My Mission This Morning

To give you:

- Exciting report of my visit to this Congress
- Exciting Introduction to ACI
- Boring talk about concrete

I have seen and enjoyed beautiful things this week…

And I have seen the bright future

of IBRACON

and our Industry


UHE TUCURUÍ

American Concrete Institute®

Advancing concrete knowledge

Quick Intro to ACI

ACI's Leadership:

Good Friend,

Trusted Companion,

Expert Concrete Engineer

ACI's Leadership:

And
Executive Vice President

(Chief of Staff)

(Executive Director)
of
ACI

ACI IS

- Technical & educational society
- Dedicated to improving design, construction, maintenance, & repair of concrete structures
- Large and growing connecting point for access to world-wide concrete knowledge

ACI is NOT

- A Trade or Promotional Association
- A Government Agency
- A University

ACI's Mission:

"Provide knowledge and information for the best use of concrete"

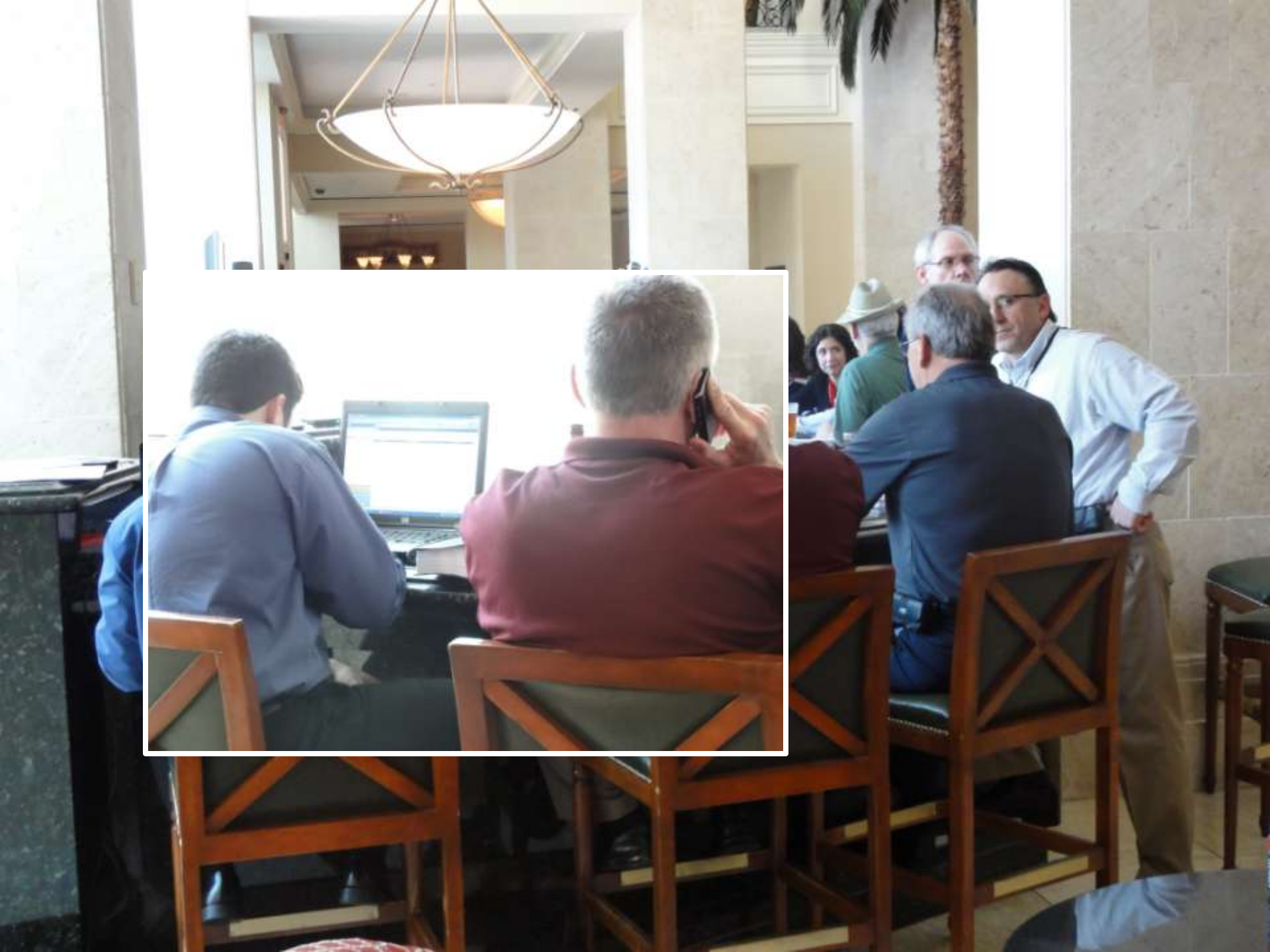
ACI's Vision:

A worldwide unified concrete community made up of equal partners

ACI Headquarter, Michigan, USA

In Reality ACI is…


FELLOW



ACI Membership

- Nearly 20,000 Members in 129 countries
- 5400 members outside North America
- Over 6000 Student Members
- 1000 Organizational Members
- 3900 Volunteers

ACI members are:

Architects
Consultants
Contractors
Educators
Engineers
Materials Suppliers
Lawyers
Researchers
Students
Laboratory Technicians

ANYONE interested in concrete

ACI Committees

- 120 Technical Committees
- 25 Education and Certification Committees
- 30 Administrative Committees

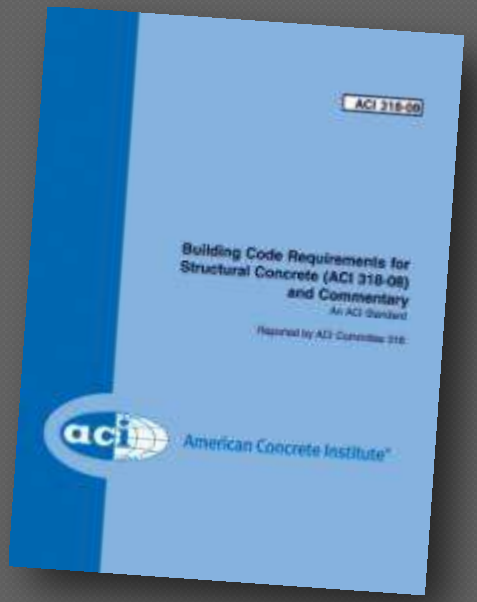
280,000 hours donated

$35,000,000 cash value


Priceless!

More than 400 technical documents, including:

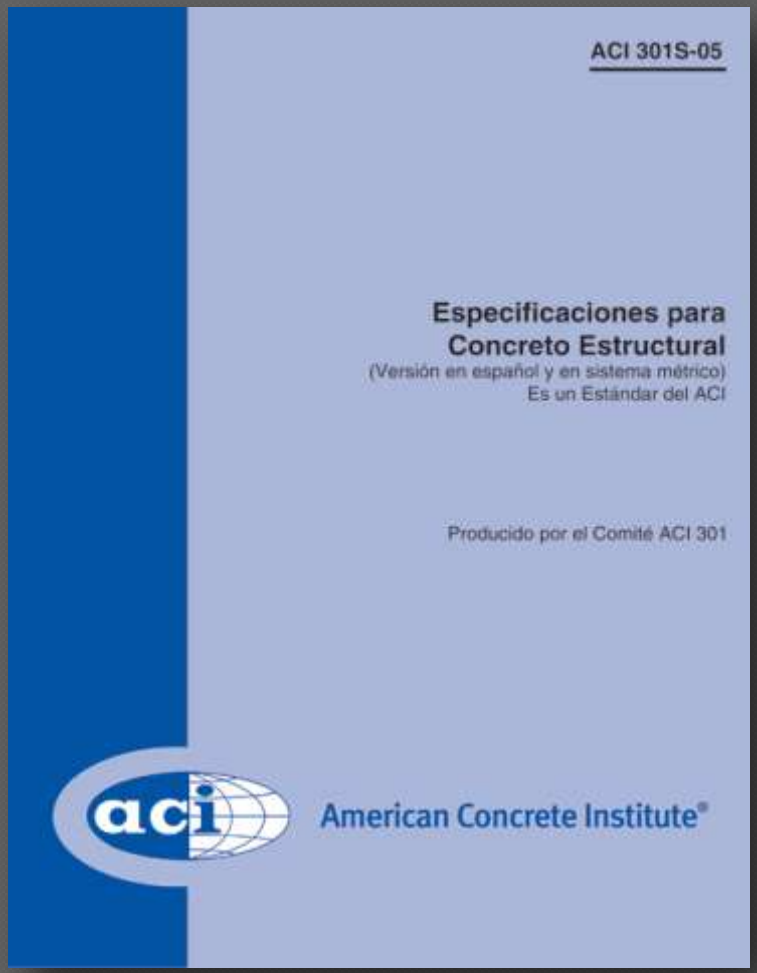
- **Codes**
- **Specifications**
- **Reports and Guides**
- **References**
- **Annual *Manual of Concrete Practice***



New Publications

Requisitos de Reglamento para Concreto Estructural

Especificaciones para Concreto Estructural



Guía del Contratista para la Construccíon en Concreto de Calidad

ACI Periodicals

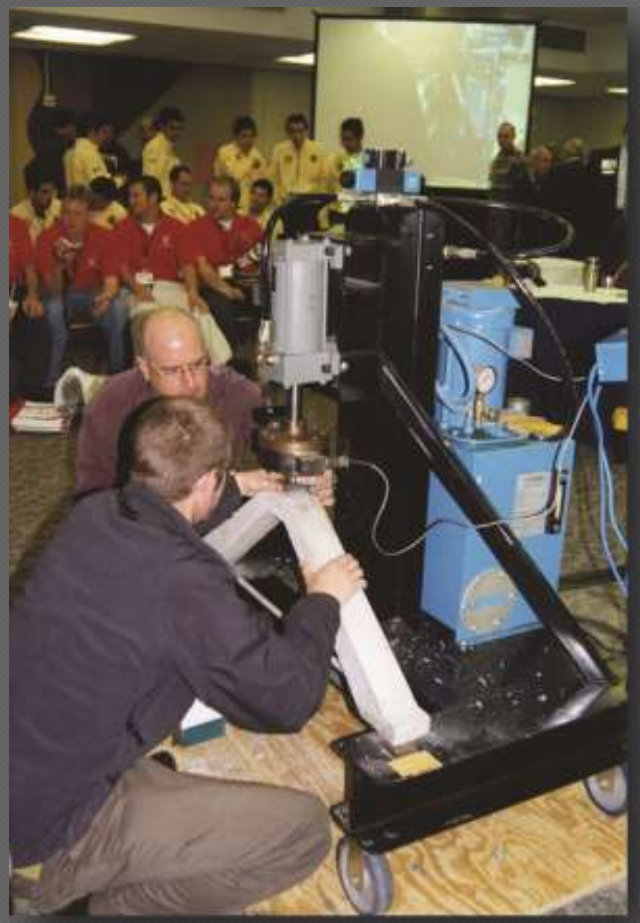
- *Concrete International (CI)*
- *ACI Structural Journal*
- *ACI Materials Journal*

Online Concrete Knowledge Center

- **Information for the design, construction, and repair of concrete and concrete structures**

Educational Activities

- Scholarships and fellowships
- Seminars
- Publications
- Online learning
- Student competitions
- Technical sessions at ACI conventions



Chapters

- 101 Chapters Worldwide
- 58 Chapters in the U.S.A.
- 43 Chapters outside the U.S.A.

Certification

- Largest certifying body in the concrete industry
- Over 400,000 exams administered
- Over 26,000 exams conducted per year
- Certified individuals residing in 54 countries
- Certification programs in English, Spanish, French, Chinese

Certification Programs

- Flatwork Finisher
- Field Technician
- Craftsmen
- Strength Technician
- Laboratory Technician
- Aggregate Technician
- Inspector
- Tilt-Up
- Shotcrete Nozzleman
- Transportation Inspector
- Adhesive Anchor Installer

Conventions

- Spring and fall conventions
- 330 committee meetings
- 40 technical sessions
- Student competitions
- 1400 to 1600 attendees representing 34 countries
- 2012 Spring Convention
  - March, 2012
  - Dallas, Texas, U.S.A.

Educator Membership Program

- Full-time Concrete Educators
- Not ACI member 5 years
- Free E-Membership

Magazine & Journal Subscriptions

- Member & Student access to ACI resources
- Member rates for convention

ACI International Partner Program

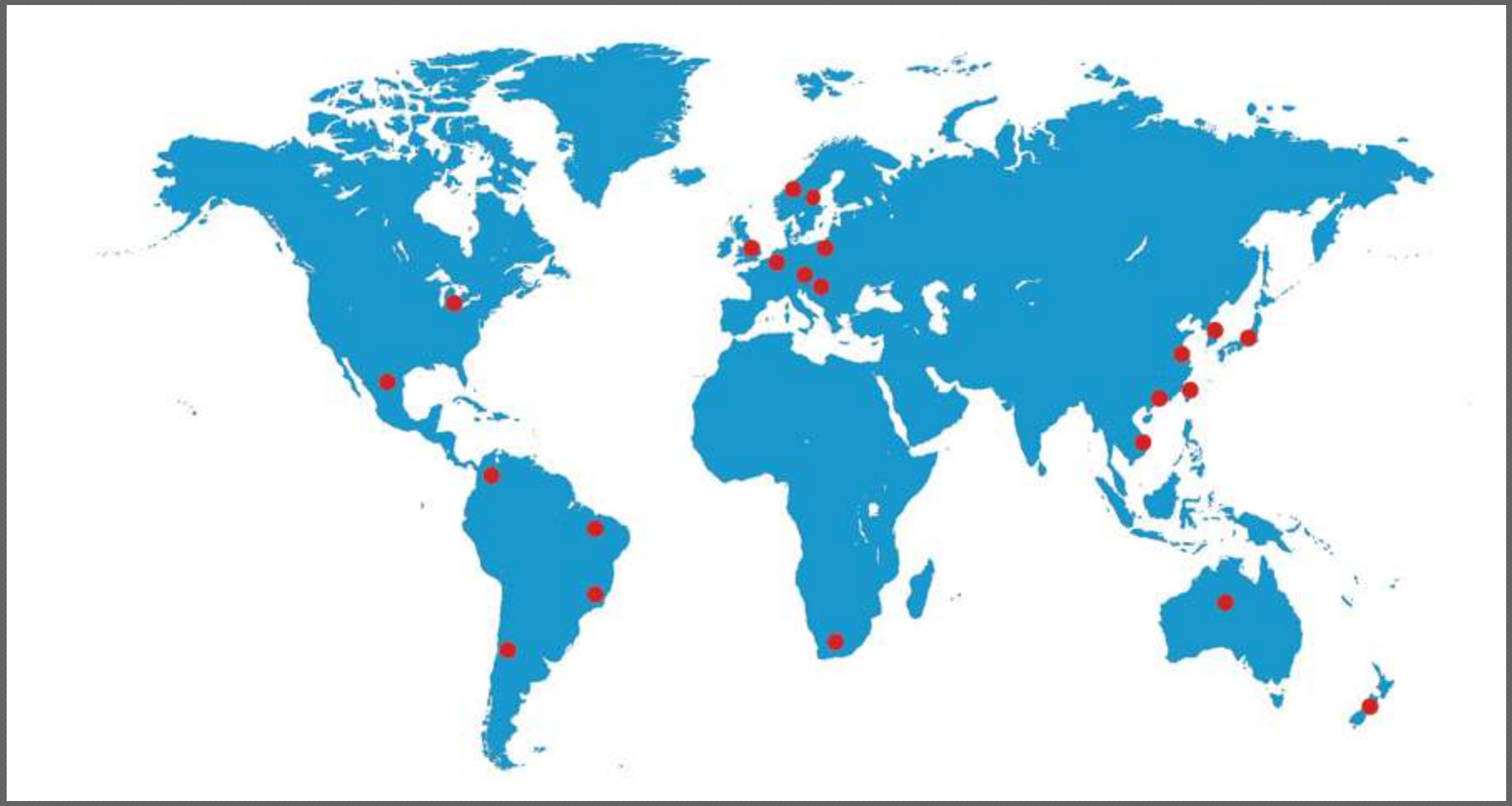
A unified, worldwide community of equal partners

