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Lesson 3: Is the Maturity Concept Valid?

By L. K. Crouch and T. Adam Borden

Introduction

The recent TDOT/TCA/ACPA Evaluation of New PCC Maturity Technology Project generated a large quantity of data. The data generated can be analyzed to provide valuable lessons about PCC behavior. This paper is the third in a series of technology transfer articles. The authors appreciate the financial support of TDOT and TCA. We hope you find the information presented helpful in better understanding PCC behavior. In the third article, the validity of the maturity concept is discussed.

Maturity Background

Portland cement concrete (PCC) gains strength and durability from reactions between Portland cement, supplementary cementing materials and water. The continuation of the chemical reactions is commonly termed curing. Curing progress is most commonly measured with compressive strength development. Curing progress is a function of time, temperature and moisture conditions. Provided that adequate moisture is available, curing progress is a function of time and temperature. The maturity index is a function of time and temperature. Nurse and Saul [1] performed some of the early research on the maturity concept and suggested the following equation.

$$M = \sum_{0}^{t} (T - T_0)\Delta t$$

Where: M = maturity index
T = average concrete temperature during time Δt
T_o = datum temperature (usually -10°C (14°F)) (2)
T = elapsed time hours
Δt = time interval (hours)

Just as depressing the accelerator on a vehicle makes the vehicle speed up; increasing the curing temperature makes the chemical reactions in PCC speed up. To continue the analogy, the maturity index measures the progress of curing like mile markers on an interstate measure the distance the vehicle has traveled. The maturity index is simply an alternative to compressive strength development for measuring the progress of PCC curing.

Materials and Procedure

The validity of the maturity concept was evaluated by casting 120 6x12 cylinders [3] from 1.25 cubic yards of TDOT Class A PCC and curing them at different temperatures encompassing the TDOT specification limits [4, 5, 6]. Plastic properties of the PCC are shown in Table 1. Immediately after casting, the cylinders were placed into respective storage tanks and the loggers were activated (see Figure 1). The limewater level in the tanks was elevated to the tops of the cylinder molds to ensure acclimation to the desired curing temperature as quickly as possible. At approximately 800°C-Hrs, the molds were removed and the limewater level was elevated to completely immerse all specimens within each tank.

Figure 1. Activation of Maturity and Temperature Loggers

Table 1. Plastic Properties of the Laboratory Evaluation Mixture

Property	Result	TDOT Specification [11]
Slump [7]	2 inches	0.5-2
Air Content [8]	6.1 %	3-8
Unit Weight [9]	143.2 pcf	No requirement
Temperature [10]	43 °F	50-90

The three curing temperatures used were 90, 73.4 and 45°F (32, 23, and 7°C). Thirty of the 120 cylinders were cured at each temperature. The remaining thirty cylinders began in the 90°F bath and changed curing temperatures approximately every 8 hours as shown in Figure 2. The rotation of cylinders in different curing temperature tanks was intended to simulate a daily cycle of temperature changes.

Testing protocol and approximate test ages in days, estimated using the Nurse-Saul equation with a datum temperature of 14°F (-10°C) are shown in Table 2. The predetermined maturity indices for compressive strength testing were based on standard curing [5] for 1, 2, 3, 4, 5, 7, 14 and 28 days. Two 6x12 cylinders in each group contained maturity loggers and two of each group contained temperature loggers. Actual maturity indices for compressive strength testing were determined by averaging the values from the two maturity loggers. During the experiment, one maturity logger failed to perform and those logger values were no longer recorded for experimental use.

