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In Situ Strength Assessment of Concrete using Maturity Method

Jenishtalouis.J, Sharanya Balki, R.Arun Prathap, Seena Simon

***Abstract:** There is a necessity for a modern method to evaluate the insitu strength of concrete thereby increasing the rate of productivity in concrete industry. This method can address immediate challenges faced such as predicting right time for formwork removal, post-tensioning, at low temperatures while the strength gain of concrete is hindered, optimizing concrete mix design and cold weather protection. The temperature is measured using wireless sensor that offers a simple solution to concrete maturity monitoring. The temperature and humidity on various days is observed. The compressive strength at 1,3,7,14 and 28 day is observed. This paper includes calculation of maturity index using Nurse-Saul equation. A graph is plot between maturity index and compressive strength. The best fit strength-maturity equation is chosen based upon the obtained curve and thereby the in-situ strength of concrete is evaluated.*

***Keywords:** cementitious paste, hydration, insitu strength, maturity index, Nurse-Saul equation*

I. INTRODUCTION

In order to save money and time in concrete industry, several methods are analyzed. Maturity method is one among those solutions that accounts for the combined effect of temperature and age on the strength gain of concrete. In-situ strength should be estimated for an efficient and speedy construction. Strength-Maturity relationship varies with respect to the concrete mix. This paper aims to introduce more efficient and ecofriendly alternative to concrete testing. Sensors used are rugged waterproof wireless sensors that allow real-time temperature and maturity monitoring of concrete. The data from the sensor can be transmitted to an app via Bluetooth technology where the data can be stored and the properties can be evaluated.

Strength of specimens cast is evaluated at particular time. Also, temperature is measured by thermometer in fresh concrete. Using the temperature data, maturity index (Nurse-Saul maturity function) is estimated for the time in which strength test is performed.

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* Correspondence Author

Jenishtalouis.J*, Department of Civil Engineering, R.M.K. Engineering College, Thiruvallur, India. Email: jeni222.louis@gmail.com

Sharanya Balki, Department of Civil Engineering, R.M.K. Engineering College, Thiruvallur, India. Email: sharanyabalki@yahoo.co.in

R.Arun Prathap, Department of Civil Engineering, R.M.K. Engineering College, Thiruvallur, India. Email: awakearun@gmail.com

Seena Simon, Department of Civil Engineering, R.M.K. Engineering College, Thiruvallur, India. Email: ssn.civil@rmkec.ac.in

$$M = \sum_{0}^{t} (T_c - T_o) \cdot \Delta t$$

where, M = Nurse-Saul maturity index at age t (°C • hours),
T_c = average temperature of concrete in time interval Δt (°C),
T_o = datum temperature (°C)
Δt = time interval (hours).
The minimum temperature after which the concrete strength does not increase is the datum temperature.

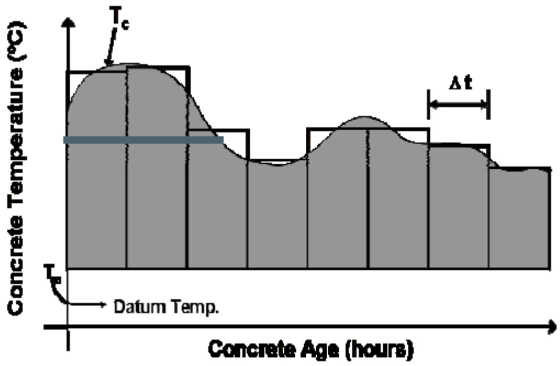

Fig. 1. Temperature-age graph

Nurse-Saul maturity index for different time interval is shown within the shaded rectangle and temperature of concrete is depicted with curved line in figure 1.

A strength-maturity relationship can be drawn using strength gain of a concrete mix and corresponding maturity indices.

Three strength maturity relationships commonly used are compared in figure 2.

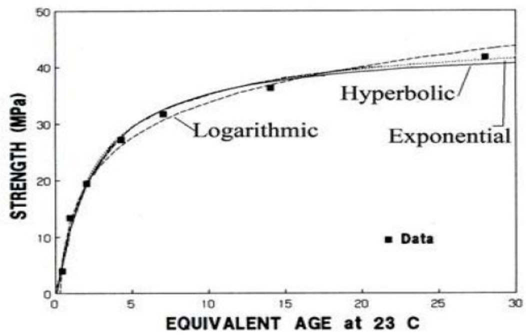

Fig. 2. Strength relationship curves

II. MATERIAL DESCRIPTION

A. Concrete

Angular, well graded coarse aggregate is used conforming to IS: 383 – 1970. Sand from nearby river is used as fine aggregate.

