



The Effect Of Curing Types On Compressive Strength Of High Performance Concrete

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Abstract

The present investigation considers the effect of curing temperatures (30, 40, and 50°C) and curing compound method on compressive strength development of high performance concrete, and compares the results with concrete cured at standard conditions and curing temperature (21°C). The experimental results showed that at early ages, the rate of strength development at high curing temperature is greater than at lower curing temperature, the maximum increasing percentage in compressive strength is 10.83% at 50°C compared with 21°C in 7 days curing age. However, at later ages, the strength achieved at higher curing temperature has been less, and the maximum percentage of reduction has been 5.70% at curing temperature 50°C compared with 21°C curing temperature in 91 days curing age. Also, the results showed that the specimens which are cured under field condition (using curing compound) have a various strength development rate, and the results indicate 92.11% as minimum field-standard curing strength ratio.

Key Words: High Performance Concrete, Compressive Strength, Standard Curing, Curing Temperature, Curing Compound, Field Conditions.

تأثير طرق الانضاج على مقاومة الانضغاط للخرسانة العالية الاداء

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الخلاصة

هذا البحث اخذ بنظر الاعتبار تأثير درجات حرارة الانضاج (30، 40، 50 م°) وكذلك طريقة الانضاج الذاتي باستخدام المركبات الكيميائية على تطور مقاومة الانضغاط للخرسانة العالية الاداء، ومقارنة النتائج مع خرسانة منضجة تحت ظروف ودرجة حرارة قياسية (21 م°). النتائج المختبرية اظهرت، في الاعمار المبكرة، بان معدل تطور مقاومة الانضغاط في درجات حرارة الانضاج العالية اعلى من درجات الانضاج الواطئة، حيث يصل نسبة الزيادة في مقاومة الانضغاط الى 10,83% عند درجة حرارة انضاج 50 م° مقارنة بالدرجة القياسية (21 م°) بعمر 7 ايام. اما في الاعمار المتأخرة، فان مقاومة الانضغاط في درجات الحرارة العالية تكون اقل، حيث تصل نسبة النقصان الى 5,70% عند درجة حرارة 50 م° مقارنة بالدرجة القياسية (21 م°) بعمر 91 يوم. وكذلك النتائج اظهرت، بان النماذج المنضجة تحت الظروف الحقلية باستخدام المركبات الكيميائية، تمتلك معدلات متغيرة في تطور مقاومة الانضغاط وان اقل نسبة مقاومة حقلية الى قياسية كانت 92,11%.

Abbreviations

C°:	Celsius Degree
C.A.:	Coarse Aggregate
F.A.:	Fine Aggregate
F:	Field Curing
DRUW:	Dry Rodded Unit Weight
F _{cu} :	Cube Compressive Strength
HPC:	High Performance Concrete
HRWRA:	High Range Water Reducer Admixture
SF:	Silica Fume
W/(C+P):	Water to Cementitious Material Ratio

Introduction

Curing is the process of maintaining satisfactory moisture content and temperature in the concrete for a definite period of time. Hydration of cement is a long-term process and requires water and proper temperature. Therefore, curing allows continued hydration and consequently, continued gains in concrete strength (Mamlouk, 1999).

The curing period is defined as the time period beginning at placing, through consolidation and finishing, and extending until the desired concrete properties have developed (ACI308R-01).

Two types of curing are used throughout the experimental works to determine the effect of curing conditions on compressive strength HPC; the first type based on water curing under standard curing temperature 21C° and temperatures above standard (30, 40, and 50 C°) using special curing water tank for this purpose, to study the effect of high temperatures curing on compressive strength developments and comparing these with standard curing temperature. The second type of curing based on self curing, using curing compound materials, to investigate the efficiency of the

curing compound type with low water cement ratio (0.28) and also to study the compressive strength development under field conditions in different weathers (cold and hot).

Curing temperature is the major factor that affects strength development rate. In general, increasing curing temperature has adverse effect on the concrete properties, especially on the compressive strength. When concrete cured at high temperature normally develops higher early strength than concrete produced and cured at lower temperature, but strengths are generally lower at 28 days and later ages (ACI305R-99). The explanation is that rapid initial hydration appears to form products of a poorer physical structure, probably more porous, so that a proportion of the pores will always remain unfilled, and on the other hand, rapid initial rate of hydration at higher temperatures retards the subsequent hydration and produces a non-uniform distribution of the products of hydration within the paste. The reason for this is that, at high initial rate of hydration, there is insufficient time available for the diffusion of the products of hydration away from the cement particle and for uniform precipitation in the interstitial space. As a result, a high concentration of the products of hydration is built up in the vicinity of the anhydrate particles, and this retards the subsequent hydration and adversely affects the long-term strength (Neville 1995).

