What is Maturity?

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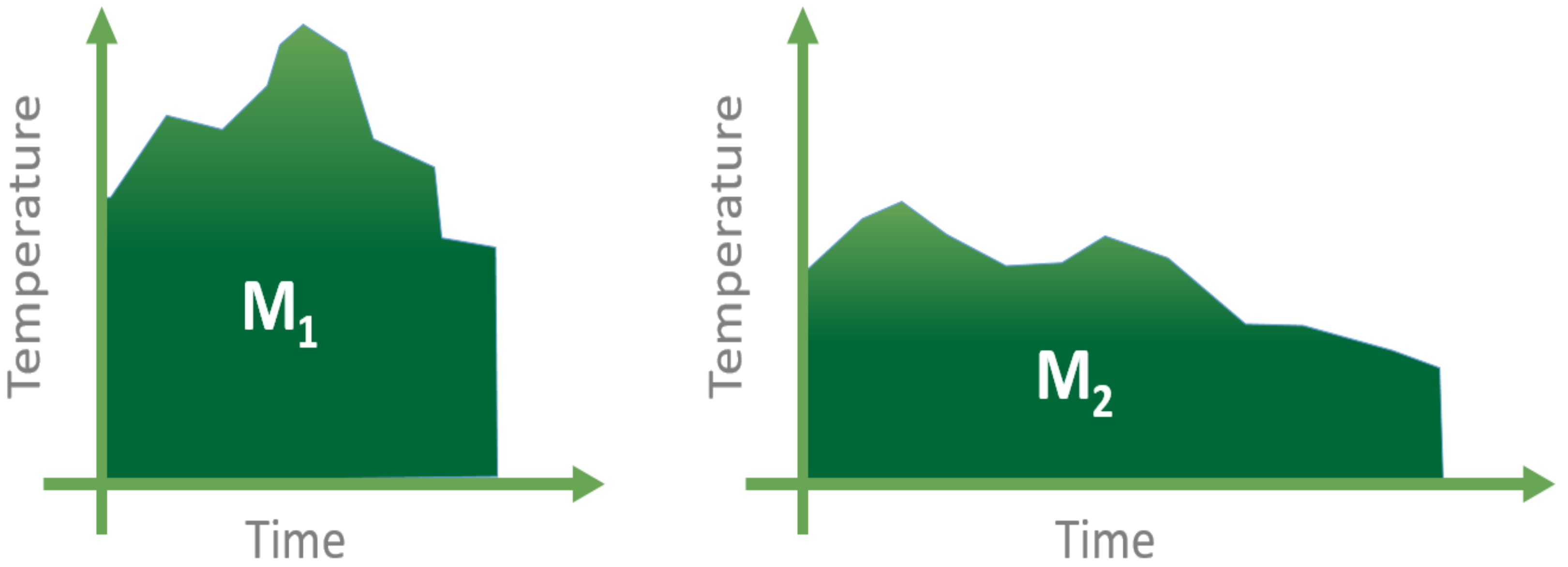
A non-destructive method to estimate the **real-time strength** development of in-place concrete, specifically at **early ages** less than 14 days.

It uses the **temperature history** of concrete during curing to estimate strength development. Maturity method requires a **calibration** prior to use in order to correlate the maturity to strength. Maturity **calibration is specific for a mix design**.

What is Maturity?

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



$$\text{if } M_1 = M_2 \rightarrow f_1 = f_2$$

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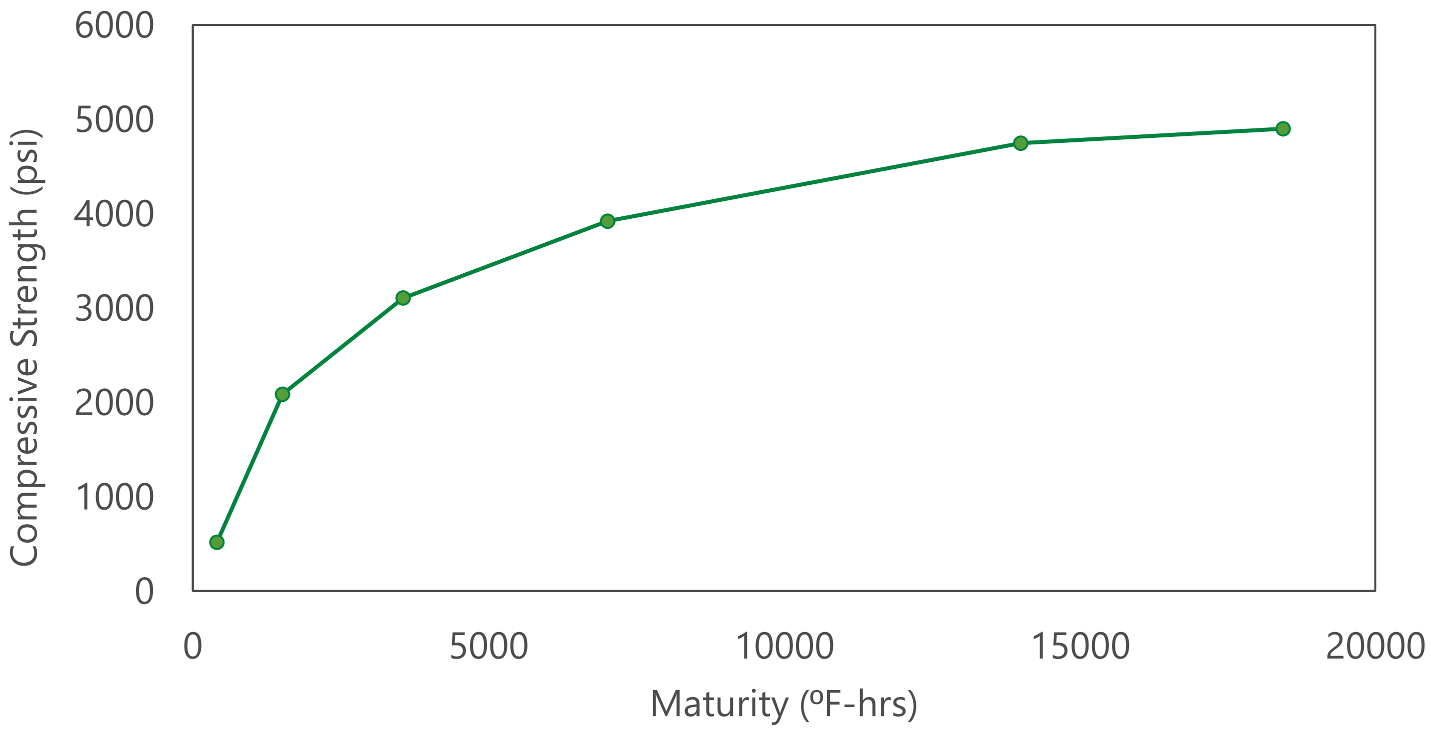
What is Maturity?

