Vol.(5),No.(3),(2017),57-66
MUTHANNA JOURNAL OF ENGINEERING AND TECHNOLOGY (MJET)
مجلة المثنى للهندسة والتكنولوجيا
Journal homepage:www.muthjet.com
Print ISSN:2572-0317, Online ISSN:2572-0325

Comparison of Non-Destructive Testing Methods of Concrete With The Aid of Maturity Concept

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ARTICLE INFO

Received:22/8/2017

Accepted:3/12/2017

Keywords
Concrete, Maturity Concept, Non destructive testing

ABSTRACT

This research aims at the evaluation of concrete compressive strength by non destructive testing techniques namely, the maturity concept test in addition to the hammer (rebound), and the ultrasonic scan tests. A comparison of results is then to be conducted to estimate the accuracy of the method. The real ability and the introduction of the maturity concept test is the main focus of this work since it takes into consideration the combined effect of temperature and age on the mechanical properties of concrete, as well as the interaction between site and laboratory testing . A total number of 14 cylinders and a square slab of 900 x 900 x 70 mm of the same mix were tested for the maturity strength relationship with heat sensors imbedded into the specimens slab and two additional cylinders also at the age of 56 days the same concrete was tested by the hammer and ultrasonic scan, the results showed good agreement giving a compressive strength of 32.2 MPa, 28.0 MPa and 29.7 MPa for the maturity, ultrasonic and hammer tests respectively.

مقارنة طرائق الفحوصات غير الاتلافية بمساعدة مفهوم الانضاج

الكلمات المفتاحية
خرسانة، مفهوم الانضاج، الفحوصات غير الاتلافية

الخلاصة

تهدف هذه الدراسة إلى ايجاد مقاومة الانضغاط بواسطة احدى تقنيات الاختبارات غير الاتلافية وهو اختبار مفهوم الانضاج بالإضافة إلى اختبار المطرقة واختبارات المسح بالموجات فوق الصوتية. و إجراء مقارنة بين النتائج لتقدير دقة الطريقة المتبعة. تركز هذه ألدراسة على اظهار المقدرة الحقيقية لمفهوم الانضاج لأنه يأخذ في نظر الاعتبار التأثير المشترك لدرجة الحرارة والعمر على الخواص الميكانيكية للخرسانة، وكذلك التداخل بين ظروف الموقع والفحص المختبري .تم اختبار 14 اسطوانة وبلاطة مربعة 900 × 900 × 70 ملم من نفس الخلطة الخرسانية لايجاد قيمة الانضاج باستخدام أجهزة استشعار الحرارة المدمجة في العينات واثنين من الاسطوانات الإضافية أيضا في سن 56 يوما من نفس الخرسانة، حيث تم اختبارهم باستخدام فحص المطرقة والموجات فوق الصوتية، وأظهرت النتائج توافق جيد يعطي بمقاومة انضغاط 32.2 ميكاباسكال، 28.0 ميجا باسكال و 29.7 ميجا باسكال للانضاج، والموجات فوق الصوتية واختبار المطرقة على التوالي .

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DOI:10.52113/3/eng/mjet/2017-05-03/57-66

Introduction:

The term (maturity) in concrete, is represented by an index that stands for the relationship between time and the concrete temperature.

Although, this concept (maturity) was used before by many authors through different studies. A useful use of this index was used here, represented by finding the concrete compressive strength through forming this relation using cylinder tests at different ages.

A correlation between the development of the maturity and the hydration degree of the used cement was found [1]. For continuous hydration, if sufficient moisture was available for the specimens, the correlation found to be good and valid. The maturity development shows no difference between beam and cylinder specimens, the air curing was more effective on the maturity strength relation of beams than cylinders.

A study was conducted to investigate the effect of type and locations of different sensors on the concrete maturity and strength. Two types of sensors were used at different portions in drilled shafts and columns (top, middle and bottom). Both sensors were found in good agreement and the choice between them should be depending on their cost or on the field conditions [2].

Also, it was found that the lower values of the in-place strength were measured at the sensors in the bottom portion of the drilled shaft and at the sensors in the top portion of the columns, for other types of structures, the strength development is not uniform since the sensor placement depends on the location of the highest loads.

In 2008, the maturity technique was used with the time and temperature history to estimate the strength of the in placed concrete under field conditions. In order to evaluate the accuracy of the adopted technique, a precast prestressed bridge deck and girder sections were mocked and monitored, and to test the in-place strength, a compression test of cast in-place cylinders, a pullout tests and core compression test were used. It was found that the maturity method may be accurate in finding the in-place strength of concrete for up to an equivalent age of seven days [3].

For the girders and the bridge deck sections, a good agreement was found between the results of the compression strength and the in-place strength using the cast in-place cylinders and the pullout test.

A reduction of the best fit strength maturity function was recommended in this study, after it has been determined for estimating the strength of the concrete. Also, using two maturity sensor (tied to the steel reinforcement but not in a direct contact way) at least for a structural parts that is subjected to exposure conditions.

