# ESTIMATION THE 7 AND 28- DAY NORMAL COMPRESSIVE STRENGTH BY ACCELERATED TEST METHODS IN CONCRETE

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## ABSTRACT

Curing of concrete is the maintenance of a satisfactory moisture content and temperature for a period of time immediately following placing so the desired properties are developed. Accelerated curing is advantages where early strength gain in concrete is important. The expose of concrete specimens to the accelerated curing conditions which permit the specimens to develop a significant portion of their ultimate strength within a period of time (1-2 days), depends on the method of the curing cycle.

Three accelerated curing test methods are adopted in this study. These are warm water, autogenous and proposed test methods. The results of this study has shown good correlation between the accelerated strength especially for the proposal curing test method and normal strength using normal curing method at ages 7 and 28 day for the five different chemical composition of cement with different water to cement ratios equal to 0.45, 0.55, 0.65 and 0.75. Linear and nonlinear regression analysis show high correlation for the different types of the accelerated curing methods with coefficient of correlation ($R^2$) more than 0.9.

# تخمين مقاومة الانضغاط الاعتيادية بعمر ٧ و ٢٨ يوم بأستخدام طرق الفحص المعجلة في الخرسانة

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## الخلاصة

معالجة الخرسانة هي من أجل المحافظة على كمية الماء المناسبة و درجة الحرارة لفترة من الزمن مباشرة بعد عملية الوضع من أجل تطوير الخصائص المطلوبة. المعالجة بالطريقة المعجلة هي مفيدة عندما يكون من المهم الحصول على القوة المبكرة. تم دراسة النماذج الخرسانية المعرضة الى المعالجة المعجلة من أجل الحصول على الجزء الاكبر من قوتها النهائية خلال فترة تتراوح بين يوم و يومين بالاعتماد على طريقة المعالجة.

أعتمدت ثلاثة طرق في المعالجة المعجلة و هي طريقة الحمام الدافئ ، طريقة التعجيل الذاتي و الطريقة المقترحة. أظهرت النتائج علاقة جيدة بين المقاومة المعجلة و خاصة الطريقة المقترحة مع ٧ و ٢٨ يوم للخرسانة المعجلة أعتياديا للخمس أنواع سمنت مختلفة التركيب الكيمياوي و لنسبة ماء الى سمنت تساوي ٠,٤٥، ٠,٥٥ ، ٠,٦٥ و ٠,٧٥. الموديلات الاحصائية الخطية و غير الخطية أظهرت علاقة جيدة للطرق المختلفة للمعالجة المعجلة مع معامل أرتباط لا يقل عن ٠,٩.

**Keywords: accelerated strength, normal strength, warm test method, autogenous test method, proposed test method, compressive strength, regression analysis**

## 1.0 INTRODUCTION

Accelerated curing of concrete is used extensively in the production of the precast concrete structural members such as pipes and prestressed products are used to get a high early strength enough to transfer the prestress force to concrete and lift the precast element. The acceptance of concrete in the site depends on the 28 days strength, at that time, usually a considerable concrete work has been done on the first casting which makes the remedy for the weak concrete is very difficult and complicated, also if it was too strong, the mix proportion used will be uneconomical. Thus, the production control with 28 days delay is not sensible **[Neville (1995)].** Concrete specimens are exposed to accelerated curing conditions that permit the specimens to develop a significant portion of their ultimate strength within a time period of (1-day to 2-day depends on the method of curing cycle).The accelerated curing procedure provides at the earliest practical time, an indication of the potential strength of a specific concrete mixture.

The accelerated strength tests used in the experimental work is presented below:

### 1.1 Warm Water Method.

This test method is applied according to the **ASTM C684-99 (method A)** and **BS 1881: Part 112:1983**

### 1.2 Autogenous Method.

This test method is applied according to the **ASTM C 684-99 (method C)** except that the satisfactory containers are unavailable in the lab, and the average temperature lab test is approximately 30°C.

### 1.3 Proposed Method

The cycle includes the delay period, the temperature rise period, and the period of the curing at the maximum temperature. It is designed to enable a turnover of one batch per one day, allowing for cooling, demolding, cleaning, oiling, and assembling molds for the next batch. Then cubes are tested. The curing cycle is adopted below after casting the concrete in 100mm cube mold in the normal way. The molds are covered with a top plate in good contact with the top face of the mold:

1. Delay period (Presteaming period): The curing cycle is also designed to minimize the destructive processes in the structure of the accelerated –cured concrete by using an adequate delay period and a medium rate of temperature rise. **Mamillian (1982)** as reported by **Al Qassab (2006)** concluded that the loss in the 28-day strength can be reached 40% for the steam cured concrete at 75ºC with no delay period.

Results obtained by **Lewis (1968)** using 100mm cube specimens show that the optimum initial maturity prior to the steam curing and corresponding to maximum strength is about 80˚C. A study done by **Al Rawi (1974)** concludes that the use of a short delay period 1hr resulted in an appreciable in a1-day accelerated curing plus 27-day normal curing compressive strength of concrete, as compared with the strength obtained when 5 to 11-hr delay periods are used. Therefore, such short delay periods should not be used unless the large expansion of the liquid phase is counteracted by some means such as closed rigid molds. Assuming the temperature of the mix prior to steam curing was 20˚C, the optimum delay period will be 4-hr. Therefore, a delay period of 4-hr is used.

2. Rate of temperature rise: After a delay period of 4-hr, the molds are placed in a water tank at a temperature of 20˚C, the water temperature is raised to 70˚C±4˚C in about 2-hr, with rate of temperature rise about 25˚C per hour. As a practical method operation, a maximum rate of temperature rise is 22˚C to 33˚C **[ACI 517.2R-80]**.

3. Maximum curing temperature and duration: Several investigators have found that the most effective results are obtained when the concrete is cured at a temperature between 66˚C and 82˚C, lower temperature are advantageous if steaming is continued for more than 24-hr **[ACI 517.2R-80].**

The temperature is chosen 70˚C±4˚C for 16-hr which is in confidence by the results of **Al-Rawi (1977)** for choice of cured concrete. He also finds that there is no such difference between 70˚C and 90˚C. For 80˚C and above the hydration of the $C_3A$ will form the cubic $C_3AH_6$ phase, instead of hexagonal phases. High steam – curing temperatures always require longer presteaming periods. Early strengths are higher, but 28-day strengths are generally lower with high steaming temperatures **[ACI 517.2R-80]** as explained above.

The desired maximum temperature within the enclosure and the concrete is approximately 66˚C. It has been shown that the strength will not increase significantly if the maximum steam temperature is raised from 66˚C to 79˚C, and the steam temperatures above 82˚C should be avoided because of the wasted energy and potential reduction in ultimate concrete strength **[Kosmatka and Panarese (1994)].**

4. Cooling period: Rapid changes during the cooling period should be avoided so as to reduce the cracking of the members from the effects of restraints **[ACI 517.2R-80]**. The temperature of the water tank dropped approximately to 21˚C within about 2-hr.

This 24-hr curing cycle is shown in the Figure (1) and Figure (2) for typical idealized atmospheric steam-curing cycle for pipe [**ACI 517.2R-80**]. The molds then are removed from water tank and the cubes are tested in half an hour.