A unique relationship between the Maturity Index (a function of concrete temperature) and Concrete Strength for each concrete mixture



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North American Standards

- ASTM C1074, ASTM C918
- ACI 318-6.2, ACI 228.1R, ACI 306R
- AASHTO T325
- Accepted by majority of DOTs
- CSA A23.1,2

Maturity Function

Maturity Functions: Maturity Index Calculation

Maturity index can be calculated using one of the following equations:

- **Nurse-Saul (Temperature-Time Factor, TTF)**
- **Arrhenius (Equivalent Age)**
- Weighted Maturity (NEN 5970)

The maturity index is primarily dependent on the temperature history of the concrete.

Maturity Function:
Temperature Time Factor (Nurse-Saul)

Linear relationship between temperature and strength gain

- ✓ Most common in the North America
- ✓ Conservative
- ✓ Less complicated

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

$M(t) = Maturity\ index$
$T_a = Average\ temperature\ during\ time\ interval\ \Delta t\ (degree)$
$T_0 = Datum\ temperature\ (degree)$

Maturity Function:
Equivalent Age (Arrhenius)

Exponential relationship between temperature and strength gain

- ✓ Less common in the US
- ✓ More complicated
- ✓ Can be more accurate (if right assumptions)

$$t_e = \sum_0^t e^{-Q*\left(\frac{1}{T_a} - \frac{1}{T_s}\right)} \Delta t$$

t_e= Equivalent age at specified temperature t_s (days)

Q= Activation energy divided by the gas constant (K)

t_a= Average temperature of concrete during time interval (k)

t_s= Specified temperature (k) (taken as 23° C in the North America)

Δt= Time interval (days)

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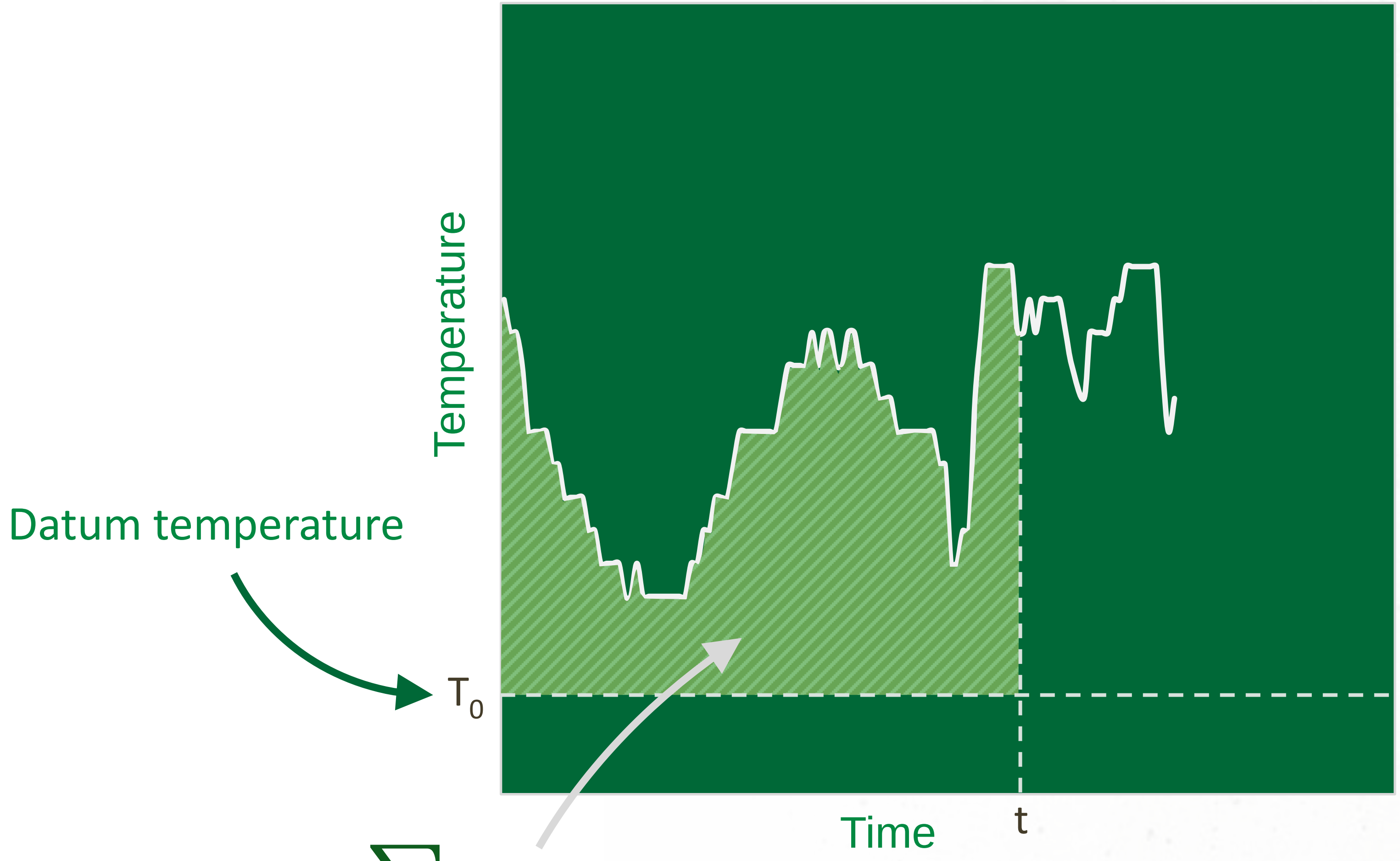
Temperature Time Factor (Nurse-Saul)



