NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Maturity for Pavements—Updates and New Guidance

October 9, 2024

11:00 AM - 12:30 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

Purpose Statement

This webinar will inform agencies and practitioners of these new approaches. Presenters will share a case study from Iowa Department of Transportation (DOT) and how they have utilized the maturity concept for determining early opening strengths for the past 25 years.

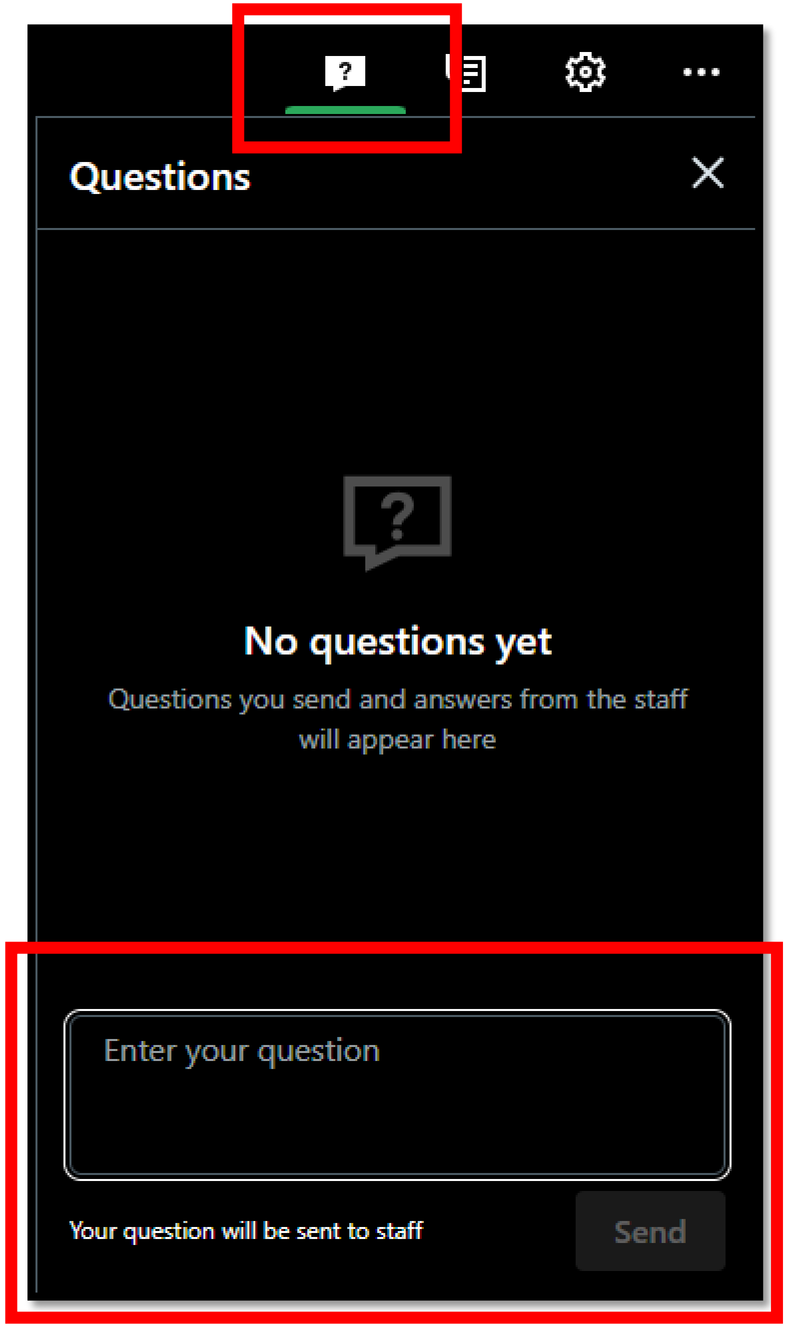
Learning Objectives

At the end of this webinar, you will be able to:

- Understand the differences between ASTM C1074 and the newly introduced AASHTO pavement-specific maturity test method
- Leverage the maturity concept using lessons learned from Iowa DOT
- Record maturity data using the latest sensor technologies

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today's presenters

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ATI Inc.

Armen Amirkhanian
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The University of Alabama

Sabrina Garber
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American Concrete Pavement Association

MATURITY METHOD FOR CONCRETE PAVEMENTS

DR. ARMEN AMIRKHANIAN, P.E.

THE UNIVERSITY OF ALABAMA®

DISCLAIMER

Certain commercial entities, equipment, or materials may be identified in this presentation in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by The University of Alabama, FHWA, TRB, or AASHTO or the listed authors, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

Any opinions or recommendations are solely those of the author and do not represent the official view or policy of The University of Alabama, FHWA, TRB, or AASHTO.

Let's Go!

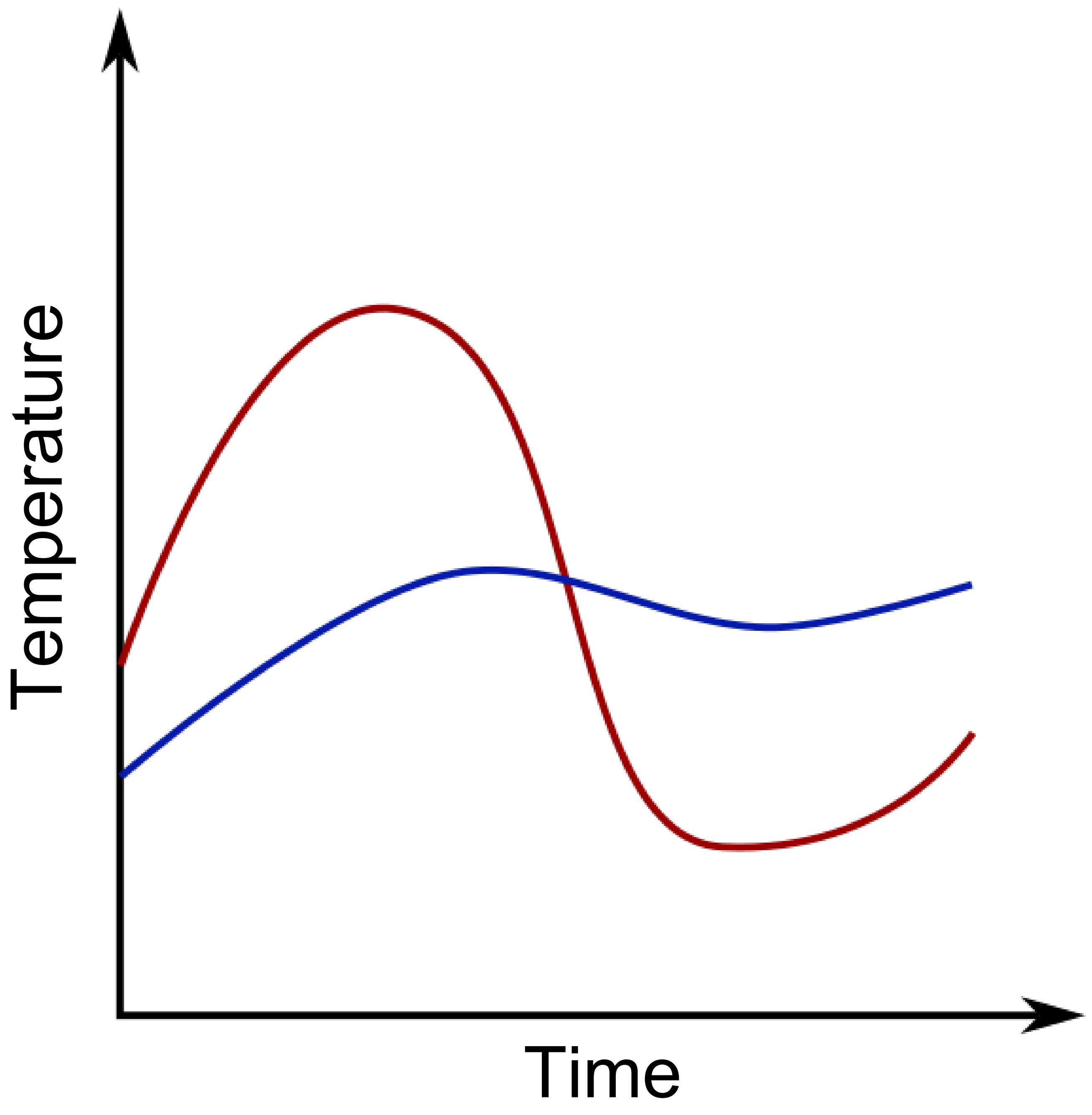
WHAT IS MATURITY?

Precast concrete industry (US) started looking at maturity in the 1950s.

Relate time and temperature.

A.G.A. Saul

"Concrete of the same mixture at the same maturity has approximately the same strength whatever combination of temperature and time go to make up that maturity."



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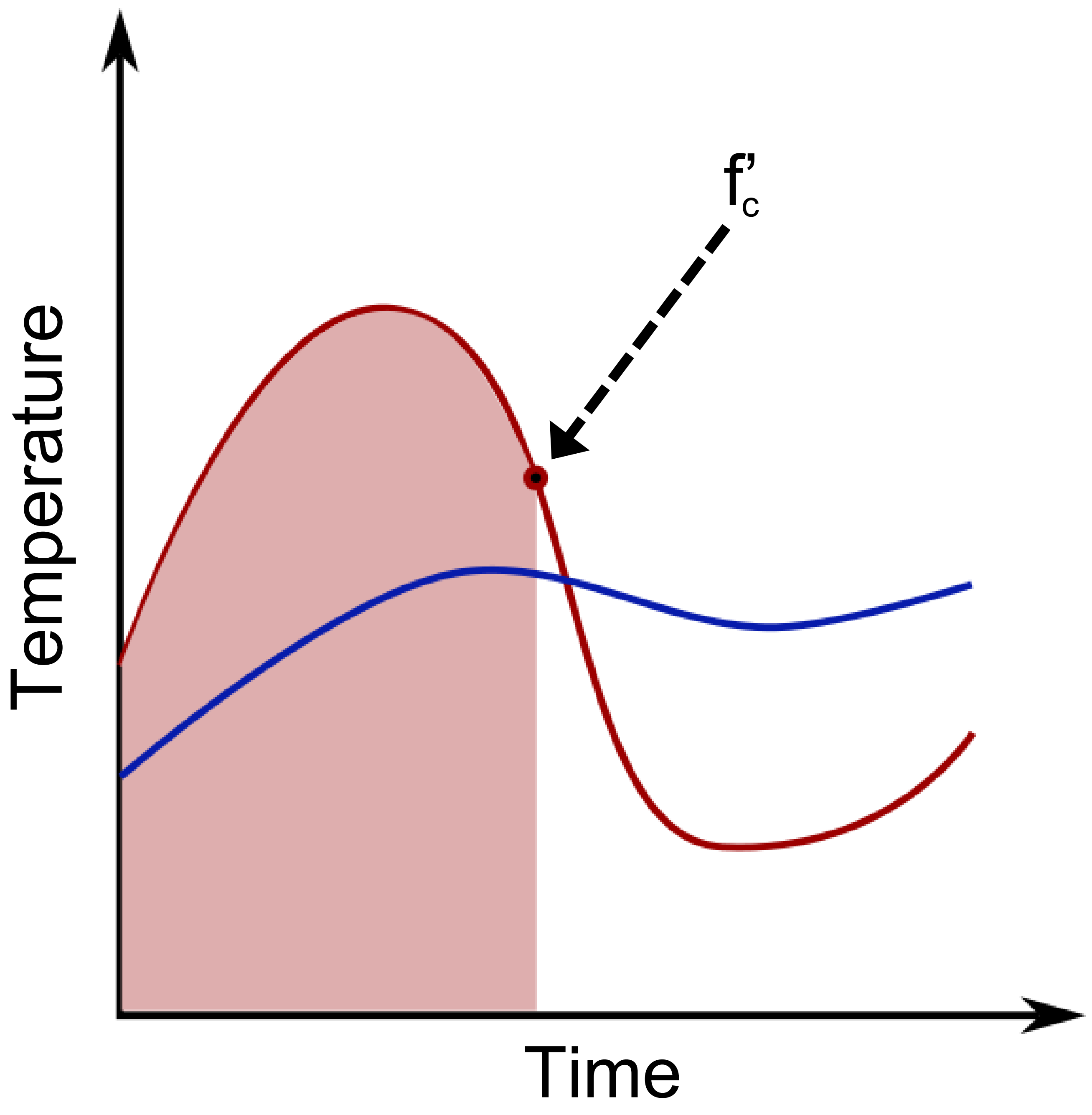

