Advancing the Use of the Maturity Meter in Hydraulic Cement Concrete Operations

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Advancing the Use of the Maturity Meter

Presentation Outline:

1. What is a Concrete Maturity Meter?
2. How the Concrete Maturity Meter works?
3. Why another presentation on the Concrete Maturity Meter?
4. Alternatives to the Maturity Meter – Methods currently in place
5. Where would there be potential value in using the Maturity Meter?
6. Laboratory Work
7. Field Work
8. Possible Applications
9. Goals and Moving Forward
10. Time for Questions

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What is it?

A Concrete Maturity Meter:

- **measures the temperature of the concrete at a user-determined time.**
- **estimates in-place concrete strength.**

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How it works?

- **Given: Concrete gains strength as the cement hydrates.**
- **Cement hydration - curing temperature and duration of curing period.**
- **Therefore, time and temperature are correlated to strength gain to estimate cement hydration (concrete maturity).**

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Basic Principle for hydraulic cement concrete:

INCREASE HEAT = INCREASE STRENGTH
INCREASE CURE TIME = INCREASE STRENGTH

Or

TIME + HEAT = MORE MATURITY
MORE MATURITY = MORE STRENGTH

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Why another presentation on the Concrete Maturity Meter?

- **VDOT goal – implement proven technology when useful and cost effective.**
- **If VDOT promotes or implements technology, the expertise must be developed to direct the implementation process.**
- **Development of the ASTM maturity method (ASTM C1074) was issued in 1987.**
- **VDOT permits the use of the maturity meter in opening concrete pavement to traffic (VDOT Road and Bridge Specifications, Section 316.04).**
- **Question: Can this technology be utilized more fully?**
- **This presentation encourages the use of the concrete maturity meter where appropriate.**

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Why are we encouraging its use?

- The maturity meter is measuring in-place concrete temperatures over time.
- FHWA has been promoting the maturity meter for decades.
- According to a survey back in 2002:
  - 32 State DOTs were researching it.
  - 12 states have adopted protocols.
- VDOT is considering where the maturity method may provide value.

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What are the limitations of the Maturity Meter Method?

- **The concrete must be maintained in a condition that permits complete hydration of the cement.**
- **This method assumes that all concrete batches of the same mix design being evaluated are the same.**
- **The mathematical curve generated from the maturity meter data is most valuable during early strength.**

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What are we not expecting with regard to the meter's use?

- **Does not replace VDOT's acceptance testing of standard laboratory-cured cylinders.**
- **Does not replace concrete coring if needed.**

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Other methods for determining in-place concrete strength are listed below.

Let's discuss these methods briefly so that we have a clear understanding of each.

1) **Cylinders cast, stored with the product and tested (ASTM C31/ASTM C39)**
2) **Match-cure molds (ASTM C31/ASTM C39)**
3) **Cores (ASTM C42)**
4) **Methods not typically used with VDOT: rebound or Schmidt hammer, Windsor probe, or any pulse-velocity test methods**

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Other methods for determining in-place concrete strength:

1) Cylinders cast and stored with the in-place concrete (ASTM C31/ASTM C39)

- Advantages
  - Gives compression test data on the mix in the field
- Disadvantages
  - Need to make cylinders with the cylinders cured on site under the same conditions as the concrete represented
  - Typically lower values than the in-place concrete – due to temperature differentials
  - Need to have a compression testing machine preferably on-site or within close distance to the project

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Other methods for determining in-place concrete strength:

2) Match-cure molds (ASTM C31/ASTM C39)

- **Advantages**
  - **Best non-destructive representation of in-place strength**

- **Disadvantages**
  - **Make cylinders in the field typically in reusable steel molds**
  - **Cured in the molds on site typically with a wire in the concrete**
  - **Cylinders tested on site or close to the project on a compression machine**

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Other methods for determining in-place concrete strength:

3) Cores (ASTM C42)

- **Advantages**
  - **Provides a compressive strength value on a core**
- **Disadvantages**
  - **Coring may compromise structural integrity**
  - **Damage to concrete must be repaired**
  - **Coring equipment needed**
  - **5 days needed to allow samples to reach equilibrium in addition to the coring, transporting, sample prep and testing time**
  - **Difficult to compare results when the acceptance test is typically based upon 28 day laboratory-cured specimens.**

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Conclusion:

ASTM C1074, Standard Practice for Estimating Concrete Strength by the Maturity Method, does not replace other tools, but represents another tool in our tool box for evaluating in-place concrete strength.

Question:

Where would there be potential value in using the Maturity Meter?

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When?

- Construction can't continue until a minimum concrete strength is met.
- We need a quick return-to-service.

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Where? **Possible applications: Any quick return to service or where the concrete needs a minimum strength to proceed with construction.**

IN THE FIELD:

- **Drilled shafts**
- **HCC pavement repair – opening to traffic**
- **HCC Overlays**
- **Closure pours**
- **Post-tensioning tendons**
- **Saw-cutting**
- **Terminating cold weather protection**
- **Form removal**

AT THE PLANT:

- **Determine when to test cylinders for stripping forms**
- **Determine when to test cylinders for shipping products**

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How do we develop a maturity curve using the maturity meter?

- **First we need to understand how the temperature and time measured by the meter are correlated to the strength of concrete**

- **There are two options available to estimate this correlation:**

  1. **Arrhenius equation: equivalent age**
  2. **Nurse-Saul equation: time-temperature factor**

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$$\mathbf{M} = \sum_{0}^{t} (T - T_0)\Delta t$$

THE NURSE-SAUL EQUATION

where: M = maturity (usually in °C-hours or °C-days) = TTF

t = time interval being considered

Δt = time interval

T = average temperature of the PCC during the time interval, Δt, being considered

T_0 = datum temperature – the temperature below which PCC shows no strength gain with time

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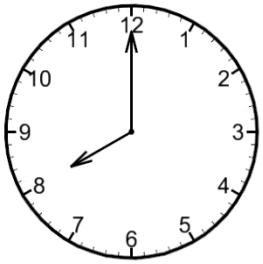
85 degrees Fahrenheit