$$M(t) = \sum (T_a - T_0).\Delta t$$

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Temperature Time Factor (Nurse-Saul)

$$M(t) = \sum (T_a - T_0) . \Delta t$$

Temperature-time factor
at time t (degree/hours)

Average concrete
temperature during
time interval Δt

Datum temperature

Time interval

Datum Temperature

ASTM C1074:" For type I cement without admixtures and a curing temperature range from 0 to 40°C, the recommended datum temperature is 0°C. For other conditions and when maximum accuracy of strength is desired, the appropriate datum temperature can be determined experimentally according to the procedures in Appendix X1."

Temperature at which concrete stops gaining strength

32°F is typically used

Example

$$M(t) = \sum (T_a - T_0).\Delta t$$

$$M(t) = \sum\left(\frac{50+50}{2} - 32\right) * 1hr = 18\text{°F-hrs}$$

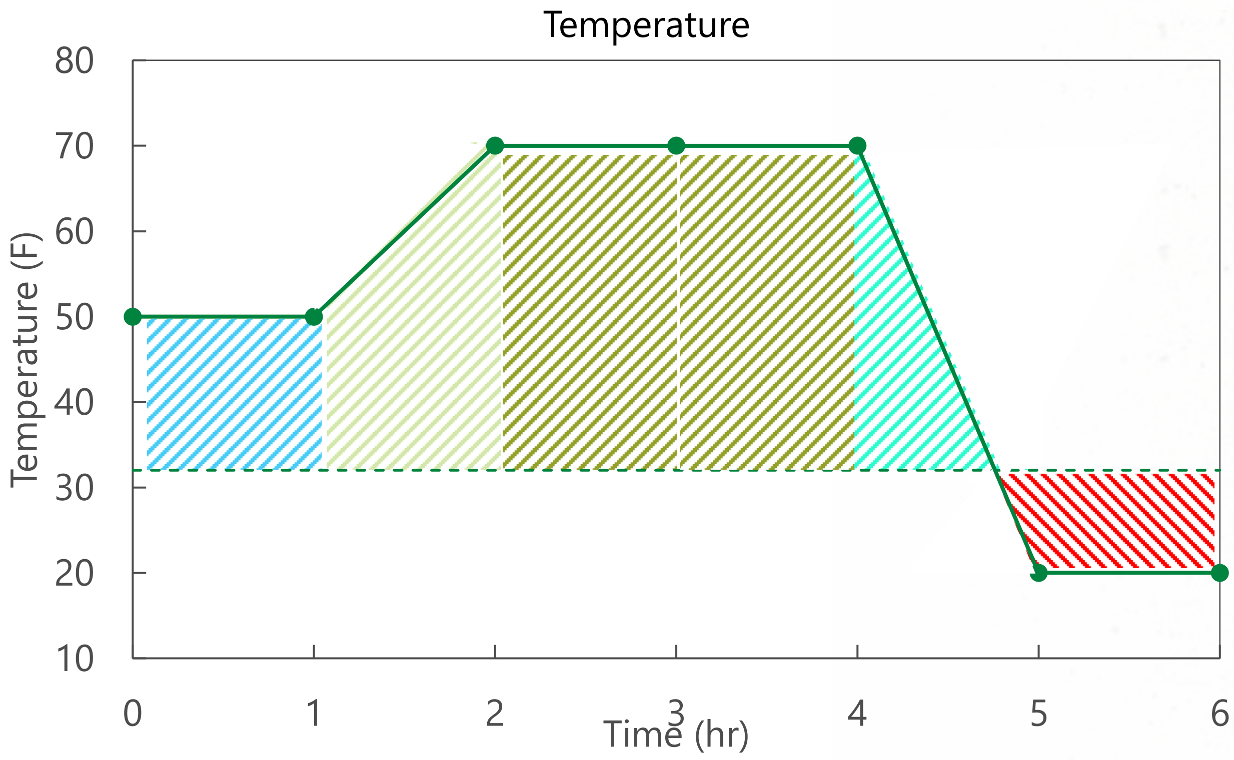
$$= \sum\left(\frac{70+50}{2} - 32\right) * 1hr = 28\text{°F-hrs} \qquad M(t) = 18 + 28 = 46\ \text{°F} - \text{hrs}$$

