ESTIMATING THE DEVELOPMENT OF CONCRETE STRENGTH BY THE MATURITY METHOD

(An Arizona Method)

1. SCOPE

1.1 This test method provides a procedure for estimating the development of concrete strength by means of the maturity method.

1.2 This procedure is normally used, when desired, for Class S and Class P concrete; however, it may be used for other classes of concrete.

1.3 The concept of the maturity method is based on the combined effects of concrete age and temperature during the hydration process versus the rate of strength gain for a specific mix.

1.4 This method requires the establishment of a relationship curve between compressive strength and calculated maturity index for a specific concrete mixture (mix design) prior to placement of the mixture in the field.

1.5 This procedure may not be used to estimate the strength of mass concrete unless the strength-maturity relationship is developed at elevated temperatures. Mass concrete is defined as concrete which has a least dimension of three feet or more.

1.6 The maturity method shall not substitute for compressive strength acceptance testing (28-day test cylinder breaks).

1.7 This test method may involve hazardous material, operations, or equipment. This test method does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine the applicability of any regulatory limitations prior to use.

1.8 See Appendix A1 of the Materials Testing Manual for information regarding the procedure to be used for rounding numbers to the required degree of accuracy.

2. REFERENCED DOCUMENTS

2.1 AASHTO Documents

- AASHTO T325 — Estimating the Strength of Concrete in Transportation Construction by Maturity Tests
- AASHTO T23 — Making and Curing Concrete Test Specimens in the Field
- AASHTO R39 — Making and Curing Concrete Test Specimens in the Laboratory

2.2 ASTM Documents

- ASTM C 1074 — Estimating Concrete Strength by the Maturity Method

2.3 Arizona Documents

- ARIZ 314 — Compressive Strength of Cylindrical Concrete Specimens
- PPD No. 15 — Submittal and Approval of Portland Cement Concrete Mix Designs

3. TERMINOLOGY

3.1 Maturity - The extent of development of concrete properties that are dependent on the hydration of cementitious materials.

3.2 Maturity Function - A mathematical expression that converts the temperature history of concrete to an index, which indicates its maturity.

3.3 Maturity Index - An index, calculated by using a maturity function, which can be used as an indicator of strength development in concrete.

3.4 Strength-Maturity Relationship - An empirical relationship between concrete strength and its maturity index, determined by comparing the strength of concrete cylinders, made from a specific concrete mix, to their maturity index at the time of strength testing.

4. SIGNIFICANCE AND USE

4.1 The estimated strength of in-place concrete determined by this procedure provides guidance useful in making decisions concerning:

4.1.1 Removal of formwork and reshoring.

4.1.2 Post-tensioning.

4.1.3 Opening of the roadways to traffic.

4.1.4 Initiation of strength tests, such as coring and pullout tests, on the in-place concrete.

4.2 The most critical limitations of the procedures presented are:

4.2.1 Concrete must be cured in a condition that supports the reaction of cementitious materials.

4.2.2 Batching or placement errors that are not detected.

4.2.3 Curing errors other than those that affect temperature that are not detected.

4.2.4 The actual strength of the concrete that is not measured.

4.3 This method provides technical personnel with a coordinated procedure for:

4.3.1 Developing a strength-maturity relationship for the approved concrete mix design in the laboratory.

4.3.2 Determining the temperature history of the in-place concrete.

4.3.3 Determining the maturity index of the in-place concrete.

4.3.4 Using the strength-maturity relationship and the maturity index to estimate the strength of the in-place concrete.

5. MATURITY METHOD

5.1 The temperature-time factor (Nurse-Saul) method shall be used to determine the maturity index.

5.2 Maturity digital data loggers shall be set at a datum factor of 0 °C.

5.3 The strength-maturity relationship shall be plotted using a linear chart or a logarithmic chart. In support of using either a linear chart or a logarithmic chart, a printout of the strength-maturity relationship test data shall be used.

6. APPARATUS

6.1 A maturity meter capable of reading a maturity digital data logger that has a secure method of collecting un-interruptible and un-alterable data, subsequent to the concrete pour and initial concrete set, for a minimum of 28 days. The system shall be accurate to at least $\pm$ 1 °C.

6.2 Maturity digital data loggers shall contain a real time clock and be capable of recording the current temperature and temperature history in real time with an associated time stamp.

6.3 Documentation shall be provided by the manufacturer that certifies the accuracy of the maturity meter and digital data loggers.

7. PROCEDURE TO DEVELOP STRENGTH-MATURITY RELATIONSHIP

7.1 A strength-maturity relationship curve shall be developed for a specific concrete mix prior to using this method on the project.