After 8 hours

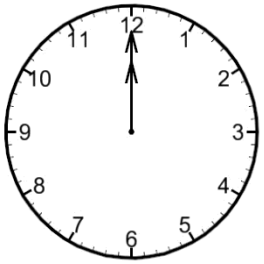


TTF 499

Strength 2250 psi

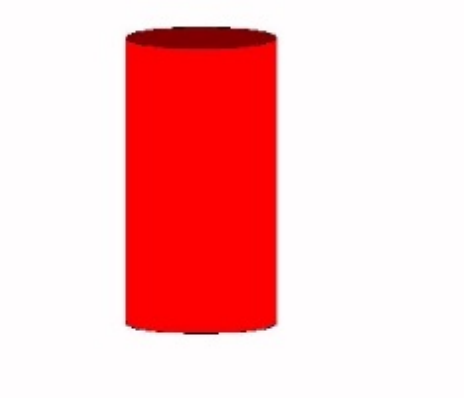
72 degrees Fahrenheit

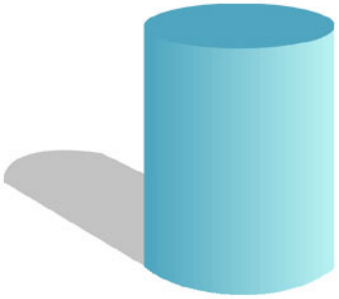
After 12 hours



TTF 502

Strength 2310 psi





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LABORATORY DATA: Trial Batches

- What conditions will affect the meter's results?
- What will the maturity curve look like under different environments?
- How user-friendly is the maturity meter?

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LABORATORY DATA: Trial Batches

1. Control Mix – 100% Portland
2. 100% Portland mix cured in oven at 100° F
3. 100% Portland mix cured in hot water bath at 100° F
4. 100% Portland mix with accelerating admixture
5. 100% Portland mix with 0.30 w/c ratio
6. 75% Portland mix with 25% fly ash replacement
7. 100% Portland mix with an additional 20% fly ash added and reduced sand

*All trial batches used the same sources for sand, stone, cement, and water.

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LABORATORY DATA: Trial Batches

CONTROL MIX: 100% PORTLAND CEMENT MIX
TRIAL 1

800 lbs of cement

1055 lbs of sand

1746 lbs of No. 57s

360 lbs of water (0.45 w/c ratio)

No addition of air

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LABORATORY DATA: Trial Batches

CONTROL MIX: 100% PORTLAND CEMENT MIX TRIAL 1

100% Portland				
Hour	**Temp (*C)**	**TTF**	**Load (lbs)**	**Strength (psi)**
0	20	0	0	0
18	25	416	24130	1900
24	24	562	29715	2350
42	23	972	41780	3290
48.5	23	1121	41675	3320
48.5	23	1121	40360	3210
65.5	24	1512	46545	3680
72	25	1685	49210	3940
94.5	24	2226	53130	4210
162	23	3779	60730	4830

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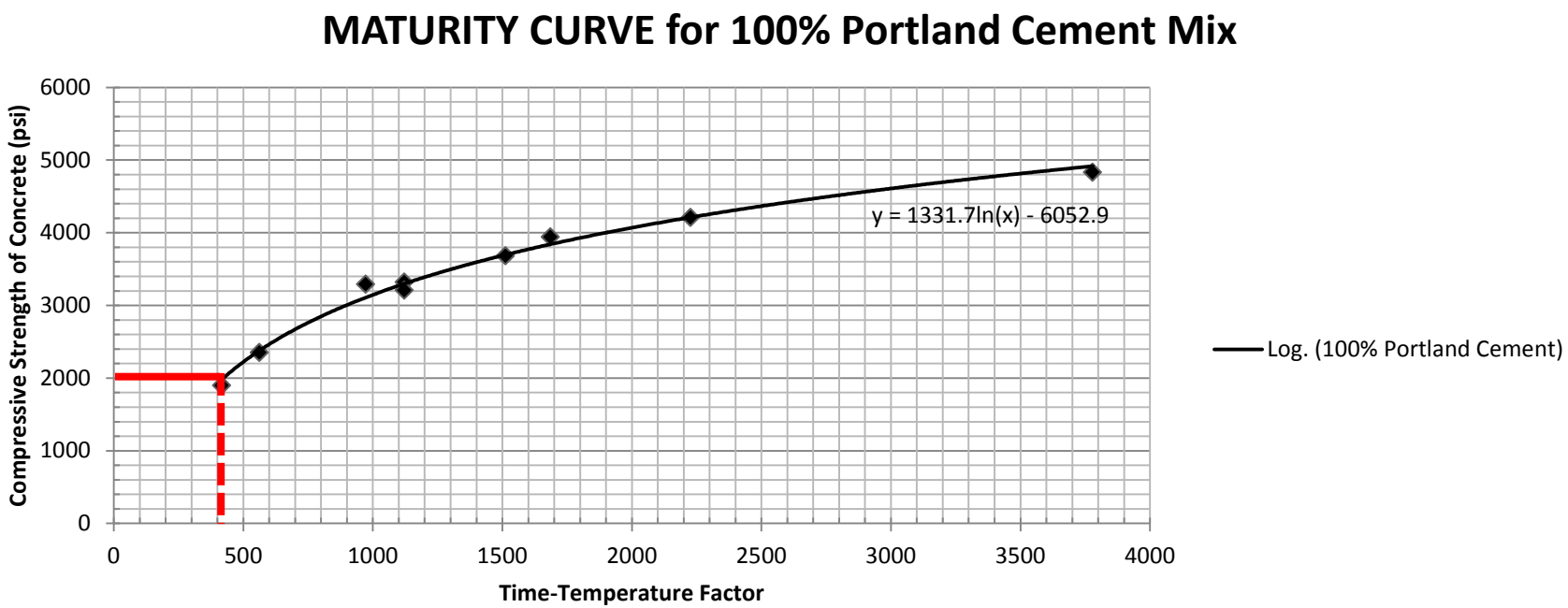
LABORATORY DATA: Trial Batches

CONTROL MIX TRIAL 1: 100% PORTLAND CEMENT MIX



TTF = 423 @ 2000 psi

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LABORATORY DATA: Trial Batches

A maturity curve is developed by comparing the strength with the Time Temperature Factor (TTF).