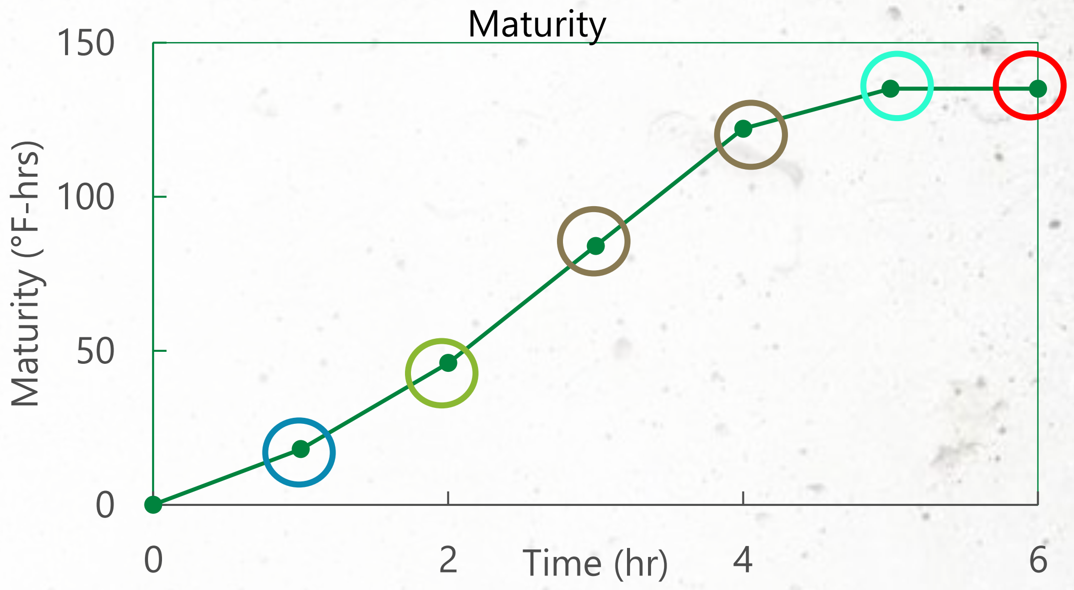
$$= \sum\left(\frac{70+70}{2} - 32\right) * 1hr = 38\text{°F-hrs} \qquad M(t) = 46 + 38 = 84\ \text{°F} - \text{hrs}$$

$$= \sum\left(\frac{70+70}{2} - 32\right) * 1hr = 38\text{°F-hrs} \qquad M(t) = 84 + 38 = 122\ \text{°F} - \text{hrs}$$

$$= \sum\left(\frac{70+20}{2} - 32\right) * 1hr = 13\text{°F-hrs} \qquad M(t) = 122 + 13 = 135\ \text{°F} - \text{hrs}$$

$$= \sum\left(\frac{20+20}{2} - 32\right) * 1hr < 0 = 0\text{°F-hrs} \qquad M(t) = 135 + 0 = 135\ \text{°F–hrs}$$





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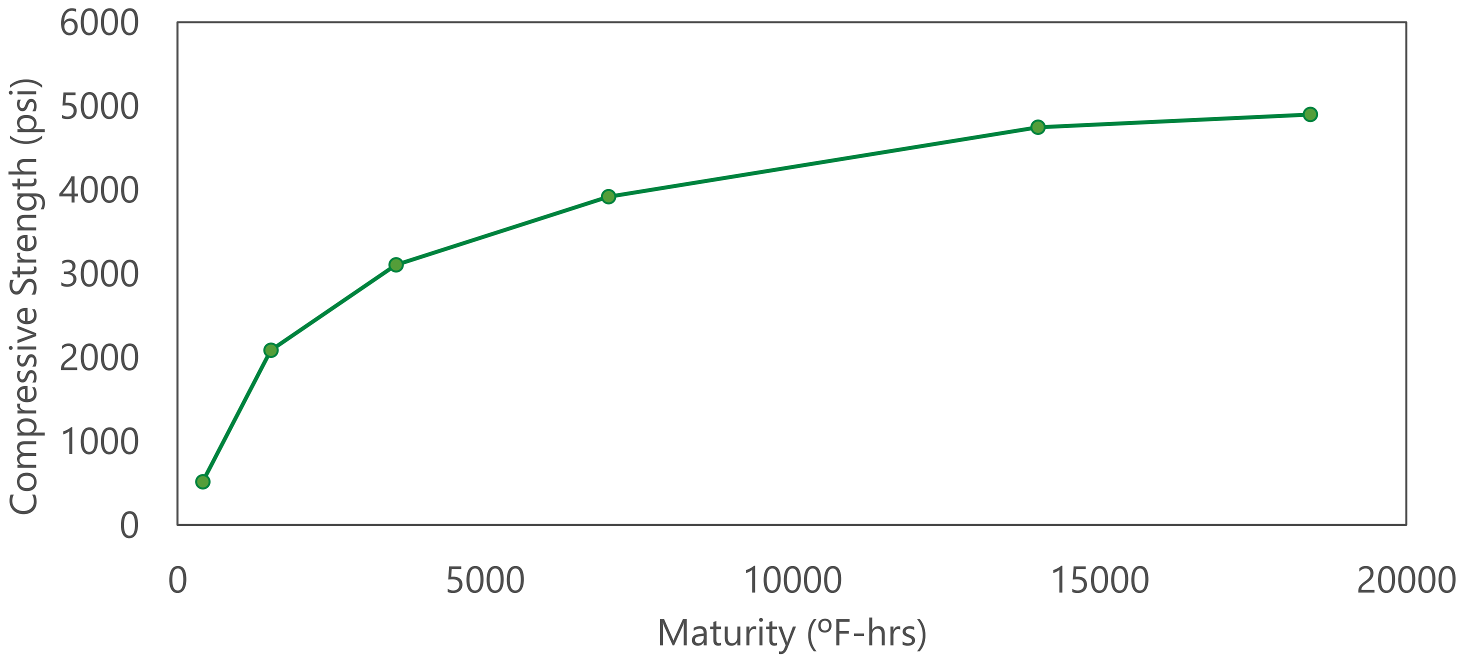
Maturity-Strength Relationship

ASTM C1074 definition: “an empirical relationship between concrete strength and maturity index that is obtained by testing specimens whose temperature history up to the time of the test has been recorded.”