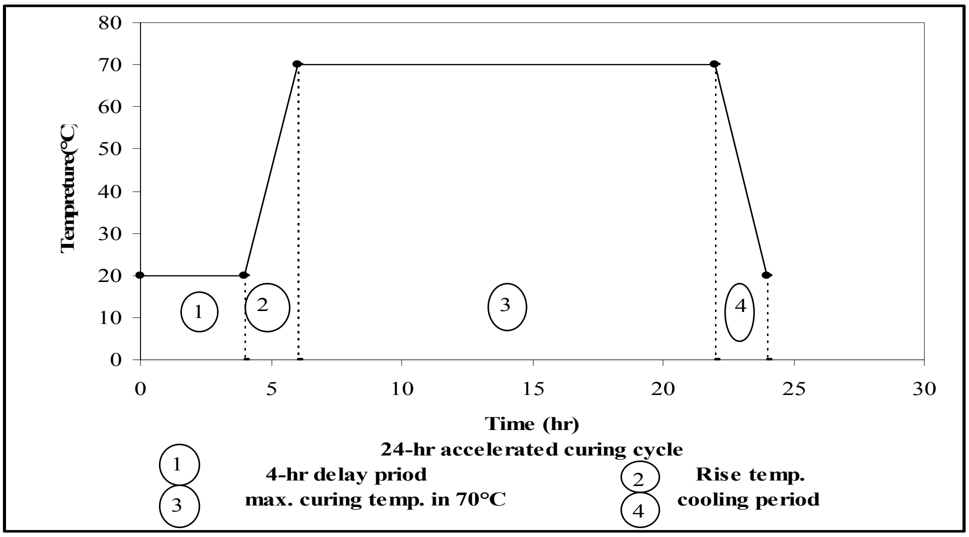


Fig. 1: Proposed accelerated curing cycle.

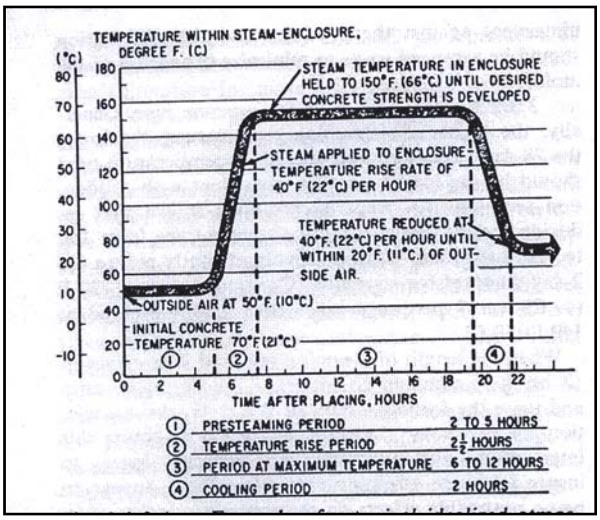


Fig. 2: Typical idealized atmospheric steam-curing cycle for pipe- **ACI 517.2R-80**.

## 2.0 EXPERIMENTAL PROGRAM

### 2.1 Materials

#### 2.1.1 Cement

Five different chemical composition Portland cements, conforming to the **IQS 5/1984** were used. Three ordinary Portland cement (Iraqi, Lebanese and Turkish) and two sulfate resisting Portland cement (Lebanese and Kuwaiti).

The chemical analysis and physical properties of these cements are listed in Tables 1 and 2 respectively.

Table 1: Chemical composition of cement used

| Oxide Content % | Iraqi (OPC) | Turkish (OPC) | Lebanese (OPC) | Lebanese (SRPC) | Kuwaiti (SRPC) |
|---|---|---|---|---|---|
| $SiO_2$ | 20.49 | 20.63 | 20.4 | 21.25 | 19.65 |
| $Al_2O_3$ | 4.56 | 4.77 | 4.94 | 3.10 | 3.78 |
| $Fe_2O_3$ | 4.35 | 4.64 | 3.84 | 4.00 | 3.89 |
| CaO | 61.82 | 61.89 | 60.34 | 59.08 | 63.93 |
| $SO_3$ | 2.31 | 2.14 | 2.68 | 2.11 | 2.30 |
| MgO | 2.59 | 2.13 | 4.58 | 2.02 | 3.30 |
| L.O.I | 2.23 | 1.47 | 2.35 | 3.10 | 2.45 |
| I.R | 1.12 | 1.50 | 0.62 | 1.74 | 1.56 |
| L.S.F | 0.92 | 0.904 | 0.89 | 0.86 | 0.85 |
| Compound Composition (Bogue` s Equation) | | | | | |
| $C_3S$ | 52.44 | 50.32 | 44.22 | 46.39 | 72.76 |
| $C_2S$ | 19.27 | 21.27 | 25.21 | 26.01 | 1.53 |
| $C_3A$ | 4.73 | 4.80 | 6.60 | 1.45 | 3.44 |
| $C_4AF$ | 13.22 | 14.10 | 11.67 | 12.16 | 11.82 |

- Chemical and Physical tests are conducted by the Central Organization for Standardization and Quality Control, Ministry of Planning

Table 2: Physical properties of cements used

| Properties | Iraqi (OPC) | Turkish (OPC) | Lebanese (OPC) | Lebanese (SRPC) | Kuwaiti (SRPC) |
|---|---|---|---|---|---|
| Specific surface (Air permeability test),$m^2/kg$ | 340 | 380 | 340 | 360 | 350 |
| Autoclave expansion,% | 0.01 | 0.04 | 0.07 | 0.04 | 0.04 |
| Setting time (vicate apparatus), | | | | | |
| a. Initial - hr:min | 2:30 | 3:35 | 3:30 | 1:40 | 2:25 |
| b. Final - hr:min | 4:0 | 4:35 | 5:30 | 4:40 | 4:30 |
| Compressive strength MPa($N/mm^2$): | | | | | |
| a. 3-days | 30.96 | 32.12 | 27.99 | 30.5 | 31.5 |
| b. 7-days | 35.71 | 33.99 | 29.6 | 31.5 | 32.5 |

- Chemical and Physical tests are conducted by the Central Organization for Standardization and Quality Control, Ministry of Planning

- L.O.I: Loss on ignition, I.R: Insoluble residue, L.S.F: lime saturation factor.

### 2.1.2 Fine Aggregate

Fine aggregate from Al-Ukhaider region was used. The grading satisfy the Iraqi specification **IQS 45/1984** and failed in the zone two. The sieve analysis is shown in Table 3. The sulfate content and the physical properties of fine aggregate are shown in Table 4.

### 2.1.3 Coarse Aggregate

The maximum size of 20mm of natural coarse aggregate from Al-Niba`ee quarry (crushed) was used. The aggregate satisfies the Iraqi specification **IQS 45/1984**. The sieve analysis for the crushed aggregate is shown in Table 5. The sulfate content and the physical properties are shown in Table 6.

