Concrete in Practice
What, why & how?

NRMCA

CIP 39 - Maturity Methods to Estimate Concrete Strength

WHAT is Concrete Maturity

In concrete technology, the term *maturity* refers to the extent of the development of properties, such as strength, that depend on the chemical reactions occurring in a cementitious mixture. The primary assumption is that provided water is available for cement hydration or the pozzolanic reaction, the maturity of a concrete mixture is related directly to its temperature history. The maturity method provides a relatively simple approach for reliably estimating the in-place compressive or flexural strength of concrete during construction. The maturity method assumes that samples of the same concrete mixture with the same *maturity index* will have similar strengths, regardless of the combinations of time and temperature yielding that maturity index. The maturity index of in-place concrete is calculated from the measured temperature history to estimate in-place concrete strength from a pre-determined *strength-maturity relationship* for that mixture.

WHY use the Maturity Method

The maturity method is a more reliable indicator of the in-place strength of concrete during construction than that indicated by testing field-cured cylinders. The traditional approach has been to use the strength of field-cured cylinders, cured in the same conditions as the structure, to schedule construction activities such as removal of forms or reshoring, backfilling walls, schedule prestressing and post-tensioning operations, determining the time for opening pavements or bridges to traffic, sawing joints, and to terminate protection measures in cold weather.

The maturity method is based on the fundamental concept that concrete properties develop with time as the cement hydrates and that temperature affects the rate of hydration. The rate of strength development at early ages is related to the rate of hydration of cement. Heat generated from the hydration reaction will cause a temperature rise in the concrete and increase the rate of hydration. The maturity method thereby uses the actual temperature history of concrete in the structure to estimate in-place strength development. The temperature of field-cured cylinders is not likely to replicate the temperature history of the in-place concrete because of size differences and thereby not likely to represent the actual in-place strength. The maturity method estimates the in-place strength in real-time as temperature is continuously monitored on-site to provide an estimate of strength at any desired time. Construction scheduling can be based on more accurate estimates of in-place strength to optimize construction workflow.

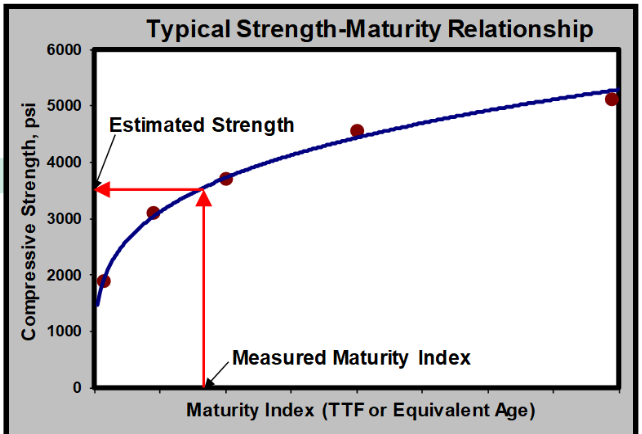

Fig 1. Strength-Maturity Relationship

HOW is the Maturity Method Used

The procedure for estimating concrete strength using the maturity method is described in ASTM C1074, *Standard Practice for Estimating Concrete Strength by the Maturity Method*. The strength-maturity relationship of the concrete mixture that will be used in the project should be developed. A maturity function that will be used for calculating the maturity index should be selected. During construction, the in-place maturity index is determined from the measured temperature history. The maturity index is used to estimate the in-place strength from the pre-established strength-maturity relationship. This is illustrated in Figure 1.

The maturity method is based on the underlying assumption that concrete samples of a given mixture will have the same strength if they have the same maturity index. For example, a portion of the concrete cured at a temperature of 50°F (10°C) for 7 days may have the same maturity index as a portion of the concrete cured at 80°F (27°C) for 3 days and therefore the two portions would have similar strengths. The maturity method accounts for the combined effects of temperature and time on strength development.