The effect of high curing temperature on hardened concrete can be limited to (ACI305R-99):

- Increased tendency for drying shrinkage and differential thermal cracking from either cooling of overall structure or from temperature differentials within the cross section of the member;
- Decreased durability due to cracking.



c. Greater variability of surface appearance, such as cold joints or color differences, due to different rates of hydration.

1. Review Of Literature

1.1 Curing of Concrete

Curing can be defined as a procedure for insuring the hydration of the Portland cement in newly placed concrete. It hydrated product is filled by cement gel, whichever limit is reached first.

Concrete derives its strength by the hydration of cement particles. The hydration of cement is not a momentary action but a continuing process for a long time and requires water and proper temperature. The rate of hydration is fast to start with, but continues over a very long time at a decreasing rate. The quantity of the product of hydration and consequently the amount of gel formed depends upon the extent of hydration (Shetty, 1982).

The curing allows the hydration to be continued and consequently, continued gains in concrete strength. In fact once curing stops the concrete dries out and the strength gain stops (Mamlouk, 1999), as indicated in Figure (1).

1.2 Curing Types

Concrete can be kept moist (and in some cases at a favorable temperature) by three curing methods:

a. Methods that maintain the presence of mixing water in the concrete during the early hardening period. These include ponding or immersion, spraying or fogging, and saturated wet coverings. These methods afford some cooling through evaporation, which is beneficial in hot weather.

b. Methods that reduce the loss of mixing water from the surface of the concrete. This can be done by covering the concrete with impervious paper or plastic sheets, or by applying membrane-forming curing compounds.

generally implies control of moisture loss and sometimes of temperature. The hydration of Portland cement is the chemical reaction between grains of Portland cement and water to form the hydration product. Hydration can proceed until all the cement reaches its maximum degree of hydration or until all the space available for the

c. Methods that accelerate strength gain by supplying heat and additional moisture to the concrete. This is usually accomplished with live steam, heating coils, or electrically heated forms or pads (Kosmatka, 2003).

The term “curing” of concrete is always governed by two variables, period and temperature (CIP, 2000):

1.2.1 Period: it should be noted that the time-strength relations in concrete technology generally assume moist-cured conditions and standard temperature. At given water/cement ratio, the longer the moist curing period the higher the strength assuming that the hydration of anhydrous cement particles will go on. In thin concrete elements, if water is lost by evaporation, air-curing conditions prevail, and strength gain will become very low and once the moisture is lost completely then will be stopped.

1.2.2 Temperature: is an important factor in proper curing, since the rate of hydration, and therefore, strength development, is faster at higher temperature. Generally, concrete temperature should be above 10C° for an adequate rate of strength development. Further, a uniform temperature should be maintained through the concrete section while it is gaining strength to avoid thermal cracking.

For moist-cured concrete, the influence of temperature on strength depends on the time-temperature history of

casting and curing. This can be illustrated with the help of three cases:

- a) Concrete cast and cured at the same temperature;
- b) Concrete cast at different temperature, but cured at standard temperature;
- c) Concrete cast at standard temperature, but cured at different temperature.

In this experimental work all cubes prepared for compression test is cured as case three which casted at standard temperature ($21\pm 2C^{\circ}$) and cured at temperatures 21, 30, 40, and $50 C^{\circ}$.

The curing temperature is an important factor that affects directly the strength gain of concrete since its cement hydration rate.

It is interesting to note that concrete subjected to higher curing temperature at the early period of hydration is found to lose some of the strength gained at a later age. On the contrary, concrete cured at a comparatively lower temperature takes longer time to develop strength, but the strength attained will be higher than standard curing at later ages. The phenomenon of retrogression of strength explains that faster hydration will result in the formation of poor quality gels with porous open structure, whereas gel formed slowly but steadily compact and dense in nature (Shetty, 1982).

The effect of high curing temperature on hardened concrete can be limited to (ACI305R-99):

- a. Increased tendency for drying shrinkage and differential thermal cracking from either cooling of overall structure or from temperature differentials within the cross section of the member;
- b. Decreased durability due to cracking.

c. Greater variability of surface appearance, such as cold joints or color differences, due to different rates of hydration.