ACI would like to thank its current International Partners:

- Asian Concrete Federation
- Associação Nacional de Pisos e Revestimentos de Alto Desempenho
- Austrian Society for Construction Techn
- Cement Concrete & A
- Chilean Cement and
- China Concrete & Cer Association
- Colombian Associati Earthquake Engineer
- Concrete Institute of
- The Concrete Society
- Concrete Society of S
- Czech Concrete Soci
- Federación Iberoamericana del Hormigón Premezclado
- Hong Kong Concrete Institute
- Instituto Brasileiro do Concreto
- Instituto Mexicano del Cemento y del Concreto
- Japan Concrete Institute
- Korea Concrete Institute
- New Zealand Concrete Society
- e Association
- ciences
- ernationale des
- ais et de recherche
- et les (International Construction
- s and Structures)
- Industry Association
- h Institute of
- Association
- nstitute
- Vietnam Concrete Association

IBRACON

aci American Concrete Institute®
Advancing concrete knowledge



International Concrete Research Portal

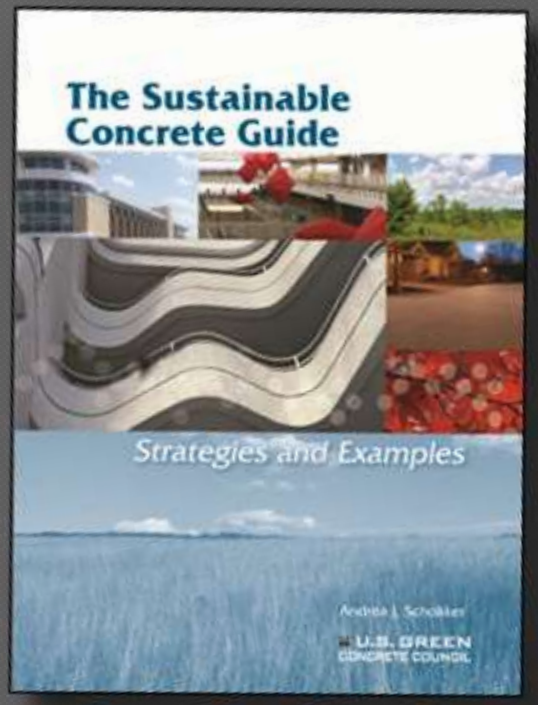
- Open to all International Partners
- Partners supply abstracts of their papers to ACI
- ACI includes partner journals on the portal.
- Full text of the journal papers can be hosted at ACI or the partner's Web site

www.concrete.org

Sustainability Initiatives

- ACI Committee 130, Sustainability of Concrete
- ISO TC-71 SC8
- Seminars, sessions, and forums at ACI conventions
- Two publications via CAM Publishing
- Concrete Joint Sustainability Initiative (JSI)

Sustainability Books



Joint Sustainability Initiative

- **An agreement between 26 U.S. Concrete-related societies**
- **Establishing an Industry Vision for a sustainable future**

American Concrete Institute®

Advancing concrete knowledge

www.concrete.org

From Liquid to Solid:
Transitions in Concrete Behavior:
or
Concrete Waits for No One

From Liquid to Solid: Transitions in Concrete Behavior:

or

Concrete Waits for No One

Roberto C. A. Pinto
and Ken Hover

UNIVERSIDADE FEDERAL
DE SANTA CATARINA

CORNELL UNIVERSITY
FOUNDED BY EZRA CORNELL

From Liquid to Solid: Transitions in Concrete Behavior:

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UNIVERSIDADE FEDERAL DE SANTA CATARINA

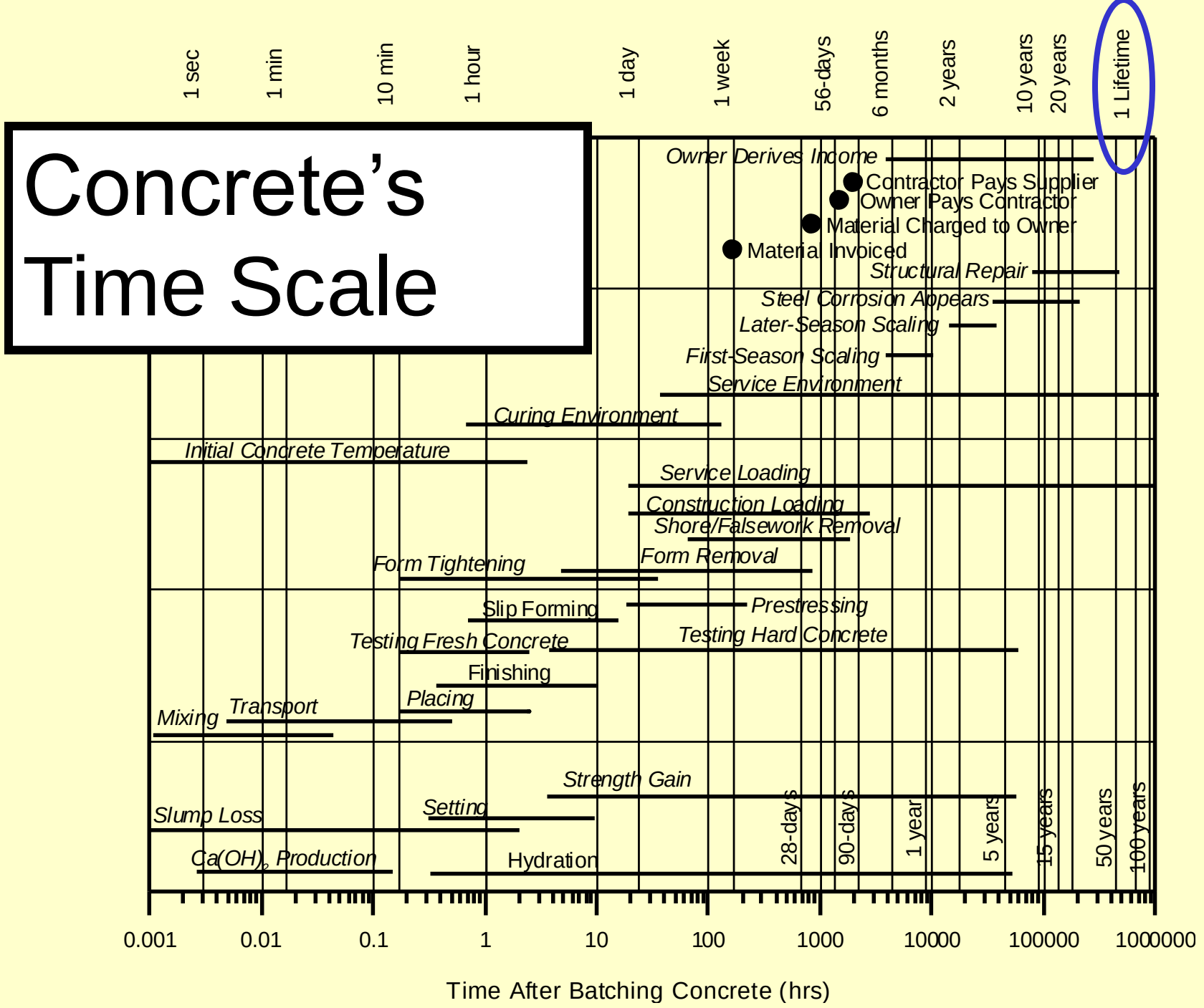
CORNELL UNIVERSITY · FOUNDED BY EZRA CORNELL ·

Monitoring the Liquid to Solid Transition in Concrete with Conventional Tests

Jon Abel, Roberto Pinto
and Ken Hover

Abel, J.H., Pinto, R.C.A., Hover, K.C., Monitoring the liquid to solid transition in concrete with standard tests, ACI Special Publication SP-259: Transition from Fluid to Solid: Re-Examining the Behavior of Concrete at Early Ages, Kyle Riding, Editor, American Concrete Institute, March 2009.

Concrete's Time Scale



Concrete's Time Scale

1 sec
1 min
10 min
1 hour
1 day
1 week
56-days
6 months
2 years
10 years
20 years
1 Lifetime

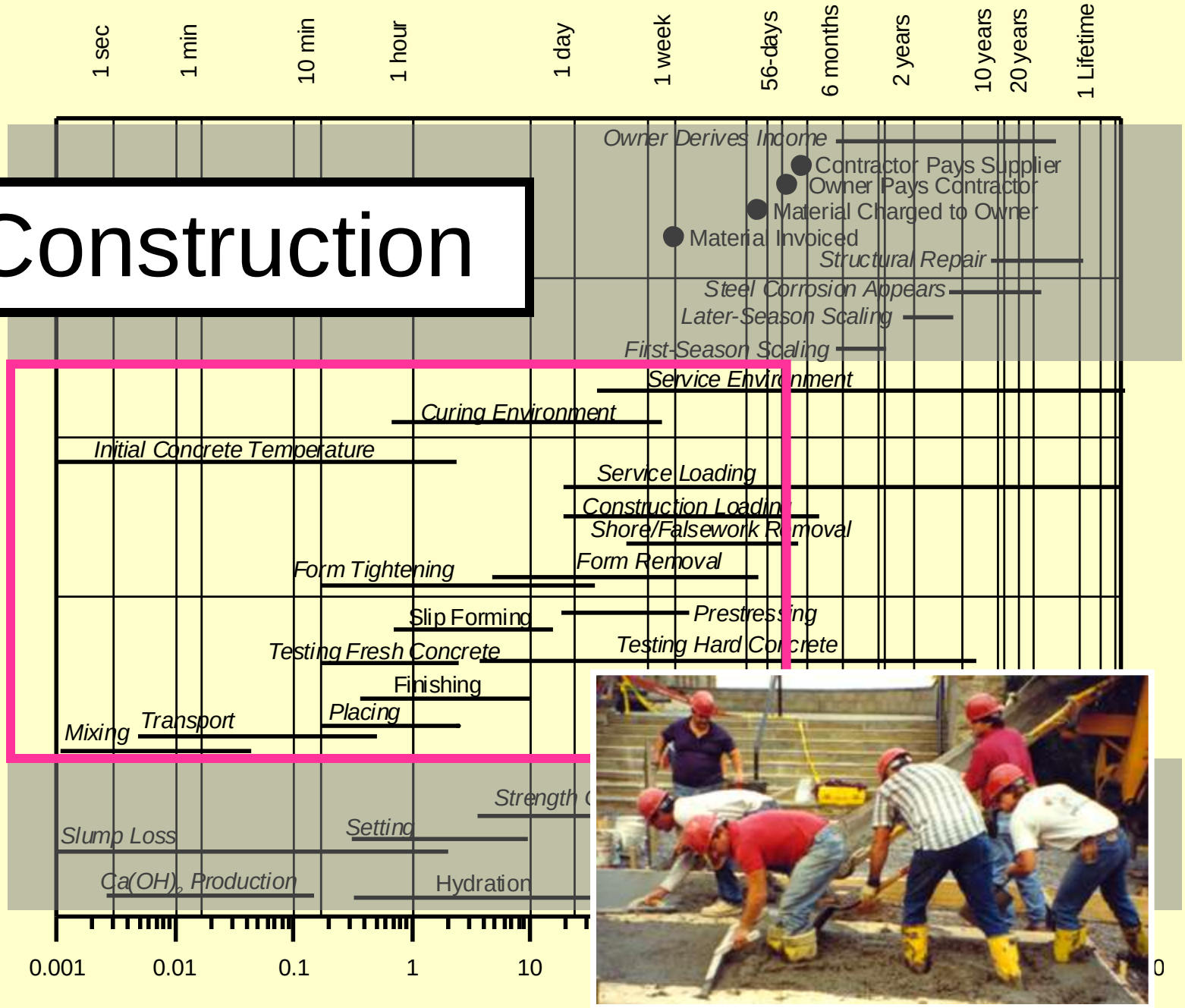
Owner Derives Income
Contractor Pays Supplier
Owner Pays Contractor
Material Charged to Owner
Materia Invoiced
Structural Repair
Steel Corrosion Appears
Curing Environment
Initial Concrete Temperature
Form Tightening
Slip Forming
Testing Fresh Concrete
Finishing
Placing
Transport
Mixing
Strength Gain
Setting
Slump Loss
$Ca(OH)_2$ Production
Hydration

28-days
90-days
1 year
5 years
15 years
50 years
100 years

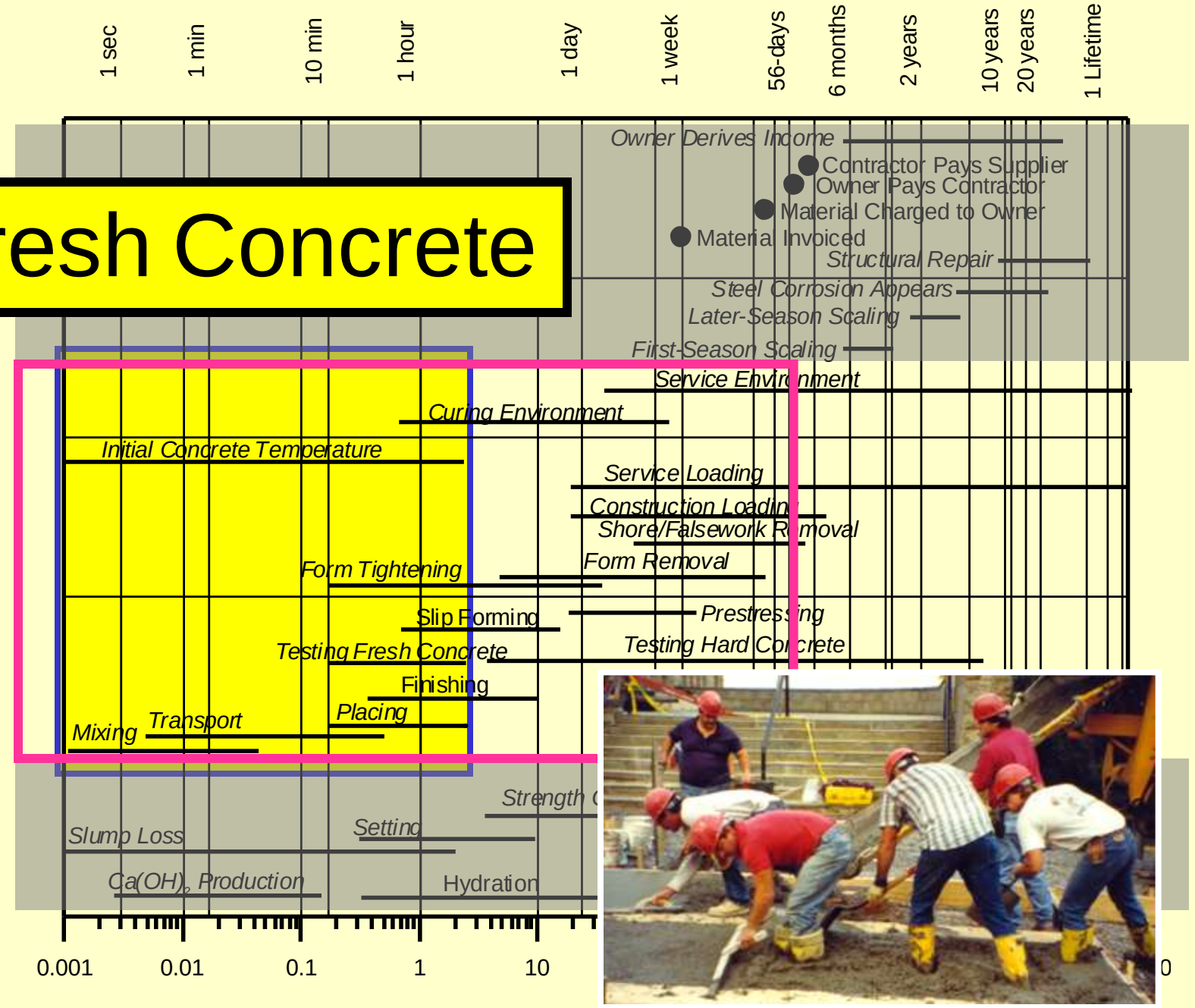
0.001
0.01
0.1
1
10
100
1000
10000
100000
1000000