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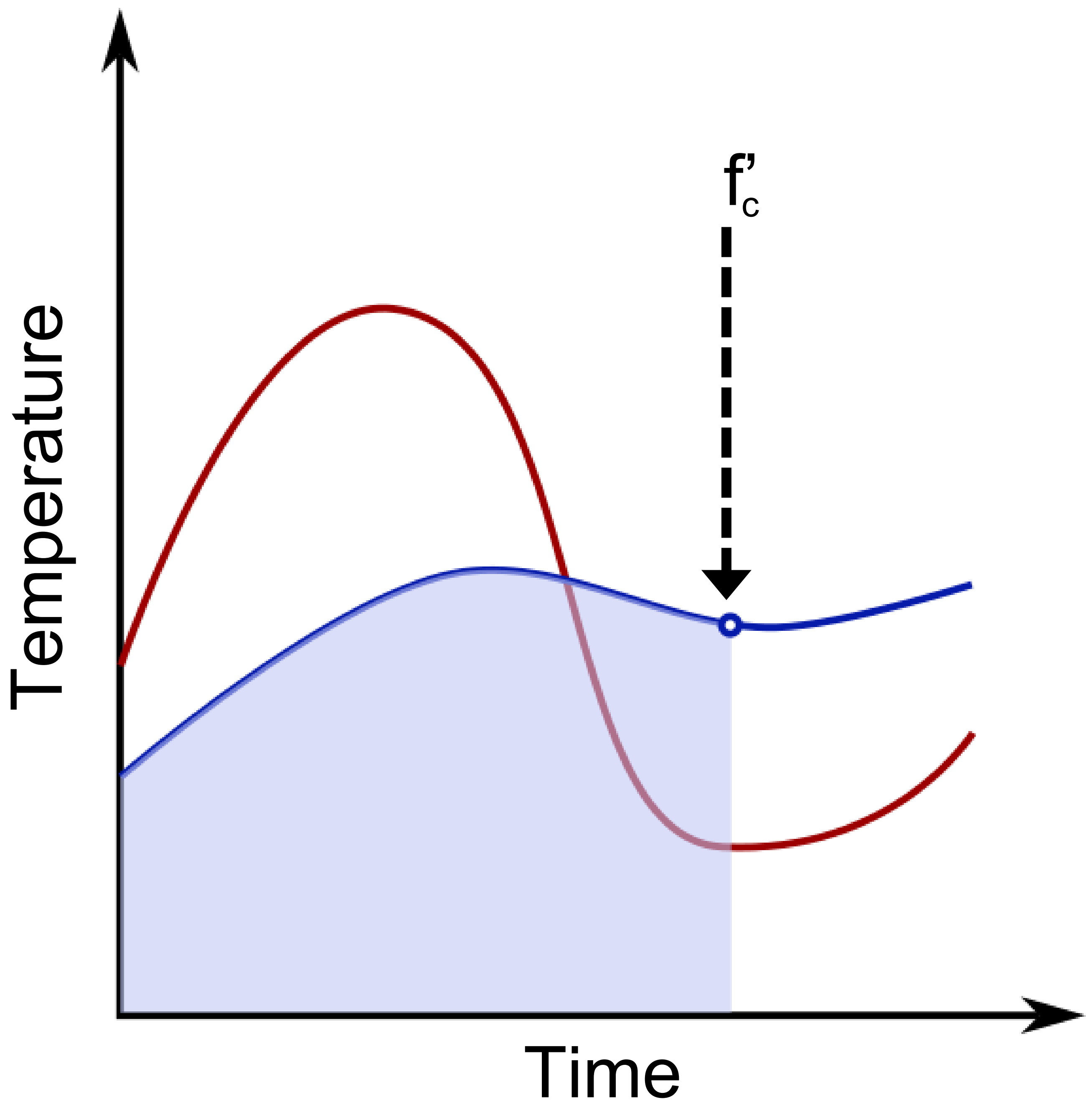

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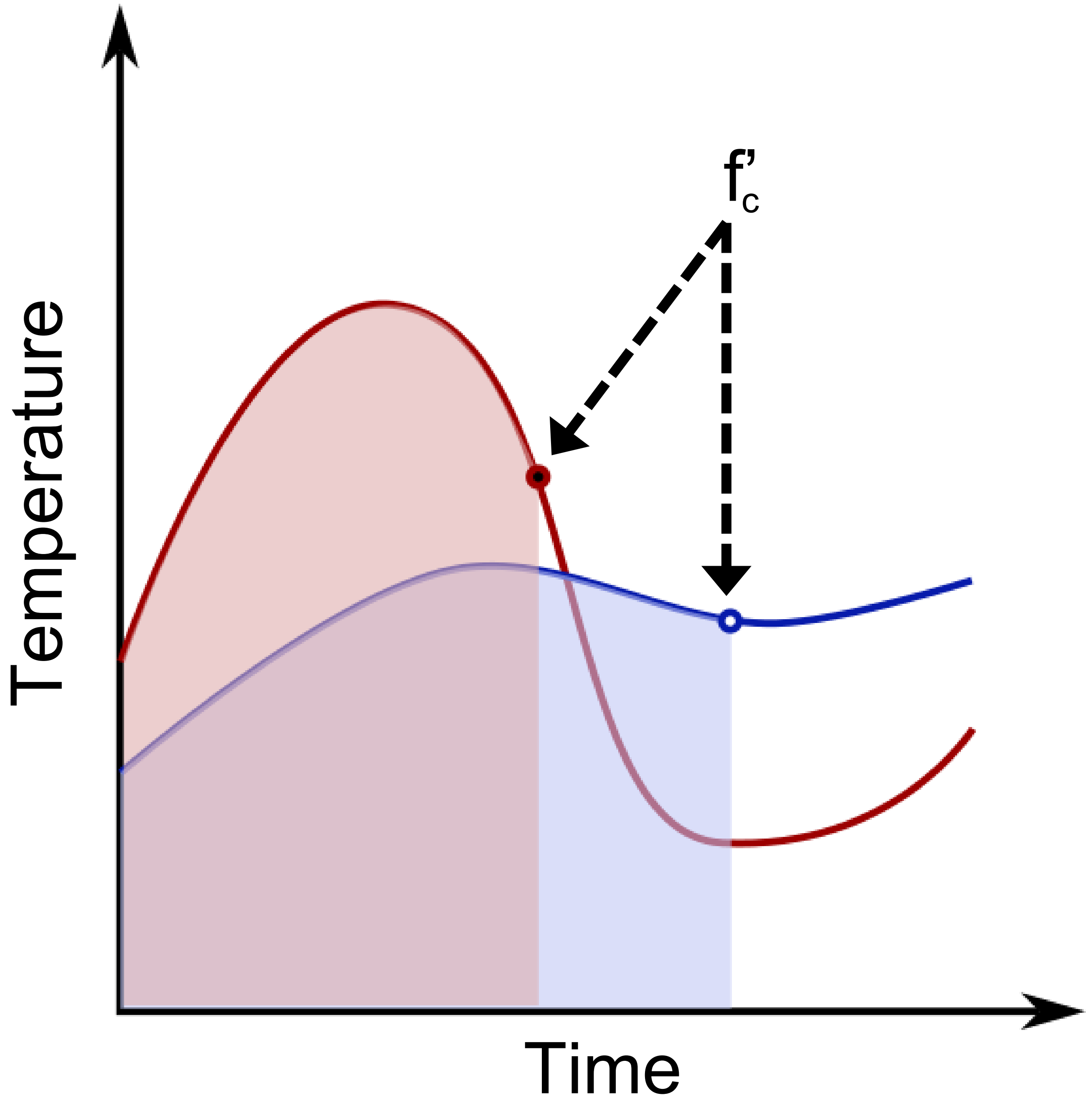


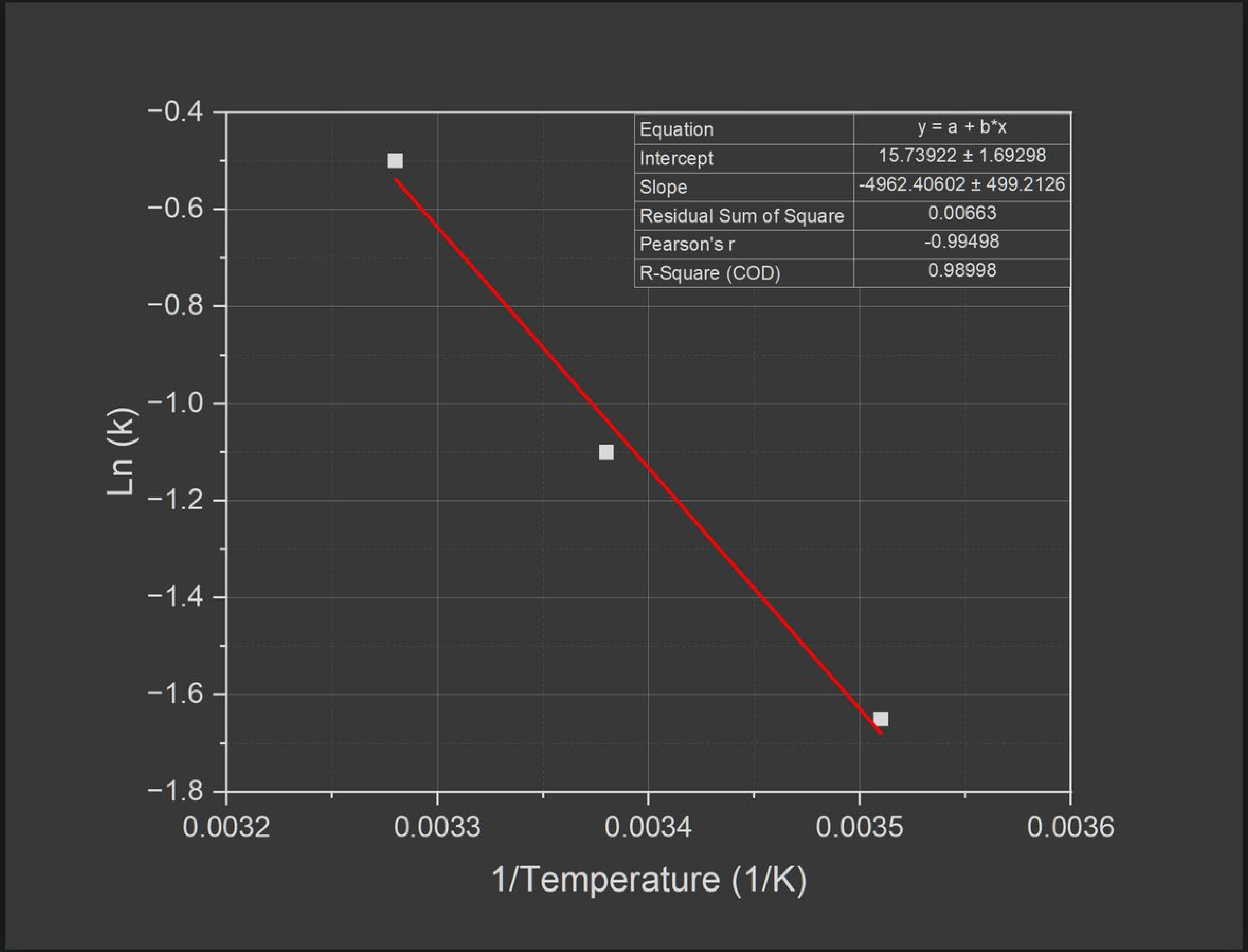
TWO MODELS

Nurse Saul

$$M = \sum (T - T_o)\,\Delta t$$

Arrhenius

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



ARRENHIUS

We have a significant challenge with using the Arrenhius method:

we need to experimentally determine the activation energy, *Q*.

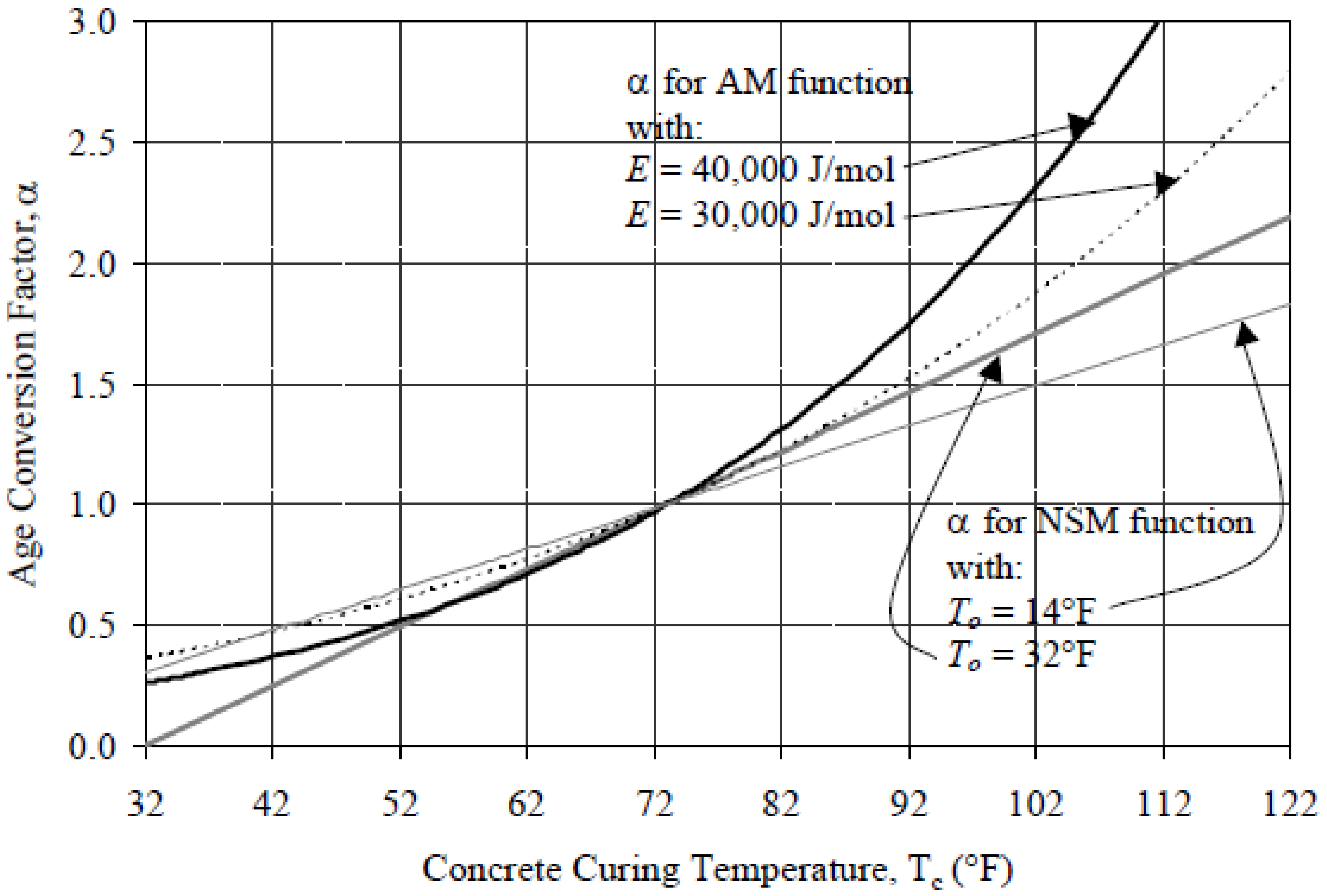
Mortar mixtures tested at three constant temperatures

WHICH IS BETTER?

