Center for Transportation Research
The University of Texas at Austin

CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

Project Summary Report 1714-S
Investigation of Match-Cure Technology and the Maturity Concept as New Quality Control/Quality Assurance Measures for Concrete

Authors: Russell J. Kehl, Cesar A. Constantino, and Ramón Carrasquillo
August 1998

PROJECT SUMMARY REPORT

Match-Cure and Maturity: Taking Concrete Strength Testing to a Higher Level

In the concrete industry, an owner buys quality-control specimens but pays for structural members. This practice can be a problem, given that the acceptance criteria may be less concerned with the quality of concrete in the member and more with the strength of the concrete in the quality-control specimen. However, new technologies can close the gap between these separate entities.

Maturity has been shown to be an excellent indicator of in-place strength development and quality from fresh to hardened concrete. The concept is based on the fact that temperature is a critical factor in the progress of cement hydration and thus of strength development of concrete, especially at early ages. The maturity of concrete is determined by multiplying an interval of time by the internal temperature of the concrete in question. This product is summed over time, and the maturity of the concrete is equal to the sum of these time-temperature products.

Match-cure technology harnesses the maturity concept to the curing of quality-control specimens, resulting in quality-control specimens that are representative of the in-place concrete. The quality-control specimens experience the same temperature profile over the same time period as the actual concrete member and have a maturity equal that of the concrete in the member. The match-cure procedure is best applied for release strengths of precast prestressed concrete members.

What We Did...

Match-Cure Technology

The research work plan included collecting temperature data from precast members in the field and investigating the effect of curing temperatures on the compressive strength, modulus of elasticity, and permeability.

The internal temperatures generated in a member are affected by several factors, the most important being type and quantity of cementitious materials, ambient temperature, and member size. Two normal-strength concrete (NSC) mixes were evaluated. The first mix was a six-sack mix with no fly ash. The second was a modification of the first containing 25 percent cement replacement with fly ash. Consistency was controlled from mix to mix by keeping the slump at about 2.5 inches. A high-strength concrete (HSC) mix having a slump of 8 inches was also evaluated.

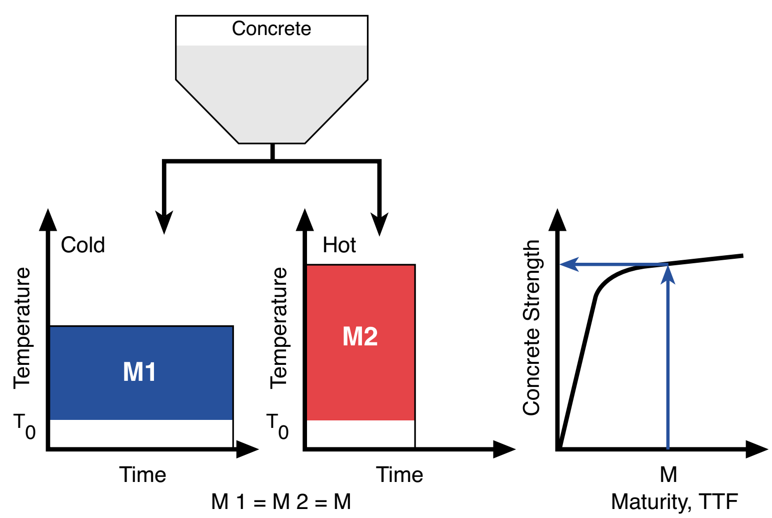
A match-cure system was used that allows the user to cure cylinders following a specified temperature profile, either a reference temperature profile being monitored simultaneously or a temperature profile programmed by the user. A PC is used to monitor the temperature of the match-cure cylinders and guide the input/output unit in regulating the power needed to heat the concrete in special cylinder molds.

Temperatures in the precast prestressed beams were measured using shielded thermocouples placed at various locations within the cross-section along the beam. The thermocouple arrangement was modified as the critical temperature regions of the section were identified.

Temperatures were also measured within the standard quality-control cylinders that were cured directly next to the member. This measurement was done to determine the curing temperature differences between the standard quality-control specimens and the actual concrete in the member.

