**Use of the Maturity Method in Quality Control of Concrete: A Review**

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**Abstract**—Conventional methods for determining the strength development of in-place concrete require casting, curing and breaking test specimens. The curing conditions of the in-place concrete are, however, rarely the same as those of the test specimens. As a result, there has been a need for test methods to measure the in-place properties of concrete for quality assurance. The concrete maturity method is an approach to quality control that estimates the strength of in-place concrete based on its internal temperature. The thermal history of concrete is used to calculate a quantity called the maturity index. A relationship between concrete strength and the maturity index is then established in the form of a calibration curve. This relationship and the maturity index of the in-place concrete are used to estimate the in-place strength. Although this method continues to evolve, it has inherent limitations. The purpose of this paper is to provide a review of the history, theory, application, benefits and limitations of the maturity method.

**Keywords**—Concrete, Maturity, Quality, Strength

I. **INTRODUCTION**

Strength is the most universally used measure for concrete quality [1]. Concrete strength development occurs due to the hydration reaction between cement and water. This increase in strength with age continues as long as unhydrated cement is present, and an appropriate moisture content and temperature are available. For a given concrete mixture, the curing conditions (relative humidity and temperature) are known to have the greatest effect on the rate of strength development.

The determination of concrete strength by testing standard specimens fails to take into account variations in conditions that occur during consolidation and curing of the concrete in a structure [2]. As a result, attempts have been made to use in-place test methods to determine the actual rate of strength gain. These methods include the rebound hammer, ultrasonic pulse velocity, probe penetration, pullout, break-off, and the maturity method.

The maturity method relies on the measured temperature history of concrete to estimate strength development during the curing period, when moisture is available for cement hydration [3]. It provides a relatively simple approach for estimating the in-place strength of concrete during construction.

Maturity is computed as the product of time and temperature above some datum temperature following concrete casting [2]. Two maturity models are generally used to determine the maturity (time-temperature history) of concrete: the Nurse-Saul function and the Arrhenius equation.

The Nurse-Saul function is based on the assumption that the initial rate of strength gain is a linear function of temperature. The Arrhenius equation is used to describe the effect of temperature on the rate of hydration.

The maturity concept requires the development of a mixture-specific calibration curve to establish a relationship between the maturity of concrete and the compressive strength of the concrete. This relationship and the measured maturity of in-place concrete are then used to estimate the in-place strength as illustrated in Fig. 1.

![Fig. 1: Application of the maturity method, [3]](image)

II. **BRIEF HISTORY OF THE MATURITY METHOD**

The concrete maturity method has been available for more than fifty years [4]. It became an American Society for Testing and Materials (ASTM) standard in 1987 (ASTM C 1074). The National Bureau of Standards (NBS) developed interest in this new approach to quality control after encountering difficulty in using published relative strength development data obtained under constant temperature conditions to obtain a reliable estimate of in-place concrete strength at the time of failure.

Initial research at NBS confirmed that the maturity method could be used to estimate the development of compressive strength, and other mechanical properties of concrete, under...
different curing temperatures [3]. Further research revealed that field-cured specimens experienced different early-age concrete temperatures than lab-cured specimens. As a result, NBS conducted an in-depth study of the maturity method. This research laid the foundation for the development of the standard on the application of the maturity method.

III. THEORETICAL BACKGROUND OF THE MATURITY METHOD

The origin of the method can be traced to work on steam curing of concrete. It was proposed that the product of time and temperature could be used to account for the combined effects of time and temperature on strength development for different elevated-temperature curing processes [5]. This led to the famous Nurse-Saul maturity function:

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

Where:
- \( M \) = maturity index, degree Celsius-hour (or degree Celsius-day).
- \( T \) = average concrete temperature (degree Celsius) during the time interval \( \Delta t \).
- \( T_0 \) = datum temperature (usually taken to be 10°C).
- \( \Delta t \) = time interval (hour or day).

The index computed by equation (1) was referred to as the maturity. This equation is based on the assumption that the initial rate of strength gain is a linear function of temperature.