In theory, each concrete mix should have one maturity curve, regardless of at what temperature it cures.

TRIAL BATCH 2: HEAT APPLIED (Cured in 100° F Oven)

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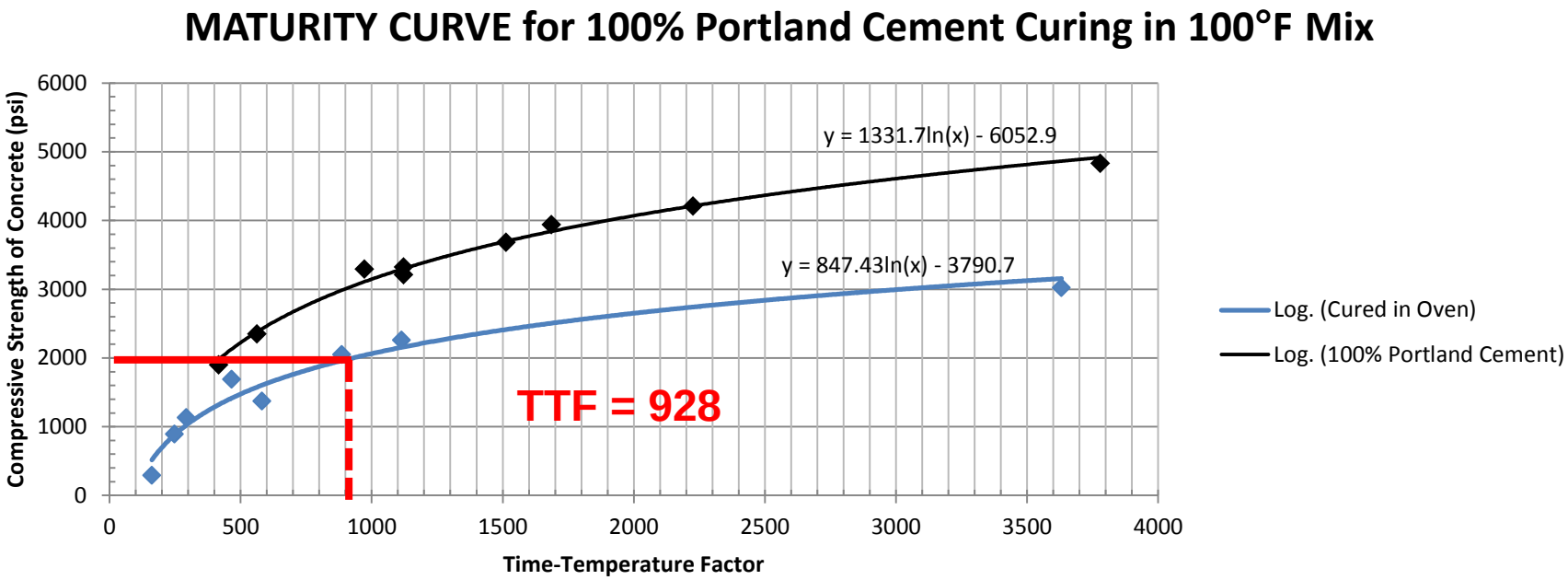
LABORATORY DATA: Trial Batches

TRIAL 2: 100% PORTLAND CEMENT MIX Cured in 100° F Oven



TTF 423 ≠ TTF 928 @ 2000 psi

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LABORATORY DATA: Trial Batches

TRIAL 2: 100% PORTLAND CEMENT MIX Cured in 100° F Oven

Concerns:

- Cylinder molds may not have been sealed enough.
- Oven may have evaporated moisture very quickly.

Conclusions:

- Sufficient moisture must be present to produce an accurate maturity curve.
- IMPROPER CONCRETE CURING TECHNIQUES LEAD TO INVALID DATA.
- This trial batch data does not accurately represent the same mix cured at a heated temperature.

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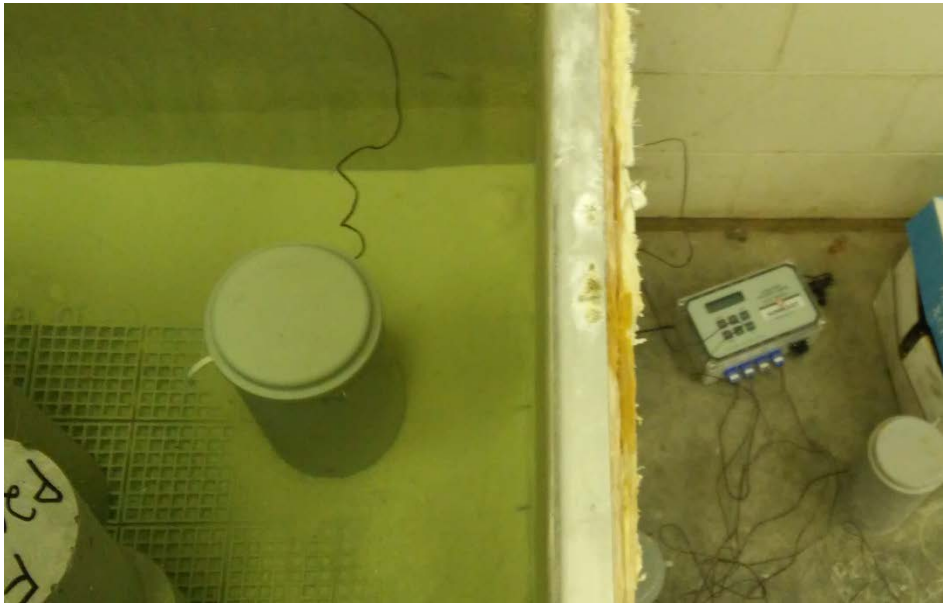
LABORATORY DATA: Trial Batches

A maturity curve is developed by comparing the strength with the Time Temperature Factor (TTF).

In theory, each concrete mix should have one maturity curve, regardless of at what temperature it cures.