A temperature profile model was developed from this data. This model provided consistent temperature profiles that could be used for curing specimens in the laboratory. By curing specimens using the same temperature profiles every time, comparisons could be made of the concrete characteristics from different casting dates. This model was not developed to predict member temperatures in the field; it represented only a typical temperature profile from the field. The model did not fit every curve exactly, but it did fit most of the curves in general.

After collection of 24-hour release data and design data from specimens made and cured in the field, laboratory testing was performed to verify the field data. The field specimens were cured using actual member temperature profiles that were being monitored simultaneously with the curing of the specimen. The laboratory specimens were cured using the model temperature profile that was developed from actual field temperatures. The data were



Saul's maturity rule using temperature-time factor then compared to determine the effect of curing temperatures on the 24-hour release characteristics of precast concrete.

Maturity Method

During the first of three phases, strength-maturity curves were generated in the laboratory for various concrete mixtures. These mixtures were selected because they were already approved for use in several TxDOT projects including the North Central Expressway in Dallas, IH 30 in Ft. Worth, and IH 10 in E1 Paso. During the second phase, maturity meters were used in the field to monitor maturity values and compare the maturity predicted strength values with those from the conventional quality-control specimens. In the third phase, specifications were developed to address implementing maturity technology in highway applications.

The strength-maturity relationships for five mixtures approved for use in the US 75 North Central Expressway S-2 Project in Dallas, Texas, were generated following ASTM C 1074-93. Approximately 4 yd^3 of each concrete mixture were delivered to the laboratory by the ready-mix producer. The 105 standard 6 x 12 inch cylinder specimens were cast to allow for testing three cylinders at each test age for each mix. Along with the standard test ages (i.e., 1, 3, 7, 14, and 28 days), an additional compressive strength determination was obtained at 2 days, supplementing data gathered during high heat evolution.

Two cylinders from each concrete mixture were instrumented with thermocouple wire and connected to four-channel maturity meters. The temperature sensors were centered on the top surface of the specimens and embedded to approximately 6 inches. The meters were configured to automatically compute maturity values corresponding to the Nurse-Saul function and the Arrhenius-based function using a datum temperature of 14°F and a ratio of activation energy to universal gas constant of 5000 K.

Twenty-four hours after casting, the first groups of three cylinders were tested for each mixture in accordance with ASTM C 39-94. As the cylinders were tested, the maturity meter monitoring the corresponding mixture was read and the maturity indices were recorded. A log was kept that included test age and the maturity values up to that time for each mixture.

Once the 28-day test age was achieved, the maturity meters were turned off and their data downloaded to a personal computer. A regression analysis was used to generate three best-fit curves for the data. The three best-fitting curves were a natural logarithmic fit, a rectangular hyperbola fit, and a hyperbolic fit with a shift or offset.

To test the ability of the maturity concept to account for field conditions, the strength-maturity relationships were used to predict strength of the same mixtures cured at different temperature profiles. Since this exercise was carried out during the summer, field conditions would typically be hotter than the 73°F laboratory conditions. A constant 93°F curing condition was used to simulate the hotter field conditions. A second set of cylinders of the same number was made from the same 4 yd^3 concrete load delivered for each mixture. Maturity measurements were also recorded for these sets cured at the 73°F standard temperature. Combining the tabulated data for both curing conditions permits the comparison of how well a strength-maturity curve generated at a standard temperature predicts strength of the same mixture at a different temperature.

After the procedures to develop strength-maturity relationships were understood, curves were generated to predict flexural and compressive strengths of additional mixtures. The same procedure utilized for the field simulation was used to create the new compressive strength-maturity curves. A similar procedure was used for the flexural strength-maturity curves, except that only two 6 x 6 x 12-inch beam specimens were tested at each test age. The thermocouple wire was embedded at the center of the top of the beam specimen to minimize the thermocouple's influence in the flexural strength determination because this location corresponds to the neutral axis of the beam in flexure.

Field Phase

Once the strength-maturity relationships were finalized, TxDOT field personnel were provided with a set of tables that clearly stated the required maturity values for each of the mixtures before any strength-driven operations could be performed. An interim maturity testing special specification was also used by TxDOT personnel. Hands-on experience with the use of the maturity meters was provided, and the initial tests implementing the maturity technology in the field were initiated.