1.3 Curing Effect on Hardened Concrete

1.3.1 Strength Gain: laboratory tests show that concrete in dry environment can lose as much as 50 percent of its potential strength compared to similar concrete that is moist cured. Concrete placed under high temperature conditions will gain early strength quickly but later strength may be reduced. Concrete placed in cold weather will take longer to gain strength, delaying form removal and subsequent construction.

1.3.2 Durability: well-cured concrete has better surface hardness and will better withstand surface wear and abrasion. Curing also make concrete more water tight, which prevents moisture and water borne chemicals from entering into the concrete, thereby increasing durability and surface life.

1.3.3 Serviceability and Appearance: a concrete slab that has been allowed to dry out too early will have a soft surface with poor resistance to wear and abrasion (Shetty, 1982).

1.4 Previous Researches on Concrete Curing

Al-Foadi, has studied the effect of ambient temperature on properties of high performance concrete. Different curing temperatures are used for specimens curing (5, 23, 40, and $57C^{\circ}$). He has reached the following conclusions:

1. The compressive strength for all mixes at early ages (7 and 28days), increases with the increase of the curing temperatures.



The range of increase at 7 days is between 2% to 11.11%.

2. The compressive strength for all mixes at later ages (56 and 90 days) decreases with the increase of curing temperatures. The range of decreases at 90 days is between 3.41% to 13.63%.

Burg, has reported the influence of casting and curing temperature on concrete properties. He has cast concretes at temperatures (10, 23, and 32C°) and these concretes have been cured at their casting temperature. He had observed that the effect of high temperatures on the early age strength are reversed after seven days when absolute strength of concrete cast and cured at 32C° is lower than concrete cast and cured at 23C°.

Safiuddin, et al, have studied the effect of curing methods on the properties of silica fume concrete. They have used concrete with 10% silica fume cement replacement and three curing methods such as water curing, wrapped curing and dry air curing applied at 20±2C°. They conclude that water curing is the most effective method; it produces the highest level of compressive strength.

Bushlaibi, has also showed the effect of curing methods on the compressive strength of silica fume high strength concrete. Five curing conditions are used, water curing (for 28 days), no curing, sprinkle curing (sprinkling two times in a day for seven days), plastic curing (sprinkling two times in a day with plastic cover sheet for seven days) and burlap curing (sprinkling two times in a day with burlap cover for seven days), and found that following conclusions:

1. The compressive strength of the silica fume high strength concrete, as is also

true with normal strength concrete, is directly related to curing duration.

2. The adverse effect on the development of concrete compressive strength increases with increased temperature and test duration.

3. At curing ages of 28 days and beyond, the strength reduction reaches up to 12% of the control strength in some curing conditions.

4. Silica fume high strength concrete is adversely affected by hot dry environment in a manner similar to the way normal strength concrete is adversely affected by excessive moisture evaporation and badly dispersed hydration products resulting from high curing temperatures.

2. MATERIALS AND EXPERIMENTAL WORKS

2.1 Materials

2.1.1 Cement

Iraqi Ordinary Portland cement supplied from Taslooja Factory is used in casting all specimens throughout the experimental work. The required quantity of cement is delivered as one lot to avoid any difference in physical or chemical properties, and stored in sealed plastic container in the laboratory to prevent humidity effects until casting the specimen. Table (1) and (2) shows the physical properties and chemical analysis respectively, which confirm with the Iraqi Specifications I.Q.S. 5/1984.

2.1.2 Silica Fume

Silica fume of Turkish origin densified type is used throughout this work as a partial replacement of cement, which is supplied from "Dost Kimya Industrial Materials Co. Ltd". It is stored in airtight plastic containers to avoid exposure to different atmospheric conditions.

Table (3) and (4) show the physical properties and chemical analysis of silica fume used respectively, results of tests show that the properties of silica fume used to comply with ASTM C1240-05 standard specification.

2.1.3 Super-Plasticizer

High-range water reducers admixture (HRWRA), according to ASTM C 494-05 Type G (water reducing and retarding), is used as super-plasticizer in preparing all the specimens in this study. It is commercially known Proplast PC260. Its produced by Ayla Company (from Jordon) and described as a high performance super-plasticizing admixture based on polycarboxylic with long chains specially designed to enable the water content of the concrete to perform more efficiency. Table (5) shows properties of the admixture according to manufacturer information.