However, it was realized that this approximation may not be valid when curing temperatures vary over a wide range [5]. A new function was proposed. It was based on the Arrhenius equation, which is used to describe the effect of temperature on the initial rate of the hydration reactions in concrete. This function allowed the computation of the equivalent age of concrete at a reference temperature as follows:

\[
t_e = \sum_{t=0}^{t=T} e^{-E/RT} \Delta t
\]

Where:
- \( t_e \) = equivalent age at the reference temperature (hour or day).
- \( E \) = apparent activation energy (J/mol).
- \( R \) = universal gas constant = 8.314 J/mol-K.
- \( T \) = average absolute temperature of the concrete during interval \( \Delta t \) (degrees Kelvin).
- \( T_r \) = absolute reference temperature (degrees Kelvin).

The actual age of the concrete is converted to its equivalent age, in terms of strength gain, at the reference temperature. Although comparative studies showed that this new maturity function was superior to the Nurse-Saul function, ASTM C 1074 permits the user to express the maturity index using either the temperature-time factor based on the Nurse-Saul function or equivalent age based on the Arrhenius equation. Further investigation is, however, required to determine the factors that affect the Arrhenius equation in the field [6].

IV. APPLICATION OF THE MATURITY METHOD

The standard practice on the use of the maturity method to estimate in-place strength is based on ASTM C 1074. It requires the following steps:

1. Determining the datum temperature or activation energy for the specific concrete to be used in construction — The datum temperature \( T_0 \) in equation (1) is the temperature below which no strength gain of concrete takes place [7]. The procedure for determining the datum temperature involves curing mortar cubes (made with the materials to be used in construction) at three temperatures. Two of the curing temperatures should be the minimum and maximum curing temperatures expected for the in-place concrete. The third temperature should be midway between the extremes. The cubes are then tested for compressive strength at regular time intervals.

The key parameter in equation (2) is the activation energy \( E \). It defines the temperature sensitivity of a concrete mixture [8]. Determining the activation energy involves the following steps:
   i. Curing mortar specimens at different constant temperatures.
   ii. Determining compressive strengths at regular age intervals.
   iii. Determining the value of the rate constant at each temperature by fitting a strength-age relationship to each set of strength-age data.
   iv. Plotting the natural logarithms of the rate constants versus the inverse of the curing temperature (in Kelvin).
   v. Determining the best-fit Arrhenius equation to represent the variation of the rate constant with the temperature.

2. Determining the relationship between compressive strength and the maturity index — The constituents and mixture proportions of the concrete to be used in construction are used to prepare cylindrical concrete specimens. These specimens are prepared according to the usual procedures for making and curing test specimens in the laboratory [3]. Temperature sensors are embedded at the centers of at least two cylinders. The sensors are connected to temperature recording devices.

The specimens are cured in a water bath or in a moist curing room and compression tests are performed on at least two specimens at ages of 1, 3, 7, 14, and 28 days. At the time of testing, the maturity is evaluated according to equation (1) or equation (2) and the average maturity value is recorded. The average compressive strength is plotted as a function of the average maturity index. A best-fit smooth
The method needs to be supplemented by other indicators of the potential strength of the concrete mixture—ASTM C 1074 requires verification of the potential strength of the in-place concrete before performing critical operations, such as formwork removal or post-tensioning [3]. This is because there is no assurance that the in-place concrete has the correct mixture proportions. Methods for verification of concrete strength include:

i. other in-place tests that measure the actual strength of in-place concrete;
ii. early-age compressive strength tests on standard-cured specimens prepared from samples of in-place concrete; or
iii. compressive strength tests on specimens molded from samples of in-place concrete and subjected to accelerated curing.

VI. CONCLUSION

Proper application of the maturity method as a means for concrete quality control allows construction operations to be performed safely at the earliest possible time, resulting in reduced construction time and cost. However, the limitations of the method need to be understood in order to prevent catastrophic failure of concrete structures.

REFERENCES