In practice, if, during a given visit to the site, the maturity reading was lower than the required value for proceeding with any further construction operation, the monitoring period was extended. Once the maturity meter indicated a reading equal or exceeding the required value, the engineer was notified. The engineer approved cutting the thermocouple wires and removing the maturity meters. During the early stages, conventional quality assurance measures were also conducted.

To build confidence in the use of the developed strength-maturity curves, curve verification was conducted. It was agreed that over one year past the date when the original curve was developed, materials characteristics could change, including those of the aggregates as well as the cementitious materials. To ensure that materials' production variation would not be causing a distinct strength-maturity behavior, at least one curve for cylinder strengths and one curve for flexural strengths were regenerated.

An opportunity to test the use of the maturity meters in the field with the same guidelines adopted for the Dallas experience came on November 1997, during the reconstruction of a portion of IH 30 in west Ft. Worth.

Following events from Dallas and Ft. Worth, the E1 Paso District decided to try the maturity method. The exercise focused on training field personnel on the implementation of the maturity concept for field applications, while the compressive and flexural strength-maturity curves were being developed in the laboratory. The selected mixture was to be used in two projects simultaneously, one on IH 10 near Fabens, and the other on US 85.

What We Found...

Match-Cure Technology

1. In the precast concrete industry, specimens that are match-cured are more representative of the concrete in the member than are the current quality-control specimens cured next to the member.
2. The hottest internal concrete temperatures in the prestressed beams generally occurred in the end block region, while the lowest temperatures usually occurred in the web.
3. The prediction that concrete temperatures will increase about 10 to 12° F per 100 pounds of cementitious material per cubic yard is valid only for the hottest locations of precast concrete members.
4. In the precast concrete industry, the temperature difference between the concrete in the member and the quality-control cylinders cured next to the member was highly variable. This difference was as high as 80° F for the field conditions experienced in this research.
5. The 24-hour compressive strength and modulus of elasticity of concrete tended to increase with curing temperature up to about 160° F. This trend was observed for high-strength concrete (HSC) and normal-strength concrete (NSC).
6. For temperatures within the range of 160 to 180° F, the 24-hour compressive strength and modulus of elasticity start to decrease as curing temperature increases.
7. For temperatures above 120° to 140° F, the compressive strength of

concrete showed no benefits or even decreased as curing temperature increased. This effect was most noticeable for NSC with fly ash and least noticeable for HSC.

8. The length of the pre-set period had a significant effect on the measured compressive strength of concrete. A 4–hour pre-set period caused a 10 to 20 percent decrease in strength compared to an 8-hour pre-set period.
9. The modulus of elasticity of HCS was affected very little by curing temperatures. NSC tended to be affected more, and the effect was similar to the decrease in compressive strength that was also observed.
10. The effect of curing temperature on the permeability of HSC was not as significant or as pronounced as that for normal-strength concrete.
11. For NSC, achieving internal concrete temperatures above 140° to 160° F decreased the 28-day permeability when specimens were compared to those cured at lower temperatures.
12. Curing temperatures above 160° to 180° F resulted in higher 28-day permeability values for NSC. This effect was more pronounced for NSC with fly ash when compared to NSC without fly ash.

Maturity Method

Maturity Function

1. The empirical Nurse-Saul temperature-time factor maturity index accounted for temperature effects in the strength development of concrete mixtures at temperatures ranging between 73 and 93° F.
2. For field applications, the use of the Nurse-Saul function is simpler and thus preferred to the use of the Arrhenius-based function. As in-place concrete strength predictions from the two functions are compared, they do not differ by more than 10%.
3. Experimental determination of datum temperatures or activation energies is not necessary for strength-maturity models to provide an acceptable level of accuracy in the strength predictions for typical field conditions encountered during construction. When compared to carefully handled field-cured specimens and cores from actual structures, the strength predictions using maturity were within 10% of those measured.

Strength-Maturity Fitting Function

1. The logarithmic or natural logarithmic function as well as the rectangular hyperbola when combined with maturity indices in terms of temperature-time factor or equivalent age results in models that can predict strengths for use in construction.
2. The best fit model for a strength-maturity relationship can be selected based on the coefficient of determination, R2, as long as the coefficients have physical meaning.