TRIAL BATCH 3: HEAT APPLIED (Cured in 100° F Hot Water Bath)



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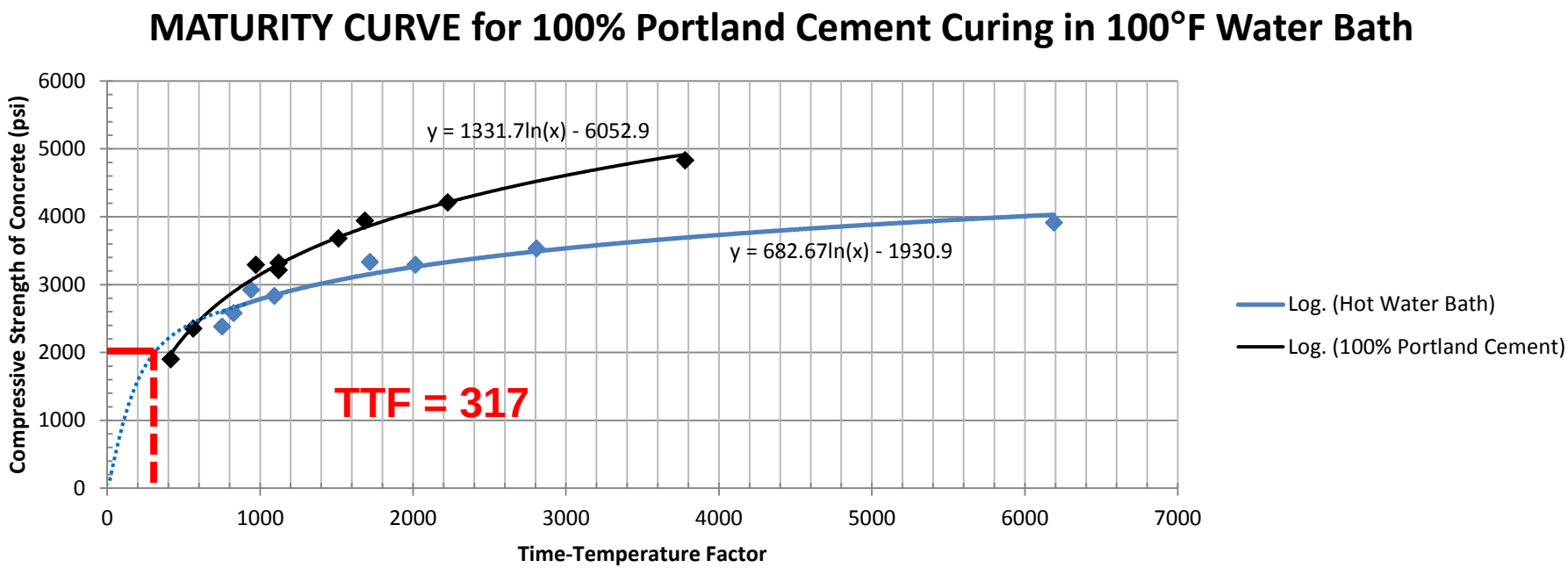
LABORATORY DATA: Trial Batches

TRIAL 3: 100% PORTLAND CEMENT MIX Cured in 100° F Hot Water Bath



TTF 423 ≠ TTF 317 @ 2000 psi

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LABORATORY DATA: Trial Batches

TRIAL 3: 100% PORTLAND CEMENT MIX Cured in 100° F Hot Water Bath

Concerns:

- **We did not begin testing compressive strengths early enough to develop the beginning of curve.**

Conclusions:

- **We would like to repeat this test, curing control cylinders in a room temperature water bath. Wet cylinders break lower than cylinders curing in air losing moisture from molds.**
- **We need more data at the beginning slope of the curve. We would like to repeat this test with more cylinders for each data point to reduce variability.**

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LABORATORY DATA: Trial Batches

A maturity curve is developed by comparing the strength with the Time Temperature Factor (TTF).

In theory, each concrete mix should have one maturity curve, regardless of at what time it cures.

TRIAL BATCH 4: ACCELERATING ADMIXTURE APPLIED
28 fl. oz./100 lbs cement

QUESTION: Will the maturity meter recognize this as a separate mix with the addition of a chemical admixture?

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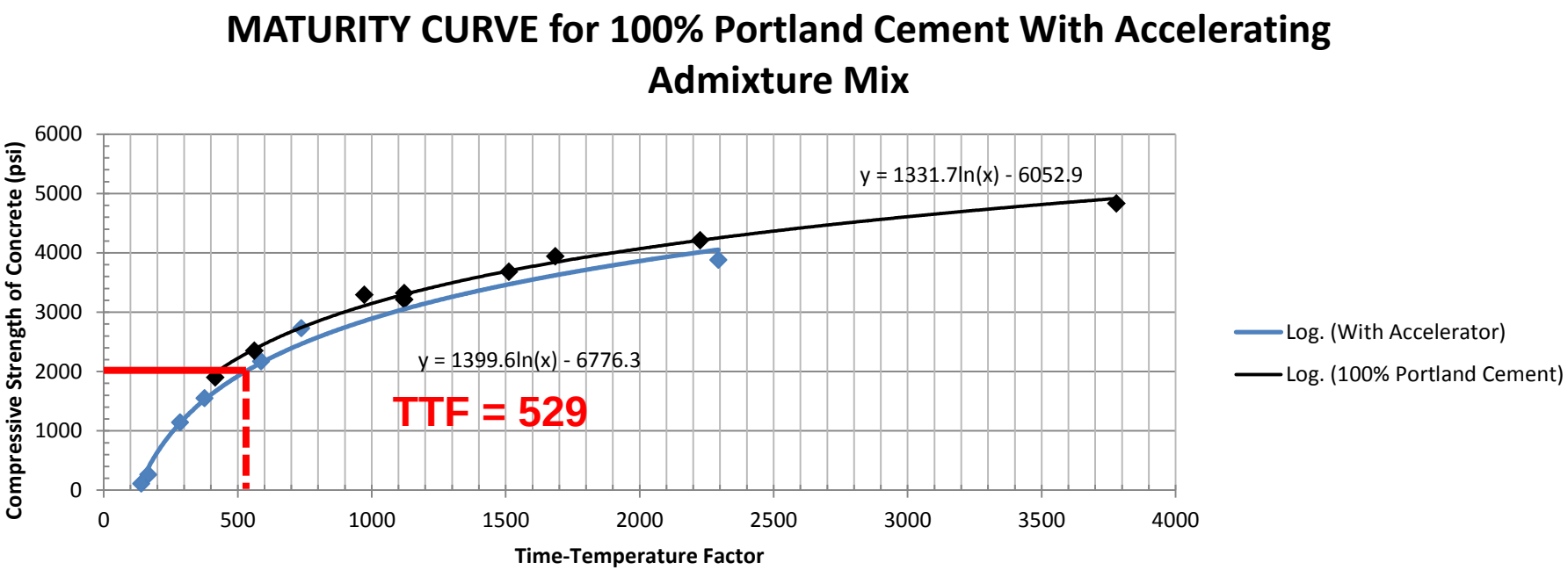
LABORATORY DATA: Trial Batches