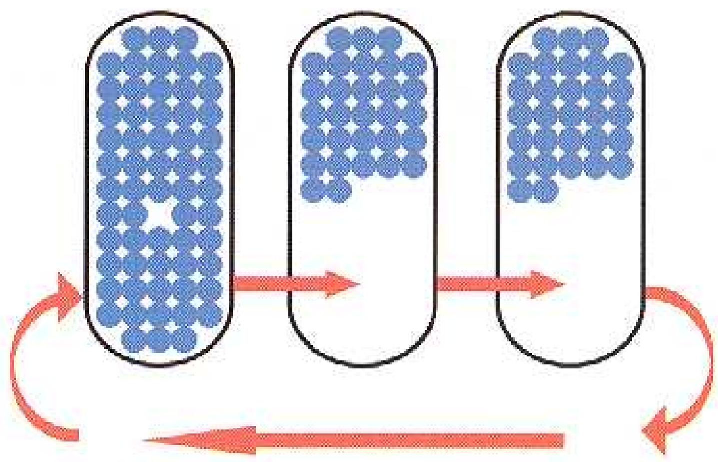

Figure 2. Schematic of Curing Tank Set-up and Rotation of Variable Cylinders

Table 2. Testing Schedule for Laboratory Experiment

Approximate Maturity Index (°C-Hrs)	Neoprene Durometer	Approximate Age of Hot (90 +/- 3 °F) (4) Cure Tank Specimens (Days)	Approximate Age of Standard 73.4 +/- 3 °F (5) Cure Tank Specimens (Days)	Approximate Age of Cold 45 +/- 3 °F (6) Cure Tank Specimens (Days)	Specimens Tested
800	50	0.8	1	2	2
1600	50	1.6	2	4	2
2400	60	2.4	3	6	3
3200	60	3.2	4	7.8	3
4000	60	3.9	5	9.7	3
5500	60	5.4	7	13.3	4
11000	60	10.9	14	26.6	3
22000	60	21.7	28	53.3	6

The laboratory storage tanks (depicted in Figure 3) were insulated on all surfaces to retain the desired temperature and equipped with two circulation pumps in either end. Each tank was also equipped with a steel grate placed upon masonry bricks (see Figure 4) to keep the cylinders exposed to the limewater conditions on all surfaces. A single tank heater provided the heat for the 90°F and 73.4°F tanks, while the installation of a circulation chiller (see Figure 5) was required for the 45°F tank. The chiller circulated a mixture of antifreeze and water through copper piping directly beneath the steel grating (see Figures 6 & 7).

Figure 3. Laboratory Storage Tanks

Results

A summary of the results of the laboratory evaluation of the new maturity technology are shown in Table 3 and Figure 8. Temperature profiles for the constant temperature and variable temperature cylinders are shown in Figures 9 and 10, respectively.

Table 3. Average Compressive Strengths for Each Approximate Maturity Index

Approximate Maturity Level (°C-hours)	45°F Cylinders TDOT Lower Curing Temperature Limit	73°F Cylinders AASHTO Standard Curing Temperature	90°F Cylinders TDOT Upper Delivery Temperature Limit	Variable Temperature Cylinders
800	1048	1606	2048	1879
1600	1969	2710	2597	2705
2400	2922	3035	3026	3013
3200	3229	3444	3221	3492
4000	3757	3568	3595	3737
5500	4288	3785	3931	4099
11000	5192	4837	5055	4742
22000	6150	5678	6132	6015