Grade of concrete	M30
Maximum size of aggregate	20mm
Exposure condition	Moderate
Type of Cement	OPC 43 grade
Maximum w/c ratio	0.5
Maximum cement content	450 kg/m^3
Fine Aggregate	Zone II
Specific gravity of cement	3.10
Specific gravity of fine aggregate	2.69
Specific gravity of coarse aggregate	2.72
Workability	100 mm slump

B. Concrete Sensors

Development of the concrete monitoring system can be effectively used for collection and transmission of information about concrete. These data can be used for timely adjustment of management strategies. High precision temperature and humidity sensors are used. The system uses ARDUINO as the core for developing sensors.

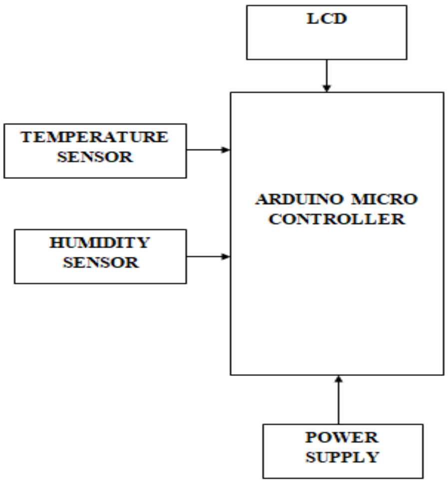

Fig. 3. Block diagram-Sensors

C. Components Required

Hardware Requirement:

- Arduino Microcontroller
- Temperature Sensor
- Humidity Sensor
- LCD
- Power Supply

Software Implementation:

- Embedded C
- Arduino IDE

Arduino board reads the input and turns it into an output which is displayed in LCD.

D. Temperature Sensor

Temperature sensor is a thermocouple or RTD , that provides temperature reading through an electrical signal. LM35 series are the integrated-circuit temperature devices (^{o}C) used in this experiment.

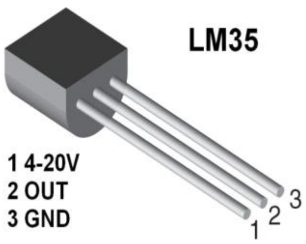

Fig. 4. Temperature sensor

E. Humidity Sensor

Humidity sensor consists of two metal plates and an insulating polymer film between them. The film changes the potential difference between the plates which is then converted into digital readings showing the level of moisture in air.

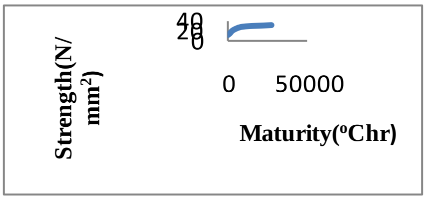

Fig. 5. Hygrometer

F. 16x2 LCD Display

It is a 16 character, 2-line alphanumeric LCD display connected to a single 9-way D-type connector.

G. Software implementation

- Embedded C
- Arduino IDE

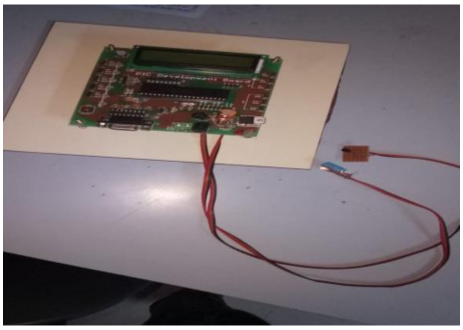

Fig. 6. Circuit connection

III. CUBE CASTING AND TESTING

Mix design is proportioned as per IS10262:2009.

Table- I: Mix Proportion

Materials	Quantity in kg (for 1m^3)
Cement	445
Fine aggregate	658
Coarse aggregate (20mm)	1125
Water	200

The mix proportion obtained is 1: 1.5: 2.5: 0.45 (Cement, sand, Coarse aggregate, Water). Using the above mix proportion, 16 specimens of 150x150x150mm size are cast in which 15 cubes are used for compression test breaks and 1 cube is used for temperature monitoring.