Arrhenius for all ages

Nurse-Saul only for early age

*But really, it depends!



Wade (MS Thesis) 2005

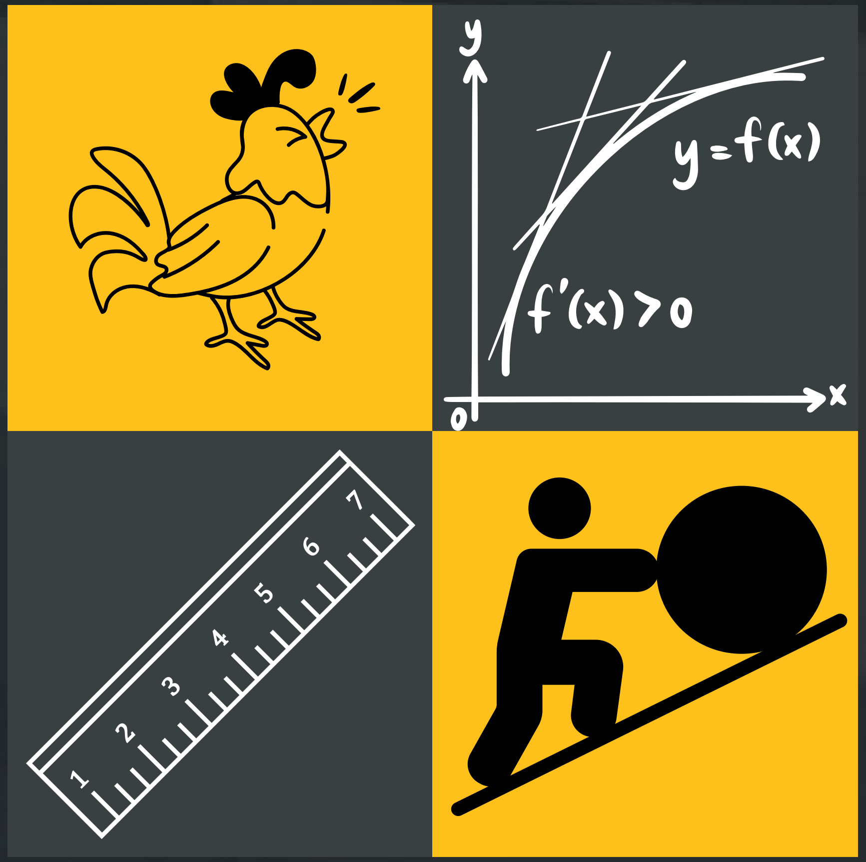
"We already have a pavement maturity specification..."

SORTA... AASHTO T325 and ASTM C1074

Not written as to be used asis in specifications! Literally has the words "Standard Practice" in the title!

Existing
CHALLENGES

01 Insufficient early-age testing is specified in both documents.



02 AASHTO explicitly recommends the use of Arrhenius (aka Equivalent Age) approach.

03 Sensor placement is solely based on yardage, not field conditions or geometry.

04 Curve validation requirements are onerous.

GENERATE THE CURVE

Compression

Easiest to do
Well established precision and bias
Agencies have decent correlations

Flexural

Challenging
Well established precision and bias
Direct use

Tensile?

Not too bad
Well established precision and bias
Does anyone use this?





GENERATE THE CURVE

Minimum of 12

Need a minimum of 12 specimens for testing. Mixture must be from a truck or central plant.

Instrumentation

At least two of the specimens need to be instrumented with a temperature logging sensor or a maturity device.

First Day

Can use the first day of production!



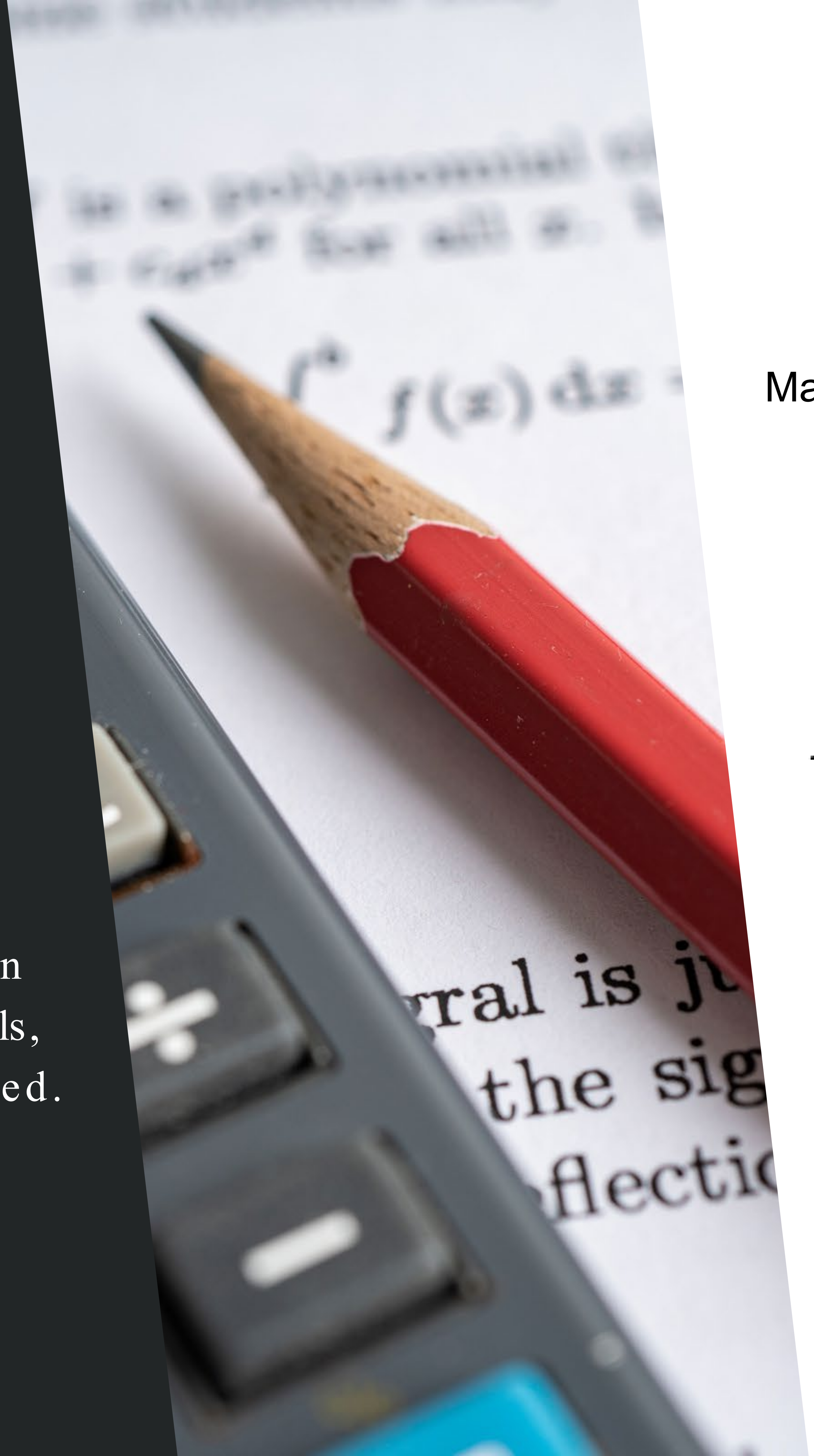


01.

Use Nurse-Saul method to determine the Time-Temperature Factor (TTF)

02.

Prior data or information on the mixture, materials, cement, etc. is not needed.



Maturity aka TimeTemperature Factor

$$M = \sum (T - T_o)\,\Delta t$$

Datum Temperature-(10C)