Also, a study of the maturity strength relationship and the effect of mix design on it was conducted [4]. A different maturity degree with various pozzolanic substitutions and cement/aggregate content between mix designs were examined and correlated with the values of flexural strength and compressive strength using data loggers to monitor the maturity of cylinders and a test slab measuring (8 x 8 ft by 8 in) at different locations (the edges of the slab and the center).

It was found that the maturity strength relationship affected by the cementitious content with a constant w/cm ratio.

A field and laboratory test was performed using flexural beams as specimens by inserting 12 maturity sensors at different locations [5].

It was found that, to describe the strength-maturity curve, flexural strength test has a relatively low variability and lends itself well to the regression conducted.

Through this study, it was recommended that the -10 C (or 14°F) temperature should be used as a datum, also specifying the ages for the maturity curve development at 1, 2, 3, 7, 28 days for normal strength mixes.

Maturity Concept

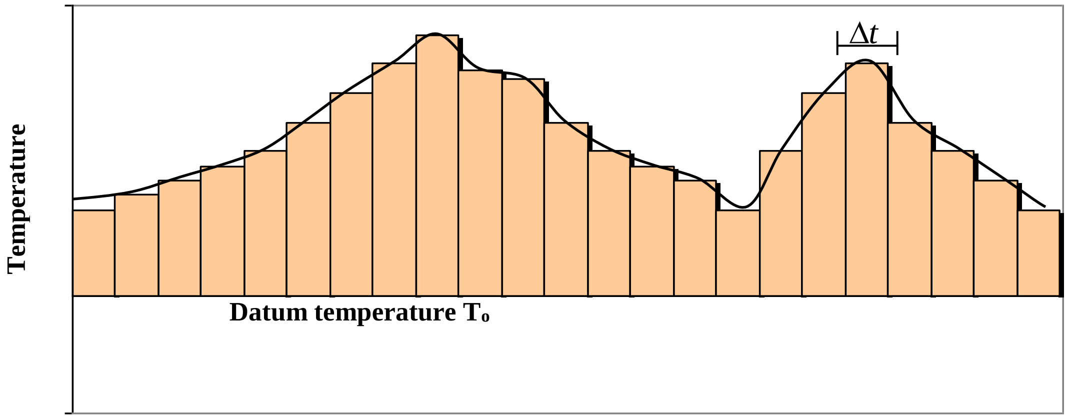
Many explanation of the maturity concept were used through different studies. Quoting from them the following:

McIntosh (1949) [6], noted that “rate of hardening at any moment is directly proportional to the amount by which the curing temperature exceeds the [datum] temperature” and defined this hardening index as “basic age”.

“Maturity is an approach to quality control that predicts the strength of the in-place concrete under any temperature condition”. And, ASTM defines the maturity method as “a technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strength if they attain equal values of maturity index”, while the pioneers of the maturity concept defines it as “concrete of the same mix at the same maturity has approximately the same strength whatever combination of temperature and time go to make up that maturity” [7].

All of these definitions gives the maturity an important role in predicting the concrete compressive strength at specific temperature.

In concrete, the product of time history and temperature above a certain datum could give a simple indication on its compressive strength, Fig. (1).



Concrete age (t)

Figure 1: Typical time – temperature relation

The datum temperature was defined as the temperature below which concrete will not harden [8]. This idea was developed in a mathematical formula to conclude finding the maturity index using the time history and temperature [9][10], this formula can be expressed as:

$$M = \sum_{0}^{t} (T_c - T_o).\Delta t \qquad \text{.................(1)}$$

Where

M: Nurse-Saul maturity index at age (t)

Tc: Average temperature for concrete during Δt

To: Datum temperature

Δt : Used time interval

This index can be used as a non destructive test which provide an early verification for the quality of the in place concrete, and reducing the cost of testing samples.

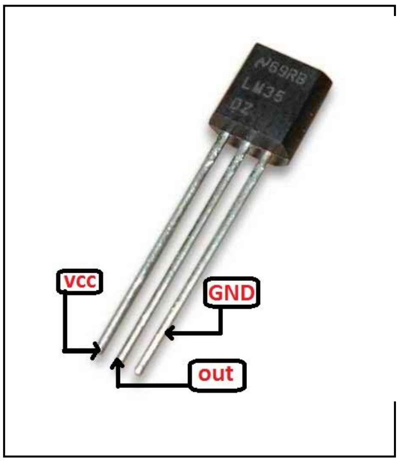
Many other maturity index functions were proposed [11], such as Exponential function, Logarithmic function and Hyperbolic function.

Experimental Program

This study contains an experimental program of casting a total number of sixteen standard cylinders (300x150) mm with a 900 x 900 x 70 mm concrete slab. Each specimen of those has an LM35 heat sensor in it.

The materials were placed in the mixer, in the order of sand, gravel, cement then water was added for 3 min mixing then the concrete were cast in the forms and after casting the samples were left for 24 hours and then moist cured (in water) for the standard curing procedure.