The goal is to correlate a maturity index with a strength value using a calibration.



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Calibration requirements

- A calibration is specific to one mix
- Follow ASTM C1074
- Minimum of 5 data points
- Needs to be cured under lab condition

* The calibration specimens will hereon be referred to as standard 4x8 cylinders, but 6x12 cylinders and 4-inch cubes can also be used. Small beams can also be used to calibrate for tensile strength.

Maturity Calibration

5 easy steps!

Maturity Steps-Overview

Step 1: Prepare Samples

Step 2: Curing

Step 3: Strength

Same process as making lab-cured cylinders, additionally measure temperature in two cylinders → Simple!

Step 4: Maturity Index

Step 5: Maturity Strength Curve

More complex steps if done manually

Step 1: Prepare Samples

- Prepare a minimum of 17 cylinders

- 15 of the samples will be used for strength

- 2 will be used for temperature monitoring by placing a temperature sensor in the middle of the specimen

Strength Monitoring

Temperature Monitoring

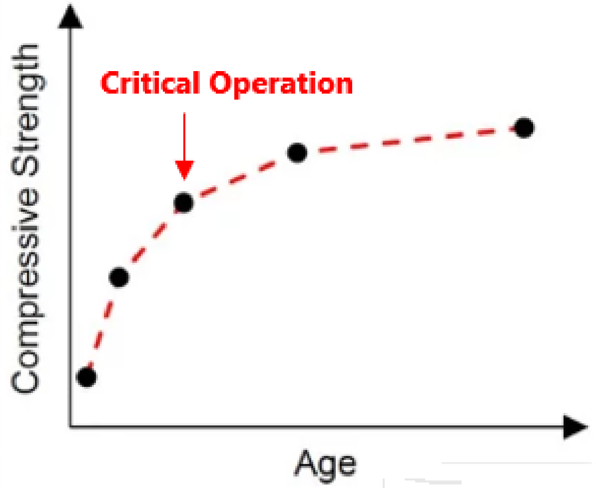
Step 2: Curing

- Provide the same curing condition for all samples

- Section 8.3 of the standard requires that the specimens be cured according to ASTM C511, in a water bath or in a moist room

Step 3: Strength

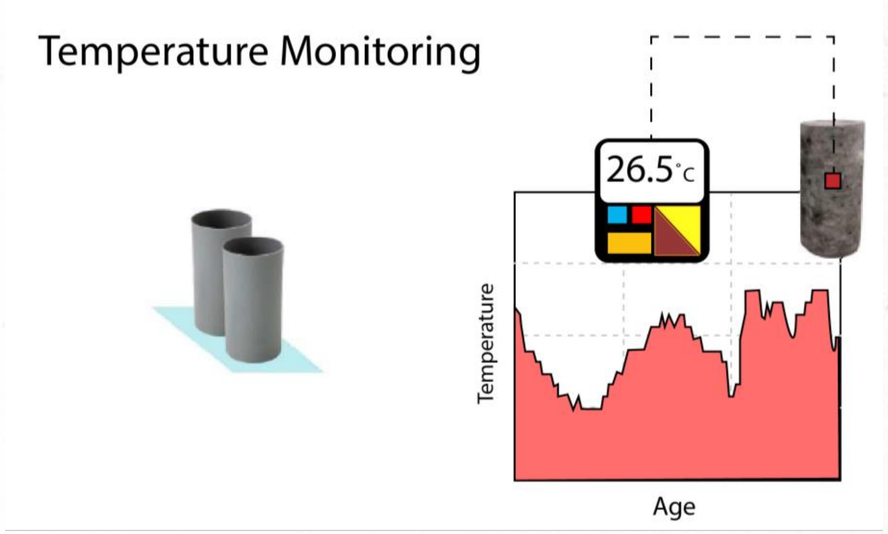
- Select a minimum of 5 measurement times (example: 1, 3, 7, 14, and 28 days)
- Break 2 cylinders for every age and use the average for your strength value
- Test the third cylinder if the difference in strength exceeds 10% of the average
- Take note of the time the cylinders were broken



Concrete compressive strength test	Age at target strength to open forms, tension, etc.		
	24 hrs	3 days	7 days
Break 1	As early as possible	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	14 days
Break 5	3 days	7 days	28 days

Step 4: Maturity Index

- Calculate average maturity at specified age
- Depending on the system used, maturity can be calculated automatically, or a manual calculation might be required



Giatec 360 as a tool to automatically calculate this Step and Step 5- Will be shown later
In the next couple slides we will cover how to calculate " manually" for when Giatec 360 is not available.