TRIAL 4: 100% PORTLAND CEMENT MIX With Accelerating Admixture



TTF 423 ≠ TTF 529 @ 2000 psi

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LABORATORY DATA: Trial Batches

TRIAL 4: 100% PORTLAND CEMENT MIX With Accelerating Admixture

100% Portland				
Hour	Temp (*C)	TTF	Load (lbs)	Strength (psi)
0	20	0	0	0
18	25	416	24130	1900
24	24	562	29715	2350
42	23	972	41780	3290
48.5	23	1121	41675	3320
48.5	23	1121	40360	3210
65.5	24	1512	46545	3680
72	25	1685	49210	3940
94.5	24	2226	53130	4210
162	23	3779	60730	4830

100% Portland WITH ACCELERATOR				
Hour	Temp (*C)	TTF	Load (lbs)	Strength (psi)
0	20	0	0	0
6	26	140	1435	110
7.5	28	166	3295	260
11	31	285	14355	1140
14	28	376	19620	1550
22.5	27	587	27360	2170
28.5	25	737	34285	2730
96	22	2294	48795	3880

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LABORATORY DATA: Trial Batches

TRIAL 4: 100% PORTLAND CEMENT MIX With Accelerating Admixture

Concerns:

- **Accelerating Admixture didn't seem to change set time or increase time for strength gain.**
- **Mix performed the same as the control mix WITHOUT accelerator.**

Conclusions:

- **This trial batch data does not accurately represent the same mix with an accelerating admixture.**
- **We will need to repeat this test since this admixture seemingly had no effect on the mix.**
- **USING THE SAME MIX, WE WERE ABLE TO REPEAT THE CONTROL MIX DATA.**

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LABORATORY DATA: Trial Batches

TRIAL BATCH 5: CHANGING THE WATER CONTENT

0.30 w/c (240 lbs water)

QUESTION: Will the maturity meter recognize this as a separate mix by altering the water content?

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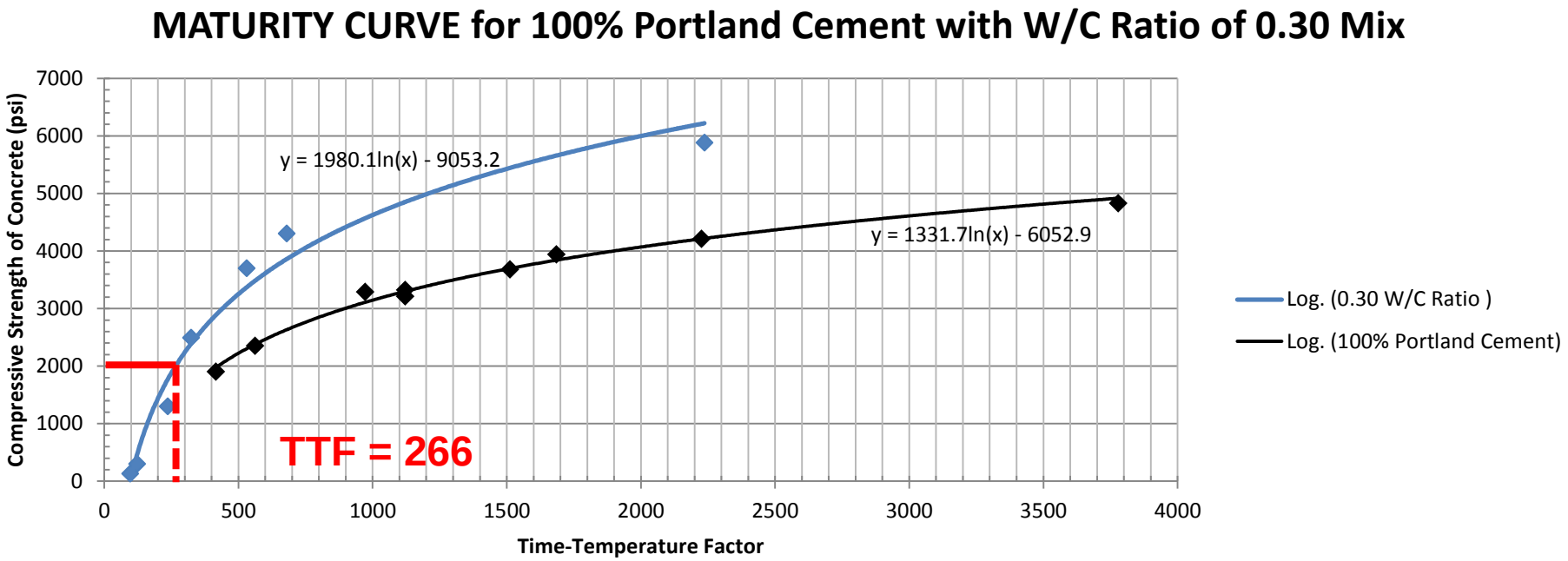
LABORATORY DATA: Trial Batches

TRIAL 5: 100% PORTLAND CEMENT MIX With Reduced Water



TTF 423 ≠ TTF 266 @ 2000 psi

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LABORATORY DATA: Trial Batches

TRIAL 4: 100% PORTLAND CEMENT MIX With Reduced Water

Concerns:

NONE.