Time After Batching Concrete (hrs)

Construction



Fresh Concrete



Hydration

1 sec
1 min
10 min
1 hour
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56-days
6 months
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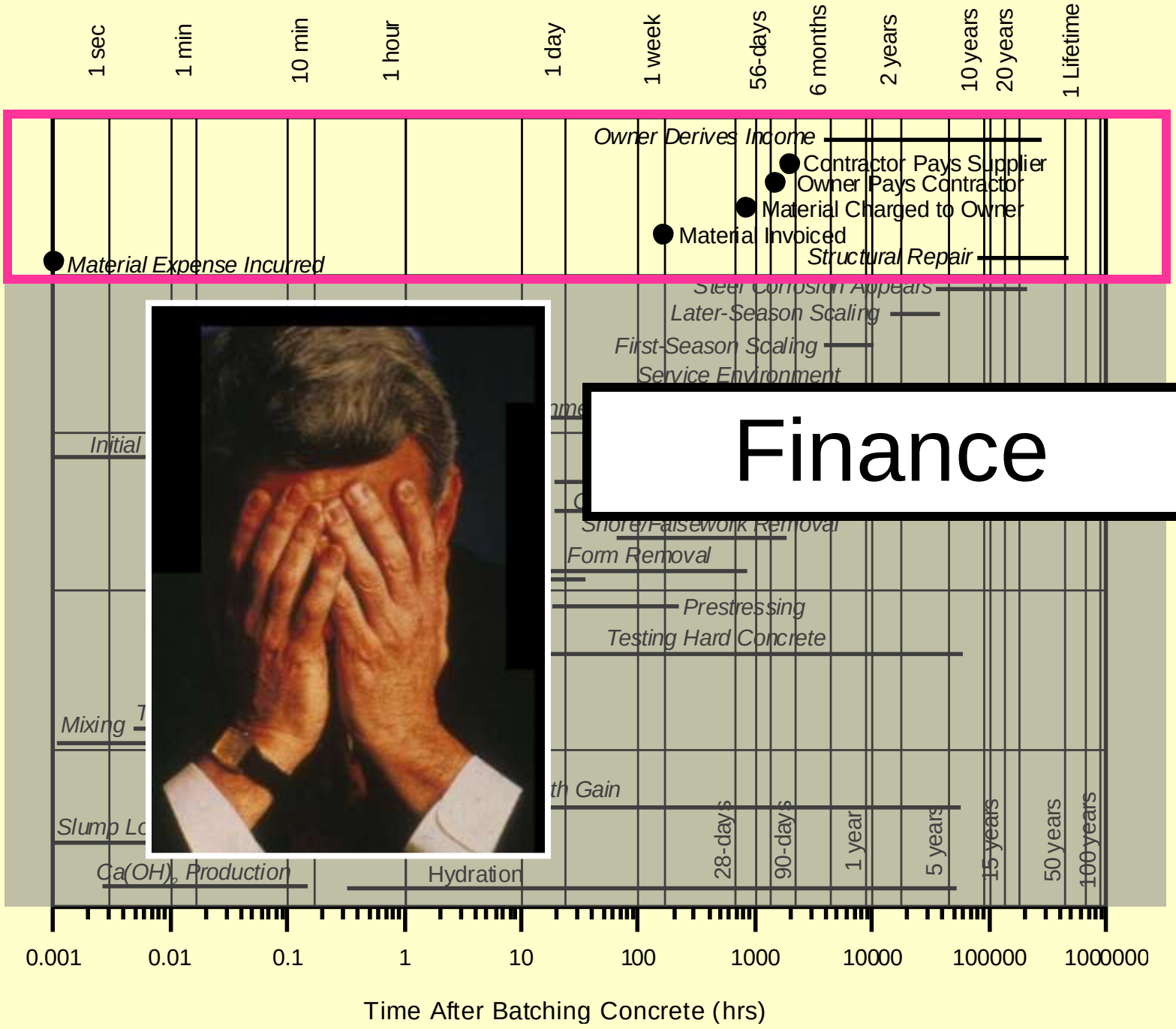
1 Lifetime

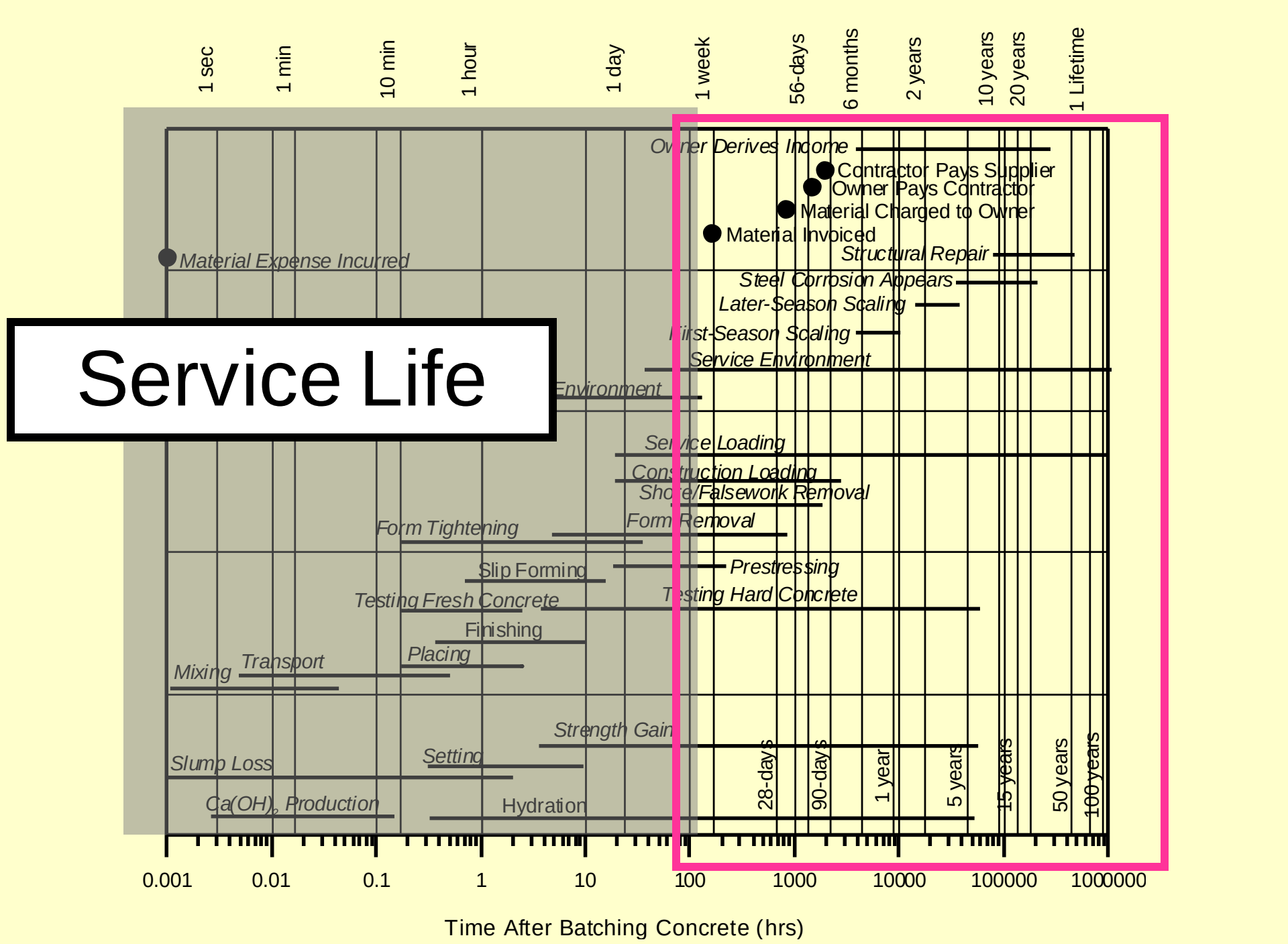
Owner Derives Income
Contractor Pays Supplier
Owner Pays Contractor
Material Charged to Owner
Materia Invoiced
Structural Repair
Steel Corrosion Appears
Later-Season Scaling
First-Season Scaling
Service Environment
Shore/Falsework Removal
Form Removal
Prestressing
Testing Hard Concrete
Finishing
Placing
Transport
Mixing
Strength Gain
Setting
Slump Loss
Ca(OH)₂ Production
Hydration
28-days
90-days
1 year
5 years
15 years
50 years
100 years

0.001
0.01
0.1
1
10
100
1000
10000
100000
1000000

Time After Batching Concrete (hrs)


1 sec
1 min
10 min
1 hour
1 day
1 week
56-days
6 months
2 years
10 years
20 years
1 Lifetime
Owner Derives Income
Contractor Pays Supplier
Owner Pays Contractor
Material Charged to Owner
Materia Invoiced
Material Expense Incurred
Structural Repair
Steel Corrosion Appears
Later-Season Scaling
First-Season Scaling
Service Environment
Initial
Shore/Falsework Removal
Form Removal
Prestressing
Testing Hard Concrete
Mixing
th Gain
Slump Lo
Ca(OH)2 Production
Hydration
28-days
90-days
1 year
5 years
15 years
50 years
100 years
0.001
0.01
0.1
1
10
100
1000
10000
100000
1000000
Time After Batching Concrete (hrs)

Finance


Service Life
1 sec
1 min
10 min
1 hour
1 day
1 week
56-days
6 months
2 years
10 years
20 years
1 Lifetime
Owner Derives Income
Contractor Pays Supplier
Owner Pays Contractor
Material Charged to Owner
Material Invoiced
Material Expense Incurred
Structural Repair
Steel Corrosion Appears
Later-Season Scaling
First-Season Scaling
Service Environment
Environment
Service Loading
Construction Loading
Shore/Falsework Removal
Form Removal
Form Tightening
Prestressing
Slip Forming
Testing Hard Concrete
Testing Fresh Concrete
Finishing
Placing
Transport
Mixing
Strength Gain
Setting
Slump Loss
Hydration
Ca(OH)2 Production
28-days
90-days
1 year
5 years
15 years
50 years
100 years
0.001
0.01
0.1
1
10
100
1000
10000
100000
1000000
Time After Batching Concrete (hrs)

Durability
Maintenance
Repair

sec
min
hour
1 day
1 week
56-days
6 months
2 years
10 years
20 years
1 Lifetime

Owner Derives Income
Contractor Pays Supplier
Owner Pays Contractor
Material Charged to Owner
Material Invoiced
Structural Repair
Steel Corrosion Appears
Later-Season Scaling
First-Season Scaling
Service Environment
Prestressing
Strength Gain
Setting
Slump Loss
Ca(OH)$_2$ Production
Hydration
28-days
90-days
1 year
5 years
15 years
50 years
100 years

0.001
0.01
0.1
1
10
100
1000
10000
100000
1000000

Time After Batching Concrete (hrs)

Construction = (1/10)% Service Life

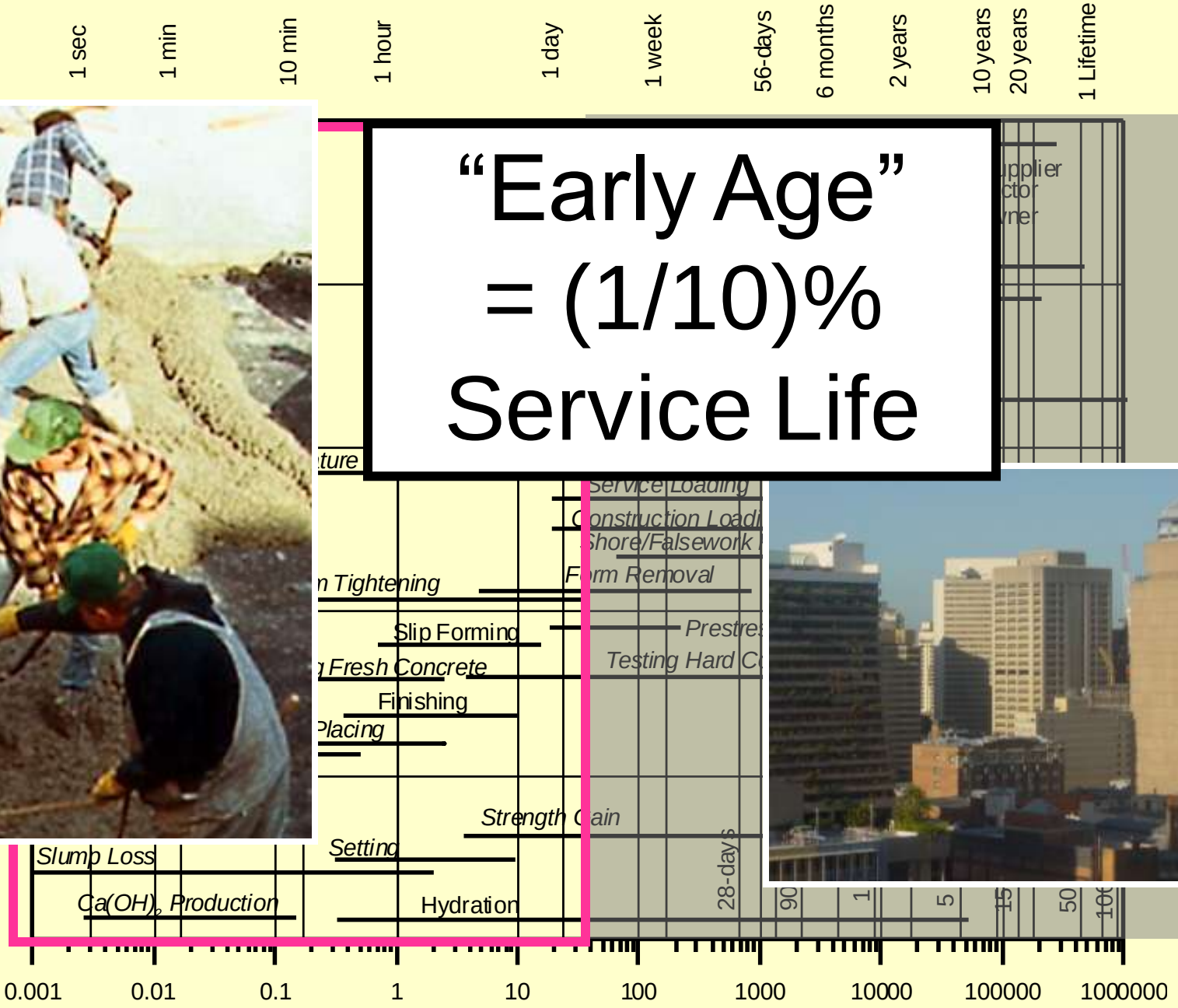
1 sec
1 min
10 min
1 hour
1 day
1 week
56-days
6 months
2 years
10 years
20 years
1 Lifetime