Table 3: Sieves analysis of fine aggregate.

| Sieve size | % passing by weight | Limits of IQS 45/1984 (Zone 2) |
|---|---|---|
| 10mm | 100 | 100 |
| 4.75mm | 96 | 90-100 |
| 2.36mm | 82 | 75-100 |
| 1.18mm | 69 | 55-90 |
| 600µm | 47 | 35-59 |
| 300µm | 21 | 8-30 |
| 150µm | 5 | 0-10 |

Fineness modulus = 2.8

Table 4: Physicals properties and sulfate content of fine aggregate used in experimental work.

| Properties | results | Specification | IQS 45/1984 |
|---|---|---|---|
| Grading zone | Zone 2 | IQS 45/1984 | |
| Fineness modulus | 2.8 | ASTM C125-03 | |
| Specific gravity | 2.6 | ASTM C128-01 | |
| Absorption ,% | 1.5 | ASTM C128-01 | |
| Moisture content,% | 0.3 | ASTM C566-97 | |
| Passing sieve size 75µm% | 2.2 | IQS No. 45-84 | Max. 5% for natural fine aggregate |
| Sulfate content ($SO_3$), % | 0.2 | IQS No. 33-89 | Max. 0.5% |

- Tests are carried out in the Material Laboratory of the College of Engineering-Baghdad University

Table 5: Sieves analysis of coarse aggregate with 20mm maximum size.

| Sieve size | % passing by weight | Limits of IQS 45/1984 |
|---|---|---|
| 37.5mm | 100 | 100 |
| 20mm | 96 | 95-100 |
| 10mm | 41 | 30-60 |
| 5mm | 2 | 0-10 |

Table 6: Physical properties and sulfate content of coarse aggregate with 20mm maximum size.

| Properties | results | Specification | IQS 45/1984 |
|---|---|---|---|
| Dry rodded unit weight,kg/m$^3$ | 1680 | ASTM 29/C29M/97 | -- |
| Specific gravity (Saturated surface dry) | 2.67 | ASTM C127-01 | -- |
| Absorption ,% | 0.8 | ASTM C127-01 | -- |
| Moisture content ,% | 0.2 | ASTM C566-97 | -- |
| Passing sieve size 75µm,% | 0.9 | IQS No. 45-84 | Max. 3% for natural coarse aggregate |
| Sulfate content ($SO_3$),% | 0.02 | IQS No. 33-89 | Max. 0.1% |

- Tests are carried out in the Material Laboratory of the College of Engineering-Baghdad University

**2.1.4 Mixing Water**

Ordinary water is used for mixing and curing of the concrete, according to the **IQS 1703/1992**. The PH equal to 7.4 and the TDS (total dissolve solids means the sum of all the minerals, metals, salts dissolved in the water) equal to 389ppm.

**2.2 Mix Proportion**

The ACI **211.1-91** mix design method recommended specifies both the maximum and minimum value for the slump which is based on the type of construction. So, it is decided to select (75-100) mm as a range for slump in all the experimental work.

In this method, the required water/cement ratio is determined by the compressive strength and the durability requirement. In the present work, four water/cement ratios are used (0.45, 0.55, 0.65 and 0.75) by weight as an attempt to use low, medium and high W/C ratios. The mix proportions and adjustment to keep the effective W/C constant used in preparing the test specimens according to **ACI 211.1-91** method is presented below in Table (7).

Table (7): The mix proportions used in preparing the test specimens according to **ACI 211.1-91** method

| **W/C** | **Water (kg/m$^3$)** | **Cement (kg/m$^3$)** | **Fine aggregate (kg/m$^3$)** | **Coarse aggregate (kg/m$^3$)** |
|---|---|---|---|---|
| 0.45* | 203 | 451 | 639 | 1036 |
| 0.45** | 209 | 464 | 628 | 1036 |
| 0.55 | 203 | 369 | 706 | 1036 |
| 0.65 | 203 | 312 | 754 | 1036 |
| 0.75 | 203 | 270 | 788 | 1036 |

* Trial batch adjustment (before adjusting)
** After adjusting

**2.3 Mixing, Casting, Curing of Concrete**

The cement was passed through the sieve No.14 (1.18mm) and the lumps were removed. The mixing of ingredients is done by hand in a plastic pan. Cast iron cube moulds, with dimensions of 100x100x100mm are prepared, cleaned and oiled before starting mixing of concrete.

Casting was made in two layers; the compaction of concrete was done by a vibrating table for 10 to 15 second for each layer. For the normal curing, after casting (30-

45minutes), the molds were covered with Nylon bag and polyethylene sheets and for the 3-cubes accelerated curing test the procedure was mentioned in the curing cycle. For the normal curing the concrete specimen was kept their moulds for nearly 24hr, then they are demolded and placed in the curing tank filled with water until the time of testing (7 and 28-day according to test procure), and for accelerated curing test the procedure was mentioned in the curing cycle.

### 2.4 Tests Performed

The following are the standard tests that were carried out on the fresh concrete, and hardened concrete.

#### 2.4.1 Fresh Concrete

A slump test is the most usual test used in Iraq for testing the workability of the fresh concrete. The **ACI 116-90** describes it as a measure of consistency. The slump test of fresh concrete is according to **ASTM C143/C143M– 00**. The present experimental work is based on the mix proportion method with a slump range (75-100mm).

#### 2.4.2 Compressive Strength Test

The compressive strength test of concrete cubes of (100) mm was carried out in the present work according to the **BS 1881: Part 116: 1983**, because it is the most suitable test for the compressive strength used in Iraq. The cubes of concrete were tested at accelerated curing test (warm water method, autogenic curing method and proposal method) with the 7, 28, 90, 180-day for normal curing strength according to the test procedure.

At each test age, three cubes of concrete are taken from the curing tank and were placed in the testing machine. The load at failure was recorded and calculates the average of compressive strength for the 3-cubes at each age test.

## 3. RESULTS AND DISCUSSION

### 3.1 Fresh Concrete –Slump Test

The slump result for different chemical compositions of the 5-cements is presented in Table 8. Figure 3 illustrates that the Turkey cement is the lowest slump result for different W/C ratios, then the Lebanese(SRPC), that is compatible with a high specific surface area of cement for Turkish- 380 $m^2$/kg and Lebanese(SRPC)-360 $m^2$/kg compared with the others lead to reduce the slump test result.

Table 8: Slump test for different types of cement and W/C ratios.

| Type of cement | Slump (cm) | | | |
|---|---|---|---|---|
| | W/C= 0.45 | W/C= 0.55 | W/C= 0.65 | W/C= 0.75 |
| Iraqi (OPC) | 8.5 | 9.5 | 10.0 | 11.5 |
| Turkish (OPC) | 7.0 | 7.5 | 8.0 | 9.0 |
| Leb. (OPC) | 8.0 | 9.5 | 10.5 | 11.0 |
| Leb. (SRPC) | 7.75 | 8.5 | 9.5 | 10.5 |
| Kuwait(SRPC) | 8.5 | 9.0 | 10.0 | 11.0 |

### 3.2 Hardened Concrete -Compressive Strength Test

The development of the compressive strength with the age (accelerated strength for different methods, 7and 28-day normal strength) for the twenty mixes used through the first part of this study is shown in the Table 9. Figures 4 to 9 show the relation between water to cement ratios (0.45, 0.55, 0.65 and0.75) with the compressive strength (accelerated strength for different methods and 7, 28 day normal strength).

The curves indicate that the proposed method is the closer to the 7-day normal then the autogenous then the warm water method for the same water to cement ratio at a given age. The difference is related to the effect of the method of the accelerated test.