Step 5: Maturity-Strength Curve

Automatically calculate the maturity-strength curve with the Giatec system

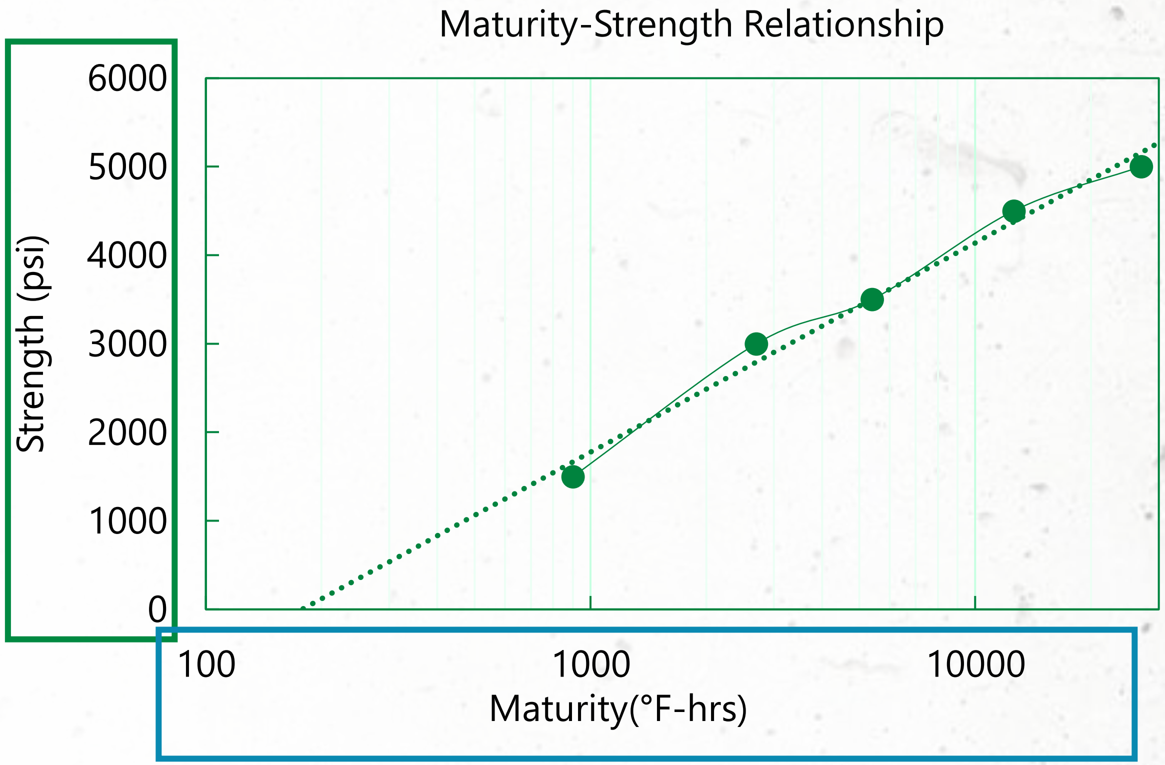
Step 3: Strength

Days	Maturity (°F-hrs)	Strength (psi)
1	900	1500
3	2700	3000
7	5400	3500
14	12600	4500
28	27000	5000

Step 4: Maturity Index

Equation of the fitted line:

$$Strength = a + b\ log10\ (Maturity)$$



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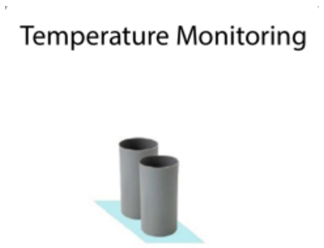
Manual Calculation of the Maturity Value

Step 1: Assign Demo Mix Calibration

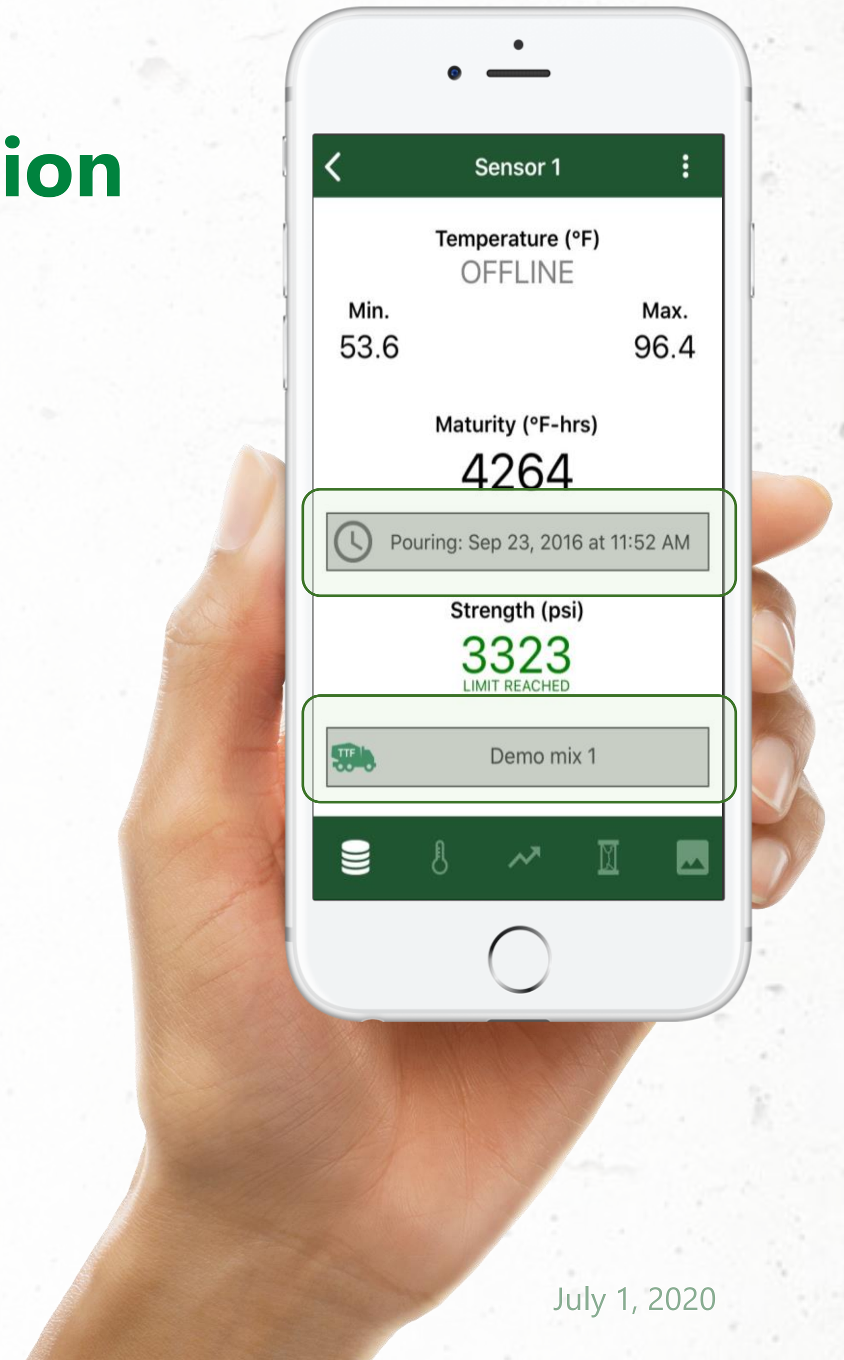
On the SmartRock application:

- Assign a pouring time and a mix to the 2 sensors installed in the cylinders for temperature monitoring in the calibration process.



- The mix must have the same datum temperature you are going to use on this calibration.

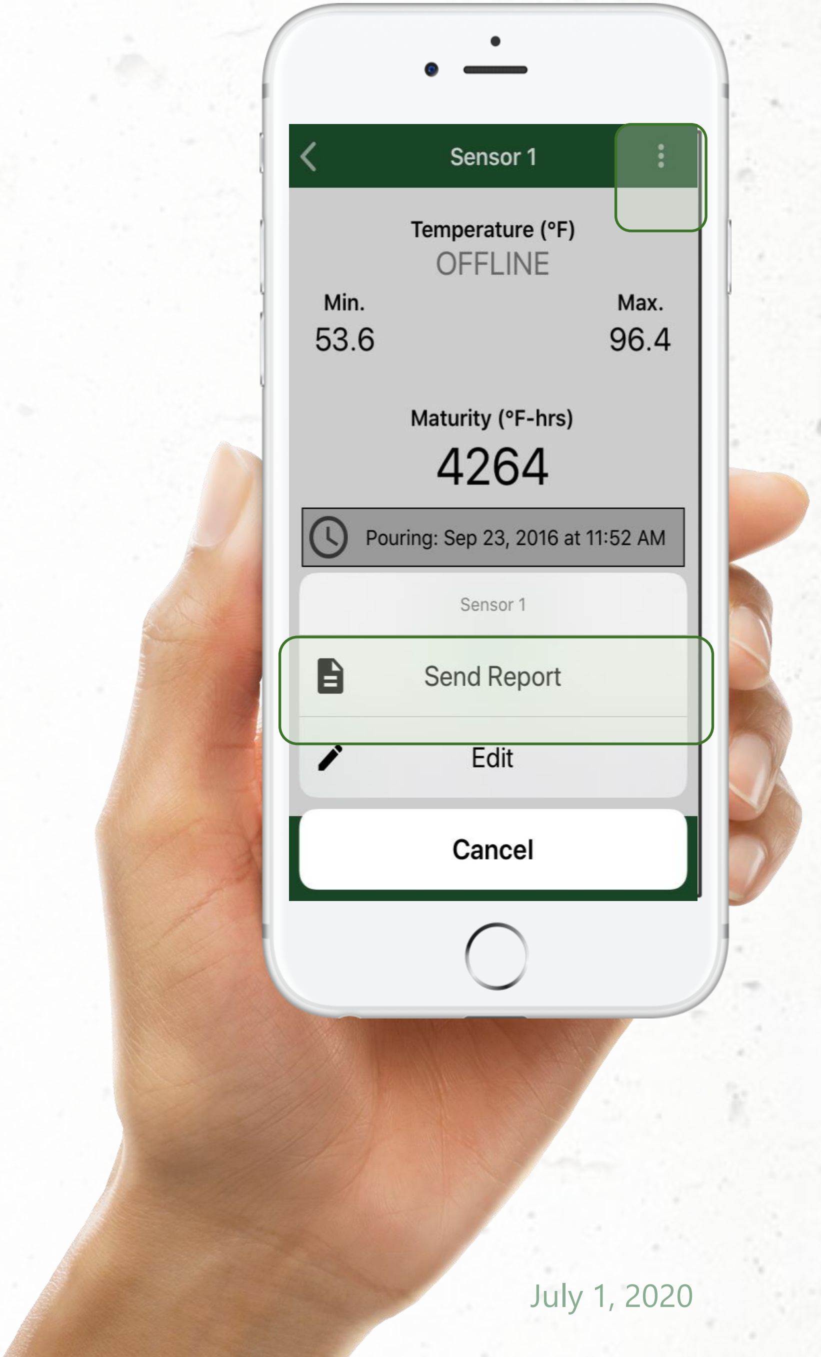
*You can use the Demo Mix 1 provided in the application if you are using 0C for° datum temperature.



Step 2: Export CSV files

On the SmartRock Application:

- Download the CSV file for both sensors.
- Ignore the Strength column in the CSV file (it is irrelevant in this case as we assigned a random mix to the sensor).



Step 4 : Compile Strength Data

Collect the strength of the concrete with it's associated time of break (or age). Data obtained from Step 3 in maturity calibration.

Ex:

Time of break	Date/Time of break	Average Strength (psi)
12hr	June 10, 2020 8:05PM	1500
24hr	June 11,2020 9:15 AM	2100
3 days	June 13, 2020 10:00 AM	2900
7 days	June 17, 2020 9:00 AM	3500
28 days	July 8, 2020 8:30 AM	4350

Step 5: Combine maturity and Strength data

Find corresponding dates and associate maturity value with strength. Take average of maturity from both sensors.