Service Loading
Slip Forming
Finishing
Placing
Strength Gain
Setting
Slump Loss
Ca(OH)$_2$ Production
Hydration
28-days

0.001
0.01
0.1
1
10
100
1000
10000
100000
1000000

Time After Batching Concrete (hrs)

“Early Age” = (1/10)% Service Life



Fresh State = (2/1000) % Service Life

1 sec
1 min
10 min
1 hour
1 day
week
-days
months
years
years
fetime

Curing Environme
ture
Service Loading
Construction Loadi
Shore/Falsework
n Tightening
Form Removal
Slip Forming
Prestres
Fresh Concrete
Testing Hard C
Finishing
Placing
Strength Gain
Setting
Slump Loss
Ca(OH)2 Production
Hydration
28-days
90
1
5
15
50
10

0.001
0.01
0.1
1
10
100
1000
10000
100000
1000000

Time After Batching Concrete (hrs)

Concrete is hard
for a very long time

(durability problems notwithstanding)

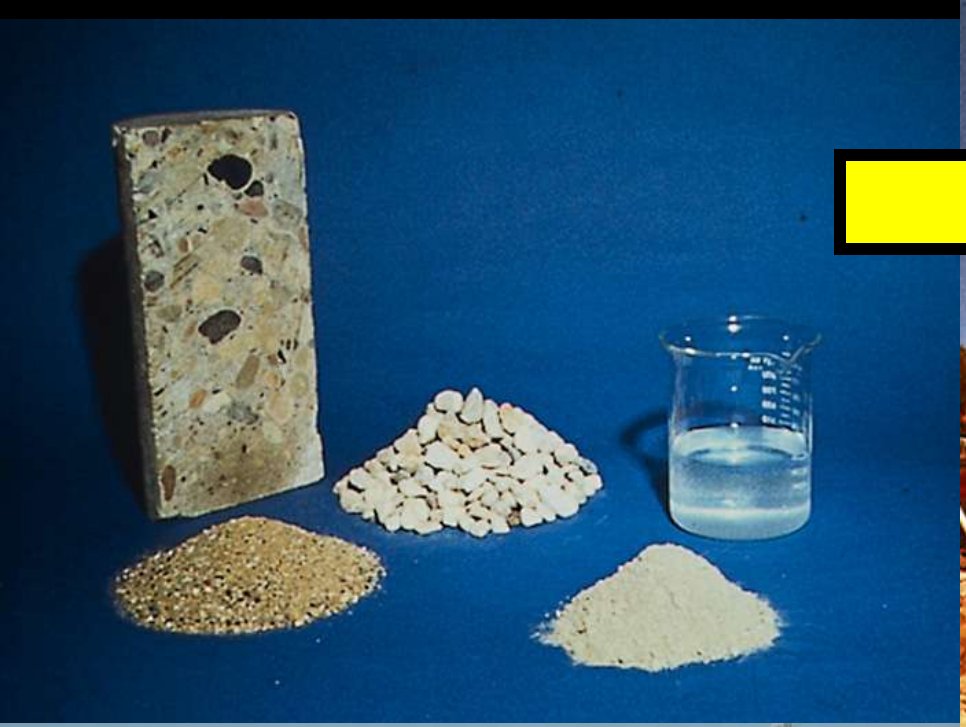
Concrete is hard
for a very long time

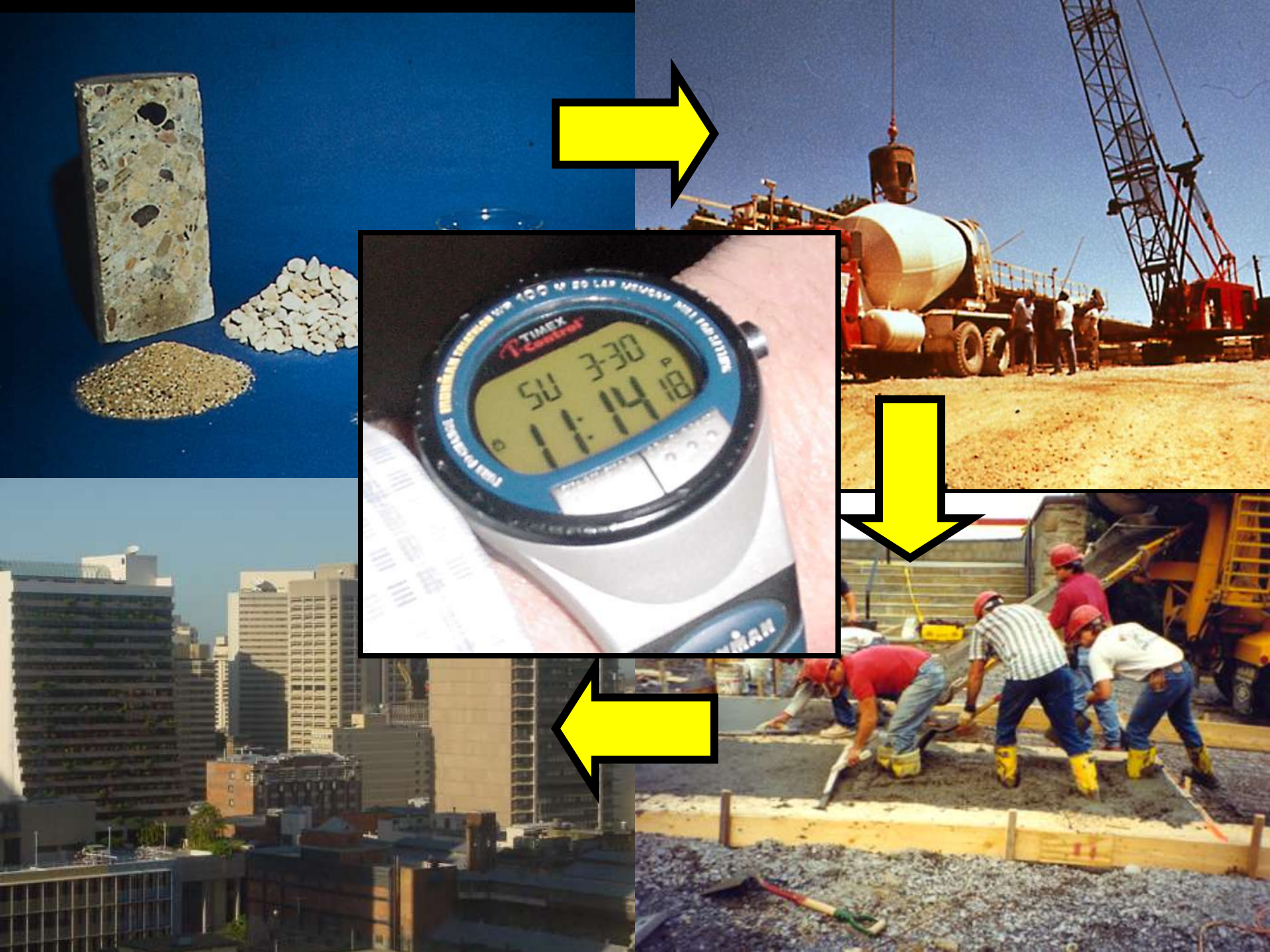
It is fresh for a very short time

Concrete is hard
for a very long time

It is fresh for a very short time

And the rate of transition matters!




TIMEX
SU 3-30
11:14
18


AMCON
CONCRETE


Food Shop

Who worries about this transition and its rate?

Who cares about this transition and its rate?

The Contractor!


The contractor is in a race with the concrete

Time,

Time,

and Tide,

Time,

and Tide,

and Concrete

wait for

no

Contractor

Time,

and Tide,

and Concrete

wait for

no

Contractor

(or Engineer)

Time,

and Tide,

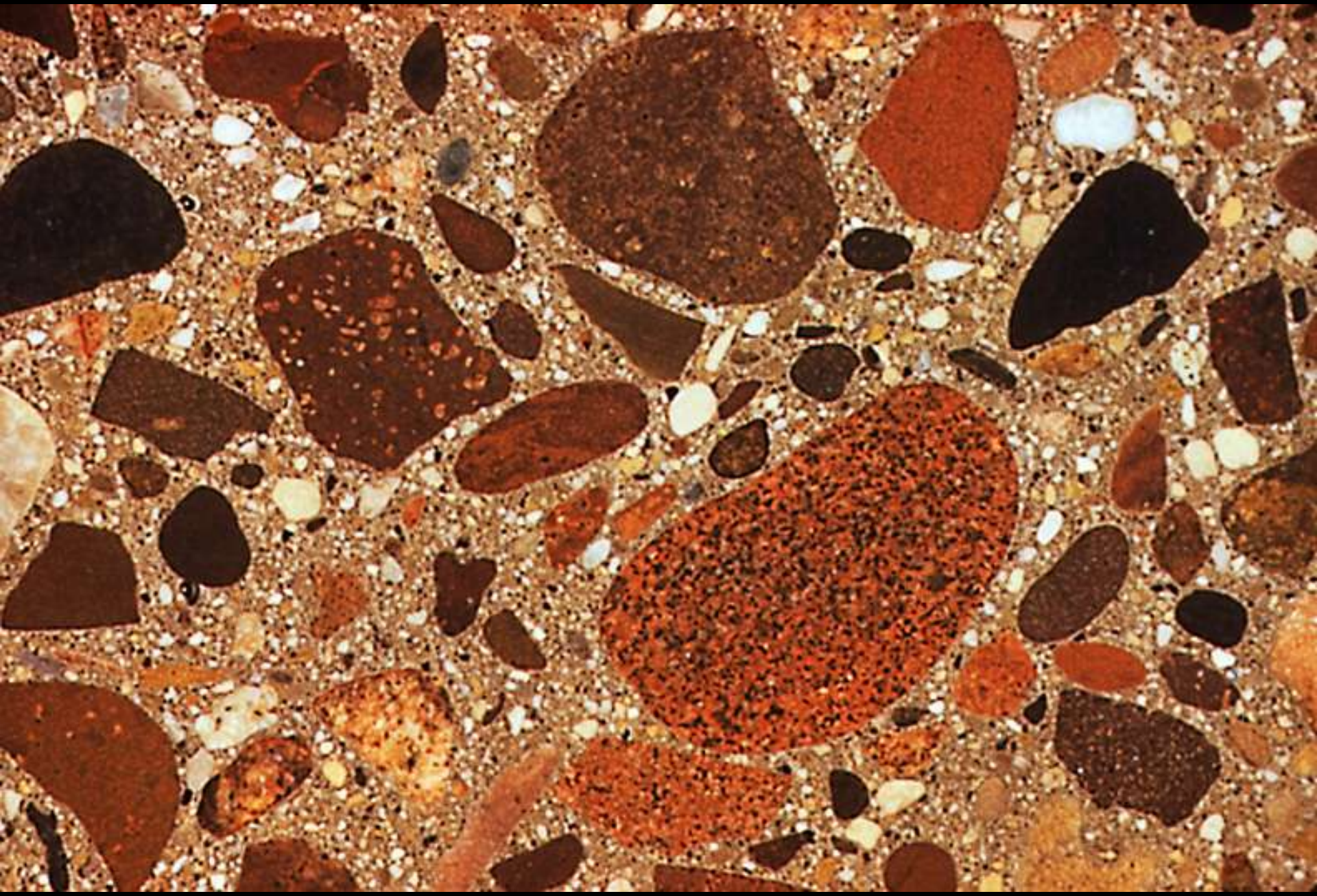
and Concrete

wait for

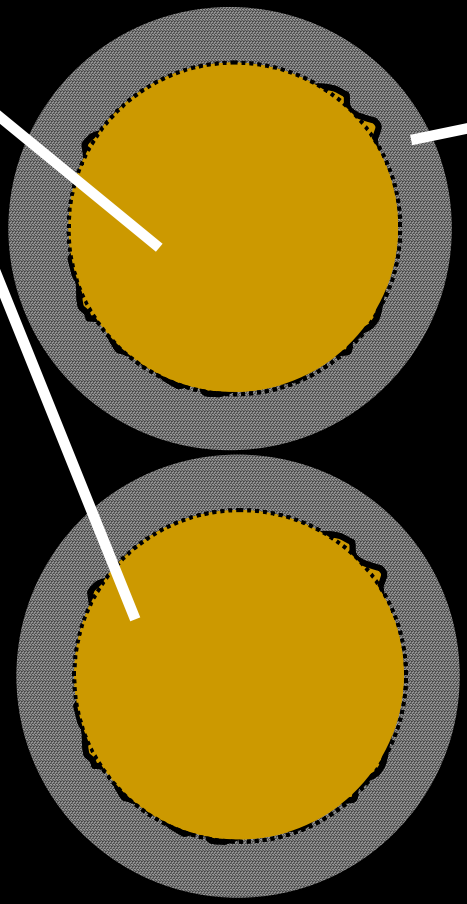
no

Contractor

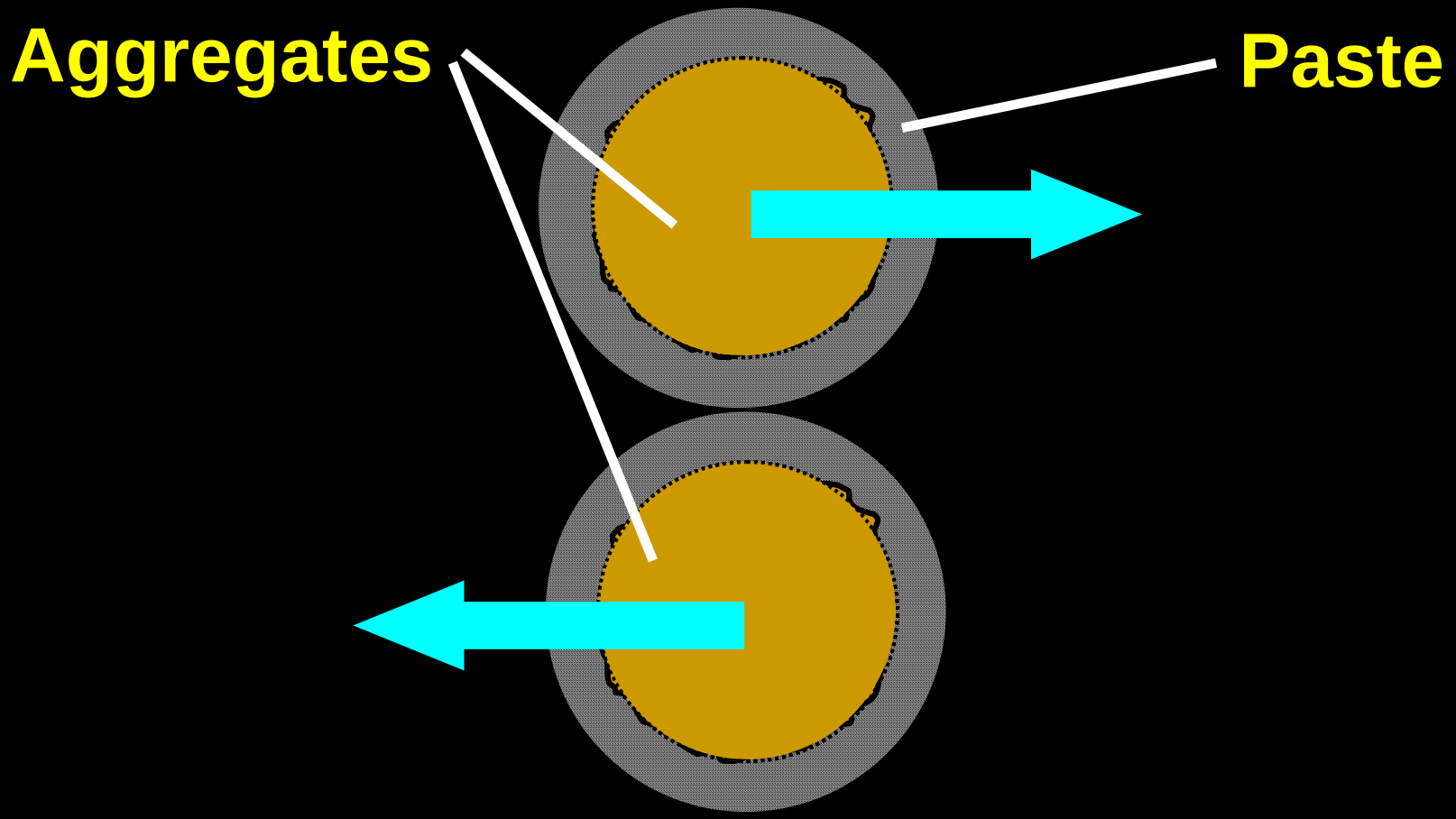
(or Researcher)



