MATURITY CALIBRATION OVERVIEW

1. Concrete Maturity

1.1 What is Concrete Maturity?

Maturity is non-destructive testing method used to estimate the early age strength development of in-place concrete in real-time, specifically at ages less than 14 days. The principle behind this relatively simple technique correlates concrete strength to the hydration temperature history of cementitious paste.

The maturity method is governed by the fundamental assumption that a concrete mix design poured during a specific project has equal compressive strength when an equal "maturity index" has been achieved. For example, a given concrete mix design may reach the same compressive strength after 7 days of curing at 10 °C as when cured at 25 °C for 3 days.

The maturity method adheres the following industry standards: ASTM C1074, ASTM C918, ACI 318-6.2, ACI 228 -2.7, and ACI 306-6.4. The testing methods have also been widely adopted by most DOTs in North America.

The maturity method requires pre-calibration of a concrete mix before it can be used in a project. Calibration's purpose is to correlate a maturity-strength relationship. A calibration is specific to a single mix design. Once a mix design's maturity calibration curve is developed through laboratory testing, using cylinder breaks, it can be used for on-site compressive strength estimation in real-time.

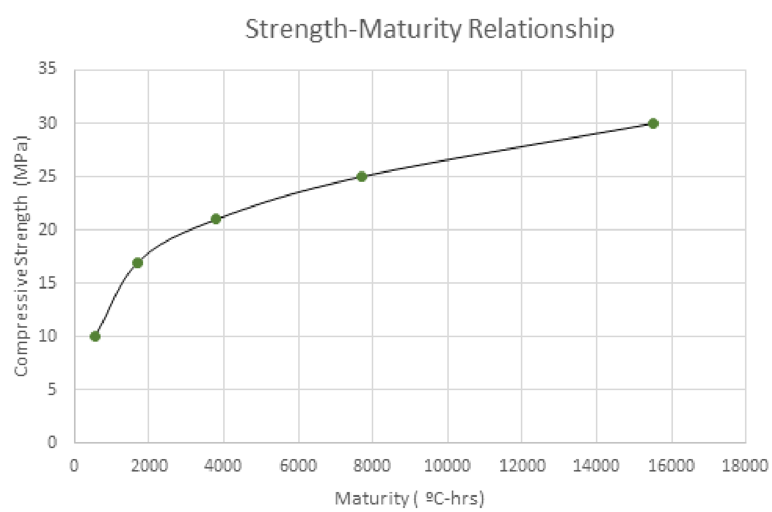

Figure 1: Example of Strength vs. Maturity Relationship

ASTM C1074 - Maturity method definition: "*a technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strengths if the attain equal value of maturity.*"

1.2 Maturity Function

A maturity calibration is specific to a concrete mix. The mix design that is calibrated in the lab must be representative of the concrete used on site.

The most commonly used equation for maturity in North America is called the Nurse-Saul Equation (Temperature-Time Factor equation). This concept is based on the principle that a linear function exists between concrete temperature and strength gain. This method sums the area under the temperature curve (Integral of the temperature curve) known as the maturity index, which is based on the following equation:

Equation 1:

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

- M(t) - Maturity (degree-hours)
- Ta - Average concrete temperature during time interval Δt (degree)
- Td - Datum temperature (degree)
- Δt - Time interval (hours)

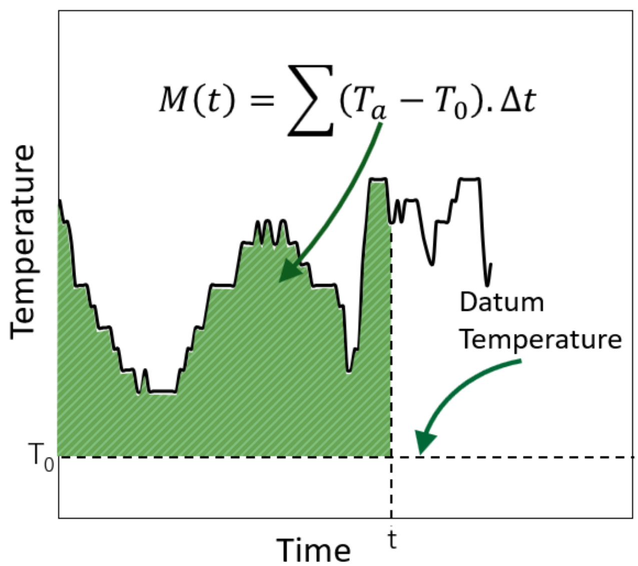

Figure 2: Maturity Concept Using Nurse-Saul Equation

There are other more complex equations to calculate the maturity index, such as the Arrhenius Function and weighted maturity. However, ASTM C1074 accepts both the Nurse-Saul Equation and Arrhenius Function. Giatec's SmartRock™ application supports both of these functions.