AASHTO T413

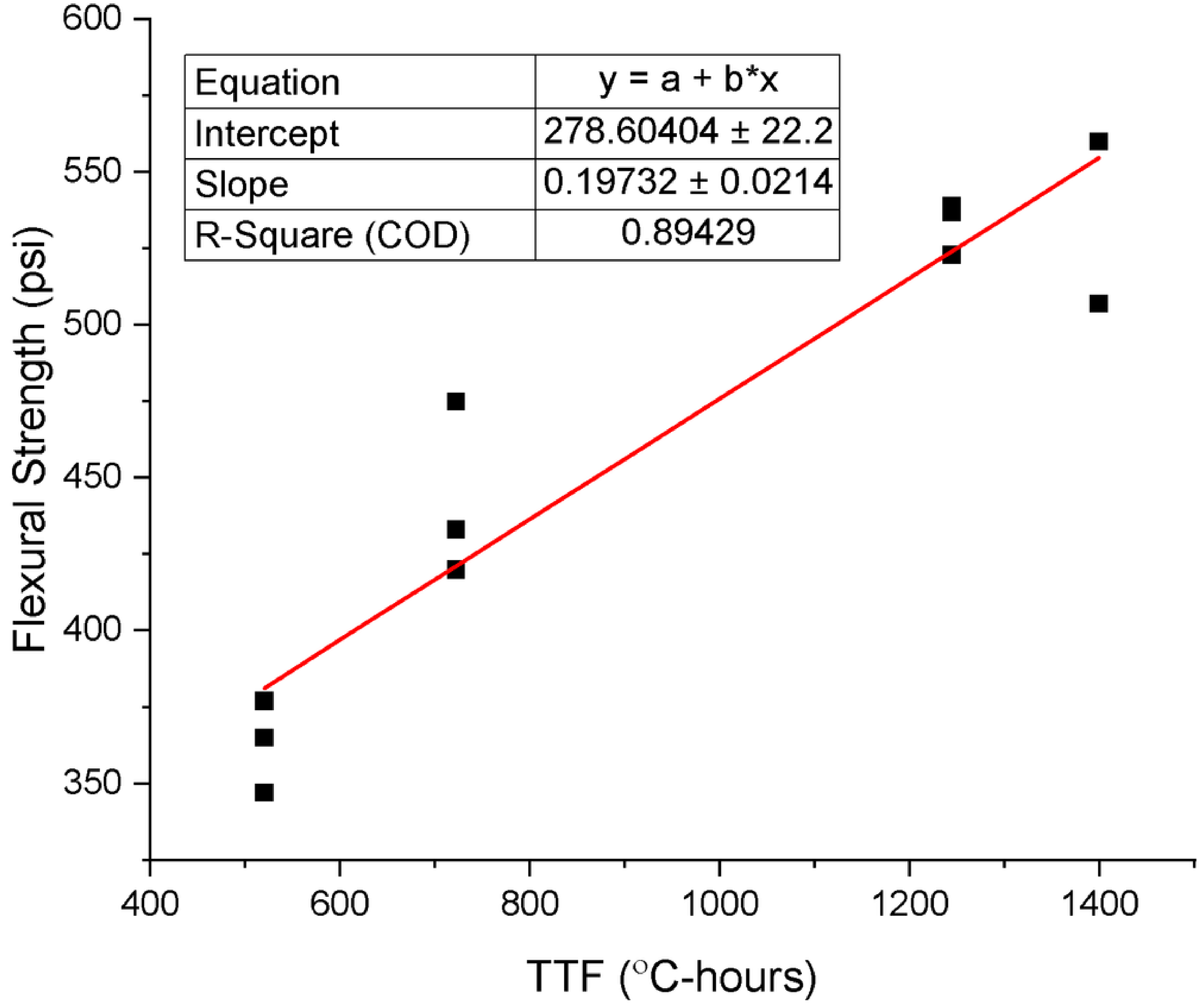
DEVELOP RELATIONSHIP STRENGTH VS. TTF

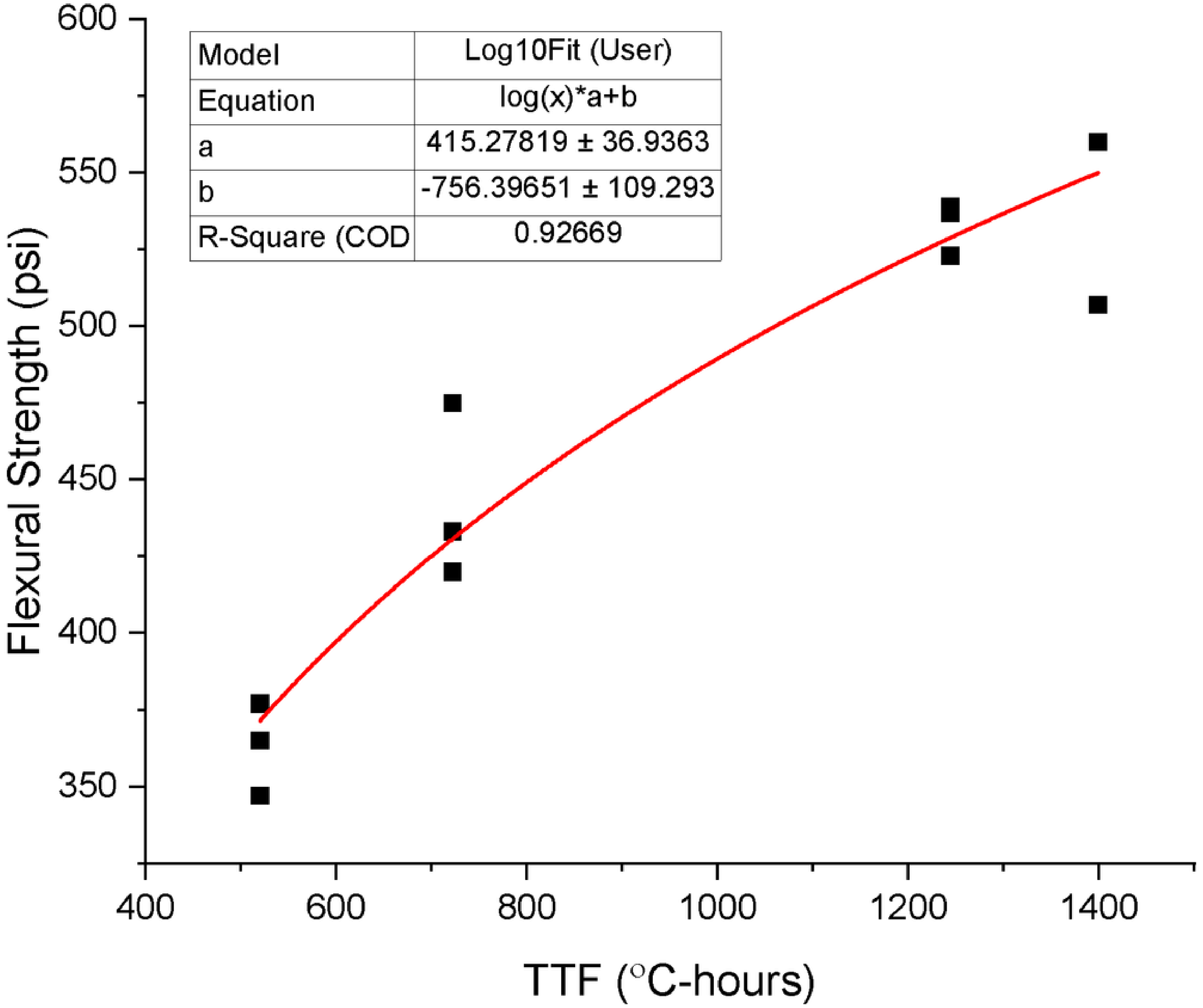
01. First strength test must be within 24 hours, as early as 18 hours is possible if high early strength.

02. First strength test must have a strength less than 85% of the target opening strength.

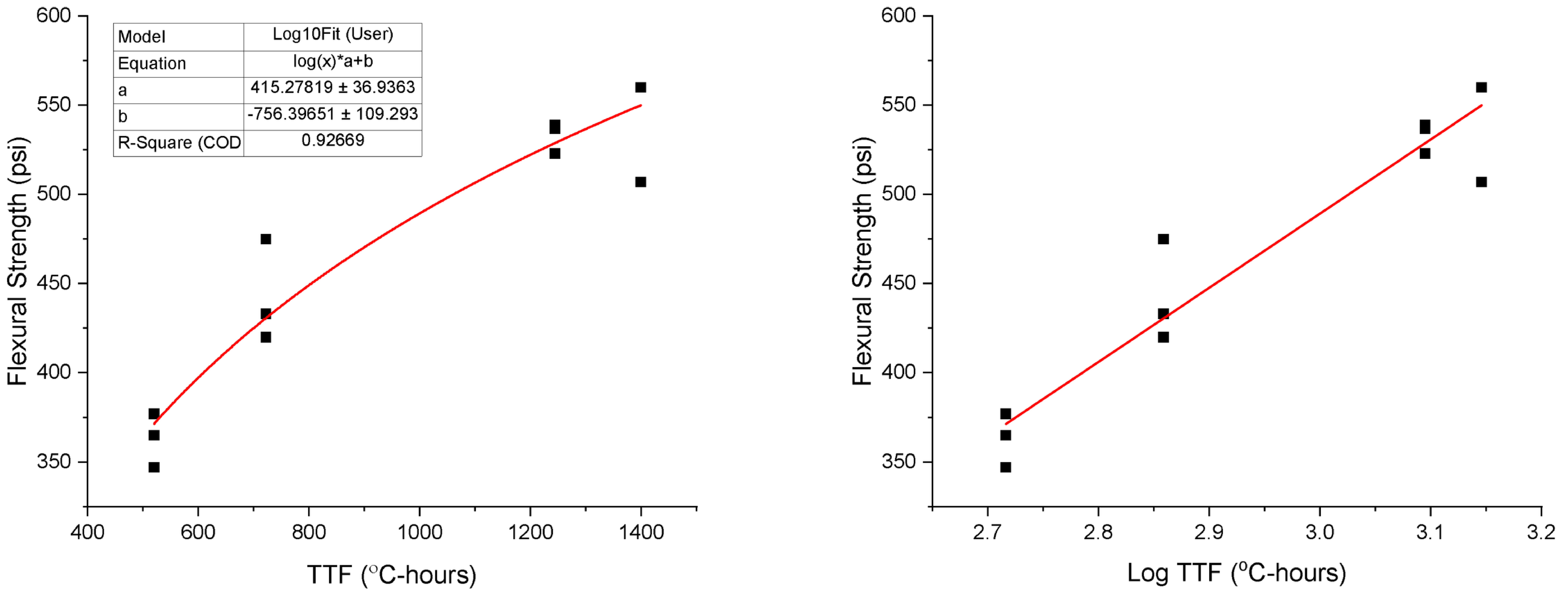
03. Strongly recommended that at least two strengths are measured below the target opening strength.

What curve fit should I use for the TTF curve?





Most mixtures at early ages (≤3 days) won't show too much difference between fits.
Linear fit usually under-predicts the true strength and thus is more conservative.


Model
Log10Fit (User)
Equation
log(x)*a+b
a
415.27819 ± 36.9363
b
-756.39651 ± 109.293
R-Square (COD
0.92669
Flexural Strength (psi)
600
550
500
450
400
350
400
600
800
1000
1200
1400
TTF (°C-hours)
Flexural Strength (psi)
600
550
500
450
400
350
2.7
2.8
2.9
3.0
3.1
3.2
Log TTF (°C-hours)

VALIDATION

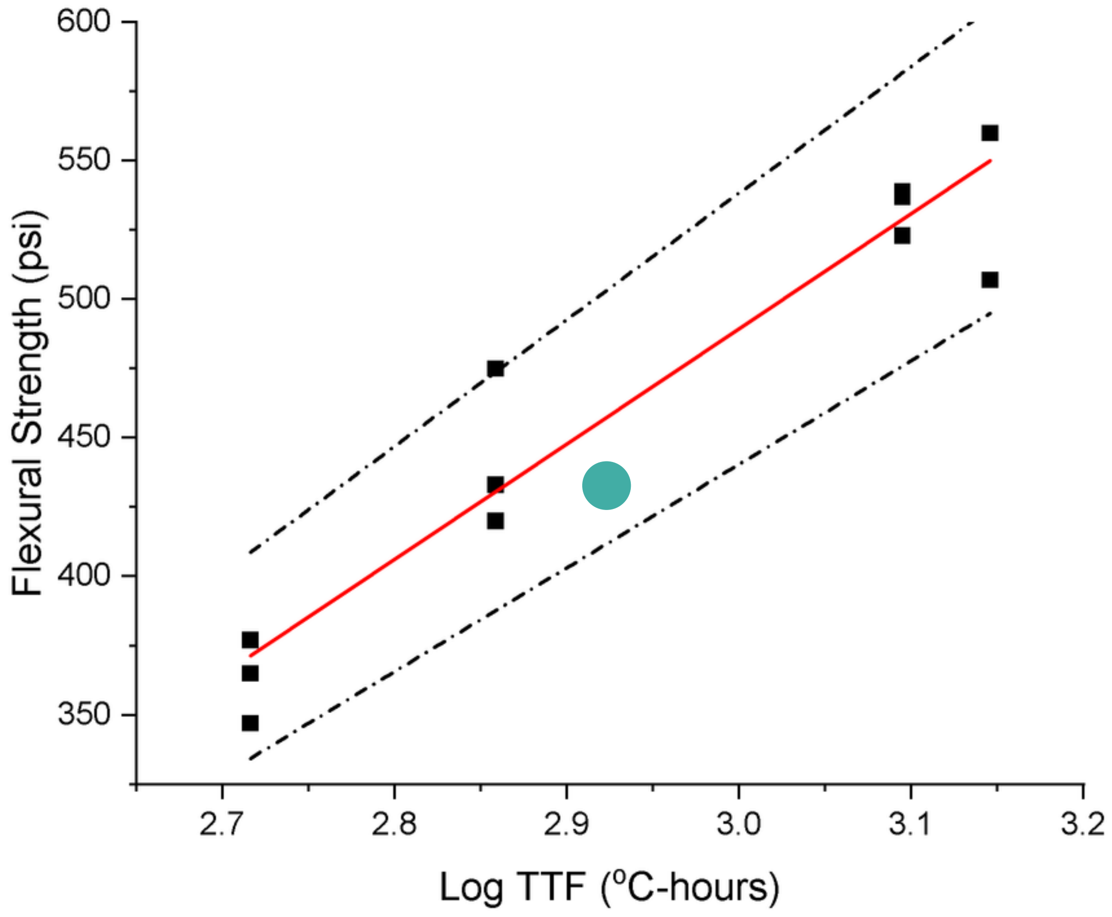
- **Every 60 days**
- w/c changes more than 0.02
- Mix proportions change more than 5% (weight)
- Cementitious change
- Aggregate change

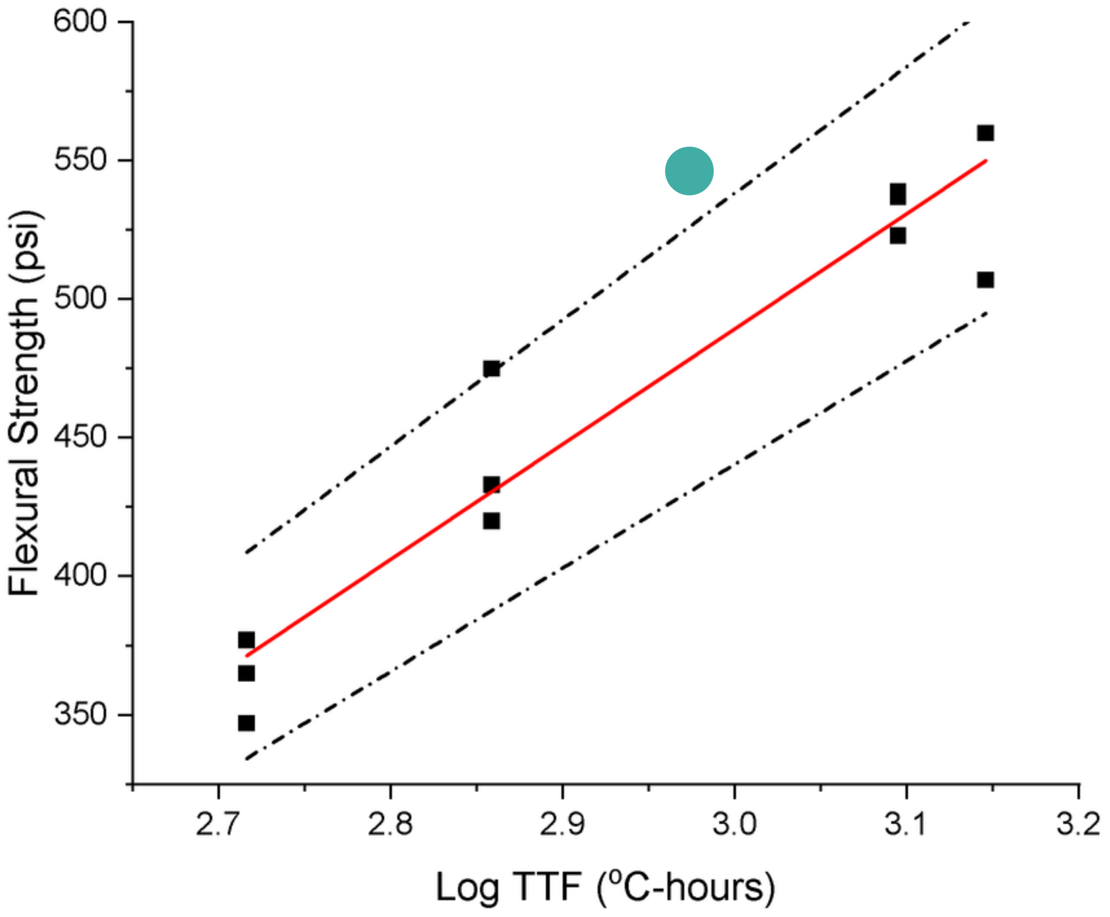
EXCERPT

If the average calculated strength–maturity test falls within ±10 percent of the maturity curve the curve is validated and no further action is necessary. If it is 10 percent higher than the maturity curve it is not considered verified. This curve <u>can still be used</u> but a new maturity curve can be developed at the discretion of the contractor. If it is 10 percent less the maturity curve will no longer be acceptable and a new curve must be developed. The maturity method is no longer approved for that concrete mixture.