7.2 As described in Subsection 7.3 below, the strength-maturity relationship curve is developed utilizing compressive strength cylinders which have been fabricated, cured, and tested from a trial batch as described in ADOT Materials Policy and Procedure Directive No. 15, "Submittal and Approval of Portland Cement Concrete Mix Designs". The concrete mixture shall meet the specification (design mix) requirements in order to determine the strength-maturity relationship curve. The concrete mixture shall be at or above the target air content.

7.3 The compressive strength testing for the development of the strength-maturity relationship curve shall be performed as follows:

7.3.1 This procedure requires the initial casting of at least 17 compressive strength test cylinders. The test cylinders shall be fabricated in accordance with the requirements of AASHTO T23.

7.3.2 Two cylinders will be outfitted with maturity digital data loggers. Readings are taken from the data loggers in each of these cylinders. The readings are averaged, and the results are correlated with the compressive strength test results to establish the maturity curve.

7.3.3 A minimum of fifteen cylinders will be tested for compressive strength as described below.

7.3.3.1 Compressive strength tests shall be performed on three cylinders, at a minimum of five different ages encompassing the age at which the desired strength is needed. For example, compressive strength tests may be performed at 1, 2, 3, 5 and 7 days for Class S concrete or 12, 24, 36, 48 and 72 hours for Class P concrete. More cylinders may be fabricated, cured, and tested at additional ages if desired. Compressive strength testing shall be performed in accordance with the requirements of Arizona Test Method 314.

Note: Tests should be scheduled to result in approximately equal increments of strength gain between ages. Additionally, compressive strength tests should bracket the estimated target strength.

7.3.3.2 The compressive strength of each of the three test cylinders at each age and their average compressive strength shall be determined. However, if the compressive strength of any one of the three test cylinders differs by more than 10 percent from the average of the three, its result shall be discarded and the compressive strength shall be the average of the remaining two cylinders. Should the individual compressive strength of any two of the three test cylinders differ by more than 10 percent from the average of the three, the results of both will be discarded and the compressive strength shall be the strength of the remaining cylinder.

8. PLACEMENT OF DIGITAL DATA LOGGERS IN THE FIELD

8.1 Maturity digital data loggers shall be placed as follows, either prior to concrete placement (with maturity digital data loggers properly secured in their proper location) or into the fresh concrete following the placement of concrete.

Class of Concrete	Frequency of Logger Placement	Location of Logger Placement
Class P (PCCP)	Every 100 cubic yards	Mid-depth of pavement ≥ 12 inches from edge of pavement
Class S (Structural)	Every 50 cubic yards*	Critical locations per exposure and/or structural requirements
Other than Class S or Class P	Every 50 cubic yards*	Critical locations per exposure and/or structural requirements
* At least two additional maturity data loggers should be available for placement as needed		

8.2 Activate the maturity digital data loggers as soon as practicable after concrete placement, but not before the maturity digital data loggers are fully encapsulated in concrete.

9. FIELD VALIDATION OF STRENGTH-MATURITY RELATIONSHIP

9.1 The maturity method does not account for variations in strength due to proportioning, mixing, placing, and moisture conditions of the field-placed concrete. Proper curing of the concrete and minimizing moisture loss is critical in achieving reliable strength-maturity relationship results.

9.2 During the initial use of this method for the concrete mixture for which the strength-maturity relationship has been developed, a field validation of the strength-maturity relationship shall be performed. A minimum of three compressive strength test cylinders shall be fabricated, cured, handled, protected, and transported in accordance with the requirements of AASHTO T23. In addition, a minimum of one test cylinder shall be fabricated and cured in the same manner as the three compressive strength test cylinders, and at least two maturity digital data loggers shall be embedded in the additional test cylinders, as close to the center (± 1/2 inch) of the cylinders as possible. The data logger readings are used in conjunction with the average compressive strength for validation of the strength-maturity relationship.

9.3 The three compressive strength cylinders shall be tested in accordance with the requirements of Arizona Test Method 314 <u>at approximately the estimated temperature-time factor target</u>. The average compressive strength of the three test cylinders shall be determined. However, if the compressive strength of any one of the three test cylinders differs by more than 10 percent from the average of the three, its result shall be discarded and the compressive strength shall be the average of the remaining two cylinders. Should the individual compressive strength of any two of the three test cylinders differ by more than 10 percent from the average of the three, the results of both will be discarded and the compressive strength shall be the strength of the remaining cylinder.

9.4 Compare the data logger readings and the average compressive strength of the field validation test cylinders to the original strength-maturity relationship curve at the estimated temperature-time factor target. The average compressive strength of the field validation cylinders is used only for comparison to the original strength-maturity relationship curve.