The mixes for the Kuwaiti cement (SRPC) show a high rate of gaining strength relative to the other mixes. This cement has relatively a high $C_3S$ to a $C_2S$ ratio, Sr = 47.4. Meanwhile ,the mixes for the Iraqi and Turkish cements (OPC) are more faster gaining strength than the Lebanese cement (OPC) , this could be attributed to a high content of the $C_3S$ = 52.44% and 50.32% with Sr = 2.72 and 2.365 for Iraqi and Turkey cements respectively, and the $C_3S$ = 44.22 with Sr = 1.754 for the Lebanese cement (OPC).

Finally the mixes for the Lebanese cement (SRPC) gained strength faster than the Lebanese cement (OPC) with closer Sr = 1.78 and 1.754 respectively, although, the reviewed literature shows that the (OPC) cements often have high early strength and gain strength faster than the SRPC cement and this can be attributed to the failure of the Lebanese mixes (OPC) to achieve the minimum average strength for different water to cement ratios.

Table 9: Accelerated strength (warm, autogenous and proposed method) with normal strength (7 and 28 day) for different type of cement -Reference mixes

| Mix. No. | Cement Type | Sr. | W/C | Accelerated strength MPa | | | Normal strength MPa | |
|---|---|---|---|---|---|---|---|---|
| | | | | Warm method 1-day | Autogenous method 1-day | Proposed method 2-day | 7-day | 28-day |
| 1 | Iraqi (OPC) | 2.72 | 0.45 | 15.0 | 16.75 | 25.5 | 28.25 | 40.5 |
| 2 | | | 0.55 | 13.75 | 15.75 | 23.75 | 25.75 | 37.5 |
| 3 | | | 0.65 | 10.25 | 13.0 | 19.0 | 21.5 | 28.0 |
| 4 | | | 0.75 | 8.25 | 9.5 | 14.25 | 14.75 | 21.5 |
| 5 | Turkish (OPC) | 2.365 | 0.45 | 14.75 | 16.5 | 25.0 | 27.75 | 40.25 |
| 6 | | | 0.55 | 13.0 | 14.75 | 22.25 | 24.75 | 35.5 |
| 7 | | | 0.65 | 9.75 | 11.25 | 17.25 | 19.75 | 27.0 |
| 8 | | | 0.75 | 8.0 | 8.75 | 12.75 | 14.25 | 20.75 |
| 9 | Leb. (OPC) | 1.754 | 0.45 | 13.25 | 15.25 | 22.75 | 26.5 | 38.25 |
| 10 | | | 0.55 | 10.25 | 12.25 | 18.0 | 20.25 | 30.5 |
| 11 | | | 0.65 | 7.25 | 9.5 | 13.5 | 16.75 | 22.5 |
| 12 | | | 0.75 | 6.25 | 7.25 | 10.75 | 12.0 | 19.5 |
| 13 | Leb. (SRPC) | 1.78 | 0.45 | 14.25 | 16.25 | 24.5 | 27.0 | 39.0 |
| 14 | | | 0.55 | 12.25 | 14.25 | 21.0 | 23.75 | 34.5 |
| 15 | | | 0.65 | 9.0 | 11.0 | 16.25 | 18.5 | 26.5 |
| 16 | | | 0.75 | 7.75 | 8.25 | 12.25 | 14.0 | 20.0 |
| 17 | Kuwaiti (SRPC) | 47.4 | 0.45 | 16.75 | 17.75 | 26.0 | 29.0 | 42.75 |
| 18 | | | 0.55 | 14.75 | 16.25 | 24.25 | 26.5 | 39.5 |
| 19 | | | 0.65 | 11.5 | 13.5 | 20.5 | 22.5 | 30.75 |
| 20 | | | 0.75 | 9.25 | 10.0 | 15.0 | 15.25 | 24.5 |

Sr. = $C_3S/C_2S$

Figures 10 to 13 show the relation between the accelerated strength (warm water method compared to proposed method) with the 7and 28-day normal strength for the OPC and the SRPC. The linear line is closer to each other for the OPC and the SRPC in 28- day normal strength than for the 7-day normal strength and it is approximately the same in the proposed method and that is referred to the proposed method correlation which is more reasonable for a less difference between the OPC and the SRPC.

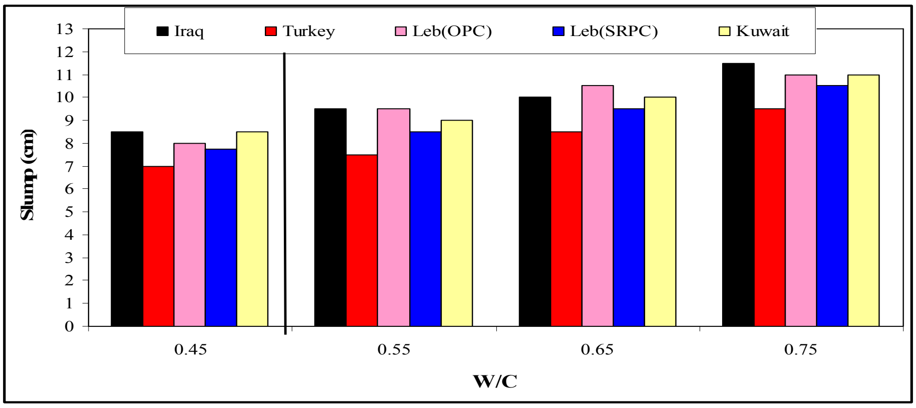


Fig. 3: Histogram for slump test for different W/C ratios.

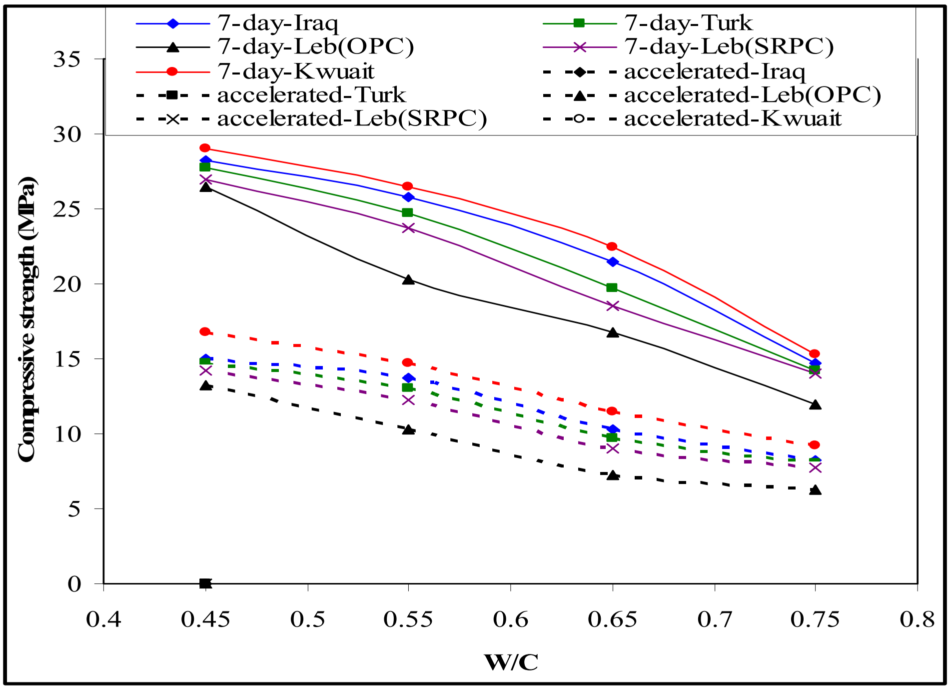


Fig. 4: Relationship between water to cement ratio and compressive strength of concrete (7-day normal strength and accelerated strength –warm water method)