2.1.4 Curing Compound

Liquid membrane-forming compounds consisting of waxes, resins, chlorinated rubber, and other materials can be used to retard or reduce evaporation of moisture from concrete. They are the most practical and most widely used method for curing not only freshly placed concrete but also for extending curing of concrete after removal of forms or after initial moist curing.

In this work, the field specimens are cured using curing compound, which is commercially known as Curecoat 220. It's produced by Ayla Company (from Jordon) and it complies with ASTM C309-07. Table (6) shows properties of the curing compound according to manufacturer information.

2.1.5 Coarse Aggregate

Crushed gravel supplied from Drbandikhan region (Sulaimaniah City) is used for preparing mixes with maximum aggregate size of 20mm. The sieve analysis of this aggregate is shown in Table (7). It conforms to the Iraqis specifications No. 45/1984. Table (8) shows the physical properties of the coarse aggregate.

2.1.6 Fine Aggregate

Natural sand supplied from Drbandikhan region (Sulaimaniah City) is used for preparing mixes with maximum aggregate size of 5mm. The sieve analysis of this aggregate is shown in Table (9). It conforms to the Iraqi Specifications No. 45/1984 zone 2. Table (10) shows the physical properties of the fine aggregate.

2.1.7 Mixing Water

Drinking tap water is used for mixing and curing the concrete.

2.2 EXPERIMENTAL PROGRAM

2.2.1 Mixture Proportioning Procedure

HSC (High Strength Concrete) is defined as concrete that has a specified cylinder compressive strength of 41MPa or greater. The ACI method (ACI 211.4) is used for calculation of the proportions of HSC, and silica fume was added to produce HPC. Table (11) shows mix proportions for HPC.

2.2.2 Preparation of Specimens

An electrical rotary mixer is used to batch all specimens with 0.05 m³ capacities. The required quantities of material have been weighed and stored at the lab temperature for 24 hour before casting to control the moisture content and moisture meter is used before mixing to calculate the mixing water.

The ingredients have been initially mixed in dry condition (without silica fume),



and then water and HRWRA are added. The constituents are mixed for three minutes from the time of water adding. Finally silica fume is added and mixed until reaching a homogenous mix.

The moulds have been compacted, and filled in the required number of layer of approximately equal volume according to ASTM C192-07. After completing consolidation, the surfaces of the specimens have been leveled by hand trawling.

All the moulds are thoroughly cleaned and oiled before casting to obtain affair-face and to prevent specimens adhesive to the mould.

After completing the pouring, the specimens are covered with Nylon sheets to prevent evaporation of mixing water from concrete, and they have been left about 24hours in the laboratory. After that all the specimens have been de-moulded and cured in the desired method and period.

2.2.3 Curing

Drinking tap water was used for curing. Two methods of curing are used to cure the specimens:

2.2.3.1 Water Curing

Special tank has been manufactured and divided into four parts (21, 30, 40, and 50C°) and used for water curing, the temperature is controlled by using a heater in each part (four heaters), and the curing tank is isolated by covering it with styrapor from each side to minimize temperature lost. Figure (2) shows water curing tank with various temperatures.

2.2.3.2 Self Curing

The field specimens have been coated with curing compound after sprinkled with water and left in site until testing day.

2.3 Compressive Strength Test

The test is conducted according to ASTM C39-05, using a digital compressive strength machine with 3000KN capacity.

This test method consists of applying a compressive axial load at a rate 0.25 ± 0.05 MPa/s until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by cross sectional area of the specimen.

Cube of 150mm specimens are used, and taken out from the curing tank before 24 hours and tested in compressive machine on its perpendicular face to casting face at the age of 7, 28, 56, and 90 days, the average of three cubes has been recorded.

Compressive Strength, MPa, = P/A

Where:

P = axial load at failure, N;

A = cross sectional area, mm².

3. Results And Discussions

3.1 Curing Temperature Effect

The results reveal that specimens cured at 21C° (standard curing) show higher late age compressive strength compared with the same mix cured at temperature higher than 21C°. These results are in complying with other researches (CIP, 2000 and Burg, 1996). Table (12) shows Compressive Strength of High performance Concrete.