Maturity Meters

1. The cost of maturity meters is dropping. Single-channel meters that compute maturity indices based on various maturity functions and have personal computer connection capabilities currently cost approximately US $350.
2. Meters with programmable features such as variable datum temperatures and/or activation energies are preferred over simpler models because of the flexibility they offer.
3. The cost of developing a strength-maturity curve has been estimated at US $5,000.
4. Care must be taken in the field to ensure that over-exposure to the sun does not occur and prevent inspectors from reading the LCD display.
5. Several meters were stolen during the field-monitoring phase. Therefore, it is recommended that they be either secured or disguised to prevent theft.

Placement of Temperature Sensors

1. Thermocouple wire used to monitor the temperature of concrete in-place should be installed as soon as possible after the concrete is placed.
2. The sensors can also be preplaced within the concrete either through small openings in the formwork or directly on reinforcing steel. The temperature-sensing tip should never establish contact with the steel.
3. Sensors must be placed at each location where an estimation of the in-place strength of the concrete is desired.
4. Sensors must be placed at all critical locations where the strength of the concrete in-place is of greatest concern due to either structural considerations or exposure conditions requirements.
5. Sensors must be placed at least 2 to 6 inches from any exposed surface or at the mid-depth of the section, whichever is less.

Changes in Mixture Proportions or Materials

1. Variability in mixture proportions that results from the batching operation is tolerable for using a unique strength-maturity curve for a given mixture only if the requirements in ACI 304R-89 and in ASTM C94-94 are satisfied.
2. A change in cement composition or physical properties, cement manufacturer, fly ash composition or physical properties, or fly ash supplier, requires the verification and possibly the development of a new strength-maturity relationship.
3. A change in water-to-cementitious material ratio of 0.05 or higher is the maximum tolerable before strengths from the maturity curve deviate significantly from that otherwise predicted.
4. If aggregate proportions are changed in excess of those acceptable within ASTM C 94, a new strength-maturity curve needs to be developed.
5. If coarse aggregate sources change, the strength-maturity curve may remain unchanged only if the concrete diffusivity remains unchanged.

The Researchers Recommend...

Match-Cure Technology

The use of match-cure technology is an excellent way to close the gap between quality-control specimens and in-place concrete. Therefore, match-cure technology should be used for curing quality-control specimens within the precast concrete industry.

Maturity

1. TxDOT should implement the maturity concept. The maturity concept can be easily implemented in field applications with significant improvements over current practices. During the Dallas North Central Expressway Project, the technology resulted in significant time savings, user cost savings, reduced project costs, and improved quality.
2. Train personnel to conduct the tests and the field inspection required in a simple one-day seminar.
3. Follow proper curing procedures to apply the maturity method with success.
4. Implement the maturity method in two phases:
   a) laboratory testing, and
   b) field measurements of in-place temperatures.
5. Do not use pullout, probe penetration, or break-off tests to supplement the maturity strength predictions, because proper implementation of the maturity concept results in more accurate strength determinations than these other in-place tests.

For More Details ...

Research Supervisor: Ramón L. Carrasquillo, Ph.D., P.E., (512) 471-4585, email: ramonc@mail.utexas.edu

TxDOT Project Director: Tomas A. Saenz, P.E., (915) 790-4350, email: tsaenz@dot.state.tx.us

The research is documented in the following reports:

Report 1714-1, *Maturity and Temperature-Match Cured Technologies: State of the Art Literature Search Executive Summary*. Unpublished.

Report 1714-2, *Investigation of the Use of Match Cure Technology in the Precast Concrete Industry*. Published April 2001.

Report 1714-3, *Investigation of the Maturity Concept as a New Quality Control/Quality Assurance Measure for Concrete*. Draft June1999.

To obtain copies of a report contact CTR Library, Center for Transportation Research, phone: (512) 232-3138, email: ctrlib@uts.cc.utexas.edu.

TxDOT Implementation Status
July 2001

TxDOT has implemented the maturity method for concrete quality control on selected projects. Current requirements are for both TxDOT field inspection and contractor quality control personnel to attend a maturity method training class before using the maturity method on a TxDOT project. The classes are being taught by the Concrete and Cement Branch of the Construction Division, Materials and Pavements Section.

For more information, please contact Tom Yarbrough, P.E., Research and Technology Implementation Office (512) 465-7685 or email at tyarbro@dot.state.tx.us.

Your Involvement is Welcome!

Disclaimer