APPROVED
APPROVED
APPROVED


REJECTED
REJECTED
REJECTED


600
550
500
450
400
350
Flexural Strength (psi)
2.7
2.8
2.9
3.0
3.1
3.2
Log TTF (oC-hours)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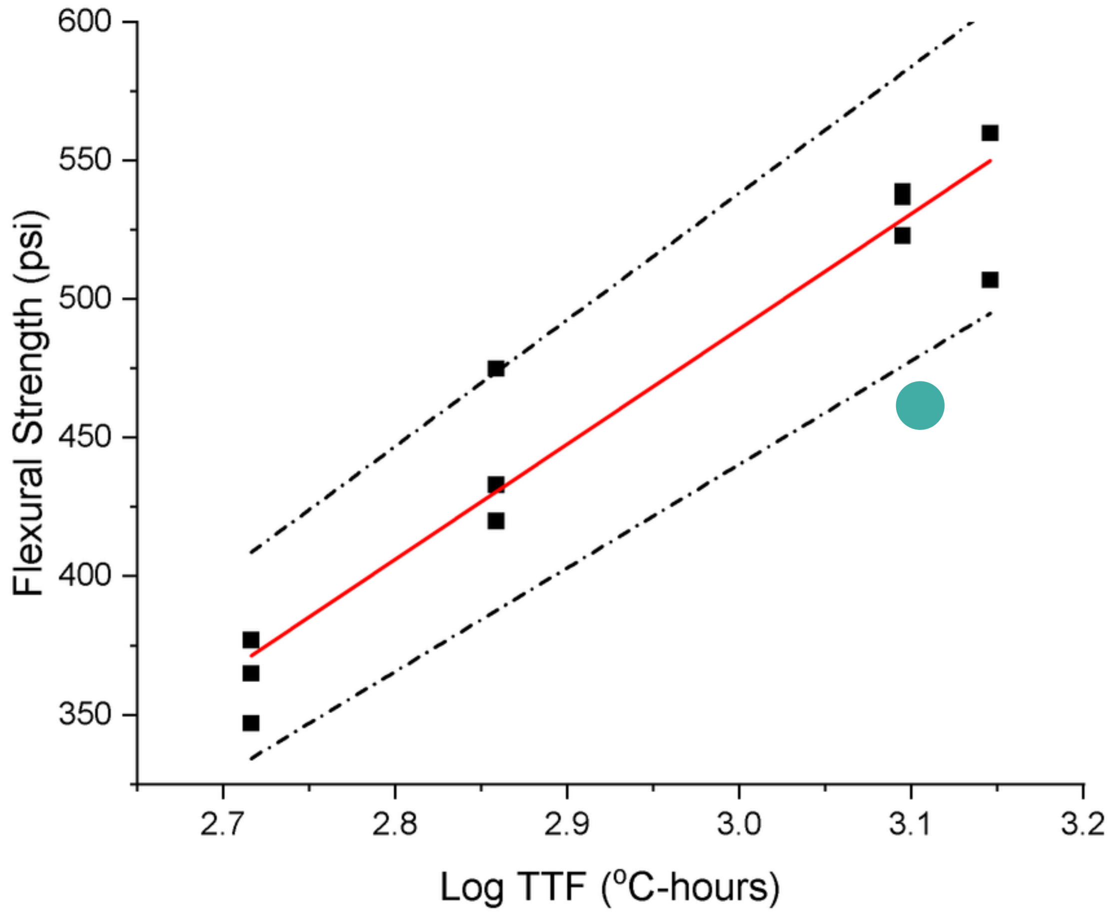
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550
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2.8
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3.1
3.2
Log TTF (oC-hours)

IMPROVEMENTS

01 Explicit early-age testing and requirement for test results below target strength

02 Simple math since early-age strength is all we're after

03 Sensor placement based on construction practice and expected weather

04 Simple and practical validation requirements

MOVING FORWARD

01.

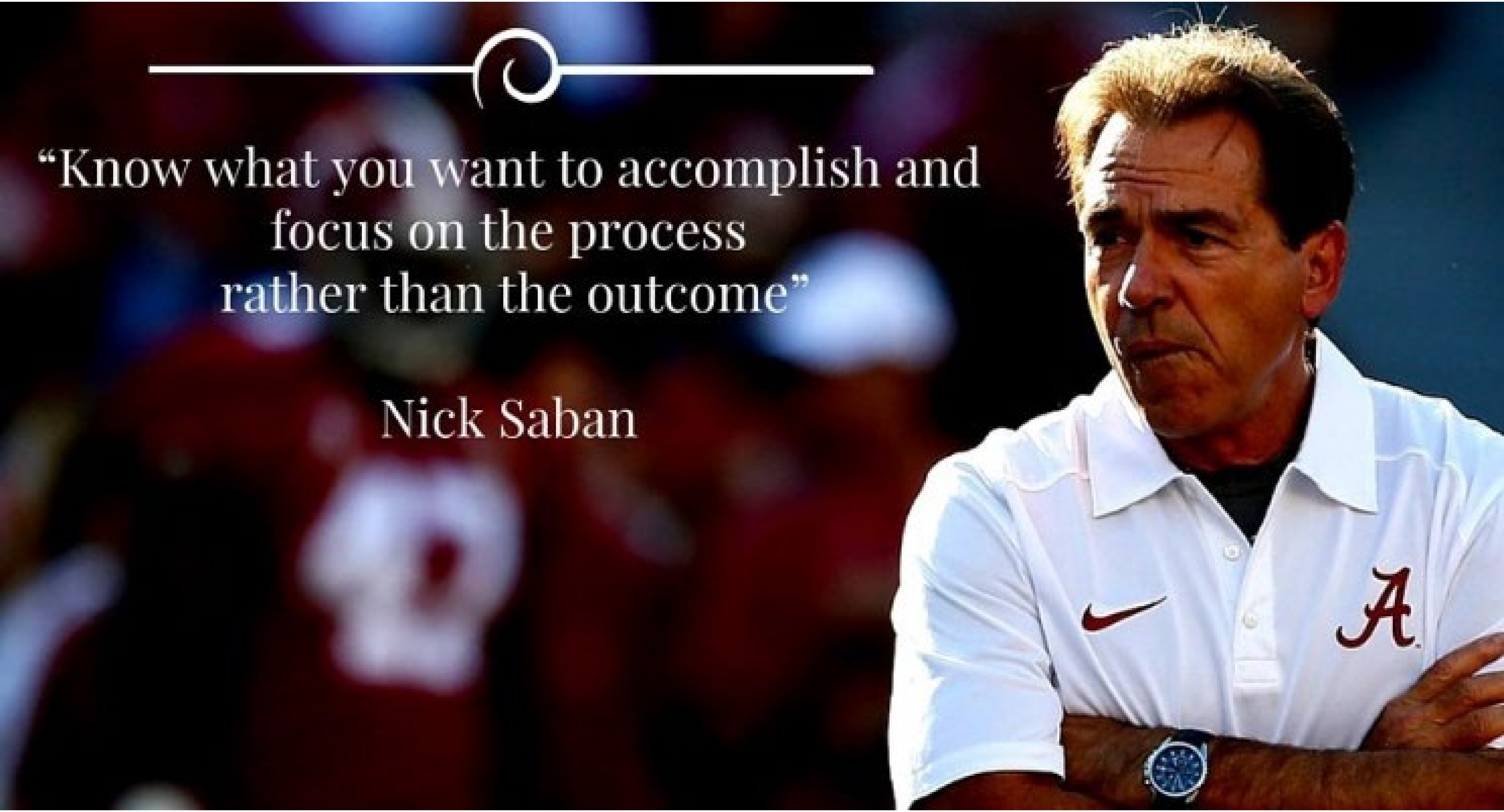
Understand the literature and be able to explain to stakeholders in clear and simple language.

02.

Understand the limitations (going out to 28 days is not terribly accurate).

03.

Understand the process and equipment needed.


"Know what you want to accomplish and
focus on the process
rather than the outcome"
Nick Saban

QA/QC AND MATURITY

- Procedures for determining, reporting, and documenting strength-maturity relationship
- Procedures for determining, reporting, and documenting in-place strength using maturity
- Details on frequency and conditions of mix verification, evaluation criteria, and corrective/investigative actions.
- Details on validation of strength-maturity relationship
- Compensating for sources of errors such as differences in batch temperatures, changes in materials, human errors

RESOURCES

ASTM C1074

AASHTO T325

AASHTO T413 (new)

Iowa DOT Specification (IM 383)

Texas DOT Specification (Tex-426-A)

Report IPRF-01-G-002-03-6

LINK

THE MATURITY METHOD: FROM THEORY TO APPLICATION

by

N.J. Carino
and
H.S. Lew
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8611 USA

LINK

ACI 228.1R-19

Report on Methods for Estimating In-Place Concrete Strength

Reported by ACI Committee 228

LINK

CP Tech Center

National Concrete Pavement Technology Center

CP TECH CENTER | PERFORMANCE-ENGINEERED MIXTURES (PEM)

Performance-Engineered Mixtures (PEM)

THANK YOU

DR. ARMEN AMIRKHANIAN, P.E.

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WHERE LEGENDS ARE MADE®

Iowa DOT's 25 Years of Experience with Maturity Testing

Jim Grove P.E.
ATI Inc., Contractor to FHWA
Office of Preconstruction, Construction, and Pavements
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TRB Webinar October 9, 2024

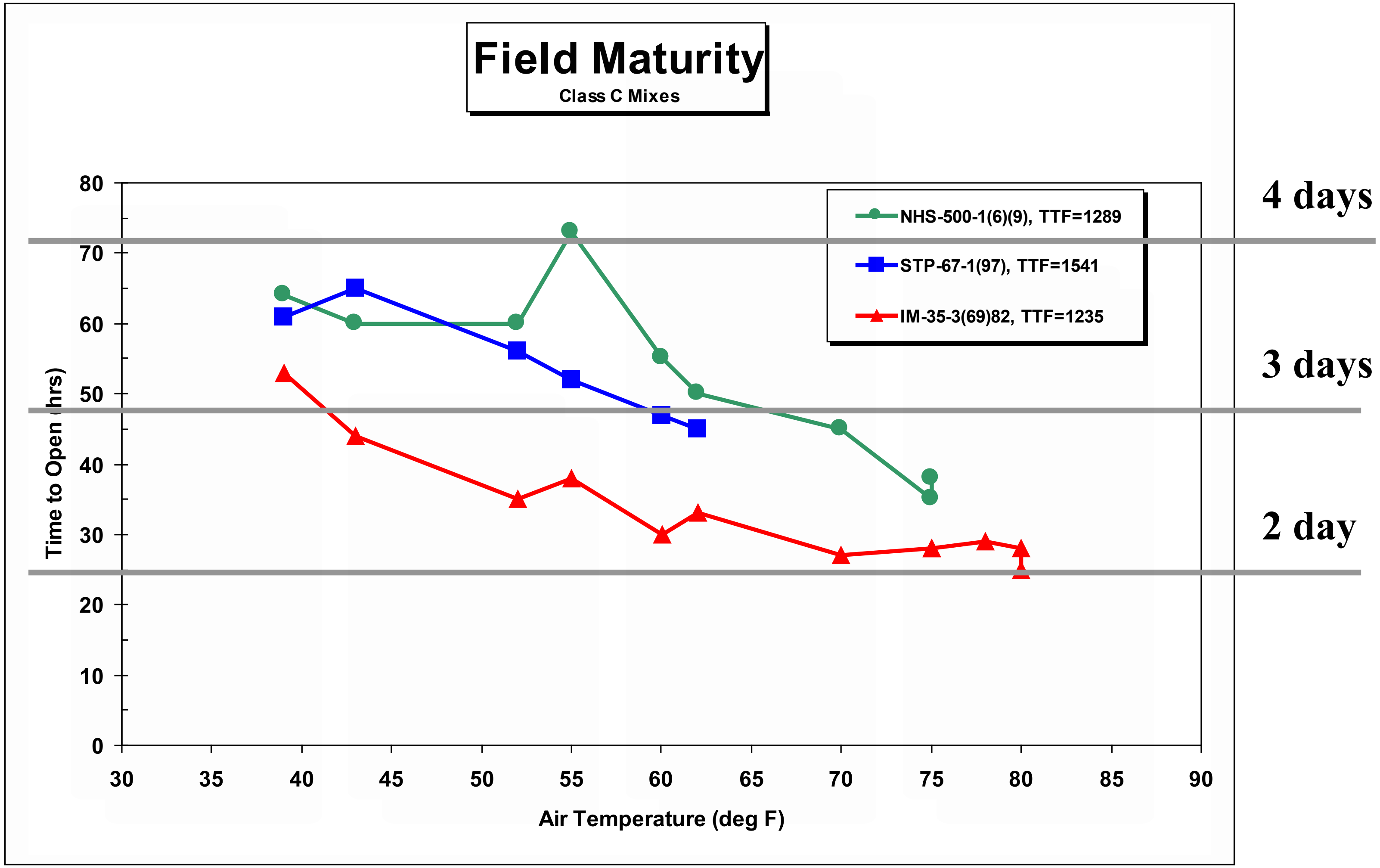
MCTC

U.S. Department of Transportation
Federal Highway Administration

When Is It Okay to Drive On?