The mix proportions were (1:2:4/0.5) by weight. After 28 days curing the samples were taken out of water, then tested in compression using compressive testing machine shown in Fig. (2).



Heat sensor LM35

Figure 2: Machine used for compression test and the heat sensor used for taking

In order to keep the determined relation between strength and maturity appropriate for the specified mixture, a quality control of mixtures and construction techniques must be maintained.

Although, in this study, some effecting factors on the concrete strength were not taken into consideration such as: Clay fines in aggregate, inadequate moisture for curing and Air entrainment.

Materials

Cement, fine aggregates, coarse aggregates and water are used in this research for preparing ordinary concrete were as follow:

Cement

Locally available cement was used in the present study. The physical and chemical properties of cement as obtained from various tests are listed in Tables (1 and 2).

Table (1) Physical properties of used cement [12]

Test	Result	IQS:5/1984 [6]
Initial setting time (min.)	90	Min. 45 min.
Final setting time (min.)	180	Max 600 min.
Fineness (%)	280	< 230 Blaine m2/kg
Compressive Strength(MPa)		
3 days	20	Min. 15 MPa
7 days	28.8	Min. 23 MPa

Table (2) Chemical properties of used cement

Chemical Composition	Value %	Limits %	Chemical Composition	Value %	Limits %
SiO	20.3	---	CaO	62.0	---
Al_2O_3	3.82	---	MgO	2.45	5% max
Fe_2O_3	4.49	---	SO_3	0.68	2.5% max
C_3S	64.1	---	C_4AF	13.66	---
C_2S	9.84	---	C_3A	2.53	---

Fine Aggregates

Locally, available sand was used as fine aggregates for the concrete mix. Sieve analysis results of sand according to (B.S882-1992) are shown in Table (3).

Table (3): Fine aggregate sieves analysis [13]

Sieve (mm)	Passing % (B.S.) 882-1992	Passing % av. sample
9.25(3/8)	100	100
4.76 mm (No. 4)	89-100	94.5
2.4 mm (No.7)	60-100	80
1.2 mm (No. 14)	30-100	65
0.6 mm (No. 25)	15-100	57.5
0.3 mm (No. 50)	5-70	37.5
0.15 mm (No. 100)	0-15	7.5

Coarse Aggregates

Locally available coarse (20) mm maximum size was used throughout the experimental study. Sieve analysis of coarse aggregate is given in Table (4) [13].

Table (4) Coarse aggregate sieves analysis [13]

Sieves (mm)	Passing %	Passing % av. Sample
37.5 mm (11/2)	100	100
20 mm (3/4 in)	90-100	95
14 mm (1/2 in)	40-80	60
10 mm (3/8 in)	30-60	45
5 mm (No. 4)	0-10	5
2.36 mm (No. 8)	---	---
1.18 mm (No. 16)	---	---

Water

Clean and potable water was used for casting the specimens in the present study.

Results and Discussion

To apply the maturity concept through this study, heat sensors imbedded into the cylinders and a slab specimens were used, then the compressive strength was tested through different ages while the internal temperature (heat of hydration) of the specimens was recorded using a data-logger through the whole study.

Fig. (3) shows the time temperature relationship through different ages of the average of the tested cylinders (3, 7, 14, 28 and 56 days). The temperature of each day represents the average reading of each 5 minutes through this specific day.