9.4.1 If the average compressive strength of the validation test cylinders is equal to or differs by less than ± 10 percent of the original strength-maturity relationship which has been developed for the concrete mixture, the development of a new strength-maturity relationship curve may not be required.

9.4.2 If the average compressive strength of the validation test cylinders differs by greater than ± 10 percent of the original strength-maturity relationship, the development of a new strength-maturity relationship curve is required.

9.5 During placement of the concrete mixture, field validations of the strength-maturity relationship curve shall be performed in accordance with the requirements of Subsections 9.2 through 9.4. The minimum frequency of field validations will be as follows:

9.5.1 For Class P concrete: every 10 days of concrete placement.

9.5.2 For Class S concrete: every 300 cubic yards of concrete placement.

9.5.3 For other than Class P or Class S: every 300 cubic yards of concrete placement.

10. REPORT FOR STRENGTH MATURITY RELATIONSHIP

10.1 Project number

10.2 Concrete Product Code and the source of each material (aggregate, cement, supplementary cementitious material, and admixtures).

10.3 Date(s) and times(s) that compressive strength testing of the cylinders is performed.

10.4 The air content, slump, water content, and the water/cementitious material ratio for each batch of concrete tested.

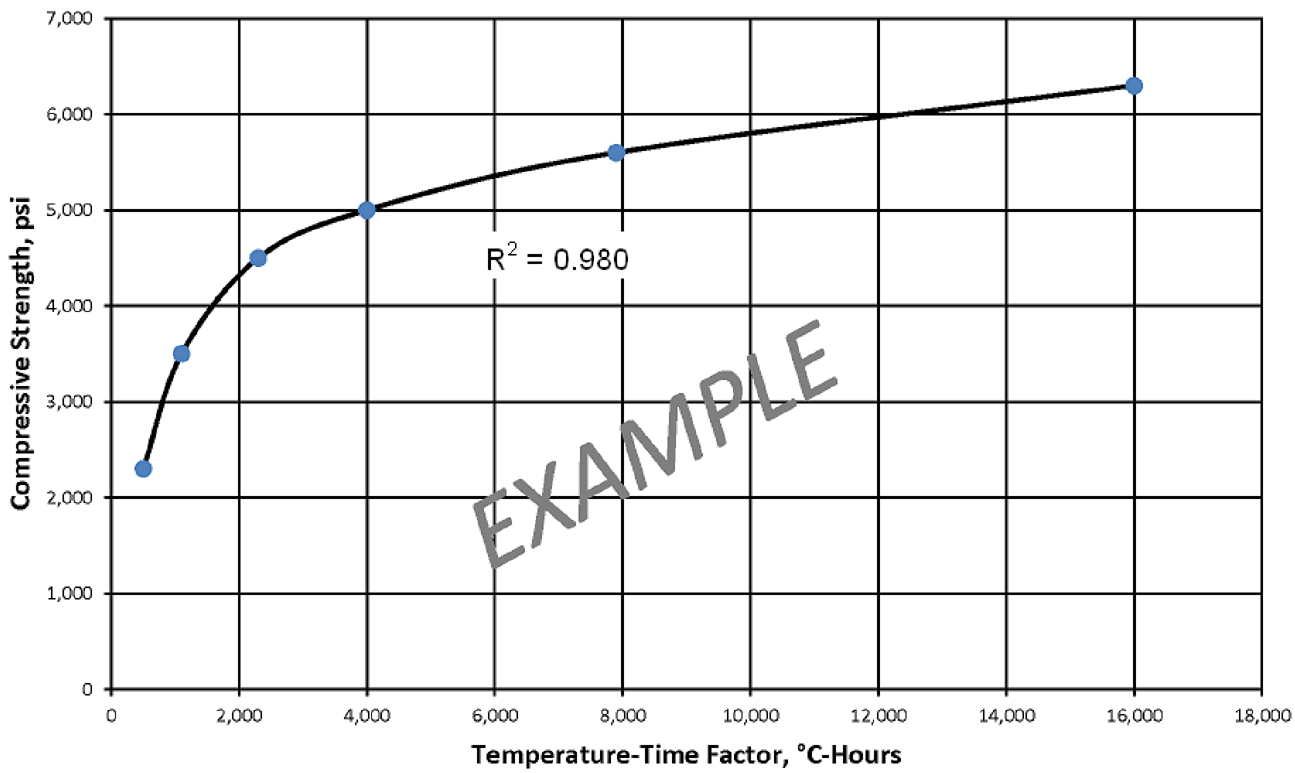
10.5 The amount and type of admixtures used in the concrete mixture.

