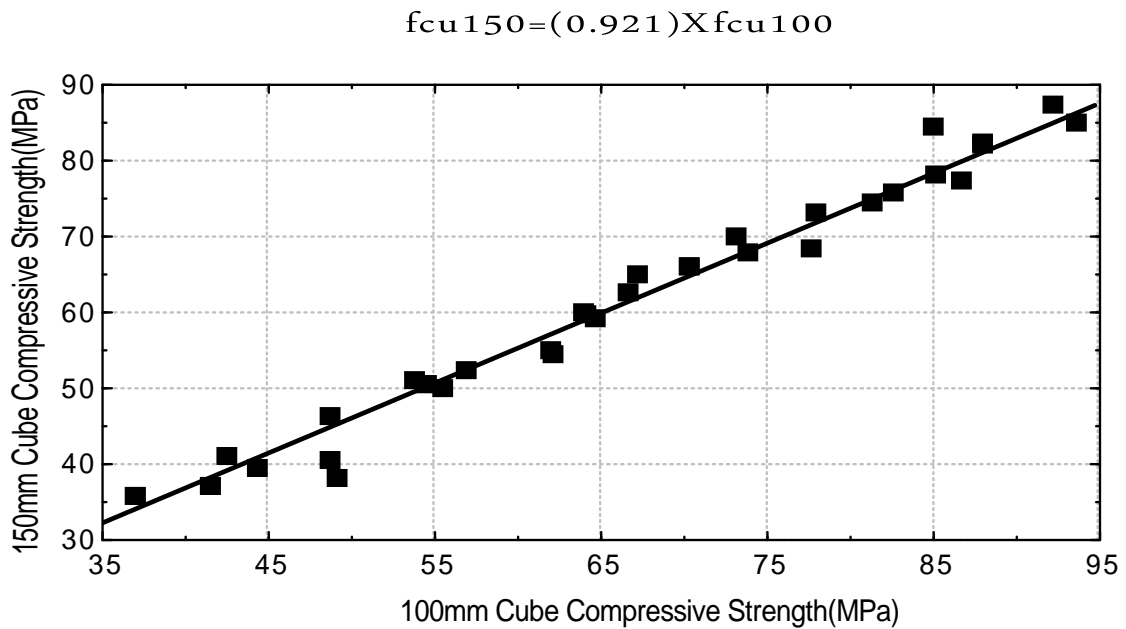


Fig.(5): Compressive Strength of 150mm Cubes versus 100mm Cubes, for All Strength Levels

5. CONCLUSION

Based on the results of the experimental work carried out in this study to the verify of types of curing and mix proportion, the following conclusions are deduced:

1. Water curing of high –strength concrete is highly recommended , because of filled to the desired extent by the products of cement hydration and get the object compressive strength .
2. Group B give compressive strength greater than specimens moist cured for 7 days in water then followed by air – drying (Group A).
3. The rate of increase in strength is (5 and12%) for mix No.3 and 6% for mix No.4, as compared with 3% for mix No.1 and (2 and4%) for mix No.2
4. The rates of increase in compressive strength for mix No.1 at 7,28 and 90 days are 20,15 and 14%, for mixes No.2 and 3 and the rates of increase are 7,11 and 5% and 13,12 and 5% respectively, while mix No4. shows an increase of 4 and 10% in compressive strength at 7 and 28 days where there is a reduction in the strength at 90 days by about 2%.
5. The volume of specimen decreases, the effect of temperature curing on compressive strength increases, and the rate of increase in compressive strength increases.
6. The curing temperature increases, the compressive strength increases at different ratios(0.5,0.38,0.3 and 0.27).

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تأثير طريقة الإنضاج على مقاومة الانضغاط في الخرسانة عالية المقاومة

علي حسين حميد

مدرس مساعد

كلية الهندسة - جامعة ديالى

الخلاصة

أن البحث المقدم يبين تأثير ثلاثة طرق للإنضاج (مجموعة A، مجموعة B، مجموعة C) على مقاومة الانضغاط في خرسانة ذات مقاومة عالية باستخدام نوعين من نماذج الفحوصات للمكعب (150 * 150 ملم و 100 * 100 ملم) فحصت بأعمار (7، 28، و 90 يوم) بالتتابع لأربع خلطات (خلطة رقم 1، خلطة رقم 2، خلطة رقم 3 و خلطة رقم 4). النتائج المقدمة بشكل عام لنماذج (المجموعة B) المرطبة لغاية الفحص أعطت أعلى مقاومة مقارنة (بالمجموعة A) المرطبة لعمر 7 أيام وإتمام الإنضاج بالهواء. معدل الزيادة (5-12%) للخلطة رقم 3 و 6% للخلطة رقم 4 مقارنة مع 3% للخلطة رقم 1 و (2-4%) للخلطة رقم 2. بزيادة الإنضاج الحراري (المجموعة C) مقاومة الانضغاط تزداد لمختلف النسب ومعدل الزيادات في مقاومة الانضغاط للأعمار (7، 28، و 90 يوم) للخلطة رقم 1 والخلطة رقم 2 والخلطة رقم 3 هي (20، 15، و 14%) (7، 11، و 5%) (13، 12، و 5%) بالتتابع. بينما معدل الزيادة في مقاومة الانضغاط للخلطة رقم 4 (4 و 10%) لعمر 7 و 28 يوم وأعطت نقصان في المقاومة بعمر 90 يوم مقداره 2%. بشكل عام عندما يقل حجم النموذج تأثير الإنضاج بزيادة درجات الحرارة (المجموعة C) يزيد مقاومة الانضغاط.