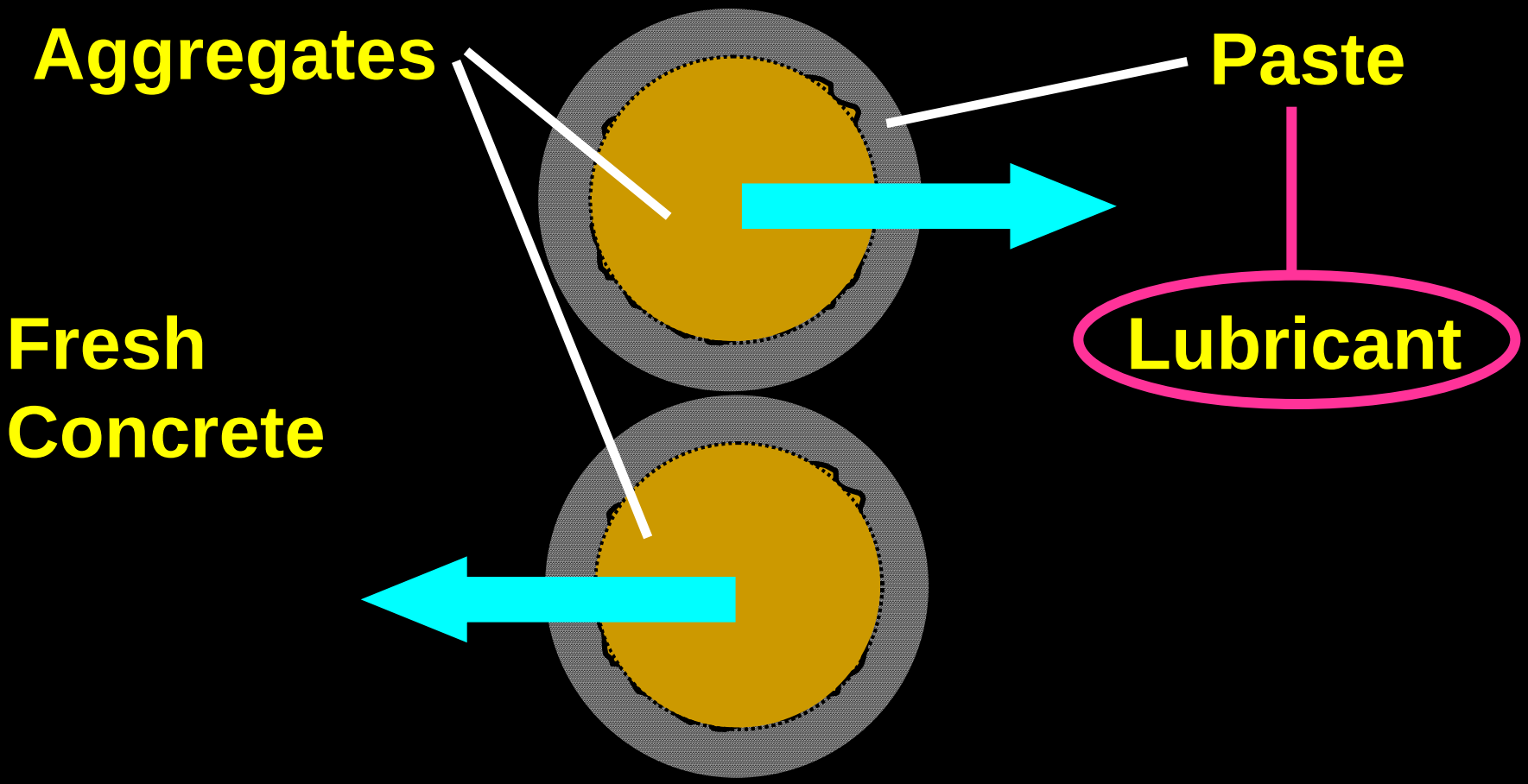
Aggregates

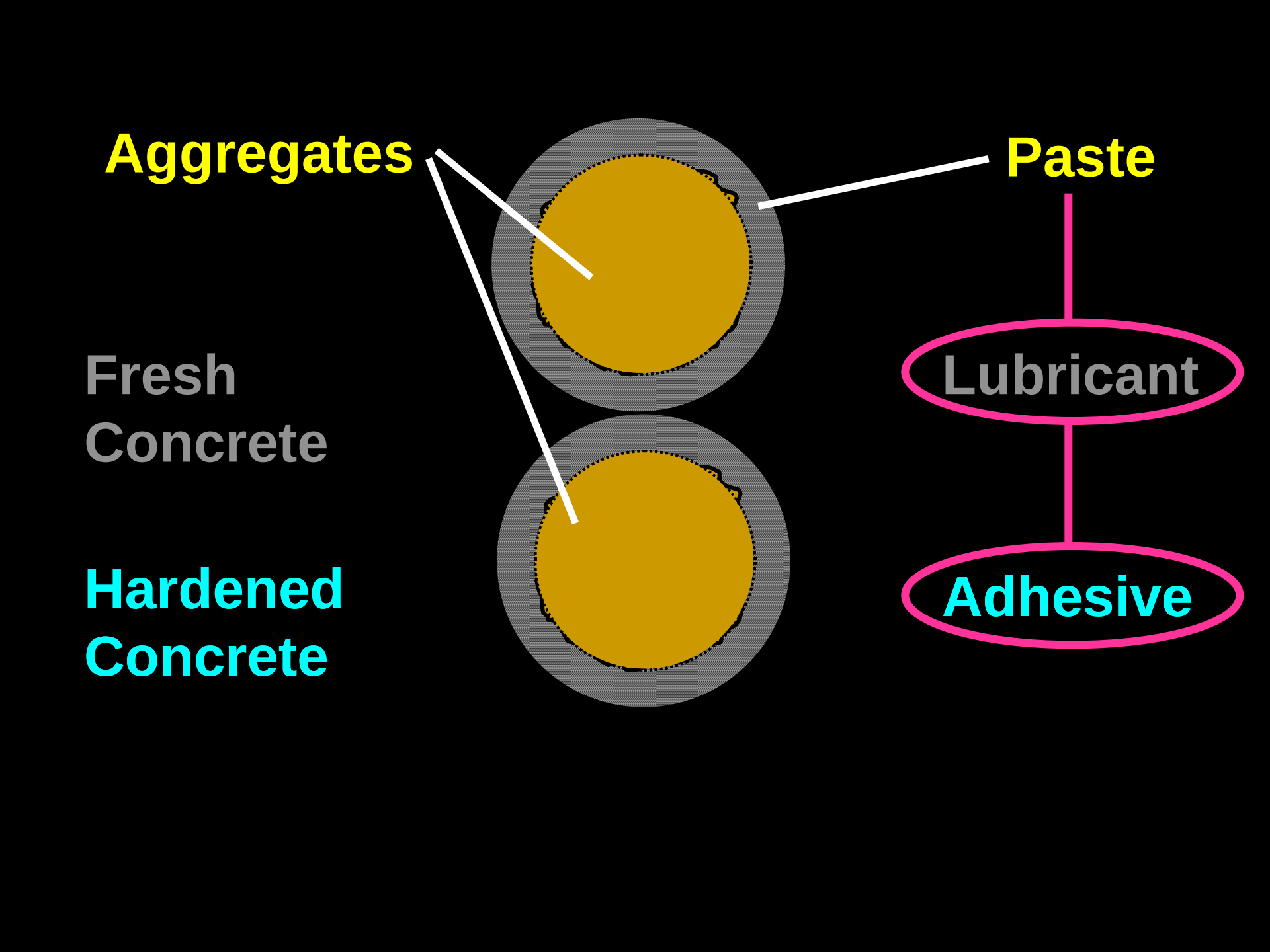


Paste



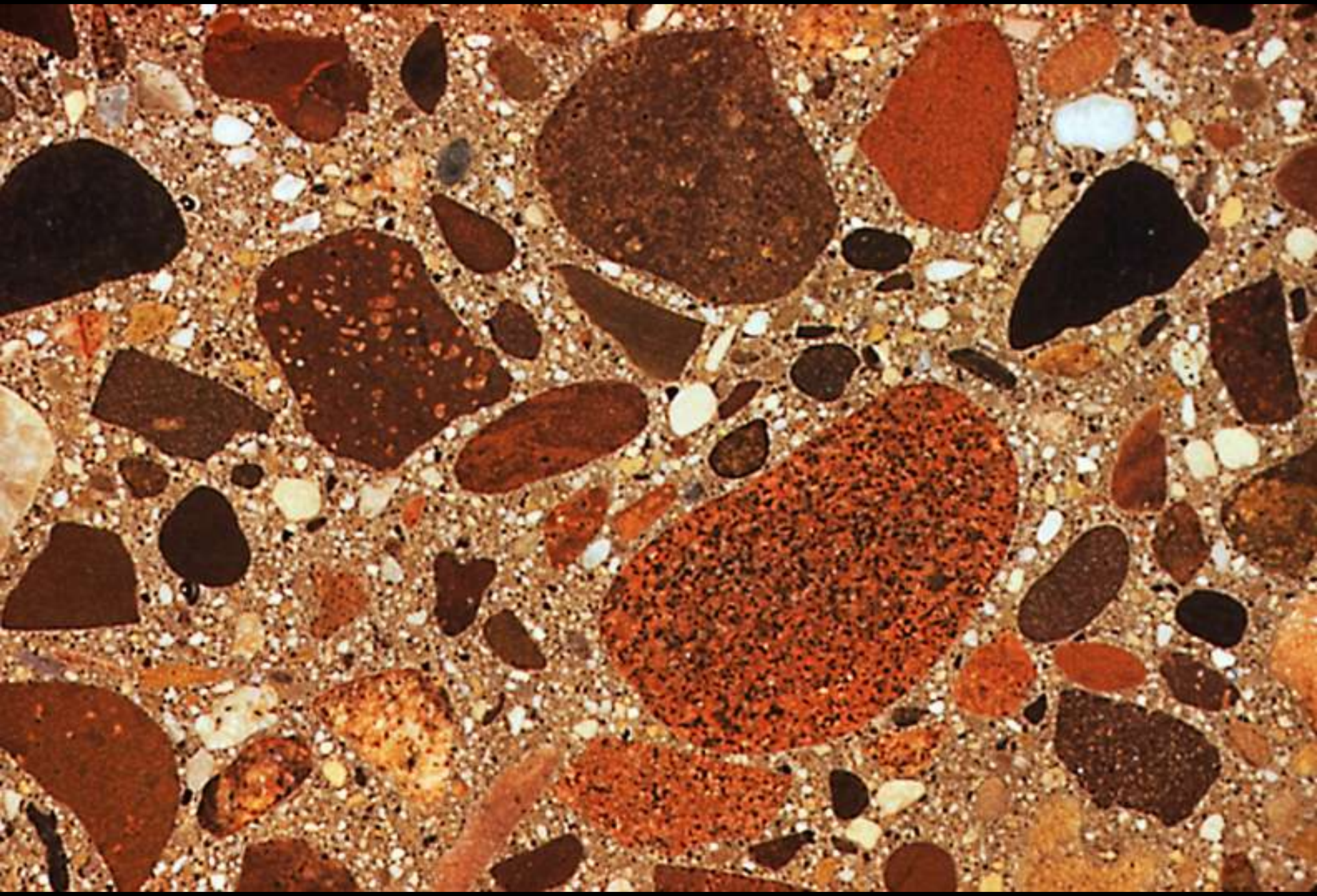
Aggregates can *Move* in Workable Concrete