1.3 Datum Temperature

The datum temperature represents the temperature at which the concrete stops gaining strength. Datum temperature is also specific for a mix design. ASTM C1074 – X1 provides a standard procedure to find datum temperature.

A practical estimation of the datum temperature suggested by previous studies is between 0 ºC and -10 °C (32 °F and 14 °F). ASTM C1074-17 standards recognizes 0°C (32°F) to be an appropriate value for cement type I.

2. Procedure to Develop the Strength-Maturity Relationship

The step by step procedure outlined in this document is a summary of the ASTM C1074-17 standard procedure. In any case, refer to the standard for further information.

Step 1: Prepare a minimum of 17 cylinders (2 for temperature and 15 for strength monitoring)

Step 2: Moist cure the 17 specimens in a water bath or in a moist cure room (according to ASTM C51)

Step 3: Obtain compressive strength and temperature measurements.

Step 4: Calculate maturity from the measured concrete temperature.

Step 5: Develop the maturity curve by correlating the maturity value and the strength.

Explanation of Calibration Steps

Step 1: Prepare Cylinders

The maturity calibration requires a minimum of 17 test cylinders. 5 sets of 3 cylinders are used for break tests at each test age, and two cylinders for temperature monitoring. During casting, embed the temperature probe of the SmartRock sensors within 15 mm from the center of the two cylinders used for temperature monitoring. Follow the tagging and activation procedure for these sensors provided by the manufacturer.

Common practice is to test for compressive strength at day 1, 3, 7, 14 and 28. However, if otherwise specified, the age for calibration can vary based on the strength development of the specific concrete mix. If needed, more data points can be taken. For example, if the desired strength to remove formwork is on day 3 then compressive strength tests can be conducted on day 1, 2, 3, 5, and 7. In general, obtaining two compressive strength values before and after the desired strength day provides an appropriate calibration curve. Refer to Table 1 for examples of compressive strength gain at specific ages. The examples provided in Table 1 are subject to change based on the project, concrete type, time, and project requirements. Always keep in mind that the maturity method was developed to approximate concrete strength only in the first 14 days.

Table 1: Example of Maturity Calibration Compressive Strength Test Ages

Concrete compressive strength test	Age at target strength to open forms, tension, etc.		
	24 hrs	**3 days**	**7 days**
Break 1	As early as possibe	1 day	1 day
Break 2	18-20 hrs	2 days	3 days
Break 3	**24 hrs**	**3 days**	**7 days**
Break 4	36 hrs	5 days	10 days
Break 5	3 days	7 days	14 days

Each maturity calibration is different depending on the mix design. The mixture proportion and properties of the concrete calibrated for maturity is the same as those used in the project. Variations in the mix including; water content, admixtures, Supplementary Cementing Materials, etc. can affect the maturity-strength relationship and should be considered when using the original maturity calibration curve for a specific mix.

Step 2: Concrete Curing

Unless otherwise specified, standard curing conditions should be applied for all the 17 cylinders. Curing should be conducted in a water bath or in a moist cure room (see ASTM C511 specifications). ASTM C1074 may have additional notes for higher concrete curing temperatures.

Step 3: Compressive Strength and Temperature Measurements

At each test age defined in step 1, a minimum of two cylinders should be tested. If the range of compressive strength between the two cylinders is larger than 10% from their average, a third cylinder must be tested. Continually measure the temperature of the two concrete cylinders for the entire length of the calibration process.