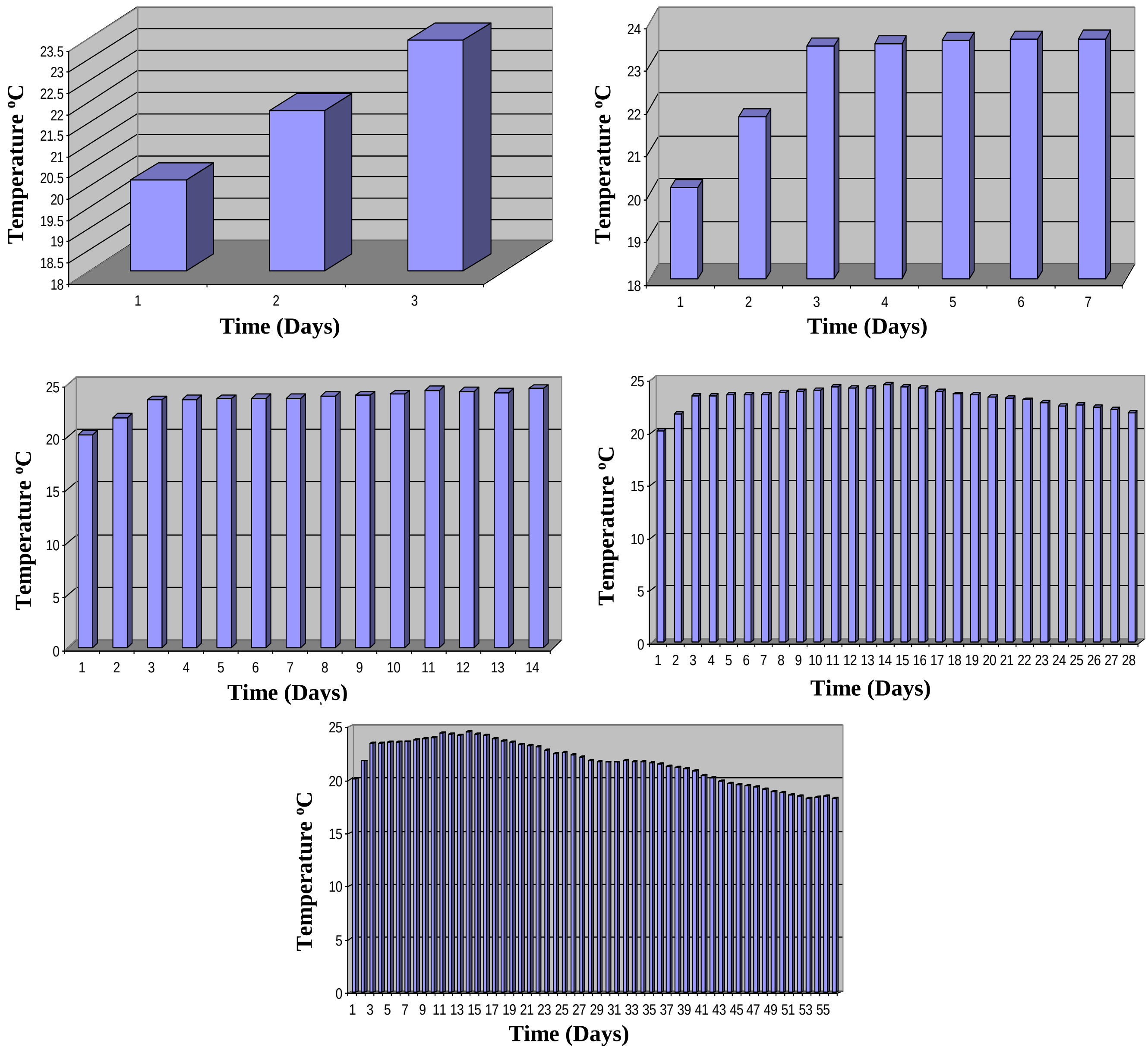


Figure 3: Time Temperature Relationship through 3, 7, 14, 28 and 56 Days

The maturity index (temperature – time relationship) was found by measuring the average concrete temperature through time intervals (hours or days), this relationship is shown in Fig. (4).

$$M_{(t)} = \sum (T_a - T_o)\Delta t$$

Where:
M(t): Factor of Temperature-Time at age (t), degree-days or degree-hours
Ta: Average temperature of concrete for time interval Δt, oC
To: Datum temperature, oC
Δt : Time interval, days or hours

The datum temperature was assumed to be 0°C according to ASTM C 1074 , if ASTM Type I cement is used without admixtures [14].

If the concrete is subjected to a lower temperature after setting, then a lower datum temperature should be used [10]. Fig. (5) shows the maturity rule, and Fig. (6) shows that for the same mixture, the maturity index for concrete cured in shorter period in a hot environment can have the same maturity index for concrete cured in longer period in a cold environment.

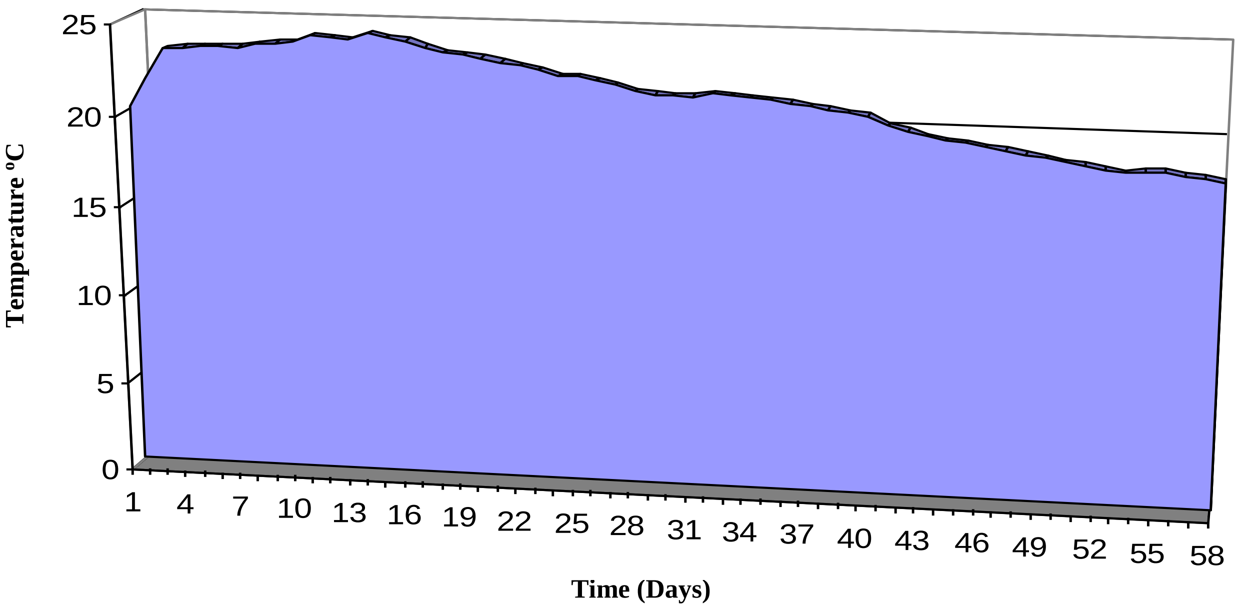


Figure 4: Time – Temperature relationship (Maturity Index)