At early ages, the rate of strength development at high curing temperature is greater than at lower curing temperature, the maximum increasing percentage is 10.83% at 50C° compared with 21C° in 7days curing age. This is attributed to an increase in the hydration reaction rate. However at later ages, the strength achieved at higher curing temperature has been less. Table (13) shows the increasing and decreasing percentage due to curing temperature effect.

The reduction in concrete compressive strength due to high curing temperature at later ages is indicated in the Figure (3), and the maximum percentage of reduction has been 5.70% at curing temperature 50C° compared with 21C° curing temperature in 91 days curing age. This reduction can be explained to be due to the reaction products not having time to become uniformly distributed within the pores of the hardening paste at high temperature. In addition, shells made up of low permeability hydration products build up around the cement gains and these hindering further reactions (Neville, 1995 and Elsageer, 2009)

The non-uniform distribution of hydration products leads to larger pores that reduce compressive strength. This is in line with other research findings, which indicate that adverse effect on the development of compressive strength increases with the increased curing temperature and test duration (Burg, 1996).

3.2 Curing Compound Effect

The specimens are cured under field condition using curing compound they have a various strength development rate with curing age. This variation is attributed to the significant influence of ambient temperature on the specimens. The compressive strength ratio of field curing to standard curing reveals that, there is no ratio fall under 85% and this complies with ACI 318 requirement, the results indicate 92.11% as minimum field-standard curing ratio.

Figure (4) show the strength gain of field curing specimen compared to laboratory standard curing (21C°), and Table (14) shows compressive strength ratios of field curing to standard curing.

4. Conclusions

1. At early ages, the compressive strength increases with the increasing of curing temperatures and reveal an increasing up to 10.83% at 50C° compared to standard curing temperature (21C°).
2. At later ages, the high curing temperatures reveal a reduction in compressive strength up to 5.70% at 50C° compared to standard curing temperature (21C°).
3. The field compressive strength is typically lower than this measured on standard curing specimens prepared with the same mixes. On average, differences of 10% have been observed at 91days. Differences in curing conditions between the standard and field curing can explain these discrepancies.

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Table (1): Physical Prosperities of Portland Cement

Properties		Results	Iraqi Specification Limits (I.Q.S. 5/1984)
Fineness(m ² /kg)		300	Min, 230
Setting	Initial setting	135min.	Min, 45min.
	Final setting	4hrs.	Max, 10hrs.
Comp. St. (MPa)	3 days	25MPa	Not less than 15MPa
	7days	36MPa	Not less than 23MPa

Table (2): Chemical Analysis of Portland Cement

Oxides	Content, %	Iraqi Specification Limits(I.Q.S. 5/1984)
SiO ₂	21.60	-
Fe ₂ O ₃	3.28	-
AL ₂ O ₃	4.52	-
CaO	62.07	-
MgO	1.93	Max, 5%
SO ₃	2.19	Max, 2.8%
L.O.I	1.78	Max, 4%
L.S.F	0.89	0.66-1.02%
In. Residue	0.5	Max, 1.5%
Compound Composition (Bogues Equation)		
C ₃ S	47.16	-
C ₂ S	26.62	-
C ₃ A	6.43	-
C ₄ AF	9.97	-

**Table (3): Chemical Analysis of Silica Fume**

Oxides	Content, %	ASTMC1240 Specifications, %
SiO ₂	87.66	Min. 85%
Fe ₂ O ₃	1.75	-
AL ₂ O ₃	1.5	-
CaO	1.55	-
MgO	1.33	-
SO ₃	0.73	-
L.O.I	2.60	Max, 6%
Moisture Content	1.16	Max, 3%

Table (4): Physical Prosperities of Silica Fume

Properties	Result	ASTM C1240 Specifications
Specific Surface, m ² /gr.	23.36	Min,15
Retaining on Sieve 45 Micron,%	3.8%	Max,10
Strength Index ,@7day%	111%	Min, 75
Bulk Density, kg/m ³	550	-

Table (5): Properties of Super-Plasticizer (PC260)

Properties	Details
Colour	Light yellow liquid
Freezing Point	-1°C approximately
Specific Gravity	1.1@25°C
Air Entrainment	Typically less than 2%
Dosage	0.5-3.0 lit. per 100kg cement
Fire	Non-flammable

Table (6): Properties of Curing Compound (Curecoat 220)

Properties	Details
Colour	white Liquid
Minimum Application Temperature	5C°
Storage	5-35C°
Health and Safety	Not-hazardous
Fire	Non flammable

Table (7): Grading Analysis of Coarse Aggregate

Sieve (mm)	Remaining (gr.)	Acc. Remaining (gr.)	Passing %	Iraqi Specification Limits (I.Q.S. 45/1984) %
20	0	0	100	95-100
14	1455	1455	70.90	-
10	1149	2604	47.92	30-60
5	2297	4901	1.98	0-10
pan	87	Dry Sample Weight=5000gr.		