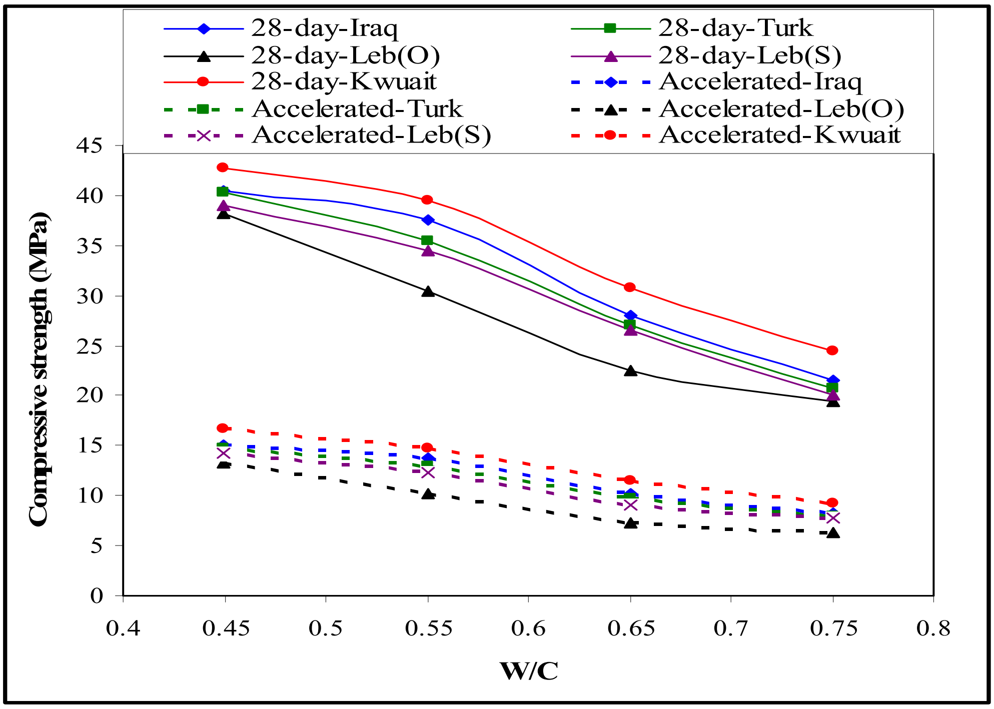


Fig. 5: Relationship between water to cement ratio and compressive strength of concrete (28-day normal strength and accelerated strength –warm water method)

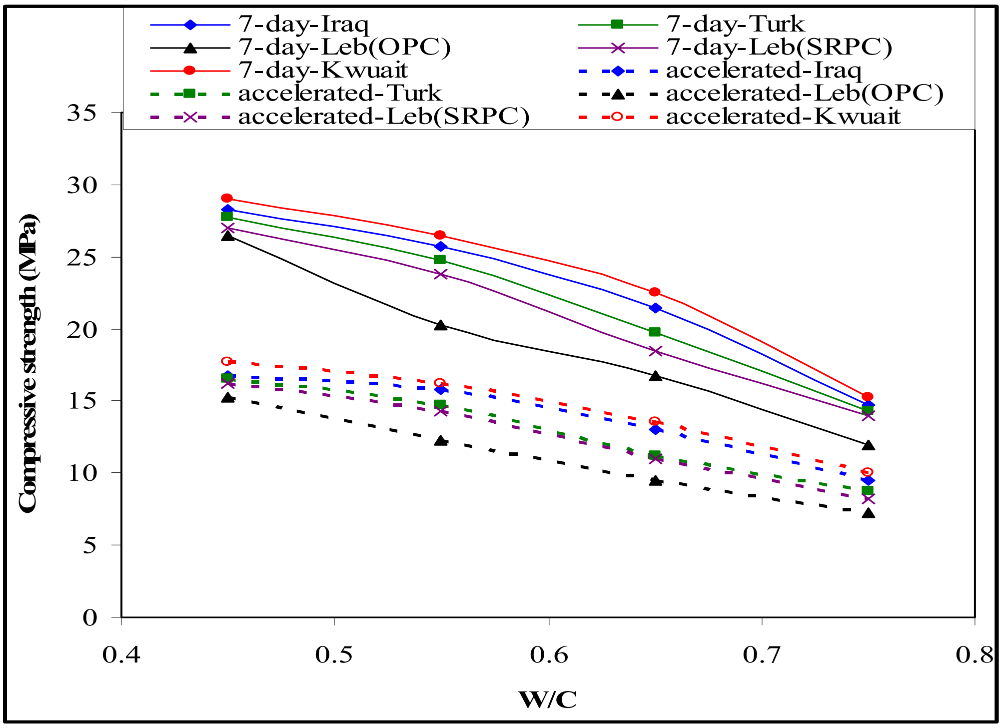


Fig. 6: Relationship between water to cement ratio and compressive strength of concrete (7-day normal strength and accelerated strength –autogenous method)

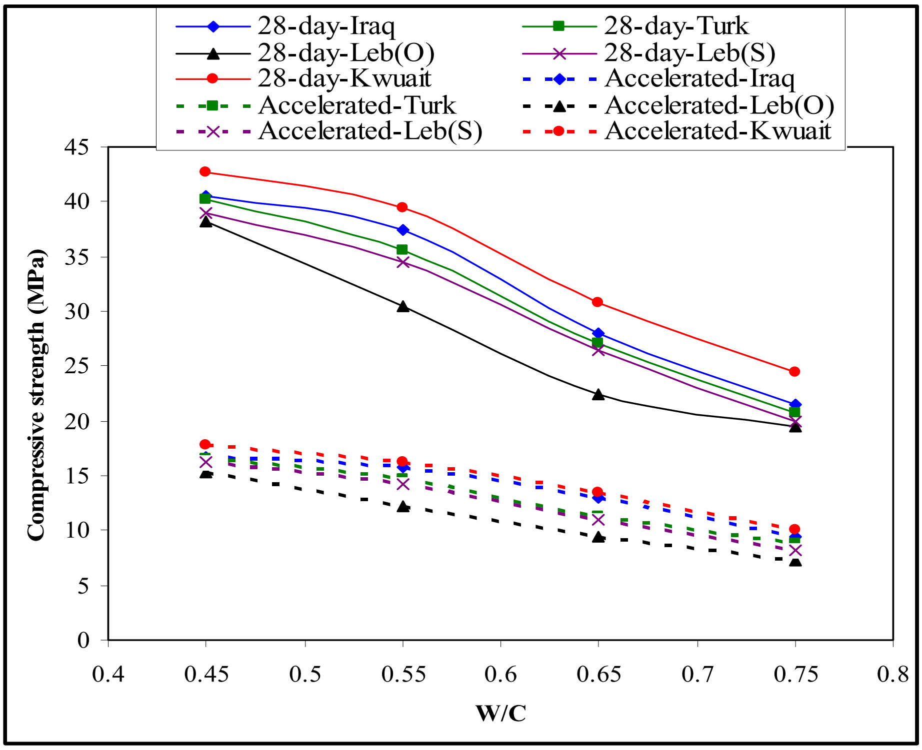


Fig. 7: Relationship between water to cement ratio and compressive strength of concrete (28-day normal strength and accelerated strength –autogenous method)