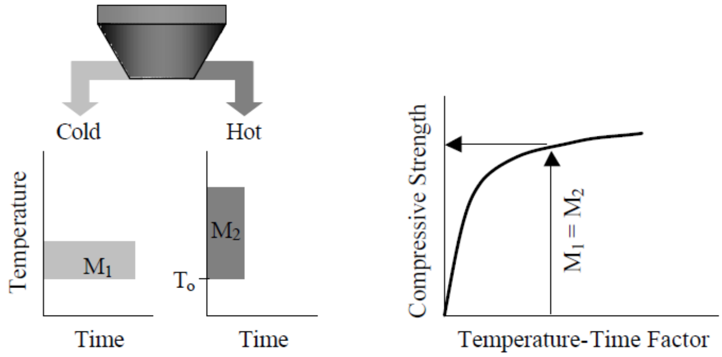


Figure 5: Saul's Maturity Rule

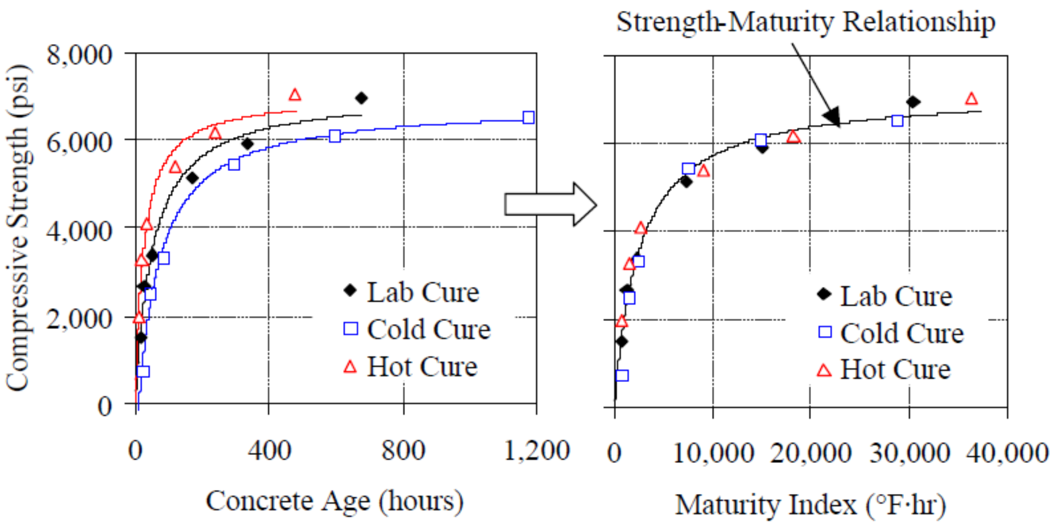


Figure 6: maturity functions convert concrete of the same mixture, cured at different temperatures [8]

The calculated maturity indices for the average of two cylinders at specified ages (2, 3, 7, 14, 28 and 56) are shown in Table (5).

Table (5) Maturity index of the cylinders at different ages

Age (Days)	Average Temp. (ºC)	Maturity Index (ºC – Days)
2	21.783015	41.92405
3	23.44737	65.372275
7	23.611765	159.657555
14	24.541665	328.74609
28	21.87522	652.490995
56	18.270835	1216.315493

By using the temperature history and the compressive strength with the maturity index shown in Fig. (7), Concrete compressive strength can be found.

Fig. (8), shows the compressive strength of the tested cylinders through different ages. As for a 28 days, the compressive strength is about 32.2 MPa.

The temperature of a slab with dimensions of 900 x 900 x 70 mm was also recorded using the data logger, and by the same procedure the time temperature relationship was found through different ages as shown in Fig. (9).