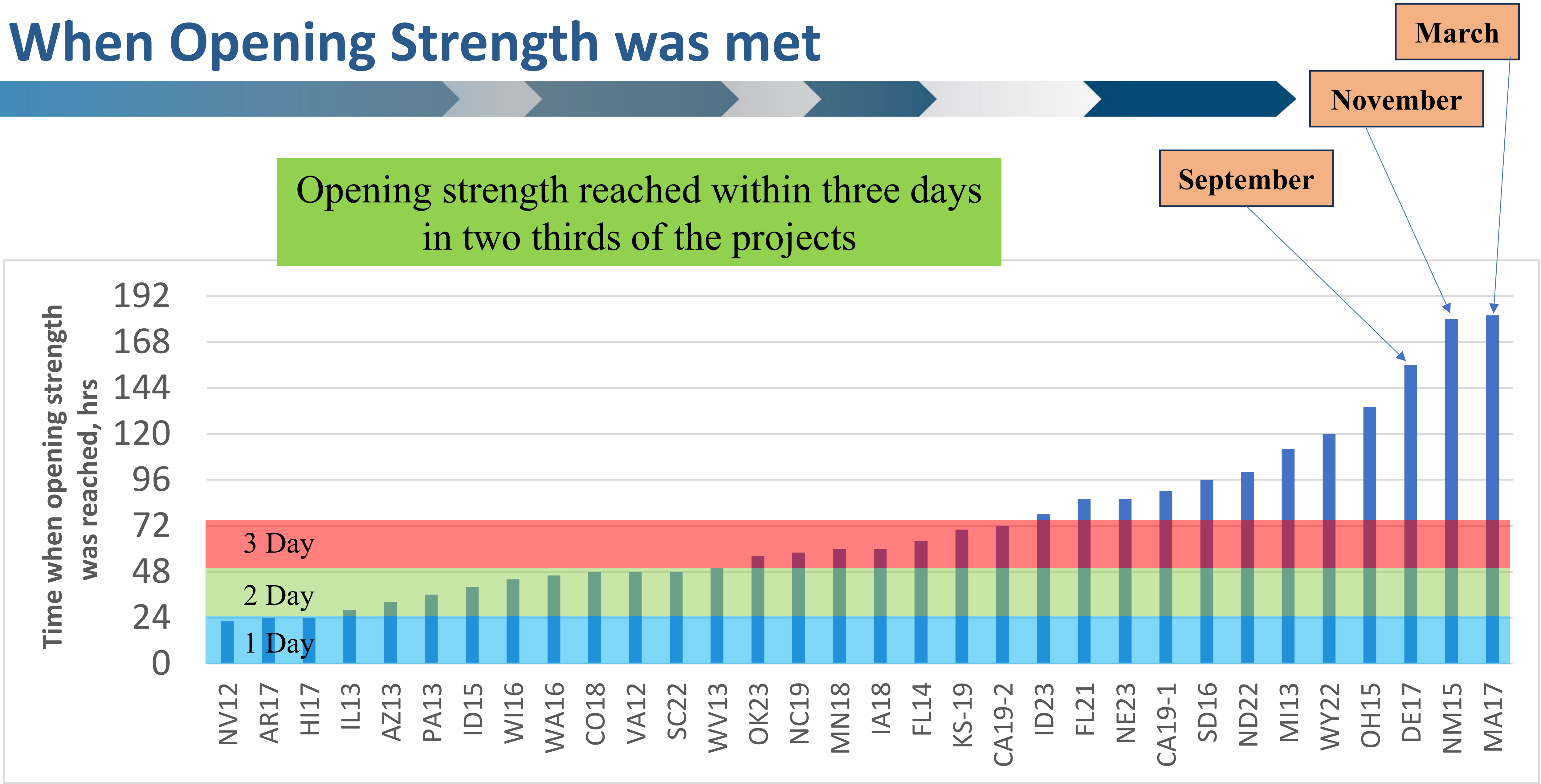
Opening Time Based on Air Temperature

Measuring in place pavement temperature is critical



Iowa DOT

When Opening Strength was met



Maturity Development in Iowa

Research Projects:

- 1988 1989 1994 1995

Field usage

- 1995: 14 field trials
- 1996: 6 designated projects

Maturity became a contractor option in 1997

- 1997: 28 projects

First MCTC Trailer-1988

First car to drive on the new Fast Track II pavement
Concrete Age: 7 hours

=>

Maturity Became a Specification Option

- Maturity has been a **contractor option in Iowa for 27 years**
- For almost all pavement in Iowa, maturity is used to determine when **opening strength** has been reached

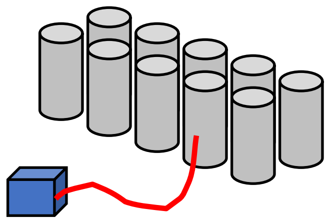
Step 1
Cast specimens to develop the strength /maturity curve

Step 2
Place the sensor in the slab

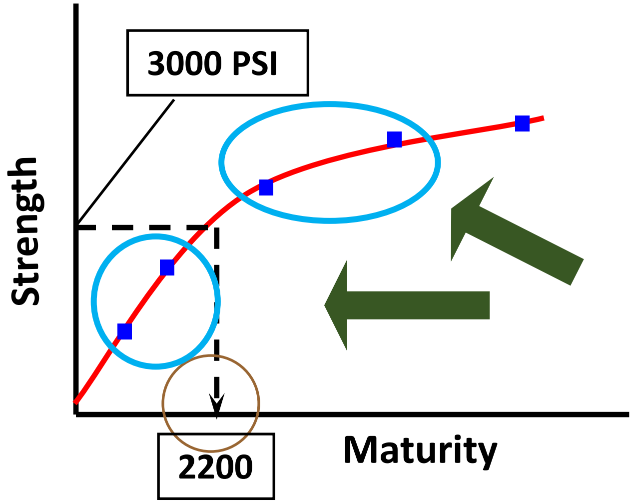
Step 3
Download the data

MCTC's Maturity Procedure

Develop the Maturity Curve (Calibration Curve) Step 1

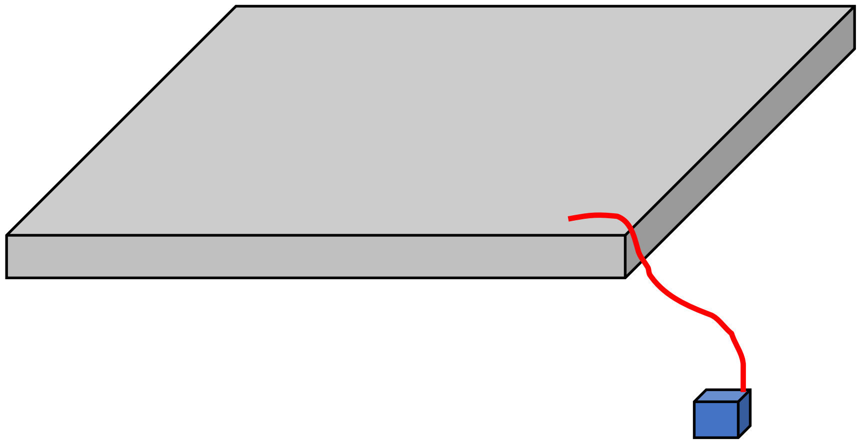


Cast the specimens and monitor the heat signature



2 points below the opening strength and 2 points above

Field Monitoring Step 2



When the maturity reaches the 2200 value, that indicates an in-place strength of 3000 PSI

Keys to success: Cast test specimens at the plant: <u>Step 1</u>

- The first day of paving, cast test specimens for the maturity curve development from plant batched concrete
  - Same concrete that is in the slab- Not “Labcrete”
- Sampled at the plant
- Field cure the specimens as per agency specifications




Advantages of Maturity Estimation of strength

- Only cast a 12 to 15 cylinders or beams
  - Once per project if it lasts less than 30 to 90 days
  - Depends on the state specification
- The slab has more mass and thereby reaches opening strength faster than test specimens
- Saves time and work and money during construction
  - NO casting specimens
  - NO transporting specimens
  - NO stripping the specimens
  - NO testing specimens

Measures the actual slab temperature => estimates actual slab strength

Built in Factor of Safety

1. **Concrete normally looses some air:**
   - ➢ During transport
   - ➢ During placement

➢ Plant samples => higher air content => lower strength

➢ Slab Concrete => lower air content => higher strength

➢ 2% air loss could cause a 10% strength gain

2. **Field maturity tested near edge => Lower temperature**
   - ➢ Mid slab temperature likely higher => Likely more strength

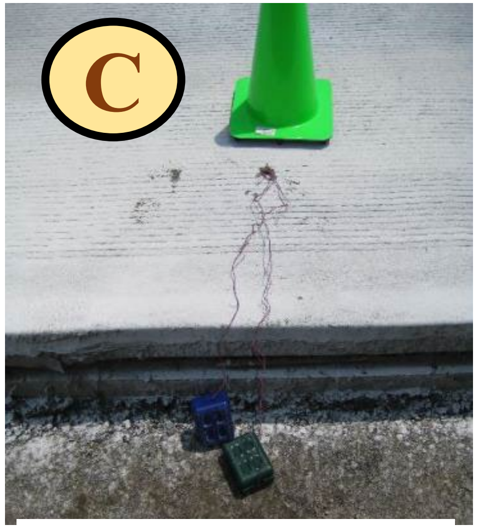
3. **Control construction traffic => Center of the slab is stronger**

Field Maturity Measurement Step 2 and 3

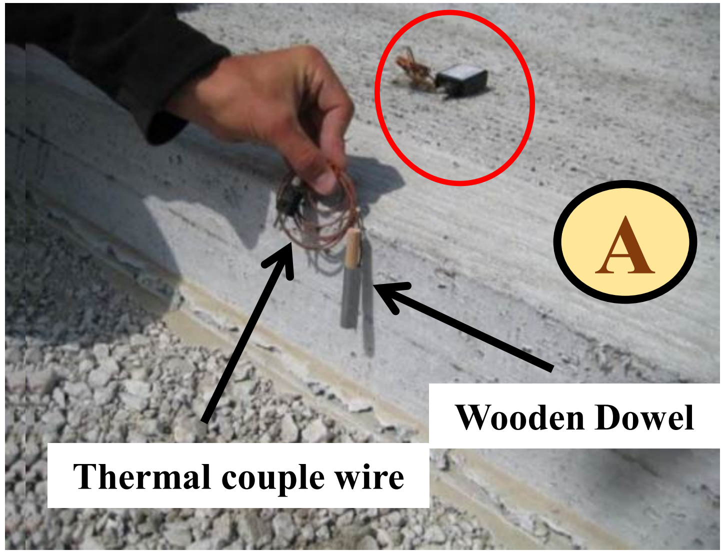
Simple / Inexpensive method – How it started

A. Place probe in the slab
B. Attach the data logger
C. Set a cone over the data logger
D. Download the data Compute/read the TTF

Download the data



Protect the data logger



Place near mid depth

Slab edge placement

Temperature Sensors Placed in the Slab

Contact based sensors

Bluetooth

Cellular

Wireless sensors

Curve Validation

- **Curve validation is required due to variability**
  - Concrete materials
  - Production variability
- **Performance Engineered Mixtures (PEM)**
  - **Standard Practices Specification AASHTO R101**
  - Outlines the concrete properties and test protocols to test during production to monitor consistency

Standard Practice for

Developing Performance Engineered Concrete Pavement Mixtures

AASHTO Designation: R 101-22[1]

Adopted: 2022

Technical Subcommittee: 3c, Hardened Concrete

AASHTO

American Association of State Highway and Transportation Officials
555 12th Street NW, Suite 1000
Washington, DC 20004

- **When concrete consistency is being monitored during production, frequent validation in not necessary**
- **Iowa DOT requires curve validation every 90 days**
- **If changes in the mixture develop, a validation should be performed**