Concrete is filled into the mould in 3 layers and each layer is compacted by hand. Standard tamping rod is used for compaction.

The specimens are removed after 24 hours of casting and then cured under fresh water. Water, in which the specimens are cured, is changed every seven days. The specimens are removed from the curing tank and dried before testing. Cubes are then tested in UTM to obtain compressive strength values.

Fig. 7. Casting of cubes

IV. RESULTS AND DISCUSSIONS

A. Sensor readings

Table-I: Temperature-humidity reading

Day	Temperature (°C)	Humidity (%)
1	14	65
2	18	21
3	20	17
4	21	13
5	21	12
6	22	12
7	23	12
8	25	12
9	26	12
10	27	11
11	27	11
12	28	11
13	29	11
14	29	11
15	30	11
16	31	11
17	33	11
18	35	10
19	36	10
20	37	10
21	37	10
22	38	10
23	38	10
24	39	10
25	39	10
26	40	10
27	40	10
28	41	10

B. Maturity Index values

The formula used for finding the maturity index is:

$$M = \sum_{0}^{t} (T_c - T_o) \cdot \Delta t$$

- The datum temperature adopted for calculations is 0°C. The time interval is taken in hours. The unit of maturity index is taken as (°C hr)
- Maturity Index for Day 1 (24 hours)
  M_1=(14-0) * 24 = 336
- Maturity Index for Day 3 (72 hours)
  M_3=(20-0) * 72 = 1440
- Maturity Index for Day 7 (168 hours)
  M_7=(23-0) * 168 = 3864
- Maturity Index for Day 14 (336 hours)
  M_{14}=(29-0) * 336 = 9744
- Maturity Index for Day 28 (672 hours)
  M_{28}=(41-0) * 672 = 27552

C. Strength table

Strength = failure load/area
Area = 0.15*0.15 = 0.0225 m^2

Table-II Compressive Strength Test Results

Day	Compressive strength of each specimen (MPa)			Average compressive strength (MPa)
	1	2	3	
1	8.8	8.977	8.266	8.681
3	10.666	12	11.511	11.392
7	18.888	19.022	19.333	19.081
14	26.666	25.2	25.688	25.851
28	28.888	29.6	28.666	29.051

D. Strength Vs Maturity index Relationship

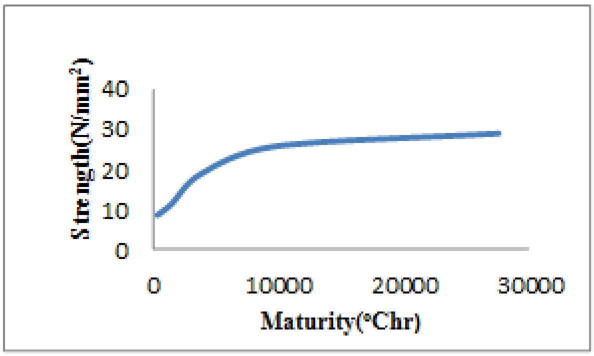

Fig 8 Strength Maturity graph

E. Estimation of in-situ strength

The curve obtained in graph (Figure 13) resembles to the hyperbolic curve in Fig 2. Hence the hyperbolic curve is adopted as the best fit curve and its corresponding equation is used to estimate the in situ compressive strength.
The hyperbolic strength equation is:

$$S = S_u \frac{k(M - M_0)}{1 + k(M - M_0)}$$

To calculate the strength, we need to determine the rate constant (k) value. Rate constant is the strength-maturity curve slope obtained in fig 8. There are various methods to find the slope of the curve, but we have chosen Newton's forward interpolation method as it satisfies all points on the curve.
The value of rate constant calculated using Newton's forward interpolation method is 1.151 x 10^{-3}. Rate constant and other values can be substituted in the hyperbolic strength equation. An example is illustrated for better understanding.
Strength on 21st day,
M_{21} = (37-0) * 504 = 18648 = M (as per formula)
M_0 = 336
k = 1.151 x 10^{-3}
S_u = 29.051 MPa
S_{21} = [29.051* 1.151 * 10^{-3} * (18648-336)] / [1+(1.151 * 10^{-3})*(18648-336)]
= 612.31/22.077
= 27.73 MPa

The strength value obtained from the graph (28.5 MPa), the 21st day laboratory compressive test result of the cube (28.3 MPa) and strength estimated using hyperbolic equation (28.41 MPa) are all coinciding. Hence this method will be very effective in assessment of in-situ strength.