10.6 The strength of each test cylinder and the average strength of the test cylinders at each test age.

10.7 The maturity index for each instrumented test cylinder and the average maturity index for the instrumented test cylinders at each test age.

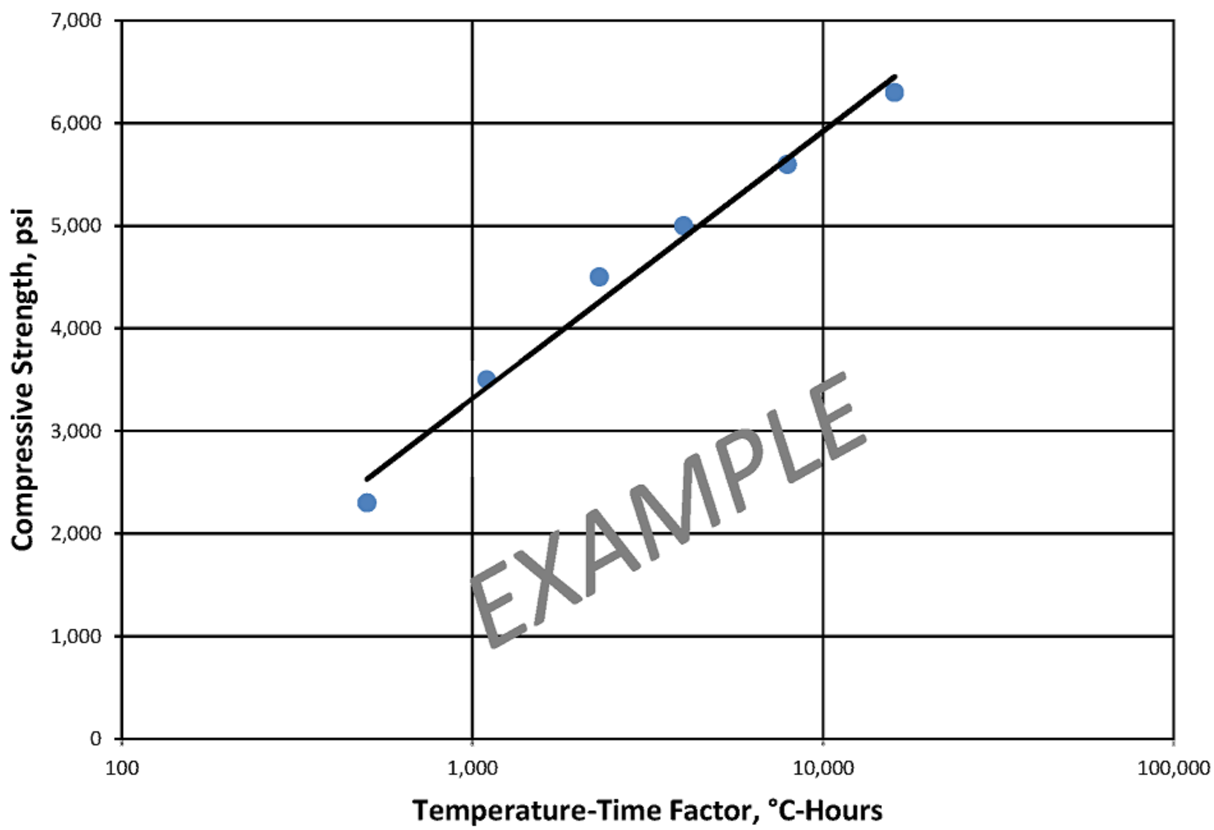
10.8 A graph of the plotted points, on either a linear chart or a logarithmic chart, for the average compressive strength at each age versus the average maturity index at each age, and the best-fit curve. An example of such a linear graph is shown in Figure 1. An example of a logarithmic graph is shown in Figure 2. To be acceptable, the plotted points shall produce a correlation coefficient (R2) of at least 0.90.

10.8.1 In support of providing either a linear chart or a logarithmic chart, a printout of the strength-maturity relationship test data used shall be provided. An example of such a printout is shown in Figure 3.



Example Strength-Maturity Relationship Curve
Linear Scale

FIGURE 1



Example Strength-Maturity Relationship Curve
(Logarithmic Scale)

FIGURE 2

Temperature-Time Factor, °C-Hours	Compressive Strength, psi
500	2,300
1,100	3,500
2,300	4,500
4,000	5,000
7,900	5,600
16,000	6,300

Example Printout of Strength-Maturity Relationship Test Data

FIGURE 3