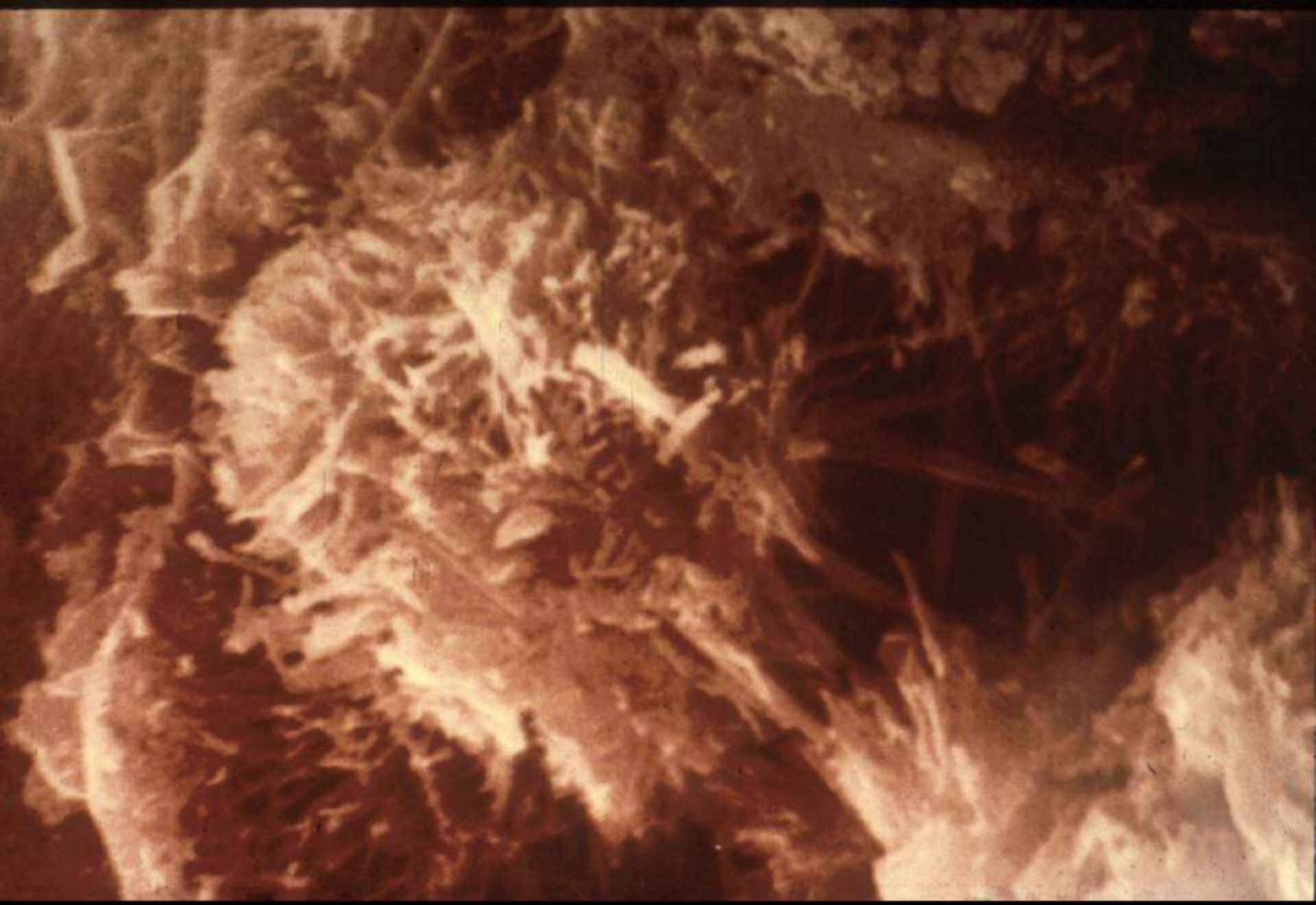

Aggregates
Paste
Fresh
Concrete
Lubricant

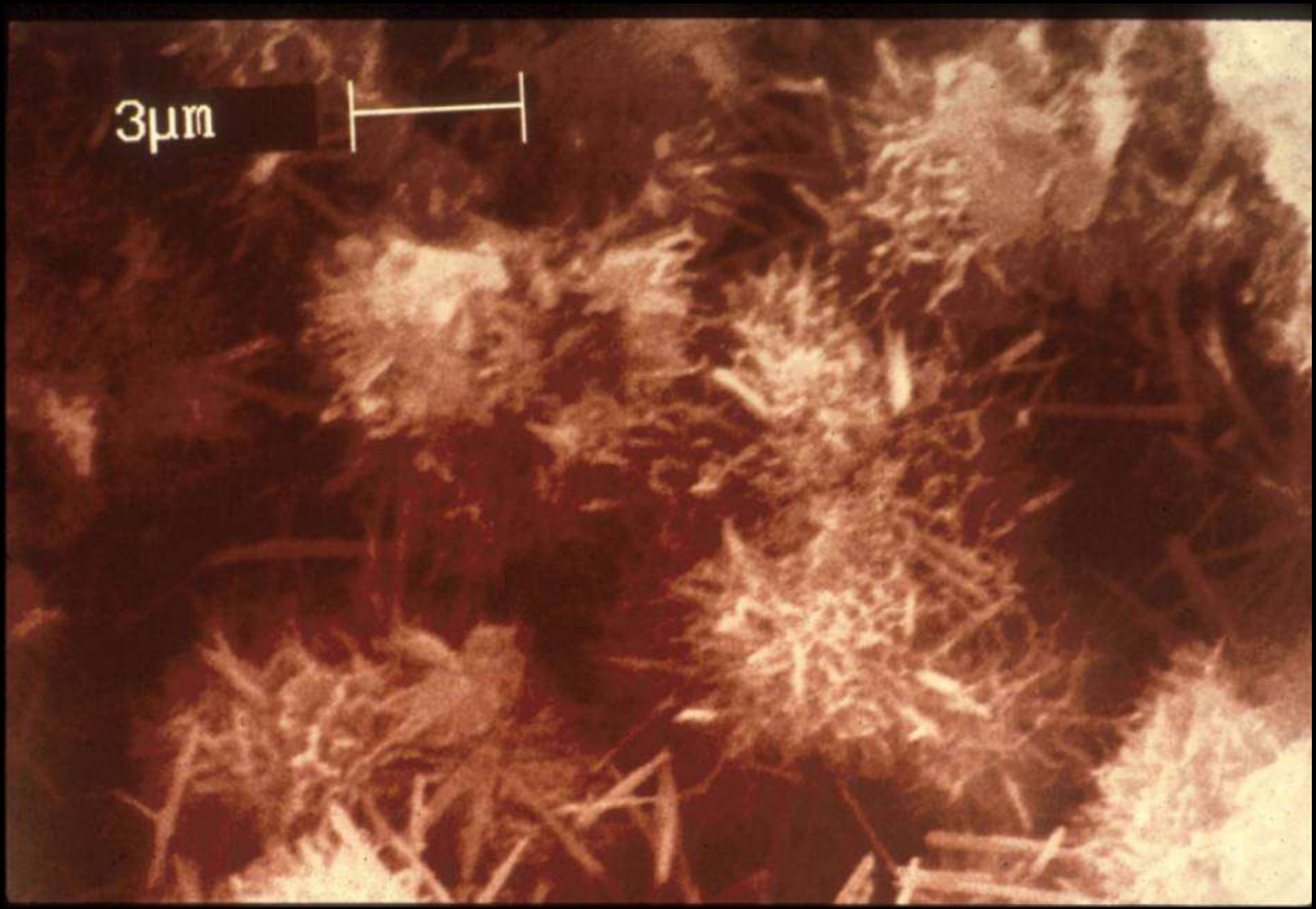

Aggregates
Paste
Fresh Concrete
Lubricant
Hardened Concrete
Adhesive

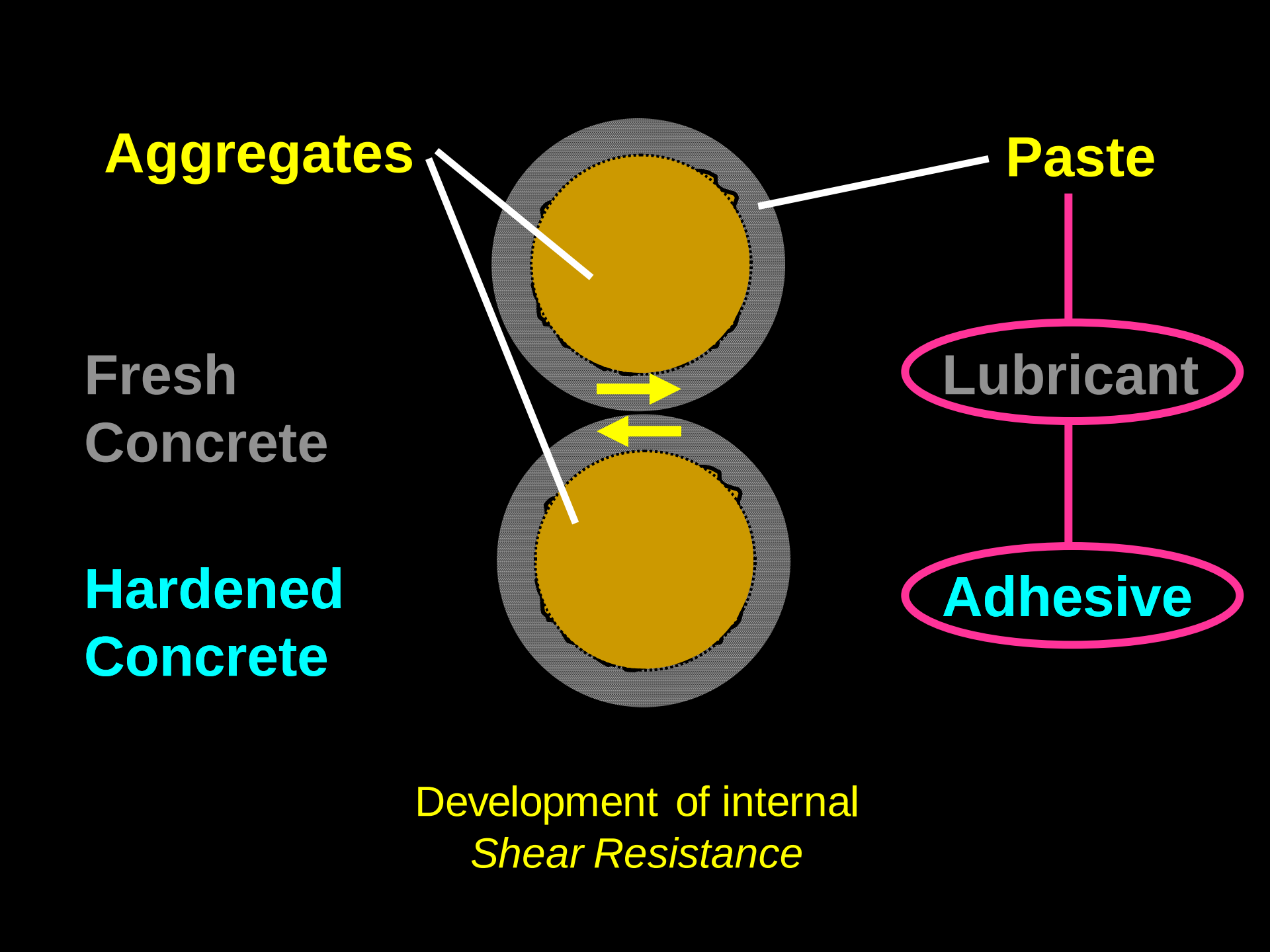
A Look Inside

What drives the liquid-to-solid transition?






3µm



Development of internal
Shear Resistance

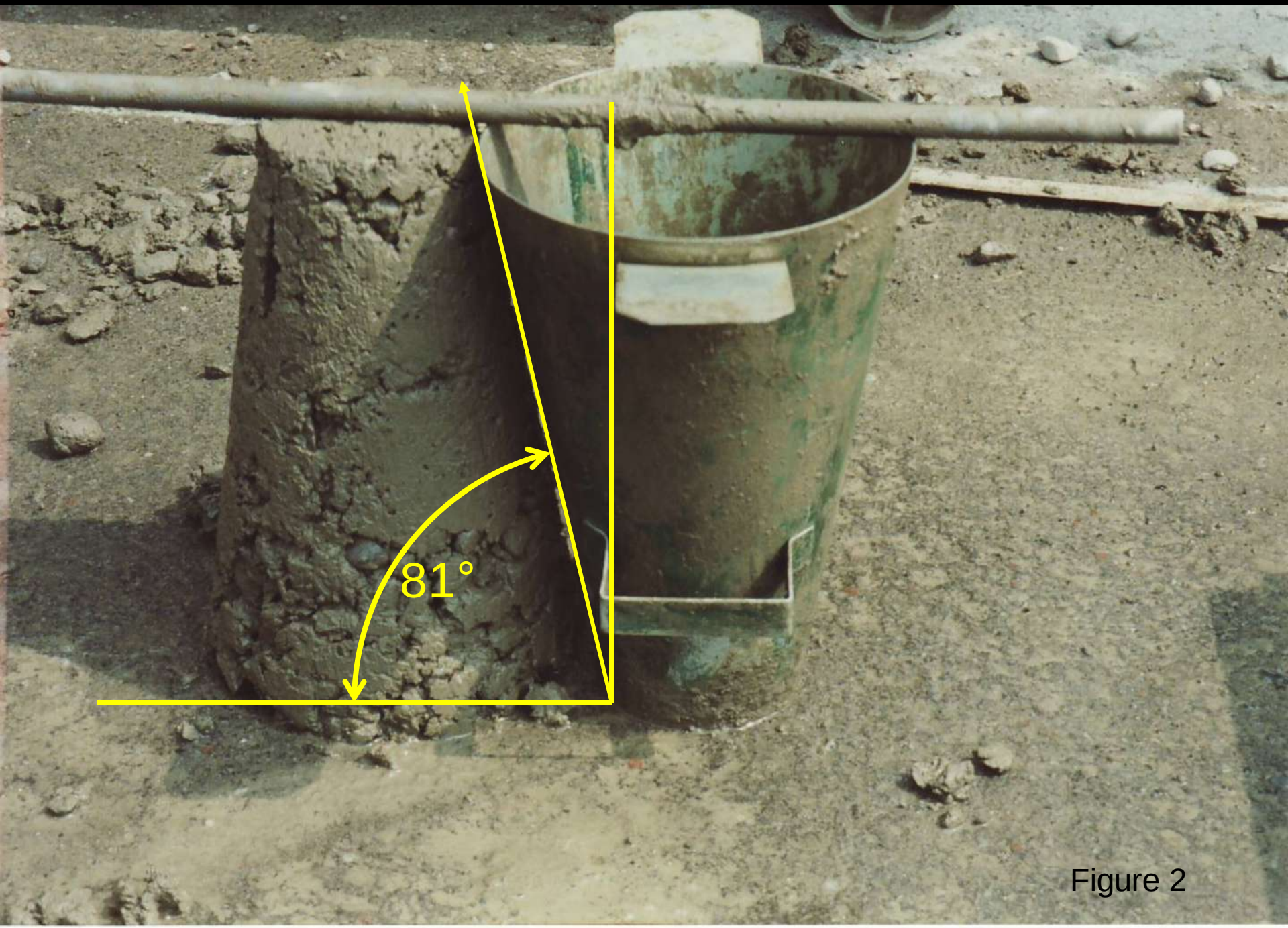
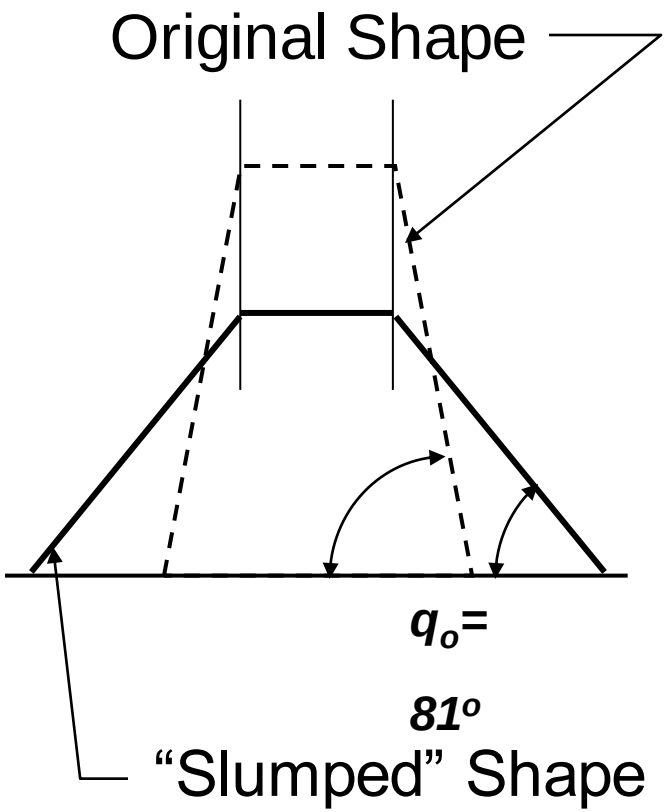
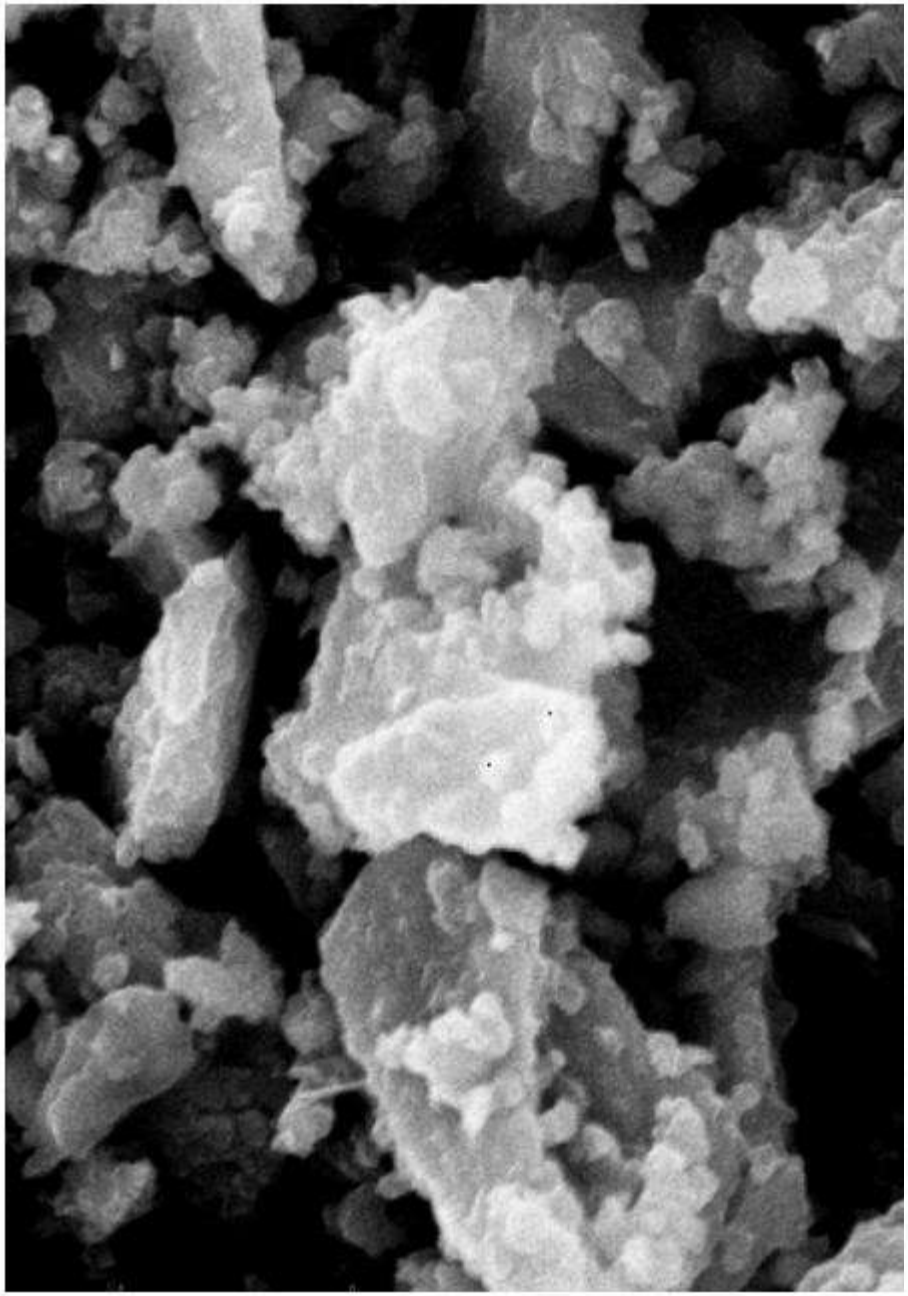