Table (8): Properties of Coarse Aggregate

Items	Results	Iraqi Specification Limits (I.Q.S. 45/1984) ,%
SO ₃ Content	0.08%	Max, 0.1%
Passing on Sieve 75 micron	1.2%	Max, 3%
DRUW	1500kg/m ³	-
Specific Gravity	2.616	-
Absorption	1.05%	-

**Table (9): Grading Analysis of Fine Aggregate**

Sieve (mm)	Remaining (gr.)	Acc. remaining (gr.)	passing %	Iraqi Specification Limits (I.Q.S. 45/1984) Zone 2, %
10	0	0	100	100
4.75	315	315	91.00	90-100
2.36	178	493	85.91	75-100
1.18	1012	1505	57.00	55-90
0.60	387	1892	45.94	35-59
0.30	1191	3083	11.91	8-30
0.15	347	3430	2.00	0-10
pan	50	F.M= 3.06	Dry Sample Weight=3500gr.	

Table (10): Properties of Fine Aggregate

Items	Results	Iraqi Specification Limits (I.Q.S. 45/1984)
SO ₃ Content	0.15%	Max 0.5%
Passing on Sieve 75 micron	4.27%	Max 5%
DRUW	1848kg/m ³	-
Specific Gravity	2.59	-
Absorption	1.77%	-

Table (11): Mix Proportion for HPC

W/(C+P)	Silica Fume kg/m ³	Cement kg/m ³	C.A. kg/m ³	F.A. kg/m ³	Water L/m ³	HRWR L/m ³
0.28	15	478	1074	709.8	138	3

Table (12): Compressive Strength of High performance Concrete

Temp.	HPC			
	7 days	28 days	56 days	91 days
21C°	55.76	60.98	67.90	68.25
30C°	59.08	61.12	67.23	67.20
40C°	60.22	61.98	65.63	66.31
50C°	61.80	62.33	64.03	65.00
Field (Ambient Temp.)	51.36	61.18	65.93	68.63

Table (13): Percentage of Increasing and Reduction in Compressive Strength due to Curing Temperature Effect

Mixes	Temp.	Compressive Strength Ratio, %			
		7 days	28 days	56 days	91 days
HPC	30C°/ 21C°	+5.95	+0.23	-0.99	-1.54
	40C°/ 21C°	+8.00	+1.64	-3.34	-2.84
	50C°/ 21C°	+10.83	+2.21	-5.70	-4.76

Table (14): Compressive Strength of Field curing Versus Standard Curing Strength

Mixes	Compressive Strength Ratio, %			
	7 days	28 days	56 days	91 days
HPC	92.11	100.33	97.10	97.63

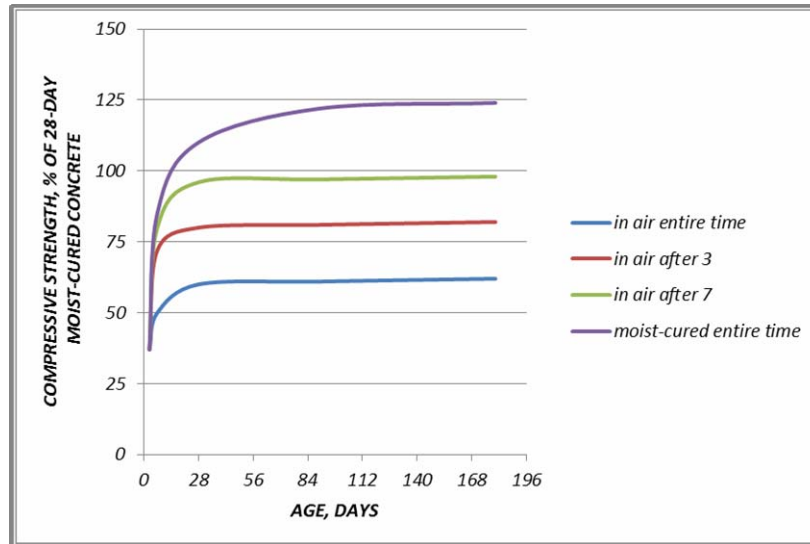


Figure (1): Compressive Strength of Concrete at Different Ages and Curing Levels (Mamlouk, 1999)