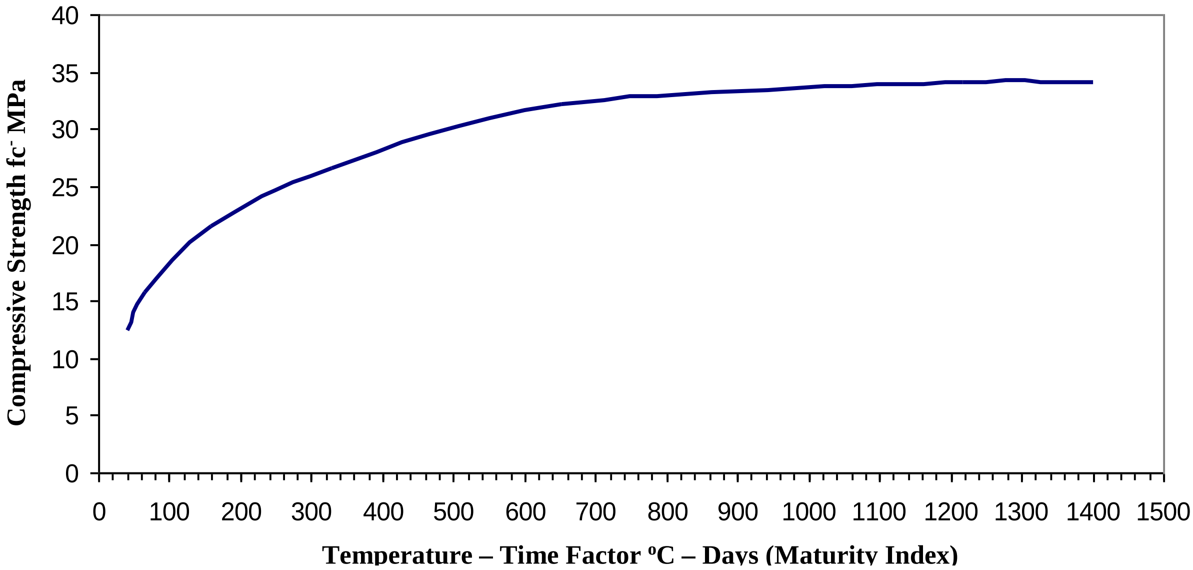


Figure 7: Strength – Maturity relationship

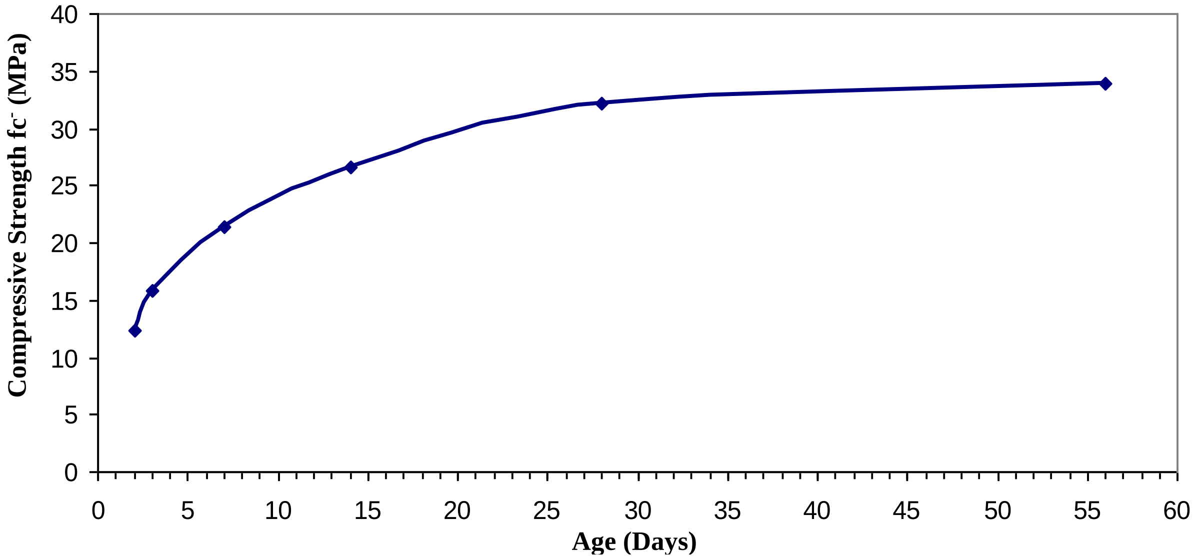


Figure 8: Compressive strength of concrete at different

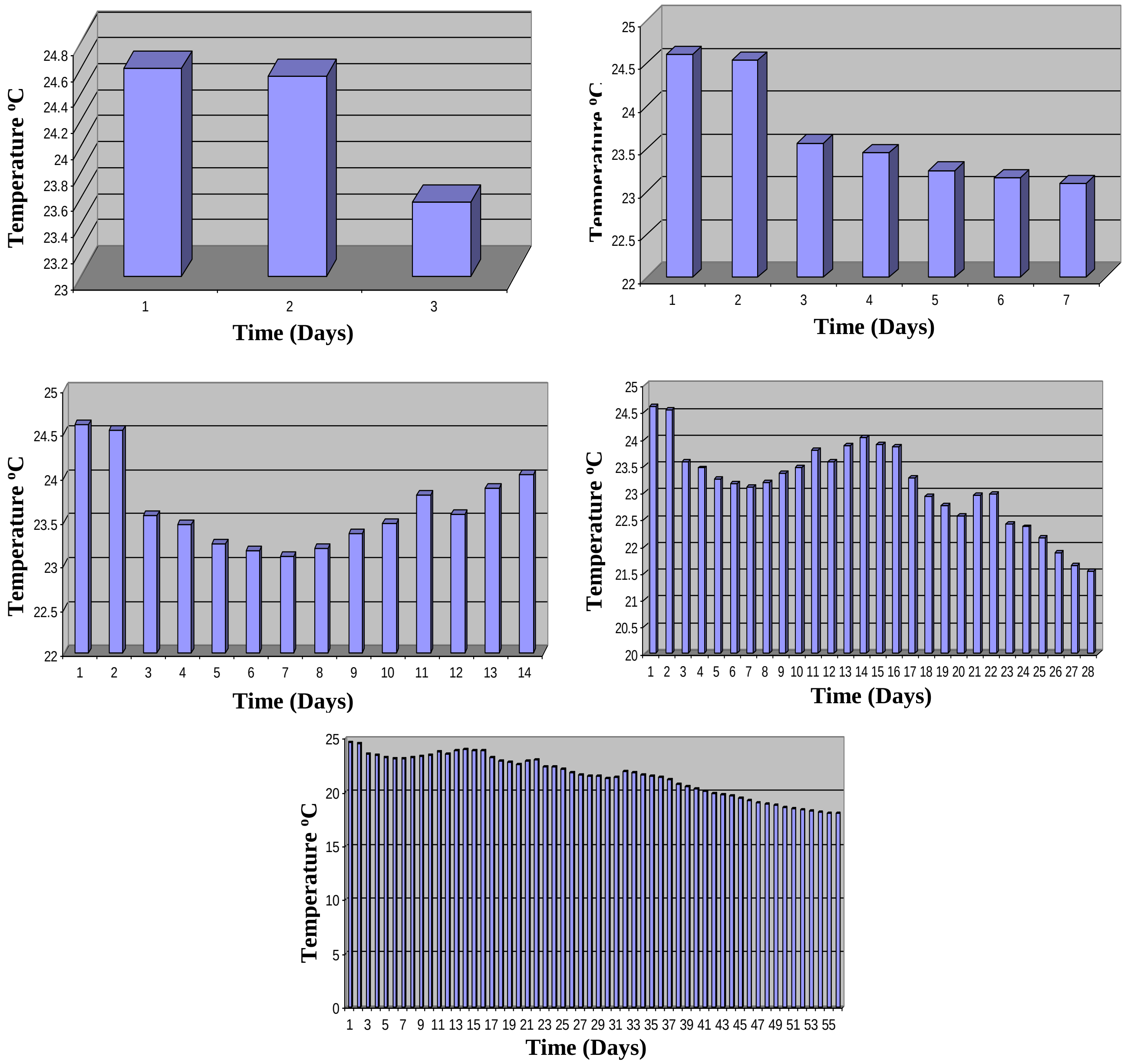


Figure 9: Time Temperature Relationship through 3, 7, 14, 28 and 56 Days For Slab Specimen

The time – temperature relationship that represents the maturity index for the slab is shown in Fig (10). From this figure, the maturity index of any age can be found. For age 28 days, the maturity index for the slab is 648.15137, Table (6).

By using this index in Fig. (7), the compressive strength is about 31.986 MPa. While using the ultrasonic test gave strength of about 28.0MPa and by using the hammer tests 29.7 MPa. A good agreement between results was found through these tests as compared to the cylinder test 32.2 MPa.

The logarithmic relationship between the maturity indices of the two ages 28 and 56 give a different of about 7.9 % from the logarithmic relation of the two compressive strength that shown in Fig. (8) of the same two ages, while this difference is about 5.6 % for the cylinders at age 28 and 14 days, as shown in Table (7).