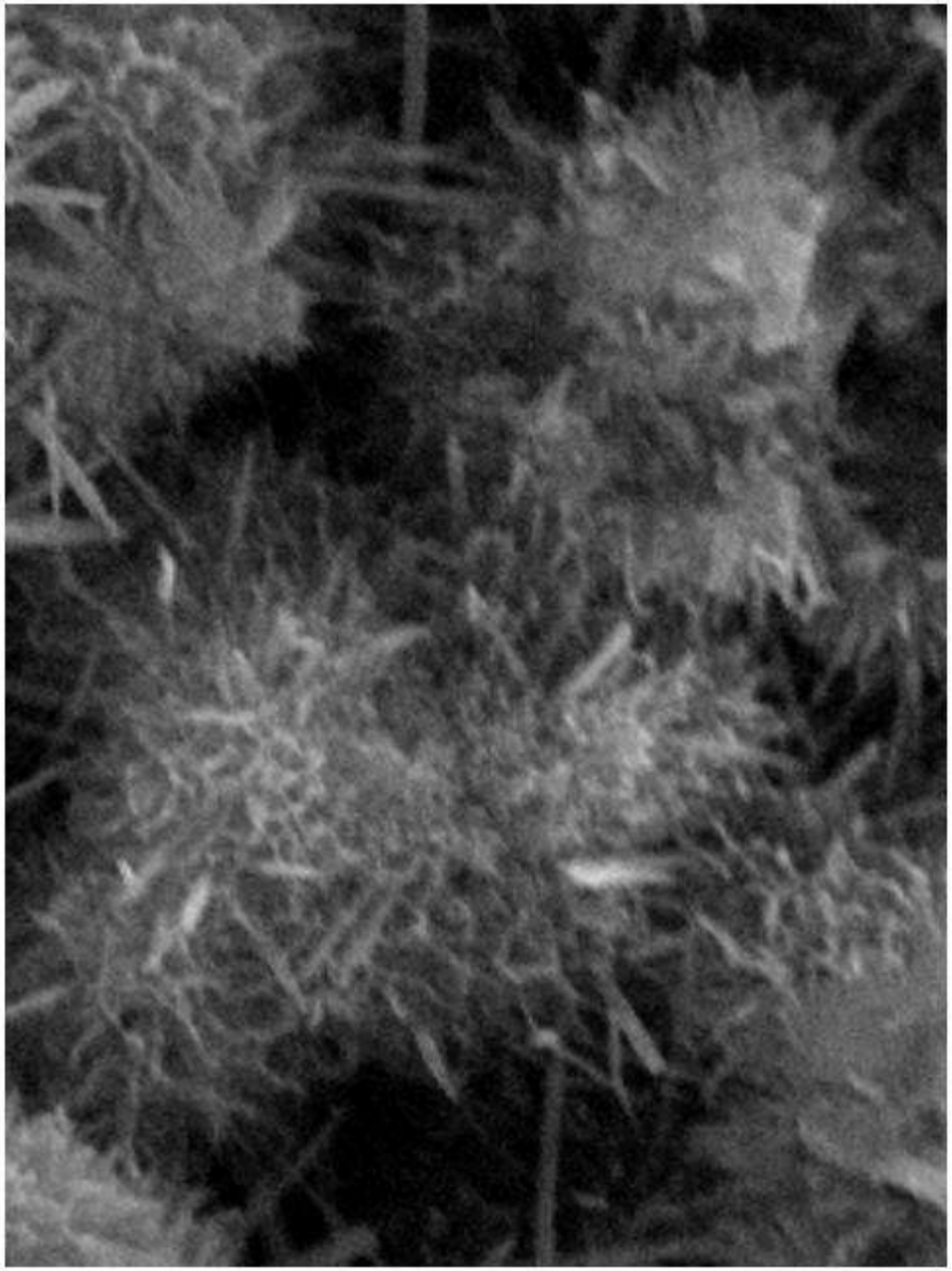
Figure 2

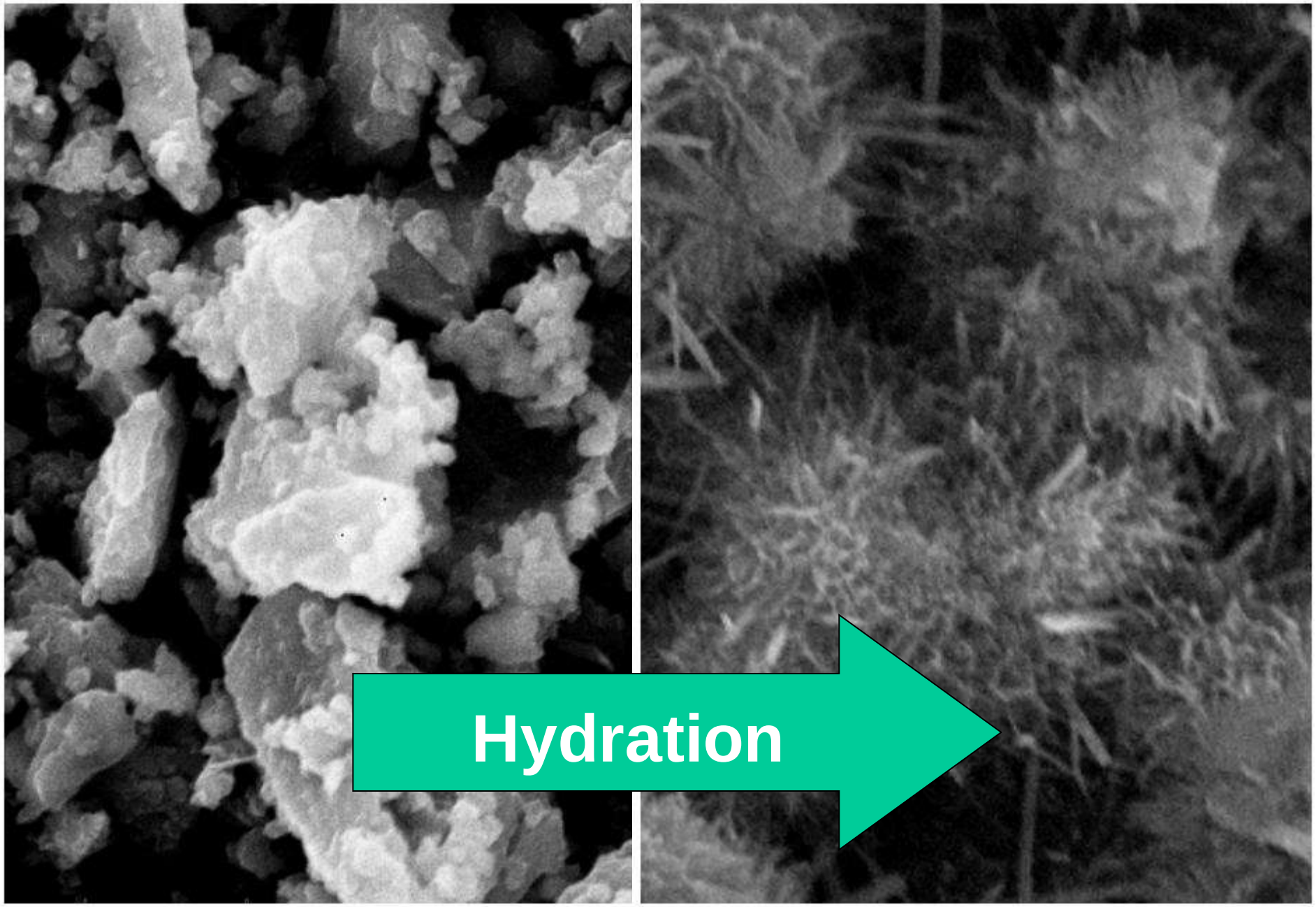
Slump	Angle of Repose
0 mm (0 in)	81°
50 mm (2 in)	76°
100 mm (4 in)	6888 68°
150 mm (6 in)	54°°
200 mm (8 in)	34°
250 mm (10 in)	11°