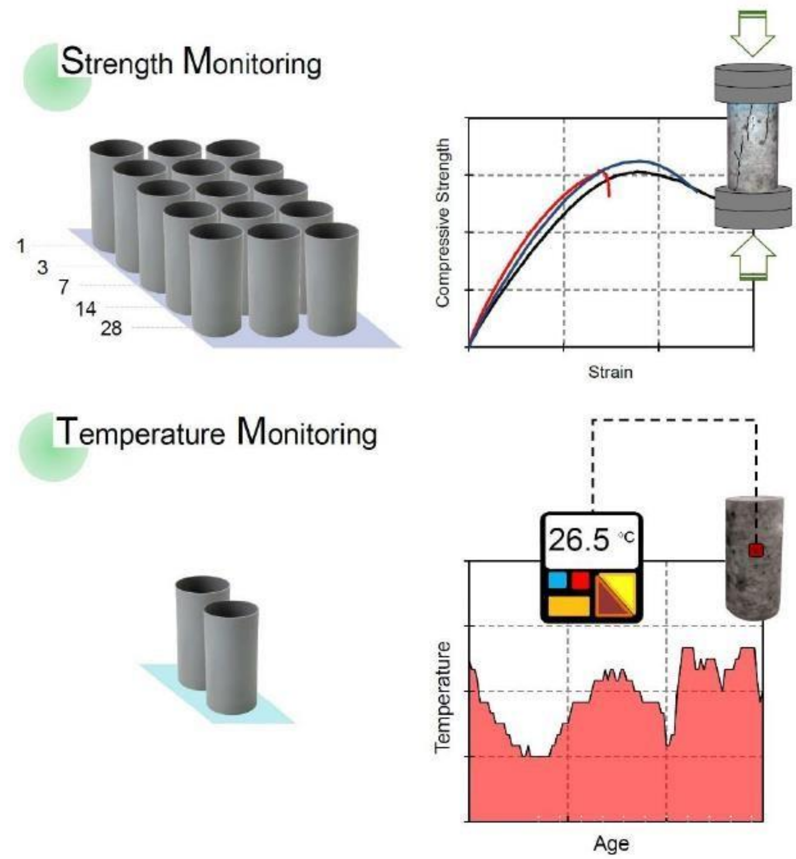

Figure 3: Strength and Temperature Monitoring

Step 4: Maturity Calculation

Option 1: Manual Calculation of Maturity

Calculate maturity manually using temperature data (obtained from simple temperature monitoring units, such as thermocouples) and the Nurse-Saul Equation 1 specified above.

Option 2: Maturity Calculated by the SmartRock Application

When SmartRock sensors are used for concrete temperature monitoring during the calibration procedure, the maturity index can be calculated using the SmartRock application. For each sensor, set a pouring time (the time at which the temperature sensor was placed inside the concrete) and select a concrete mix. Create or select a random concrete mix with the same datum temperature as the mix you are testing. The "Demo Mix 1" provided in the application has a datum temperature of 0°C (32°F). The application will automatically calculate the maturity; however, you must discard the strength display since a random mix was applied. Collect the maturity value corresponding to the time of the cylinder breaks done in step 3, either through the application graphics or through the excel file generated by the application.

Step 5: Correlate Maturity and Strength

You will now have a set of maturity and strength data similar to the one shown in Table 2. You can now define your new mix and enter the maturity and strength values, along with the datum temperature, for that mix.

Table 2: Example of Calibration Maturity and Strength Data

Time	Maturity (ºF-hrs) (from calculation or app data)	Strength (psi) (from cylinder compression test)
Day 1	500	300
Day 3	1100	1500
Day 7	3000	3000
Day 14	9000	3500
Day 28	12000	4000

Once the maturity and strength data are plotted the fitting curve in the logarithmic scale will be:

$$strength = a + b\ LOG\ (maturity)$$

Equation 2

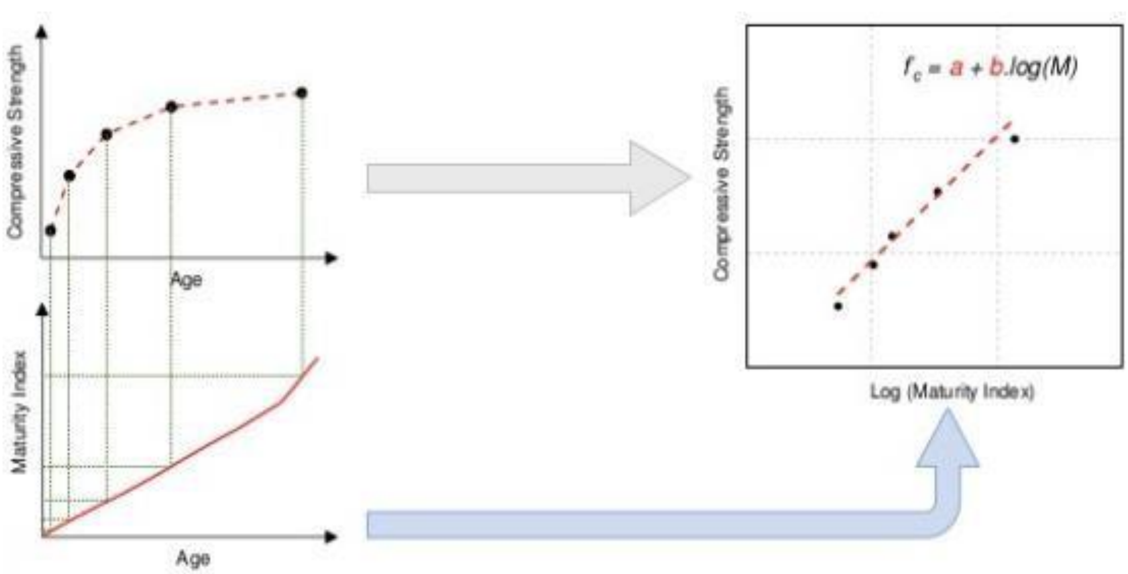

Figure 4: Calibration Curve

3. Define a New Maturity Calibration in the Application

In the SmartRock application, from the side menu select "Maturity calibration" and follow the 4 steps to enter a new calibration. All of the steps are shown in Figure 5.