Conclusions:

- **Changing the w/c ratio from a control mix produces a new maturity curve.**
- **MOISTURE SHOULD BE CAREFULLY MONITORED WHEN USING A MATURITY METER IN THE FIELD.**

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LABORATORY DATA: Trial Batches

A maturity curve is developed by comparing the strength with the Time Temperature Factor (TTF).

TRIAL BATCH 6: CEMENT REPLACEMENT WITH POZZOLAN
25% Fly Ash Replacement

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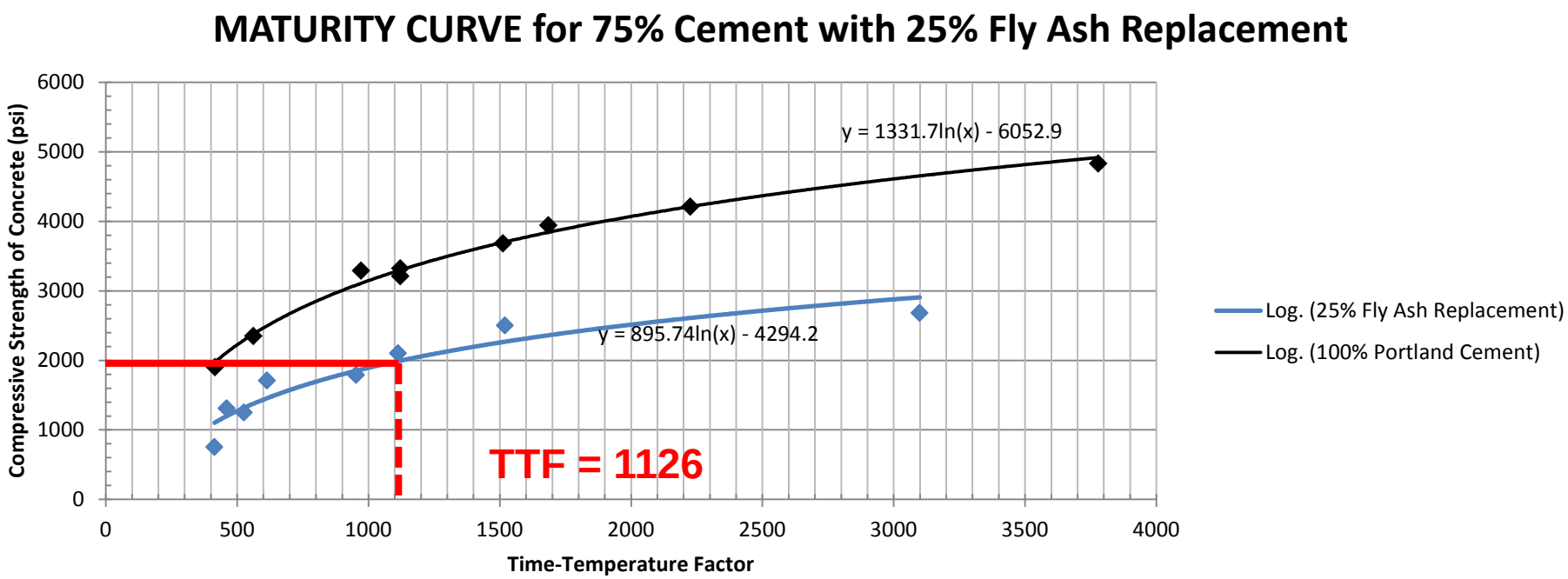
LABORATORY DATA: Trial Batches

TRIAL 6: 75% PORTLAND CEMENT MIX With 25% Fly Ash



TTF 423 ≠ TTF 1126 @ 2000 psi

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LABORATORY DATA: Trial Batches

TRIAL 6: 75% PORTLAND CEMENT MIX With 25% Fly Ash

Concerns:

NONE.

Conclusions:

- **Reducing the cement in a mix produces a new maturity curve.**
- **Even when w/c and total cementitious content remain the same, the time of cure will change, therefore increasing TTFs for the mix.**

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LABORATORY DATA: Trial Batches

A maturity curve is developed by comparing the strength with the Time Temperature Factor (TTF).

TRIAL BATCH 7: CEMENT WITH ADDITION OF POZZOLAN
20% Fly Ash Added to Control Mix (not replaced)

CONTROL MIX	20% FLY ASH ADDED MIX
800 lbs of cement 1055 lbs of sand 1746 lbs of No. 57s 360 lbs of water (0.45 w/c ratio) No addition of air	800 lbs of cement 160 lbs of fly ash 909 lbs of sand 1746 lbs of No. 57s 360 lbs of water (0.38 w/c ratio) No addition of air

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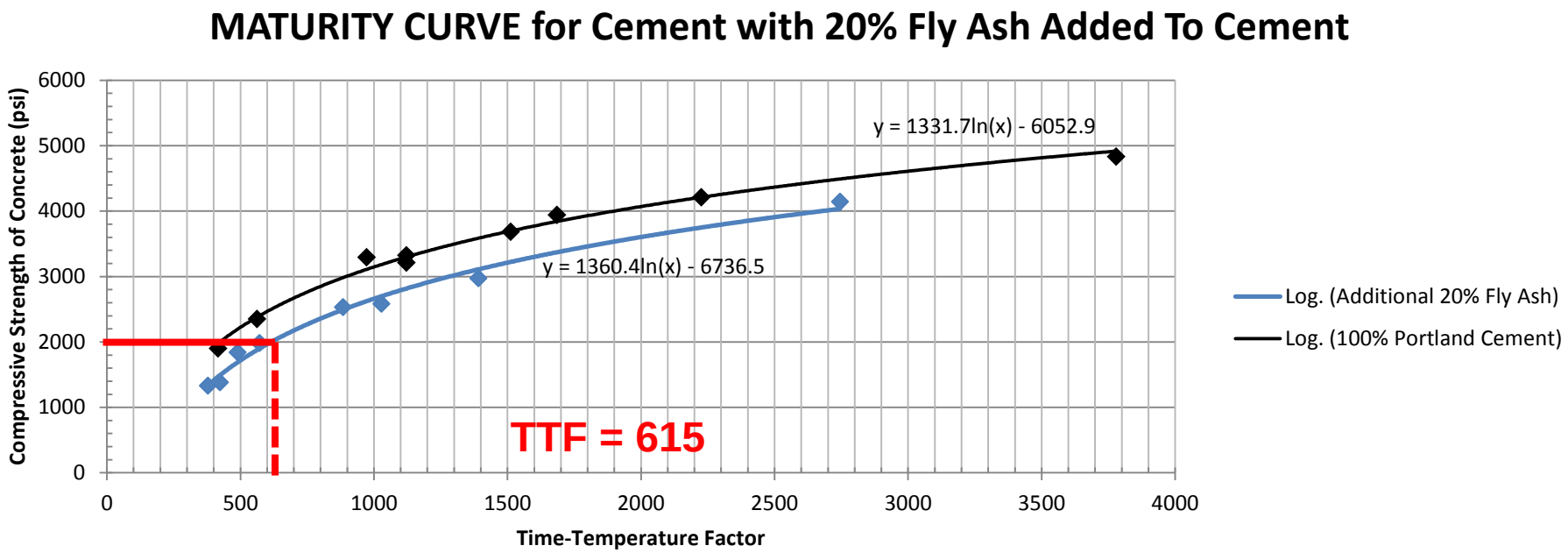
LABORATORY DATA: Trial Batches