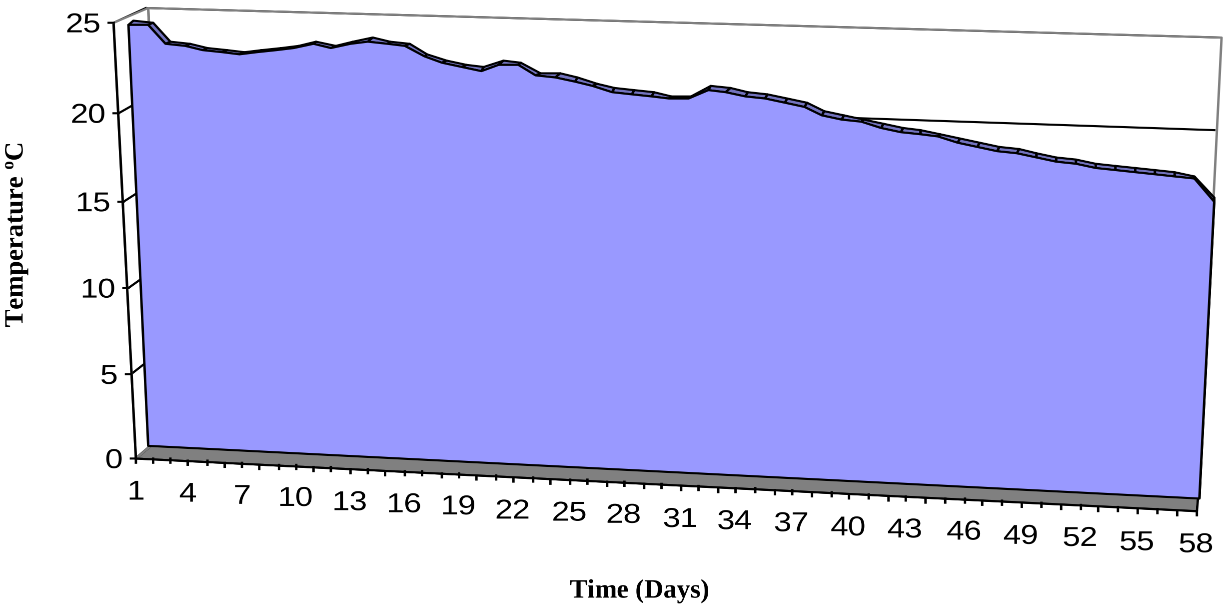


Figure 10: Time – Temperature relationship (Maturity Index) For Slab

Table(6) Maturity index of the slab at different ages

Age (Days)	Average Temp. (°C)	Maturity Index (°C – Days)
2	24.53774	49.13909
3	23.56757	72.70666
7	23.09412	165.66715
14	24.03125	330.96404
28	21.53389	648.15137
56	18.02083	1206.558161

Table (7) Compressive strength difference at different ages

Age (Days)	2	3	7	14	28	56
Compressive strength difference %	16.935	16.688	12.8	5.6	0.0	7.9

Conclusion

The maturity concept was used here to conduct the compressive strength of concrete by finding this index for a specific mixture using many specimen's tests at different ages for concrete cylinders, then this relationship between temperature-time factor (maturity index) and the measured compressive strength can be used for any other specimen such as the slab specimen that was used in this study.

The results of the predicted value for the compressive strength of the slab (31.986 MPa) shows a good agreement with other values for the compressive strength of the same slab using different tests methods like the hammer (29.7 MPa) and the ultrasonic test (28 MPa), this give a less than 8 percent difference for a predicted compressive strength value of highly edged concrete.

A slight error can be expected using the maturity index, that is the lab condition and the weather conditions might be in different, if there was not a good quality control at the construction site. So, this approach can be dependable only by ensuring a good matching between the different conditions of the construction site and the laboratory.

References

1. Scott A. Newbolds and Jan Olek November 2001. "Influence of Curing Conditions on Strength Properties and Maturity Development of Concrete", Indiana Department of Transportation and the Federal Highway Administration, Purdue University.

2. Irtishad Ahmad, et. al.,), February 2006. "Utilization of Maturity Meters For Concrete Quality Assurance", Florida Department Of Transportation (FDOT).

3. Jeffery M. Nixon, et. al February 2008.. "Evaluation Of The Maturity Method To Estimate Concrete Strength In Field Applications", Research Report No. 2, Alabama Department of Transportation,

4. Ryan J. Rohne and Bernard I. Izevbekhai, August 2009. “Demonstration of Concrete Maturity Test Process on the TH-694/ TH-35E Interchange - Unweave the Weave”, Office of Materials and Road Research Minnesota, Research Services Section, Alabama Department of Transportation,.

5. W. James Wilde. , April 2013 “Development of a Concrete Maturity Test Protocol”, Center for Transportation Research and Implementation Minnesota State University, Mankato.

6. McIntosh, J.D. 1949. Electrical Curing of Concrete. Magazine of Concrete Research. pp. 21-28.

7. Keith W. Anderson, et. al.,, April 2009 “Use of the Maturity Method In Accelerated PCCP Construction”, Report No. WA-RD 698.1, Washington State Department of Transportation.

8. Samuel Allen Wade , December 16, 2005 “Evaluation Of The Maturity Method To Estimate Concrete Strength”, M. Sc. Thesis, Auburn University, Auburn, Alabama.

9. Nurse, R. W., 1949, “Steam Curing of Concrete”, Magazine of Concrete Research, Vol. 1, No. 2: pp. 79-88,.

10. Saul, A. G. A. , 1951, “Principles Underlying the Steam Curing of Concrete at Atmospheric Pressure”, Magazine of Concrete Research, Vol. 2, No. 2: pp. 127-140.

11. Carino, N.J. and Malhotra V.M., 1991. “The Maturity Method. In Handbook on Nondestructive Testing of Concrete, eds”, CRC Press: Boca Raton, Florida. pp. 101-146.

12. IQS No. 5, 1984, Characteristics of OPC Central Agency For Standardization And Quality Control, IRAQ.

13. British Standards Institute, B.S:1992, “Aggregates from Natural Sources for Concrete”.

14. Prasad Rangaraju, “Use of Concrete Maturity For Measuring In-Place Strength of Concrete”, Department of Civil Engineering, Clemson University.