ASTM C1074 provides two types of maturity functions to convert the temperature history to a maturity index:

1. The Nurse-Saul function assumes that the initial rate of strength development, after final setting, is a linear function of temperature. The maturity index is expressed as a *temperature-time factor* (TTF) that is calculated as the product of temperature and time in °C-hours or °C-days. The method requires a value for a *datum temperature* that depends on the cementitious materials and the in-place temperature range the concrete will experience. For Type I portland cement and an expected temperature range of 0 to 40°C, a

datum temperature of 0°C. is suggested. ASTM C1074 includes guidance on selecting the datum temperature. The accuracy of the Nurse-Saul function decreases for concrete with initial strength development that is a highly non-linear function of temperature, but it is considered adequate for most applications.

2. The Arrhenius function assumes that the initial rate of strength development follows an exponential relationship with temperature. The maturity index is expressed in terms of an *equivalent age* at a reference temperature. Actual age is typically converted to an equivalent age at a reference temperature of 20°C or 23°C using the measured temperature history. A value of *activation energy* is needed for this maturity function. For concrete made with Type I portland cement, a value of 42 kJ/mol is suggested. ASTM C1074 includes guidance on selecting the activation energy for a particular concrete.

The Arrhenius function better represents the effect of temperature on strength development. The Nurse-Saul function, however, is used more commonly by state highway agencies in the US due to its perceived mathematical simplicity. Current maturity instruments do the necessary calculations.

Using the maturity method involves the following:

- Select the maturity function and establish the strength-maturity relationship for a specific concrete mixture. The mixture is prepared in a laboratory and test specimens are cast and standard-cured to measure compressive strength at various ages. Temperature probes are embedded in two cylinders to monitor the temperature history. These data are used to establish the strength-maturity relationship of the concrete.
- Measure the temperature history of the concrete in the structure by embedding sensors at locations in the structure that are critical in terms of exposure conditions and structural requirements.
- Calculate the in-place maturity index from the recorded temperature history.
- Estimate the in-place strength of concrete from the calculated maturity index and the predetermined strength-maturity relationship (Figure 1).

Limitations of the maturity method that can lead to erroneous estimates of in-place strength are:

a. Concrete in the structure is not the same as that used to develop the strength-maturity relationship due to changes in cementitious materials, admixtures, batching accuracy, air content, etc.;

b. Concrete temperature when placed impacts the rate of strength gain to incorrectly estimate in-place strength;

c. Conditions should permit continued cement hydration - ensure proper placement, consolidation and curing;

d. Using datum temperature or activation energy values that are not representative of the concrete mixture being used or conditions during construction.

Points (a) and (b) are inherent limitations of the maturity method. ASTM C1074 suggests that supplementary tests be conducted prior to performing safety-critical operations such as formwork removal or post-tensioning. While not always required, periodic verification of the validity of established strength-maturity relationship for the specific concrete is important.

Suggested methods include:

1. Tests to estimate in-place strength, such ASTM C803/C803M (penetration resistance), ASTM C873/C873 (cast-in-place cylinders), or ASTM C900 (pullout strength).
2. ASTM C918/C918 that projects later-age strength from early-age strength test results.
3. Using accelerated curing of test specimens according to ASTM C1768/C1768M to estimate later-age strength.
4. Early-age tests of field molded cylinders instrumented with maturity instruments and standard-cured in accordance with ASTM C31.

The strength-maturity relationship, datum temperature, and activation energy are concrete mixture specific parameters. Significant changes to the proportions or material source requires a re-evaluation of these values.

Commercially available maturity devices continuously measure concrete temperature, calculate the maturity index, and display the maturity index at any time. An unlimited number of locations can be monitored simultaneously.

The system selected should be rugged, provide uninterruptible and unalterable data, supports the maturity function selected for the project, and allows changing the maturity constants to that most appropriate.

Strength prediction based on the maturity method is not intended to replace testing of standard-cured cylinders for quality assurance. It cannot account for changes in the strength due to changes in mixing water, air content etc.

Strength estimates based on maturity are valid provided the strength-maturity relationship is correctand concrete is cured properly. Maturity used in conjunction with other limited in-place testing can replace field-cured cylinder testing and facilitate decision making for construction operations. Because of maturity testing, projects are proceeding more quickly, safely, and economically with the right information at the right place and at the right time.

References

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