Ex:

Time of break	Date/Time of break	Strength (psi)
12hr	June 10, 2020 8:05PM	1500

Sensor 1

Sample No.	Date Time	Temperature (Degree F)	Maturity (Degree F-hrs)	Strength (psi)	Status
1	2020-06-10 8:05	74.97	0.00	0.00	Before Pouring
44	2020-06-10 19:05	95.97	516.60	794.44	After Pouring
45	2020-06-10 19:20	98.20	532.87	831.59	After Pouring
46	2020-06-10 19:35	98.62	549.47	868.34	After Pouring
47	2020-06-10 19:50	100.90	566.42	904.70	After Pouring
48	2020-06-10 20:05	101.10	583.67	940.64	After Pouring
49	2020-06-10 20:20	105.12	601.45	976.57	After Pouring
50	2020-06-10 20:35	102.18	619.36	1011.72	After Pouring
51	2020-06-10 20:50	104.77	637.22	1045.79	After Pouring
52	2020-06-10 21:05	105.96	655.56	1079.78	After Pouring
53	2020-06-10 21:20	100.53	673.38	1111.89	After Pouring

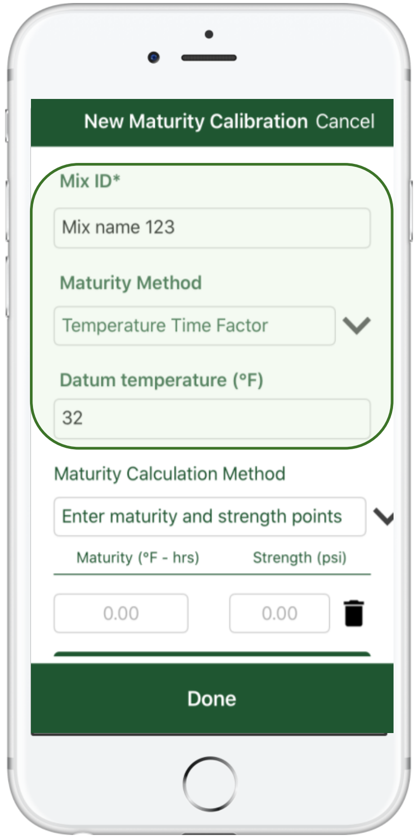
Sensor 2

Sample No.	Date Time	Temperature (Degree F)	Maturity (Degree F-hrs)	Strength (psi)	Status
1	2020-06-10 8:00	74.97	0.00	0.00	Before Pouring
44	2020-06-10 19:00	95.25	504.00	764.87	After Pouring
45	2020-06-10 19:15	98.40	520.20	802.78	After Pouring
46	2020-06-10 19:30	97.68	536.72	840.20	After Pouring
47	2020-06-10 19:45	100.90	553.54	877.17	After Pouring
48	2020-06-10 20:00	101.01	570.78	913.90	After Pouring
49	2020-06-10 20:15	105.31	588.56	950.66	After Pouring
50	2020-06-10 20:30	101.48	606.42	986.45	After Pouring
51	2020-06-10 20:45	99.88	623.59	1019.89	After Pouring
52	2020-06-10 21:00	105.89	641.30	1053.45	After Pouring
53	2020-06-10 21:15	101.86	659.29	1086.55	After Pouring

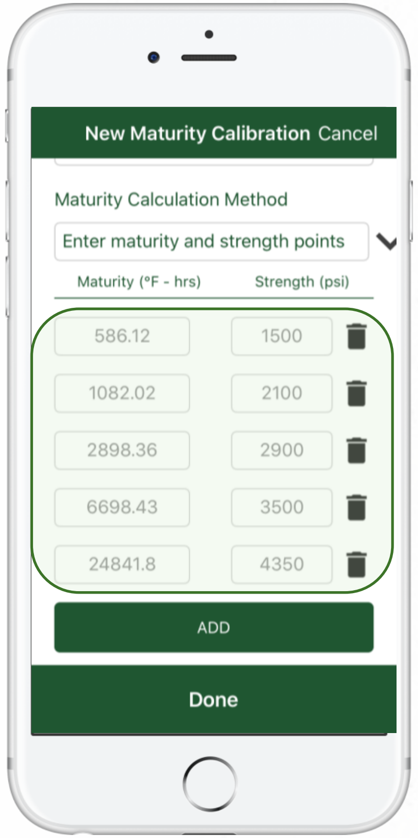
Repeat for each strength

Step 6: Implement in the app

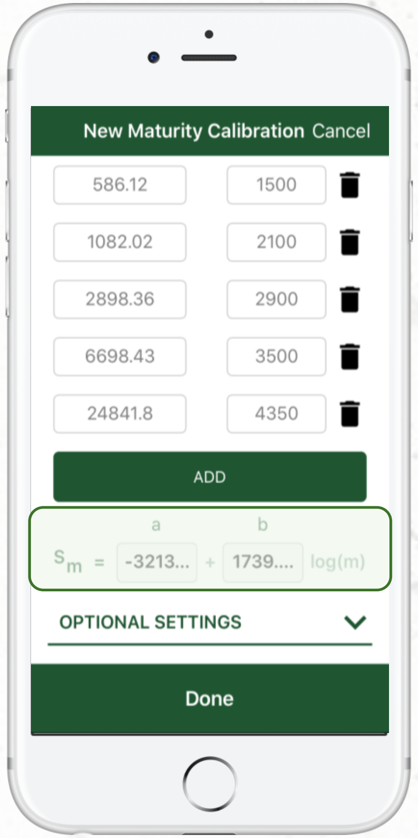
From the side menu -> Maturity Calibrations-> + New Maturity calibration



Input general information



Input values from Step 4-5



Automated calculation of a and b