Jim Grove
jim.grove@dot.gov

https://www.fhwa.dot.gov/mctc

The evolution of technology for maturity testing

By Sabrina I. Garber

2024 Transportation Research Board AKC50 Webinar

Maturity for Pavements—Updates and New Guidance

TOC

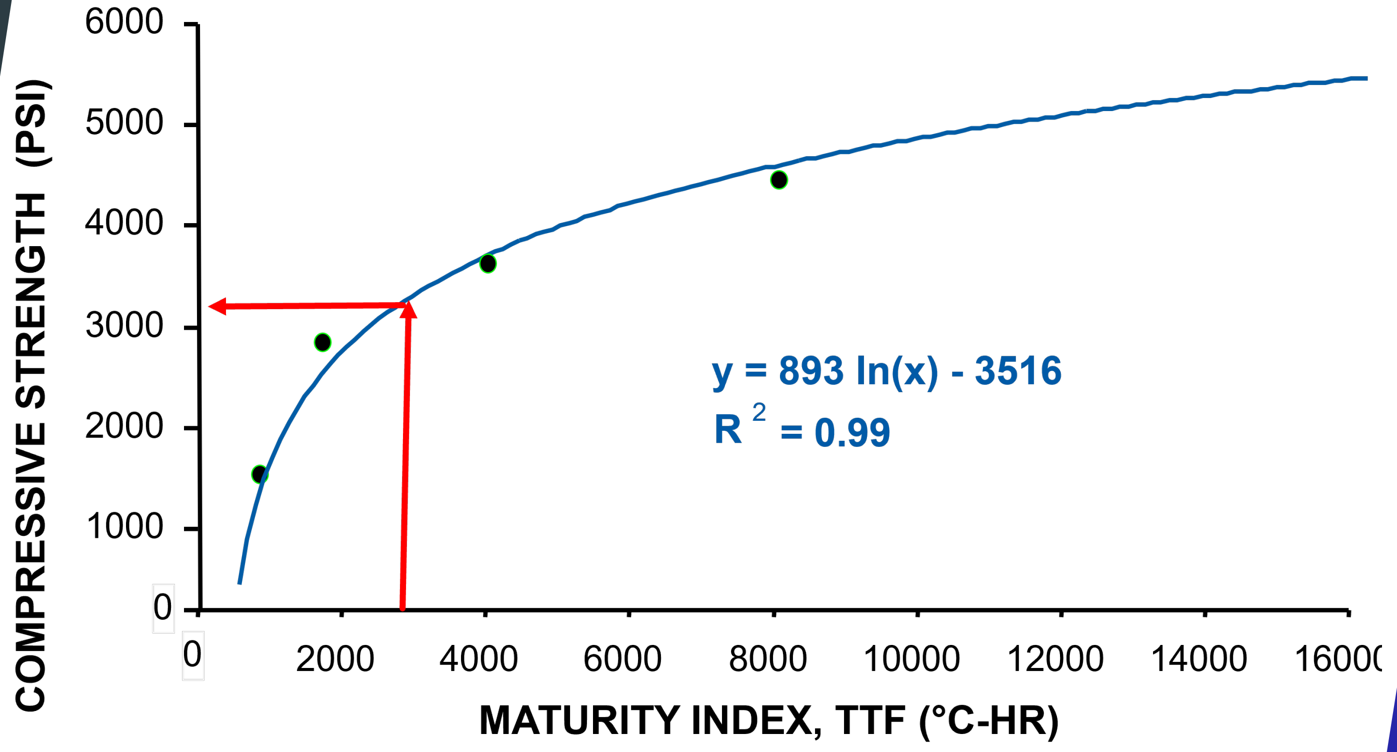
- Intro
- General description of a maturity system
- Evolution of the technologies
- Choosing the right system

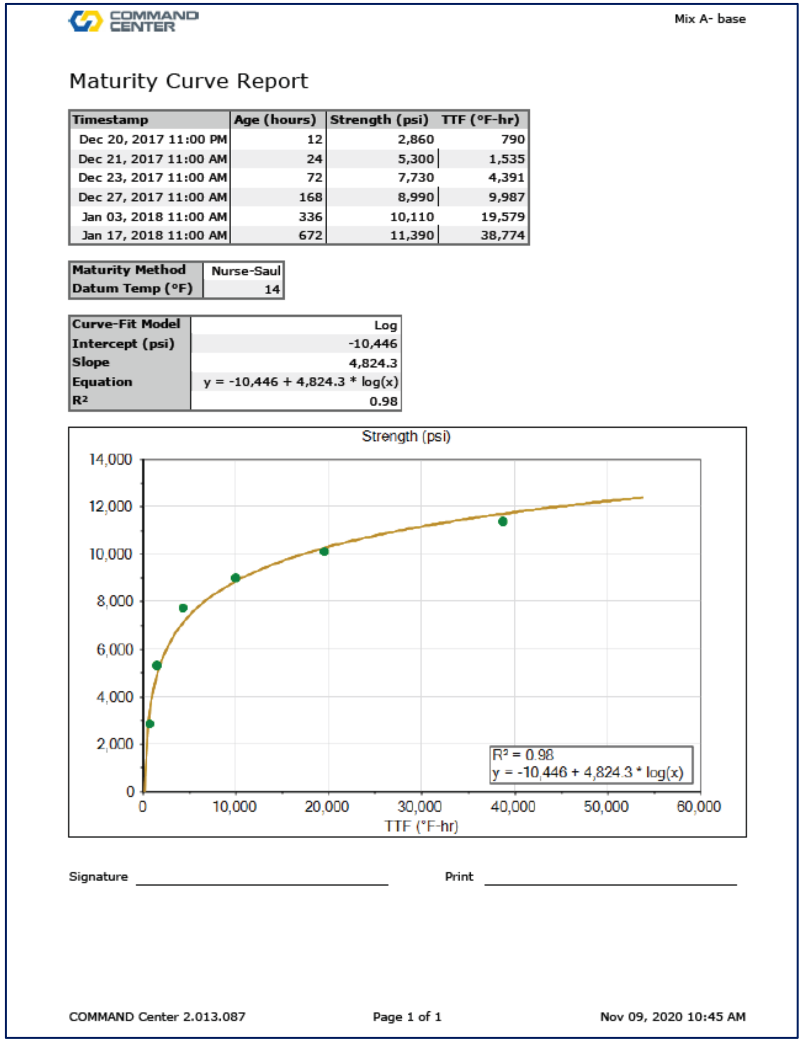
Implementing Maturity

- Create the maturity curve.
- Use the maturity curve.
- Validate the maturity curve.

You need a combination of tools.

You need a Maturity System.





COMMAND CENTER

Mix A- base

Maturity Curve Report

Timestamp	Age (hours)	Strength (psi)	TTF (°F-hr)
Dec 20, 2017 11:00 PM	12	2,860	790
Dec 21, 2017 11:00 AM	24	5,300	1,535
Dec 23, 2017 11:00 AM	72	7,730	4,391
Dec 27, 2017 11:00 AM	168	8,990	9,987
Jan 03, 2018 11:00 AM	336	10,110	19,579
Jan 17, 2018 11:00 AM	672	11,390	38,774

Maturity Method	Nurse-Saul
Datum Temp (°F)	14

Curve-Fit Model	Log
Intercept (psi)	-10,446
Slope	4,824.3
Equation	y = -10,446 + 4,824.3 * log(x)
R^2	0.98

Signature ______________________ Print ______________________

COMMAND Center 2.013.087 Page 1 of 1 Nov 09, 2020 10:45 AM

Creating a Maturity Curve

You need to:

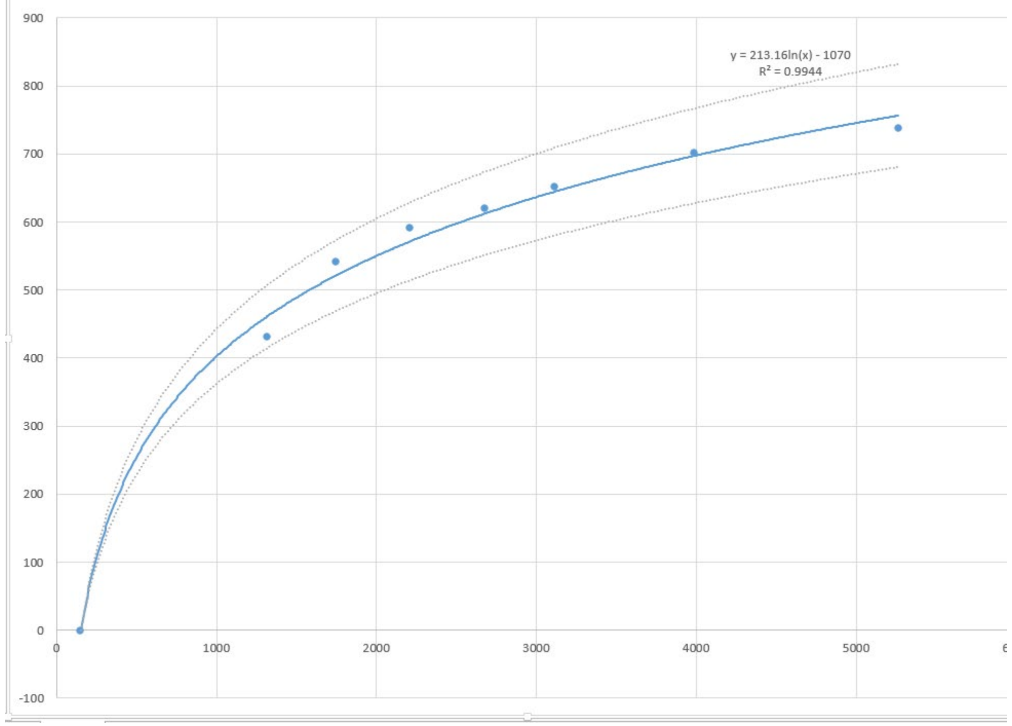
- Measure concrete temperatures continuously
- Record measured temperatures and time data
- Calculate maturity from the temperature history
- Combine maturity and strength data to create a curve
- Generate a Maturity Curve report

Courtesy: Scott Riegler

Using the Curve

You need to:

- Collect temperature continuously in the field
- Calculate maturity in the field
- Apply a maturity curve to estimate strength in the field



Validation

In the field, you need to prove data is within 10% of original curve:

- Not all systems' software presents validation data the same.
- Contractors: work with your vendor to understand and report necessary details to the EOR/owner agency
- EOR's and Owner Agencies: work with contractors and chosen systems to understand how to expect this kind of data

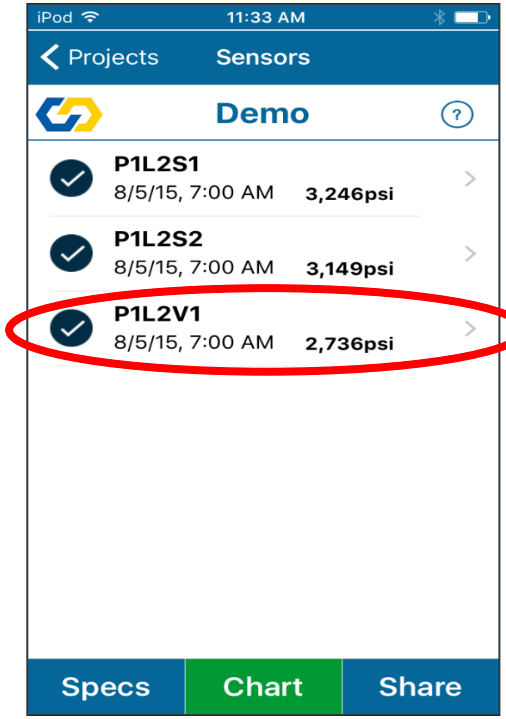
Validation:

Compare estimated strength to actual strength of specimens

Field sensor

Field sensor

Validation sensor in cylinder



If the estimated strength is within 10% of the Average break strength, you can feel more confident that field estimations are good.

Estimated = 2736 psi $\leq$ 10% Actual = 2850 psi

Implementing Maturity

Maturity Systems

- Sensors
- Software
- Data transmission

Maturity Systems on the Market

Humbolt
COMA-Meter
COMMAND Center
Con-Cur NEX
Wake HardTrack
Giatec SmartRock
Hilti Concrete Sensors
Exact
Brickeye
RPX Insite
Dewalt Converge

Quadrel vOrb
Sensytec SensyRoc
SiteBiotics eGate
Algibit
Solid Concrete Sensors
Wavelogix REBEL
ConSensor
ConXedge
Doka
Kraft Curing
Maturix
PERI
SIDCODX ObraLink
Verboom Techniek

OGs

Something simple to make implementation work

Sensors

- Thermocouple wire

Data Transmission

- Wired

Software

- Excel
- Proprietary

Courtesy: www.grainger.com

Courtesy: sea.omega.com

OGs

Benefits

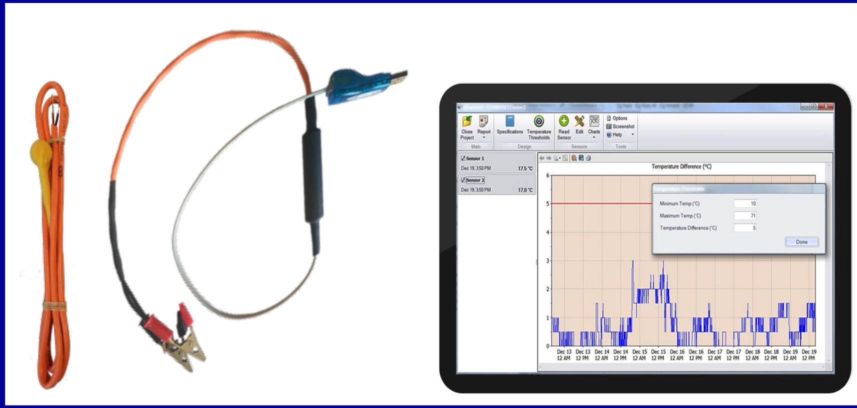
- Affordable
- Simple
- Proven

Considerations

- Increased risk for data loss
- Not field friendly
- Calibration required

Smart Sensor Wired Systems

- Sensors
  - Self-powered
  - Store data internally
  - Thermistors and thermocrons
- Data Transmission
  - On-site
  - Wired
- Software
  - Excel
  - Proprietary



Smart Sensors Wired Systems

Benefits

- Self-powered, self-storing sensors
- Improved connections
- Improved reporting capabilities
- Comparable up-front costs to basic systems
- Most transmitters do not require calibration

Considerations

- Completely wired solution
- Cable/wire durability
- More expensive re-occurring costs
- Proprietary readers/transmitters