V. CONCLUSION

This experimental investigation provides us with an introduction to the maturity method for estimating in-situ strength gain of concrete. Proper usage of this simple method can result in safe and speedy construction operations.

1. Strength-maturity relationship (figure 8) shows that the in-situ concrete has the expected strength potential. This shows that the maturity method is more reliable in estimating strength gain than absolute strength.
2. Maturity function is related to initial temperature and is obtained by measuring the variation of rate constant with respect to curing temperature.
3. Linear hyperbolic function is generally recommended to analyze strength-age data and to determine the rate constants at different curing temperatures.
4. The logarithmic strength-maturity relationship should be used with caution.

REFERENCES

1. McIntosh, J.D., "Electric Curing of Concrete", Magazine of Concrete Research, Vol. 1, No. 1, January 1949.
2. Nurse, R.W., "Steam Curing of Concrete", Magazine of Concrete Research, Vol. 1, No. 2, June 1949.
3. Saul, A.G.A., "Principles Underlying of the Steam Curing of Concrete at Atmospheric Pressure", Magazine of Concrete Research, Vol. 2, No. 6, March 1951.
4. Plowman, J.M., "Maturity and the Strength of Concrete", Magazine of Concrete Research, Vol. 8, No. 22, March 1956.
5. Alexander, K.M. and Taplin, J.H., "Concrete Strength, Paste Strength, Cement Hydration and the Maturity Rule", Australian Journal of Applied Science, Vol. 13, 1962.
6. Parsons, T.J. and Naik, T.R., "Early Age Concrete Strength Determination by Maturity" Concrete International, February 1985.
7. Carino, N.J., "The Maturity Method", In Handbook on Non Destructive Testing of Concrete, CRC Press, Inc., Boca Raton, Florida, 1991.
8. IS 456:2000 Code of Practice for Plain and reinforced concrete, Bureau of Indian Standards, New Delhi.
9. IS 10262: 2009,'Recommended Guidelines for Concrete Mix Design', Bureau of Indian Standards, New Delhi, India.

AUTHORS PROFILE

Jenishtalouis.J has more than 4 years of teaching experience. She has obtained her B. E. Civil Engineering from University College of Engineering, Nagercoil campus and M.E. Construction Engineering and Management from College of Engineering-Guindy Campus. She has secured First Rank (Gold medal) in both UG and PG programme. She has guided many under graduate projects.She has published papers in several national and international journals and Conferences. She has attended several workshops, seminars, faculty development and training programs. She is a life member of Indian Society for Technical Education(ISTE).

Sharanya Balki has more than 7 years of teaching and research experience. She has obtained her B.E. Civil Engineering from Bannari Amman Institute of Technology, Sathyamangalam and M.E. degree in Hydrology and Water Resources Engineering from College of Engineering, Guindy. She is a Anna University rank holder. She has several publications in referred international and national journals and in various conferences. She has been certified with Elite Grade as toppers for online courses by NPTEL. She is a lifetime member of Indian Society of Technical Education.

R.Arun Prathap has more than 10 years of teaching and industrial experience. He has obtained his B.E. Civil Engineering from Institute of Road and Transport Technology, Erode and M.E. Hydrology and Water Resources Engineering from College of Engineering, Guindy. He has worked as a Site Engineering in Consolidation Construction Consortium Limited, Chennai. He has guided undergraduate projects and published papers in International Journals and conferences. He has been certified with Elite Grade as topper for two online courses by NPTEL. He is a lifetime member of Indian Society of Technical Education.

Seena Simon is working as Assistant Professor in R. M. K. Engineering College, Kavaraipettai. She has obtained B.Tech in Civil Engineering from Calicut University in 2009. She obtained M.E in Structural Engineering from Anna University in 2012. She is a life member of ISTE.