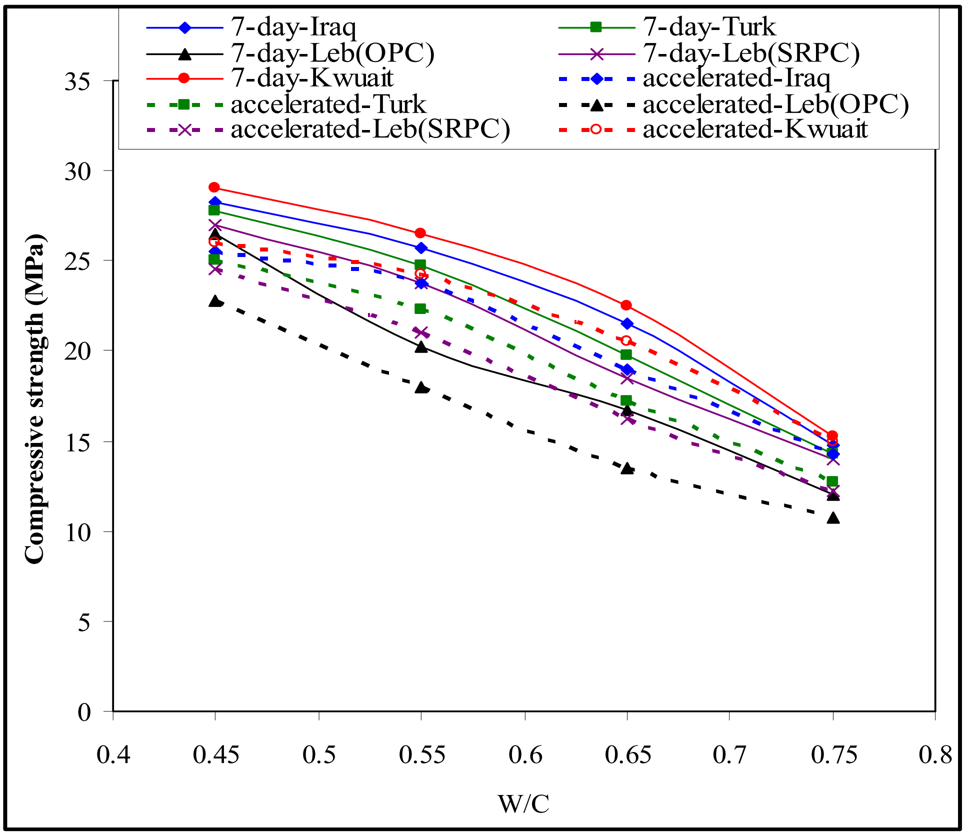


Fig. 8: Relationship between water to cement ratio and compressive strength of concrete (7-day normal strength and accelerated strength –proposed method)

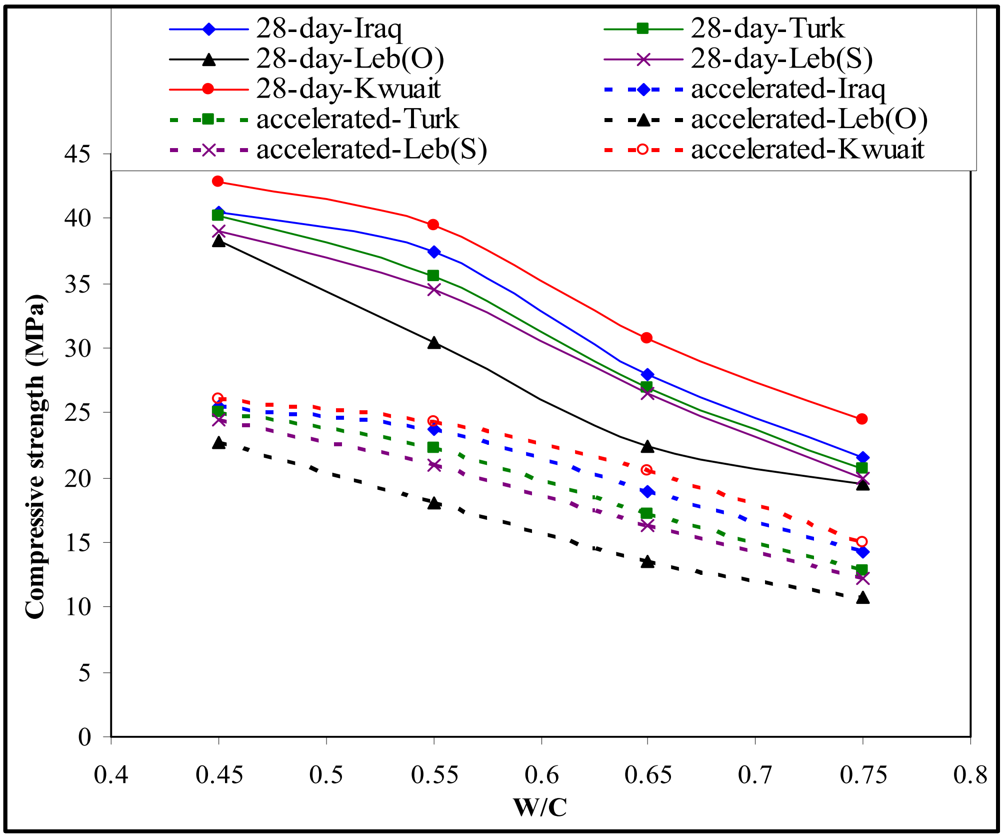


Fig. 9: Relationship between water to cement ratio and compressive strength of concrete (28-day normal strength and accelerated strength –proposed method)

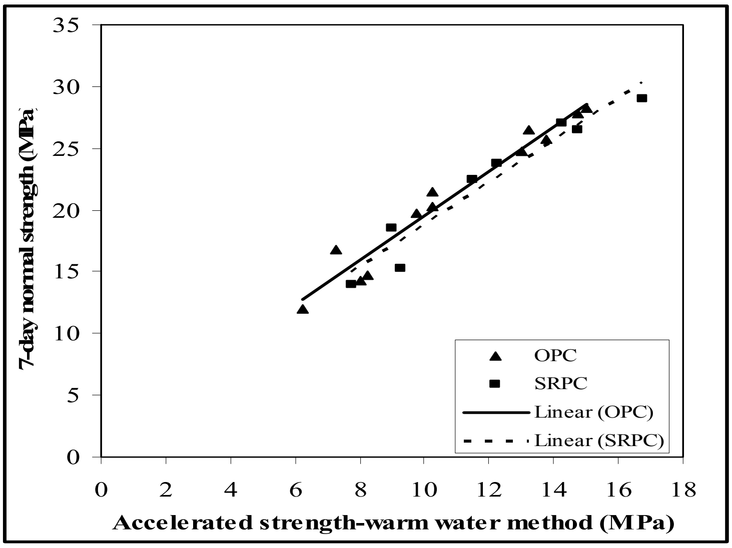


Fig. 10: Relationship between 7-day normal strength and accelerated strength using warm water method for (OPC) and (SRPC) cements.