TRIAL 7: PORTLAND CEMENT MIX With 20% Fly Ash Added and Reduced Fine Aggregate



TTF 423 ≠ TTF 615 @ 2000 psi

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LABORATORY DATA: Trial Batches

TRIAL 7: PORTLAND CEMENT MIX With 20% Fly Ash Added and Reduced Fine Aggregate

Concerns:

- **Why is the maturity curve lower in relative strength with the mix using the Fly Ash compared to the mix with the same amount of portland cement without the Fly Ash?**

Potential Conclusion:

- **Would like to investigate if Fly Ash added to the mix is competing with the portland cement for the $Ca(OH)_2$ during early age strength development.**
- **Fine Aggregate would not be competing for the $Ca(OH)_2$.**

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FIELD DATA: Tollbooth Patch

At the Concrete Plant

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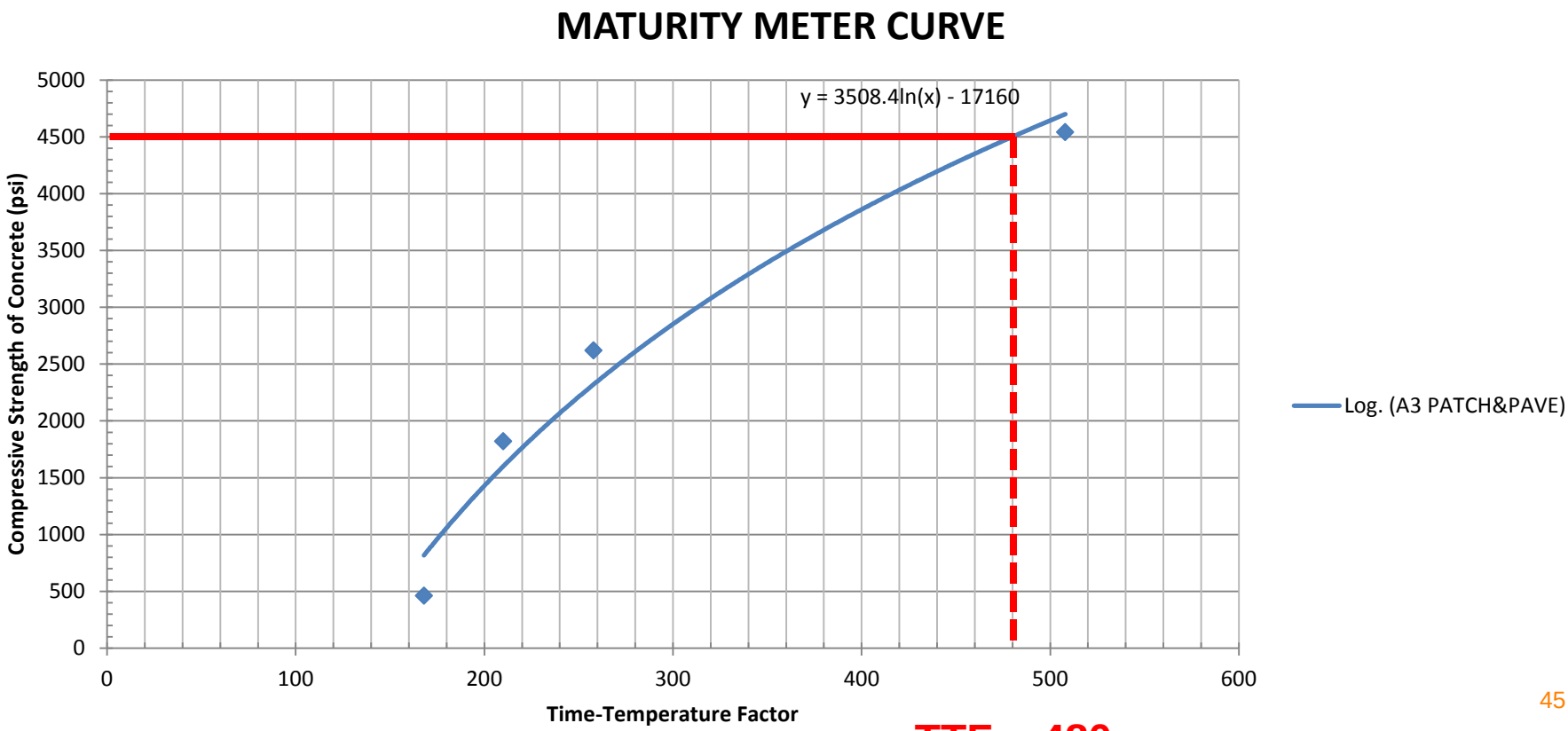
FIELD DATA: Tollbooth Patch

TRIAL BATCH AT THE PLANT:

	TTF	Strength (psi)
Recorded	508	4540
Theoretical	480	4500



TTF = 480

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FIELD DATA: Tollbooth Patch

At the Project Site

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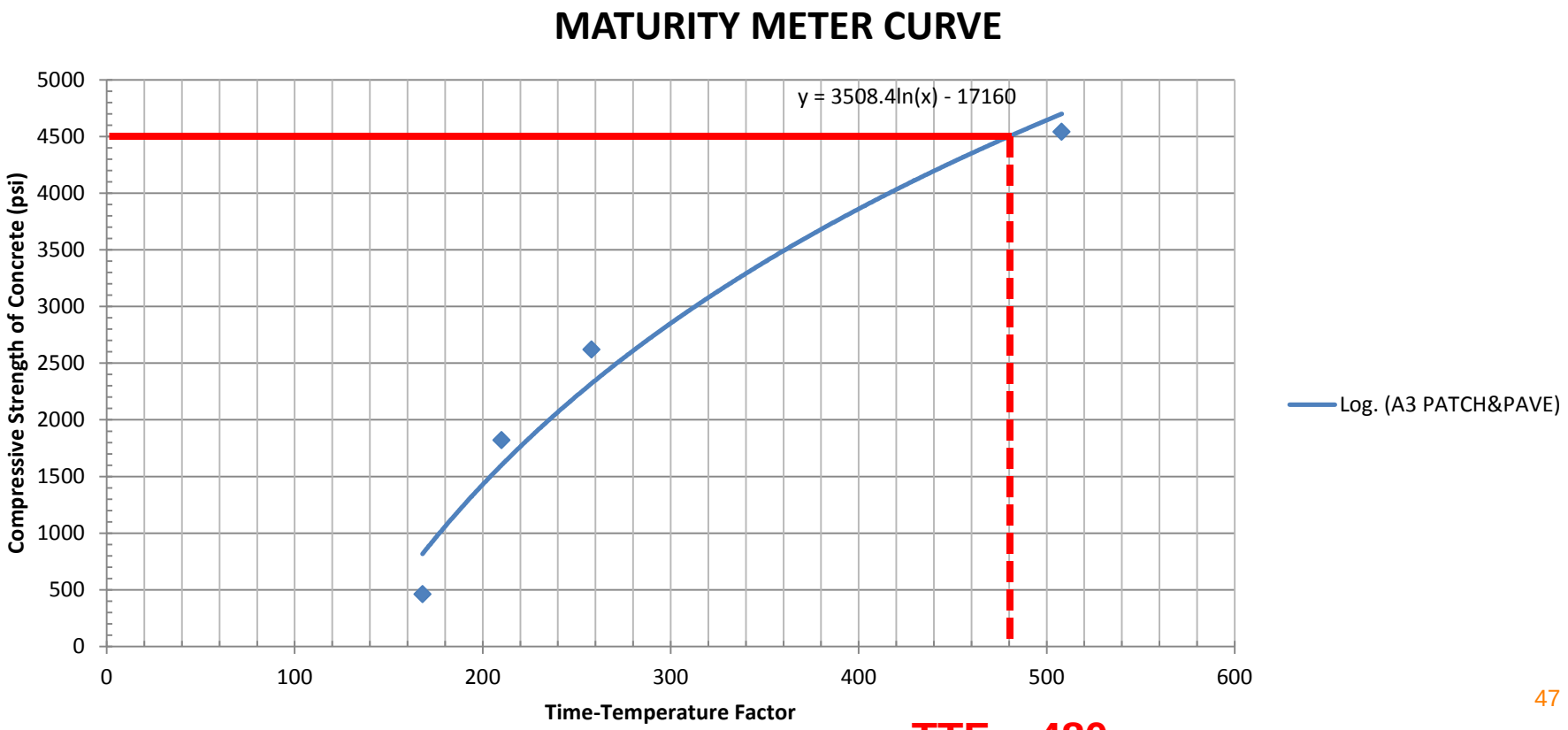
FIELD DATA: Tollbooth Patch

CYLINDER CURING WITH PATCH:

TTF	Strength (psi)
481	4620



TTF = 480

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FIELD DATA: Tollbooth Patch

Concerns:

- Field crew kicked the probe out a few times while spray curing and laying down the thermal blanket.

Conclusions:

- Maturity curve estimated the concrete strength within 200 psi.
- Conditions were very similar from day of trial batch and day of patch placement.
- Would like to repeat field investigation when trial batch conditions are different from day of placement.

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LABORATORY AND FIELD DATA:

OVERALL COMMENTS ON WORKING WITH MATURITY METER:

- **Maturity Meter battery was problematic.**
- **One of the probes on the first trial batch stopped recording temperature.**
- **Had to reinsert temperature probe due to accidental removal by field crew.**

- **The VDOT Maturity Meter is still practical for field use, but other meters may be more convenient to use.**

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Different kinds of maturity meters:

Range from basic probes for measuring and recording temperature to applications that transmit wireless data directly to the field staff.

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POSSIBLE SCENARIOS: **Do you see value here?**

CONTRACTOR:

- **Estimate that concrete has reached strength and can open to traffic ahead of schedule.**
- **Estimate that concrete has not reached minimum strength yet and needs more time to cure longer so that it doesn't have to carry loads without sufficient strength.**
- **Estimate concrete strength instead of relying on cylinders.**

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POSSIBLE SCENARIOS: **Do you see value here?**

CONCRETE PRODUCER/PRECASTER/PRESTRESSER:

- **Predict if concrete products reached release strength or shipping strength early to move project along ahead of schedule.**
- **Predict if concrete products have not developed enough strength before they are shipped so the product quality isn't compromised during handling or in transit.**
- **Could help relieve issues with not making enough cylinders.**

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GOALS AND QUESTIONS:

- **Does industry and VDOT see value in moving forward with investigating and evaluating a concrete maturity concept?**
- **Is this practical for field use?**
- **Can we implement guidelines for where to allow maturity methods for quick return to service or faster opening to traffic?**

WE WANT YOUR INPUT.

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ACKNOWLEDGEMENTS:

- **Richmond District Materials: Jeff Haddon**
- **Materials Division Physical Lab: Keith Williams, Trey Simpson, Brian Simmons**
- **Heartland Concrete: Jim Simes and crew**

THANK YOU.

Questions?

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