Wireless On-Site Systems

Sensors

- Smart Sensors
- Thermocouples
- Thermistors

Data Transmission

- RFID
- Bluetooth

Software

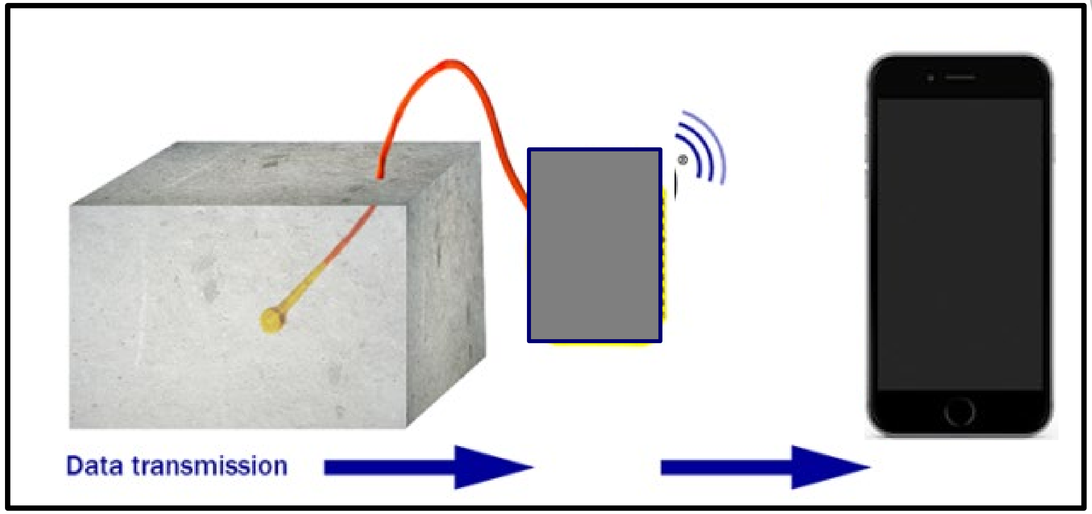
- Proprietary PC
- Apps
- Cloud storage
- Dashboards

Courtesy: www.giatec.com

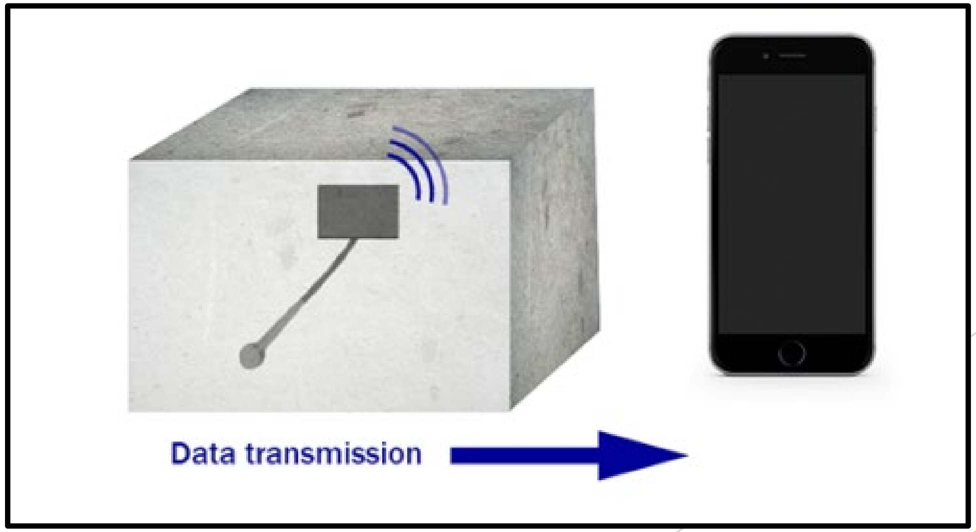
Wireless On-Site Systems

Wireless On-Site Systems

- Embedded sensors are sacrificial and may have cables that come out of the concrete that connect to a reusable transmitter.



- Embedded sensors include a transmitter and are sacraficial.



Wireless On-Site

Benefits

- Improved reporting capabilities
- Most transmitters do not require calibration
- Reduced cables along jobsite
- Use your phone/tablet with an app
- Cloud storage/sharing/dashboards
- Some systems have data redundancy
- Some systems have reusable components

Considerations

- More expensive sensors
- Data access fees in some cases
- Need to be on site
- Proprietary readers/transmitters
- Cable/transmitter durability/positioning
- Line-of-site

Wireless Remote Systems

Sensors

- Smart Sensors
- Thermocouple
- Thermistors
- Fiber Optic

Software

- Proprietary PC
- Apps
- Cloud storage
- Dashboards

Data Transmission

- RFID+Cellular
- Bluetooth+Cellular
- Cellular
- Wi-Fi
- LoRa

Courtesy: www.giatec.com

Courtesy: www.exacttechnology.com

Wireless Remote with a Hub

Wireless Remote no Hub

Courtesy: www.brickeye.com

Wireless Remote Systems

Benefits

- Improved reporting capabilities
- Reduced cables along jobsite
- Transmitters do not require calibration
- Use your phone/tablet with an app
- Cloud storage/sharing/dashboards
- Some systems have data redundancy
- Some have reusable components
- Remote data collection
- Real-time alerts

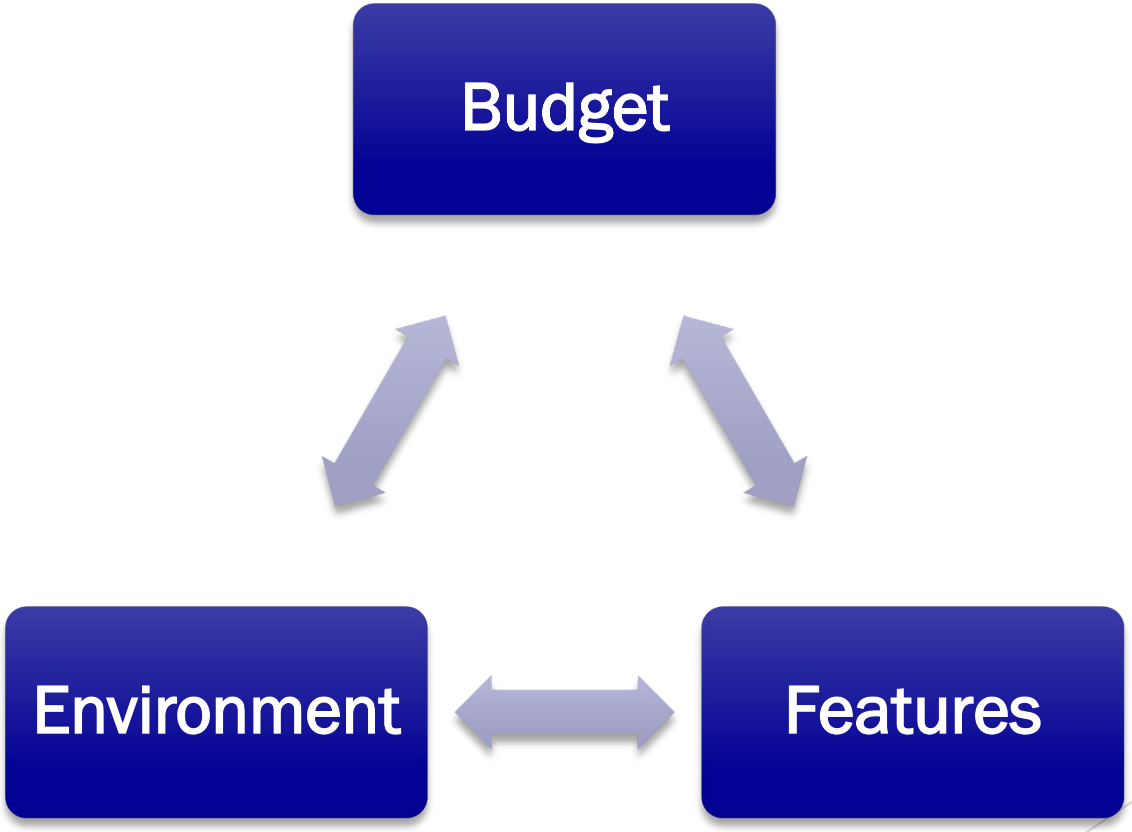
Considerations

- More expensive sensors
- Proprietary readers/transmitters
- Cable/transmitter durability/positioning
- Line-of-site
- Data access fees
- Cellular or Wi-Fi connectivity

Additional bells and whistles

- Re-usable sensors
- Multiple sensors in one
- Ability to drive cure tanks remotely
- Customizable report features
- AI component for optimizing mix designs

Choosing the right system – do the research



Choosing the right system

Figure out what you want:

- What fancy features do you want?
  - wireless
  - real-time alerts
  - smart sensors
  - Other bells and whistles
- What fancy features do you have to have?
- Where is your data stored?

Choosing the right system

Figure out if what you want will work in your project's environment:

- Are wireless signals allowed on the jobsite?
- Do you get good cell service on the site?
- Do you have to have internet connectivity to collect/store data?
- Do you have the right power supply?
- Is there a back up if power is lost in the transmitter?
- Is there a back up for getting data if wireless options don't work after all?
- Is there limited access to getting data?

Choosing the right system

Figure out if it fits your budget:

- How many sensors do you need?
- How many transmitters do you need?
- Do you need a hub?
- Do you need a booster?
- Do you need any special antennas?
- Do you need to pay for access to your data?
- Do you need to pay extra for cellular connectivity?

Questions?

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CONCRETE TEMPERATURE & MATURITY SYSTEM

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November 4

TRB Webinar: Balanced Mix Design for Climate-Resilient Unpaved Roads

https://www.nationalacademies.org/trb/events

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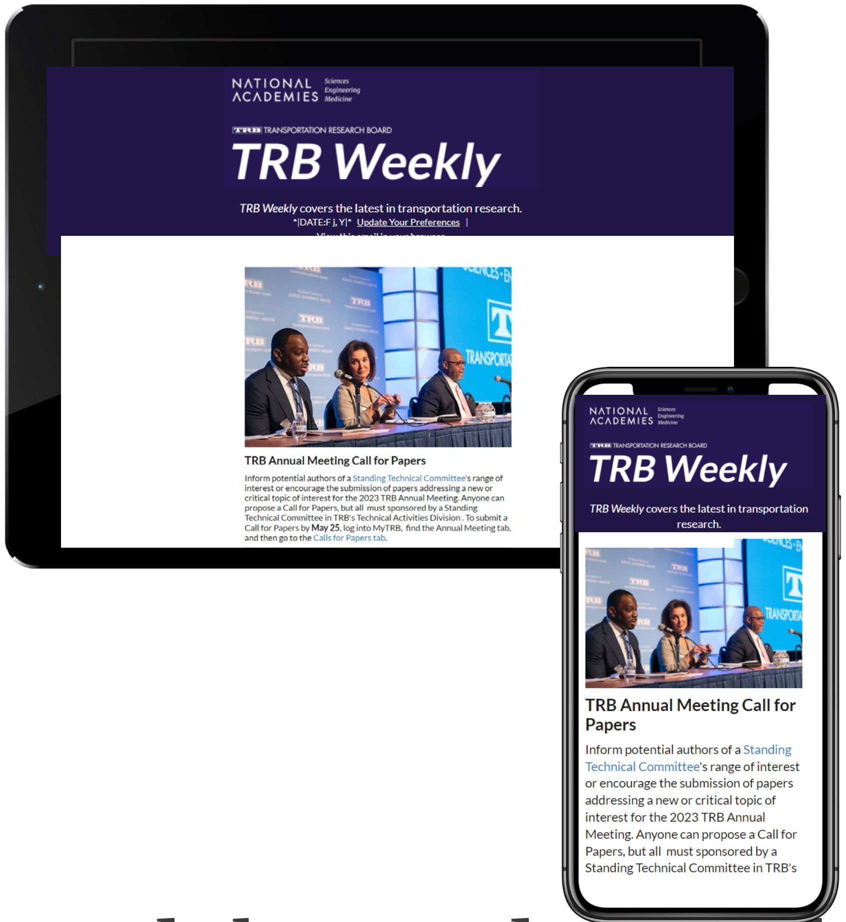

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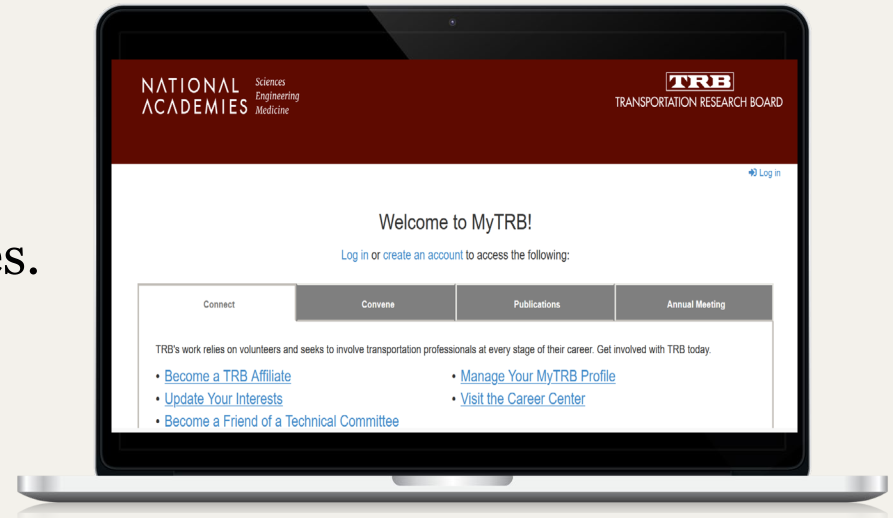

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