Figure 4. Grate supported by bricks

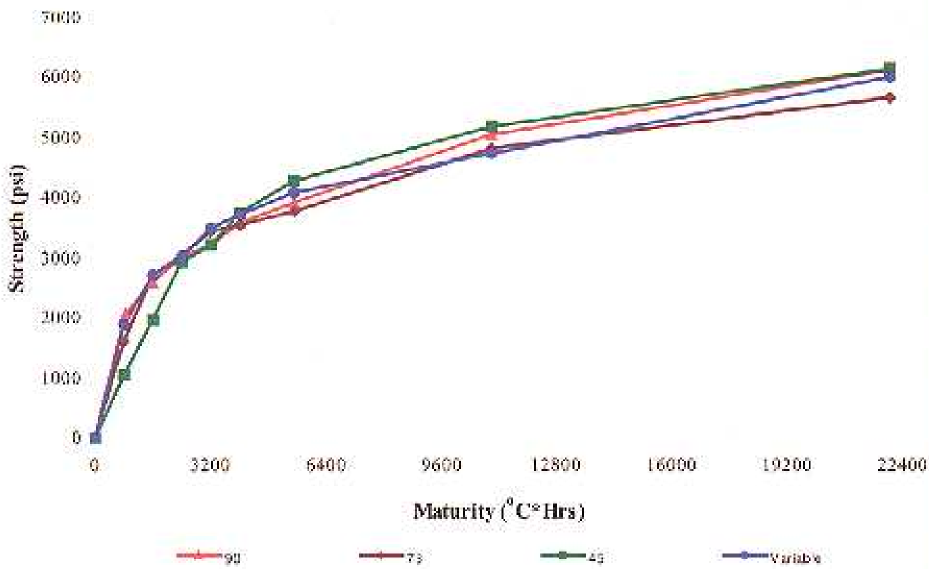

Figure 8. Compressive Strength vs. Maturity at Various Curing Temperatures

Figure 5. 45°F Tank Chiller

Figure 6. Copper Circulation Tubing

Figure 7. Close-up of Circulation System

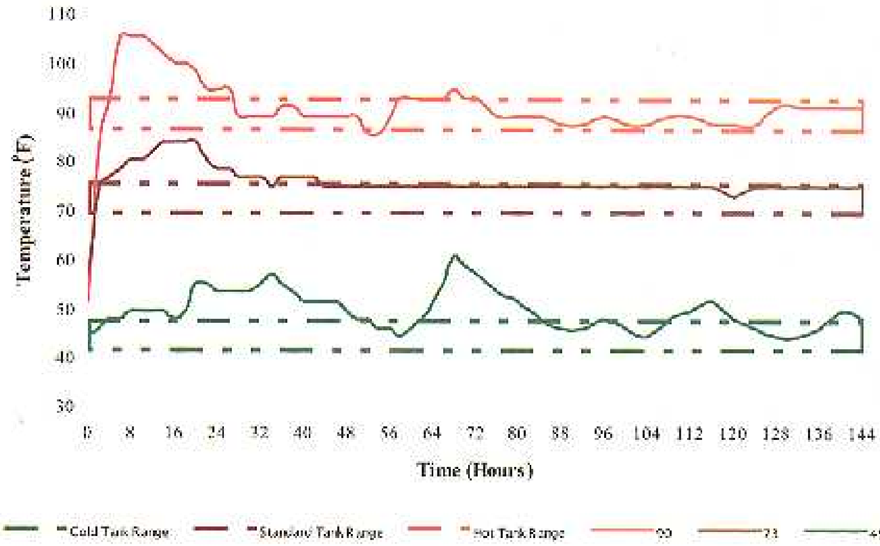

Figure 9. Temperature Logger Profiles for 90, 73 and 45° F Cylinders

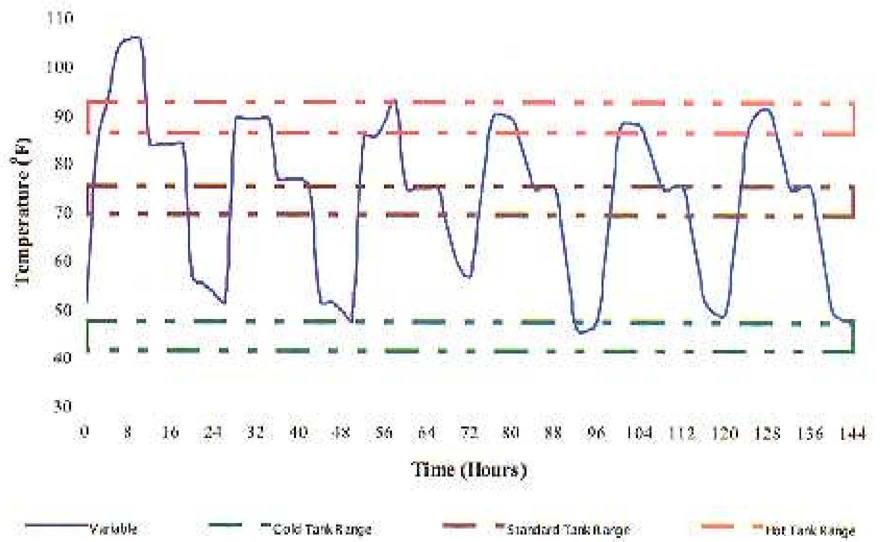

Figure 10. Temperature Logger Profiles for Variable Temperature Cylinders

Analysis of Results

The agreement between average compressive strengths obtained at various maturity indices from different curing regimes is shown in Table 4. The difference between compressive strengths of 6x12 cylinders lab-cured at temperatures between 45 and 90°F is in the range of 3.8 to 12.5% for maturities greater than or equal to 2400°C-hours. At lower maturity indices the difference is much greater. Table 5 shows combinations of time and degrees Fahrenheit that are equivalent to 2400°C-hours.

Table 4. Comparison of Average Strengths at Each Approximate Maturity Level

Approximate Maturity Level (°C-hours)	Range (High Result – Low Result)	Range as a Percent of the Mean Result
800	1002	60.9
1600	741	29.7
2400	113	3.8
3200	271	8.1
4000	189	5.2
5500	503	12.5
11000	450	9.1
22000	472	7.9

Table 5. Time and Fahrenheit Temperatures Equivalent to 2400°C-hours

Temperature (°F)	Time Required (days / hours / minutes)
90	2 days 9 hours 9 minutes
73	3 days 0 hours 44 minutes
68	3 days 8 hours 0 minutes
45	5 days 21 hours 11 minutes

Lesson Summary

Based on the available data, the following conclusion can be drawn. The maturity concept is valid for temperatures between 45 and 90°F (within TDOT curing temperature specifications) at maturities greater than or equal to 2400°C-hours. ■

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