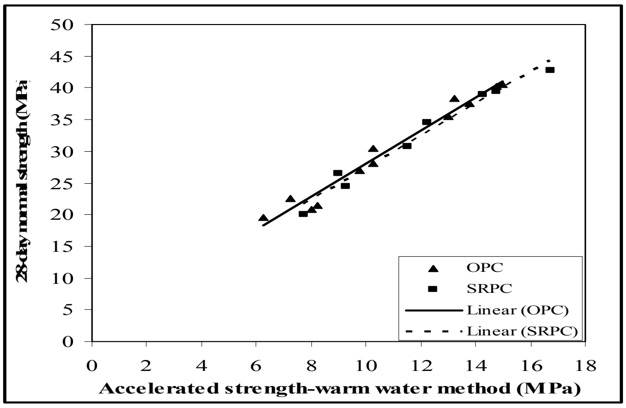


Fig. 11: Relationship between 28-day normal strength and accelerated strength using warm water method for (OPC) and (SRPC) cements.

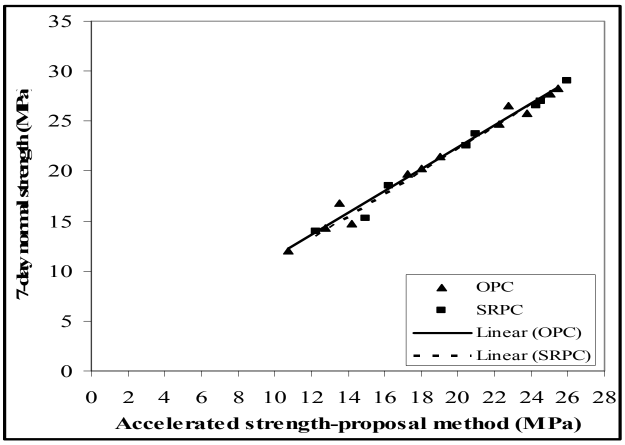


Fig. 12: Relationship between 7-day normal strength and accelerated strength –proposed method (OPC) and (SRPC) cements.

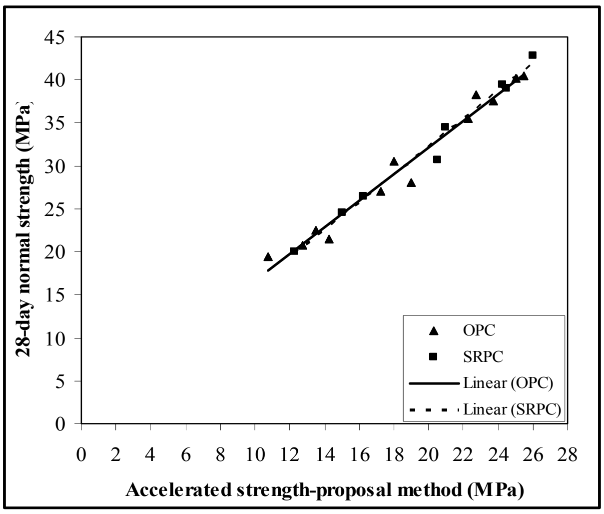


Fig. 13: Relationship between 28-day normal strength and accelerated strength using proposal method for (OPC) and (SRPC) cements.

## 4. REGRESSION ANALYSIS MODELS

The 7 and 28-day normal curing is used as the dependent variable and the accelerated curing strength is the independent variable (warm water, autogenous and proposed method). The experimental data are presented in Table 8, numbers of data enters the model is 20 in each model.

### 4.1 Descriptive Statistical Analysis

The calculated measures of central tendency and dispersion are presented in Table 10 for data enters the models.

Table 10: Descriptive statistics analysis-experimental work

| | Accelerated strength –Warm water (MPa) | Accelerated strength – Autogenous (MPa) | Accelerated strength – Proposed (MPa) | 7-day normal strength (MPa) | 28-day normal strength (MPa) |
|---|---|---|---|---|---|
| No. of data | 20 | 20 | 20 | 20 | 20 |
| Mean | 11.26 | 12.89 | 19.23 | 21.44 | 30.96 |
| Standard deviation | 3.06 | 3.26 | 4.98 | 5.50 | 7.90 |
| Variance | 9.39 | 10.64 | 24.77 | 30.29 | 62.42 |
| Minimum | 6.25 | 7.25 | 10.75 | 12.00 | 19.50 |
| Maximum | 16.75 | 17.75 | 26.00 | 29.00 | 42.75 |

No. of data = 20

### 4.2 Regression Model –Warm Water, Autogenous and Proposed Accelerated Curing Test

The regression models for linear and non linear relationship between accelerated strength (warm water, autogenous and proposed method) and 28-day normal curing strength is presented in Tables 11, 12 and 13 respectively. Tables (14), (15) and (16) respectively presents the ANOVA, $R^2$, root mean square of error and T= $\sum$residual$\times$predicted 7 or 28-day normal strength for all models.

Table 11: Linear and non linear models for 7 and 28-day normal strength – warm water method

| Model | ANOVA | | | | | $R^2$ | Root mean square of error | T value |
|---|---|---|---|---|---|---|---|---|
| | Source | D.F. | Sum of squares | Mean square | F value | | | |
| 1-L-Au. | Model(Reg.) | 1 | 568.06 | 568.06 | 1355.7 | 0.987 | 0.805 | -1.73 |
| | Error(Res.) | 18 | 7.542 | 0.419 | | | | |
| 2-Q-Au. | Model(Reg.) | 2 | 568.22 | 284.11 | 654.0 | 0.987 | 0.812 | 7.79 |
| | Error(Res.) | 17 | 7.385 | 0.4344 | | | | |
| 3-P-Au. | Model(Reg.) | 1 | 1.431 | 1.431 | 1135.18 | 0.984 | 0.188 | 18.3 |
| | Error(Res.) | 18 | .0226 | 0.001 | | | | |
| 4-L-Au. | Model(Reg.) | 1 | 1161.6 | 1161.63 | 856.93 | 0.979 | 1.079 | -2.46 |
| | Error(Res.) | 18 | 24.400 | 1.355 | | | | |
| 5-Q-Au. | Model(Reg.) | 2 | 1165.9 | 582.97 | 493.55 | 0.983 | 1.042 | -43.37 |
| | Error(Res.) | 17 | 20.08 | 1.181 | | | | |
| 6-P-Au. | Model(Reg.) | 1 | 1.321 | 1.321 | 685.82 | 0.974 | 0.209 | 46.08 |
| | Error(Res.) | 18 | .0346 | 0.002 | | | | |

Table 12: Statistical analysis for 7 and 28-day normal strength – warm water method

| Model No. | Equation |
|---|---|
| 1-L-Wr. | 7-day normal strength = 1.797+ 1.744x accelerated strength(warm) |
| 2-Q-Wr. | 7-day normal strength = -6.173+ 3.250x accelerated strength (warm) - 0.066x accelerated strength(warm)$^2$ |
| 3-P-Wr. | 7-day normal strength = 2.199x accelerated strength(warm)^ 0.941 |
| 4-L-Wr. | 28-day normal strength = 2.357+ 2.540x accelerated strength(warm) |
| 5-Q-Wr. | 28-day normal strength = -2.237+ 3.408x accelerated strength(warm) - 0.038 x accelerated strength(warm)$^2$ |
| 6-P-Wr. | 28-day normal strength = 3.321 x accelerated strength(warm)^ 0.922 |

No. of data = 20

Model 1-L-Wr. is the best for the 7-day normal strength since F value (292.77) is more than F tabulated (4.41), high $R^2$ (0.942), low root mean square of error (1.166) and the lowest T value (-0.62). Model 4-L-Wr. is the best for the 28-day normal strength since F value (578.95) is highest than others and more than F tabulated (4.41), high $R^2$ (0.969), low root mean square of error (1.187) and the lowest T value (-0.84).