Figure (2): Water Curing Tank Divided to Various Temperatures

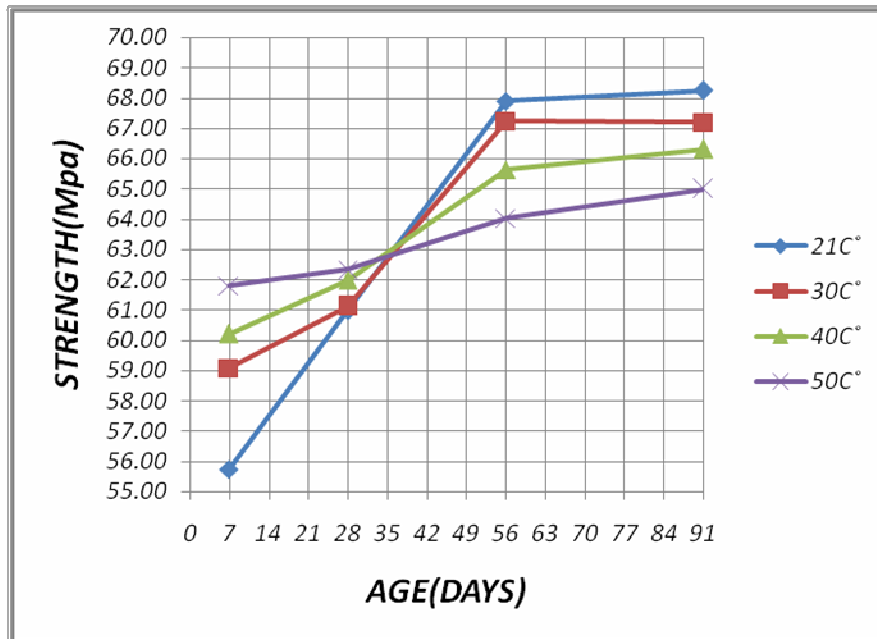


Figure (3): Curing Temperature Effect on Compressive Strength of High Performance Concrete

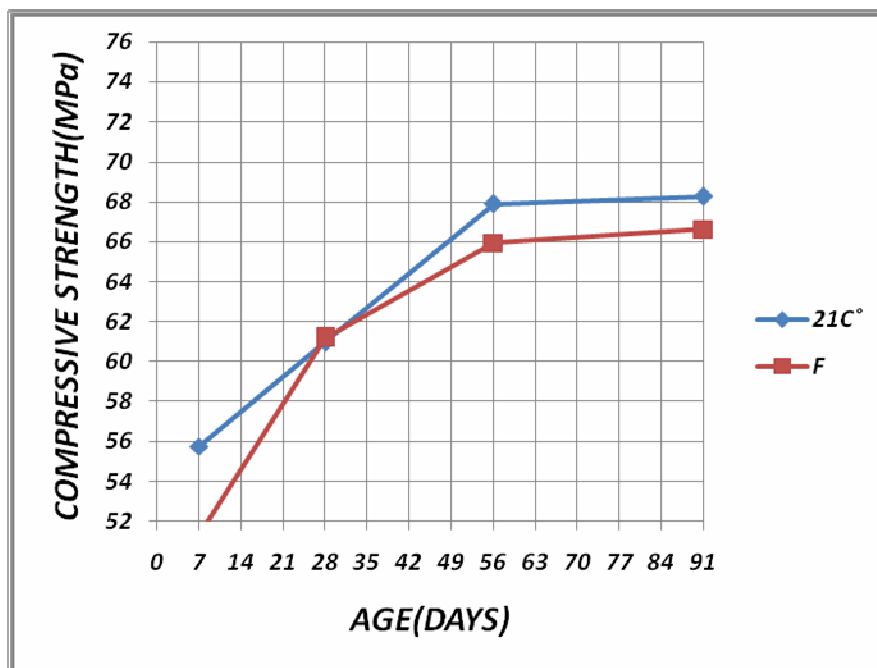


Figure (4): Compressive Strength Development of Standard Curing Compared with Field Curing HPC