Step 1 – Mix ID:

Give a name to your new mix, typically this would be the name of the mix provided by your ready-mix producer.

Step 2 - Maturity Method:

Select the maturity method you are using. The temperature-time factor is the Nurse-Saul Equation, and the equivalent age is the Arrhenius Function.

Step 3 - Datum Temperature:

If you have selected the temperature-time factor, enter the value of your datum temperature.

Step 4 - Enter Your Calibration Values:

Option 1: Enter the maturity and strength values you obtained from the calibration (similar to Table 2), select "add" to add a point to the curve. The app will automatically calculate the 'a' and 'b' values for you.

Option 2: Enter the 'a' and 'b' fitting curve parameters if this information is provided.

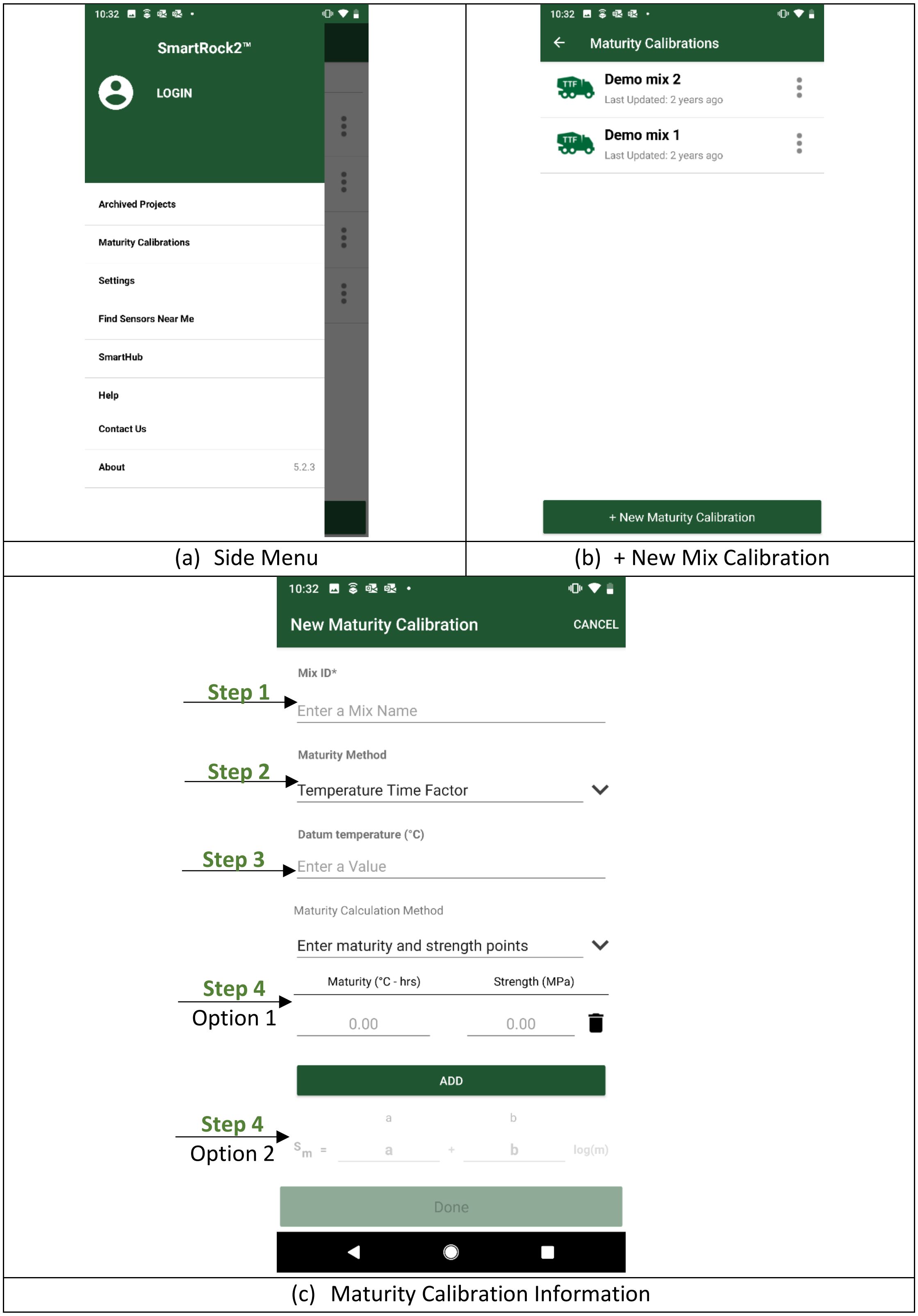

Figure 5: Maturity Calibration SmartRock Application