Table 13: Linear and non linear models for 7 and 28-day normal strength – autogenous method

| Model No. | Equation |
|---|---|
| 1-L-Au. | 7-day normal strength = -0.171+ 1.677x accelerated strength(autogenous) |
| 2-Q-Au. | 7-day normal strength = -1.784+ 1.951x accelerated strength (autogenous) - 0.011x accelerated strength(autogenous)$^2$ |
| 3-P-Au. | 7-day normal strength = 1.605x accelerated strength(autogenous)^ 1.013 |
| 4-L-Au. | 28-day normal strength = 0.062+ 2.398x accelerated strength(autogenous) |
| 5-Q-Au. | 28-day normal strength = 8.524+ 0.967x accelerated strength(autogenous) +0.057x accelerated strength(autogenous)$^2$ |
| 6-P-Au. | 28-day normal strength = 2.567 x accelerated strength(autogenous)^ 0.974 |

Table 14: Statistical analysis for 7 and 28-day normal strength – autogenous method

| Model | ANOVA | | | | | $R^2$ | Root mean square of error | T value |
|---|---|---|---|---|---|---|---|---|
| | Source | D.F. | Sum of squares | Mean square | F value | | | |
| 1-L-Wr. | Model(Reg.) | 1 | 542.27 | 542.27 | 292.77 | 0.942 | 1.166 | -0.62 |
| | Error(Res.) | 18 | 33.33 | 1.852 | | | | |
| 2-Q-Wr. | Model(Reg.) | 2 | 547.68 | 273.84 | 166.68 | 0.951 | 1.132 | -15.7 |
| | Error(Res.) | 17 | 27.928 | 1.643 | | | | |
| 3-P-Wr. | Model(Reg.) | 1 | 1.352 | 1.352 | 241.6 | 0.931 | 0.273 | -11.36 |
| | Error(Res.) | 18 | 0.101 | 0.006 | | | | |
| 4-L-Wr. | Model(Reg.) | 1 | 1150.2 | 1150.27 | 578.95 | 0.969 | 1.187 | -0.84 |
| | Error(Res.) | 18 | 35.762 | 1.986 | | | | |
| 5-Q-Wr. | Model(Reg.) | 2 | 1152.0 | 576.03 | 288.31 | 0.971 | 1.189 | -16.93 |
| | Error(Res.) | 17 | 33.96 | 1.997 | | | | |
| 6-P-Wr. | Model(Reg.) | 1 | 1.3015 | 1.301 | 431.24 | 0.959 | 0.234 | 48.64 |
| | Error(Res.) | 18 | 0.0543 | 0.003 | | | | |

Table 15: Linear and non linear models for proposed method 7 and 28-day normal strength – proposed method

| Model No. | Equation |
|---|---|
| 1-L-Pr. | 7-day normal strength = 0.349+ 1.097x accelerated strength(proposed) |
| 2-Q-Pr. | 7-day normal strength = -0.492+ 1.193x accelerated strength (proposed) -0.003x accelerated strength(proposed)$^2$ |
| 3-P-Pr. | 7-day normal strength = 1.164x accelerated strength(proposed)^ 0.985 |
| 4-L-Pr. | 28-day normal strength = 0.792+ 1.569x accelerated strength(proposed) |
| 5-Q-Pr. | 28-day normal strength = 9.250+ 0.602x accelerated strength(proposed) +0.026x accelerated strength(proposed)$^2$ |
| 6-P-Pr. | 28-day normal strength = 1.873x accelerated strength(proposed)^ 0.949 |

No. of data = 20

Table 16: Statistical analysis for 7 and 28-day normal strength – proposal method

| Model | ANOVA | | | | | $R^2$ | Root mean square of error | T value |
|---|---|---|---|---|---|---|---|---|
| | Source | D.F. | Sum of squares | Mean square | F value | | | |
| 1-L-Pr. | Model(Reg.) | 1 | 566.24 | 566.24 | 1088.3 | 0.984 | 0.849 | -0.63 |
| | Error(Res.) | 18 | 9.364 | 0.520 | | | | |
| 2-Q-Pr. | Model(Reg.) | 2 | 566.28 | 283.14 | 516.44 | 0.984 | 0.860 | 82.11 |
| | Error(Res.) | 17 | 9.320 | 0.548 | | | | |
| 3-P-Pr. | Model(Reg.) | 1 | 1.422 | 1.422 | 827.08 | 0.978 | 0.203 | 17.08 |
| | Error(Res.) | 18 | .0309 | 0.002 | | | | |
| 4-L-Pr. | Model(Reg.) | 1 | 1159.0 | 1159.01 | 772.11 | 0.977 | 1.107 | 4.25 |
| | Error(Res.) | 18 | 27.019 | 1.501 | | | | |
| 5-Q-Pr. | Model(Reg.) | 2 | 1163.5 | 581.75 | 438.88 | 0.981 | 1.073 | -56.94 |
| | Error(Res.) | 17 | 22.53 | 1.325 | | | | |
| 6-P-Pr. | Model(Reg.) | 1 | 1.3195 | 1.319 | 654.42 | 0.973 | 0.212 | 52.97 |
| | Error(Res.) | 18 | .03629 | 0.002 | | | | |

No. of data = 20

Model 1-L-Au. is the best for the 7-day normal strength since F value (1355.7) is highest than others and more than F tabulated (4.41) , high $R^2$ (0.987), low root mean square of error (0.805) and the lowest T value (-1.73). Model 4-L-Au. is the best for the 28-day normal strength since F value is highest than others and more than F tabulated (4.41), high $R^2$ (0.979), low root mean square of error (1.079) and the lowest T value (-2.46).

Model 1-L-Pr. is the best for the 7-day normal strength since F value (1088.3) is highest than others and more than F tabulated (4.41), high $R^2$ (0.984), low root mean square of error (0.849) and the lowest T value (-0.64). Model 4-L-Pr. is the best for the 28-day normal strength since F value (772.11) is highest than others and more than F tabulated (4.41), high $R^2$ (0.977), low root mean square of error (1.107) and the lowest T value (4.25).

## 5.0 CONCLUSIONS

1. A good correlation has been obtained between a 1-day accelerated test (proposed test method) and 28 days normal curing test using a period of curing at the maximum temperature 70°C with a delay period of 4 hours, and a cooling period of 2 hours.

2. Proposed test methods give the highest accelerated strength than the others and the closer to the 7-days, due to its cycle of curing.
3. A good correlation has been obtained between a 1-day accelerated test (warm water method) and a 28 days normal curing test, with respect to the easy cycle preparation.
4. A good correlation has been obtained between a 2-day accelerated test (autogenous test method) and a 28 days normal curing test, taking into consideration that this method needs a two day accelerated curing compared with the warm water and the proposal methods.
5. Linear and nonlinear regression analysis between accelerated strength (warm water , autogenouse and proposed curing test) and normal curing strength for 7 and 28-day shows high correlation with $R^2$ more than 0.94 for different models.

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