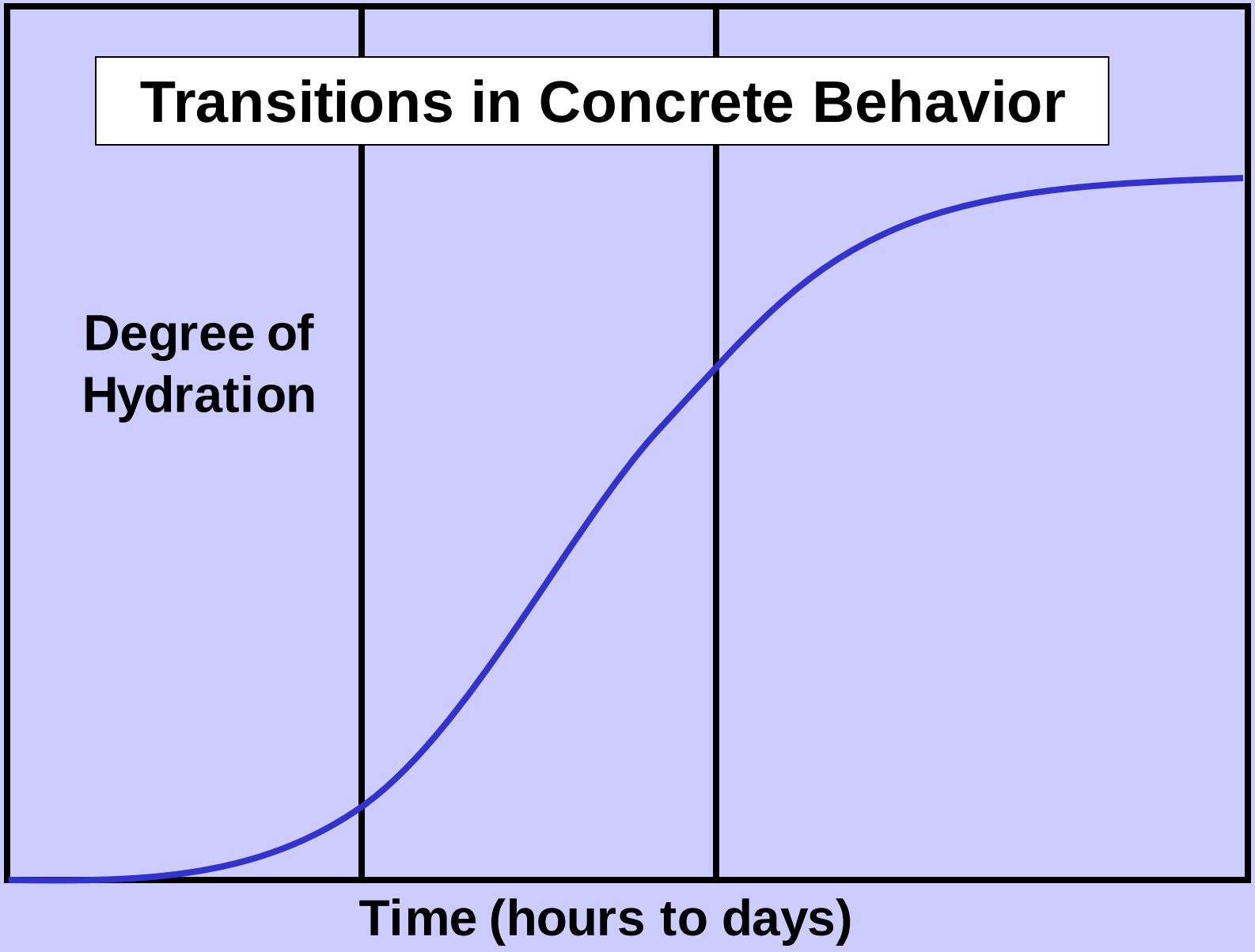


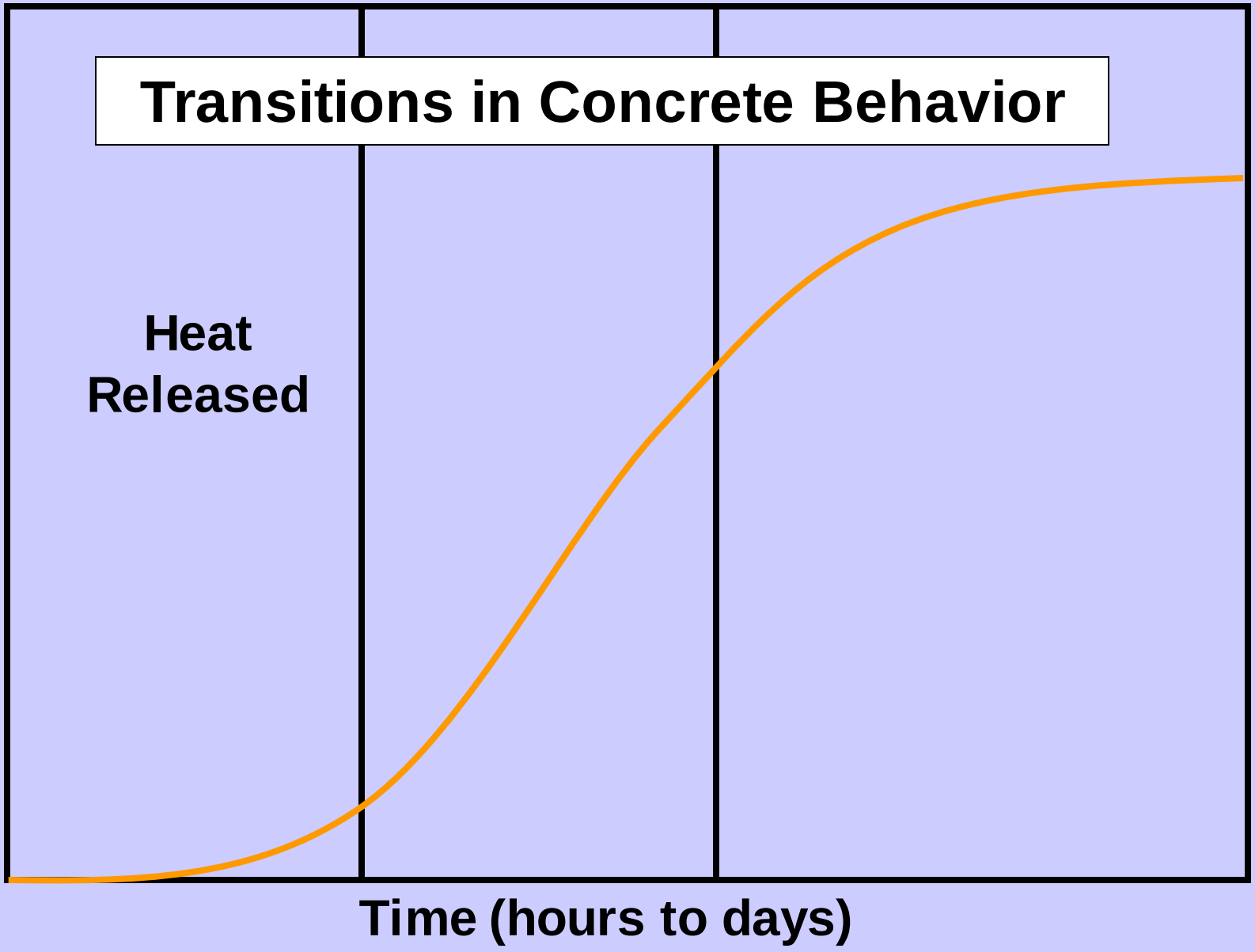
Assuming constant volume and conical shape



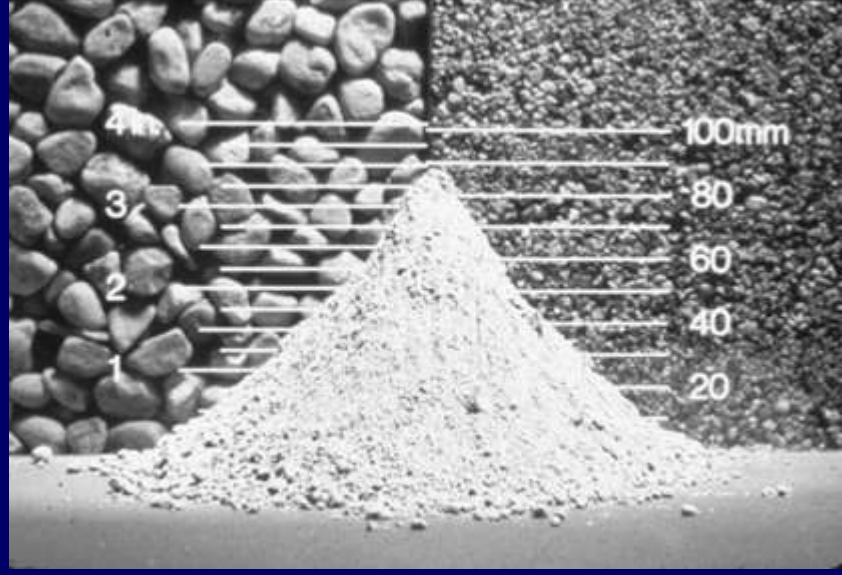



Hydration


Transitions in Concrete Behavior
Degree of Hydration
Time (hours to days)

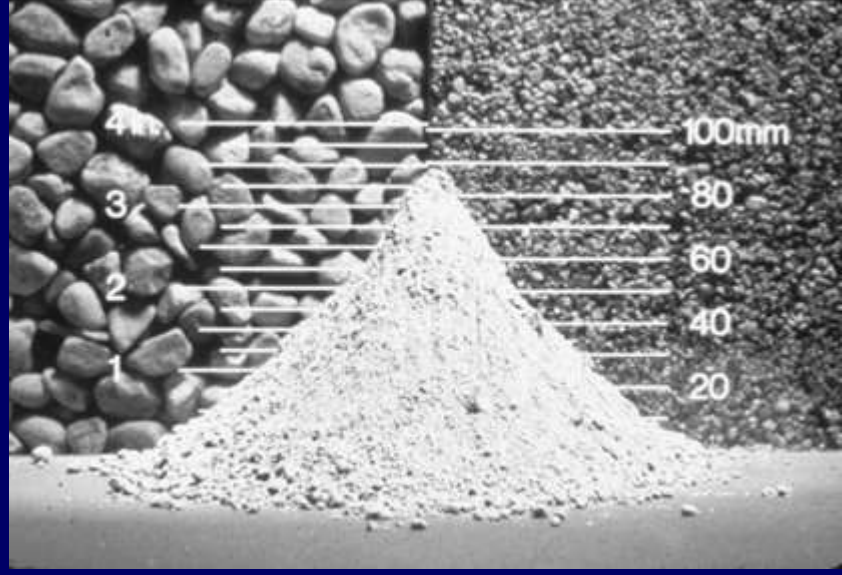

Transitions in Concrete Behavior
Heat Released
Time (hours to days)

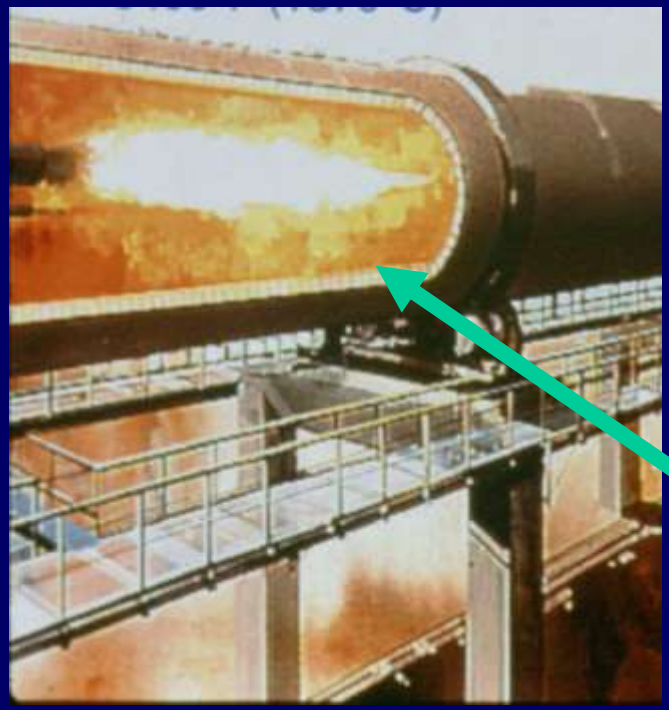
Heat of Hydration



About 450 kJ per Kg Cement

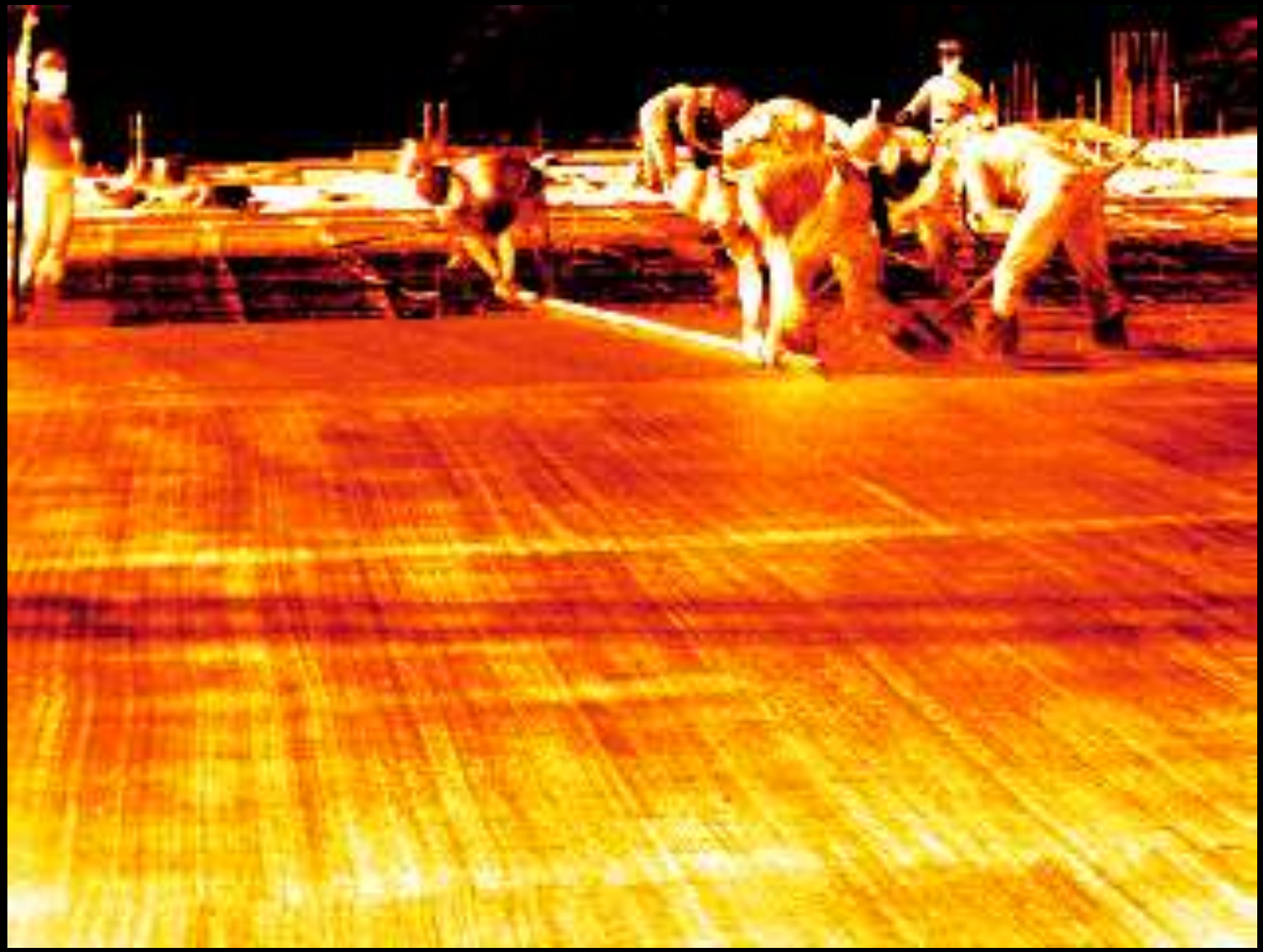
Heat of Hydration

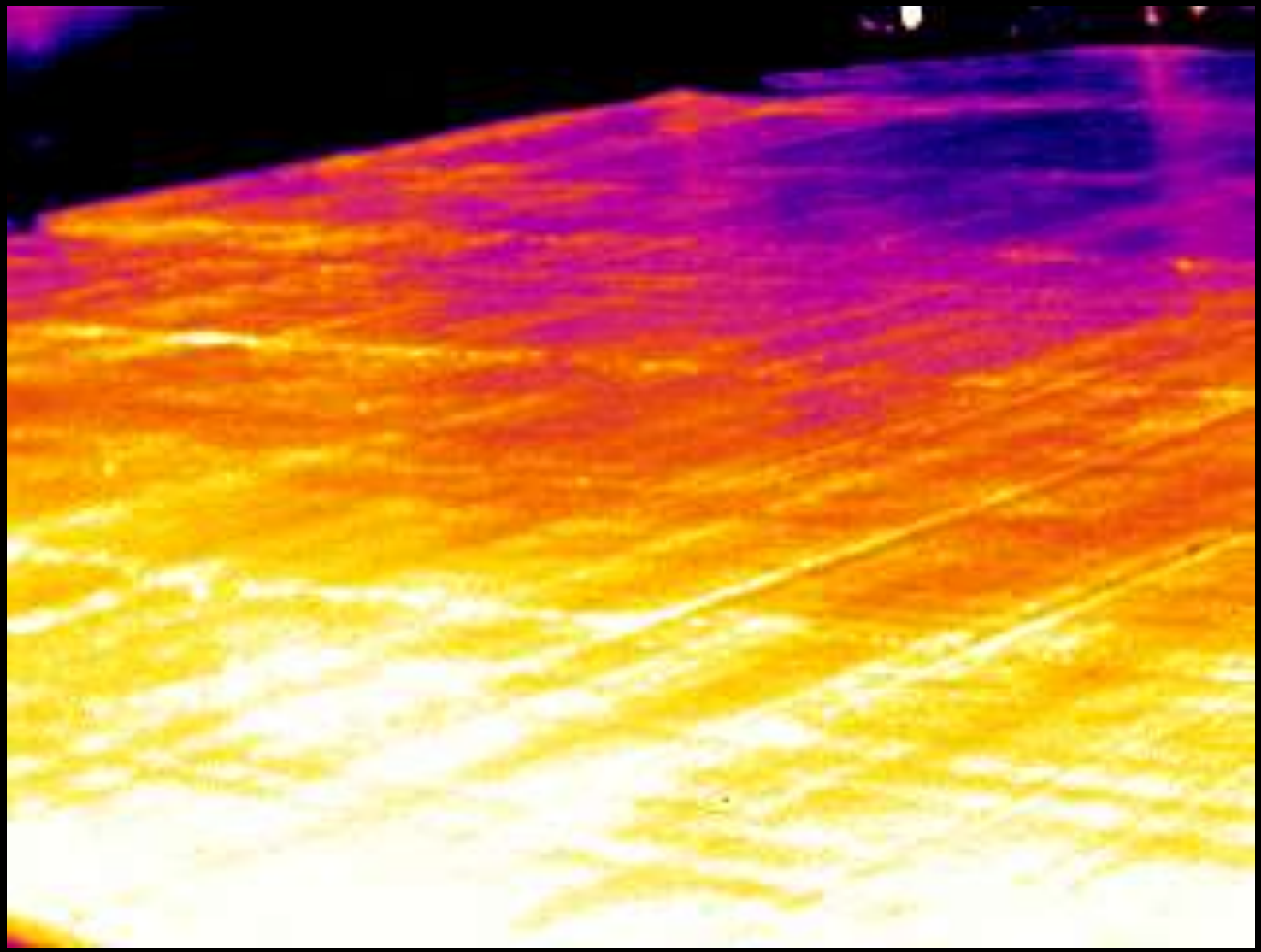




About 450 kJ per Kg Cement

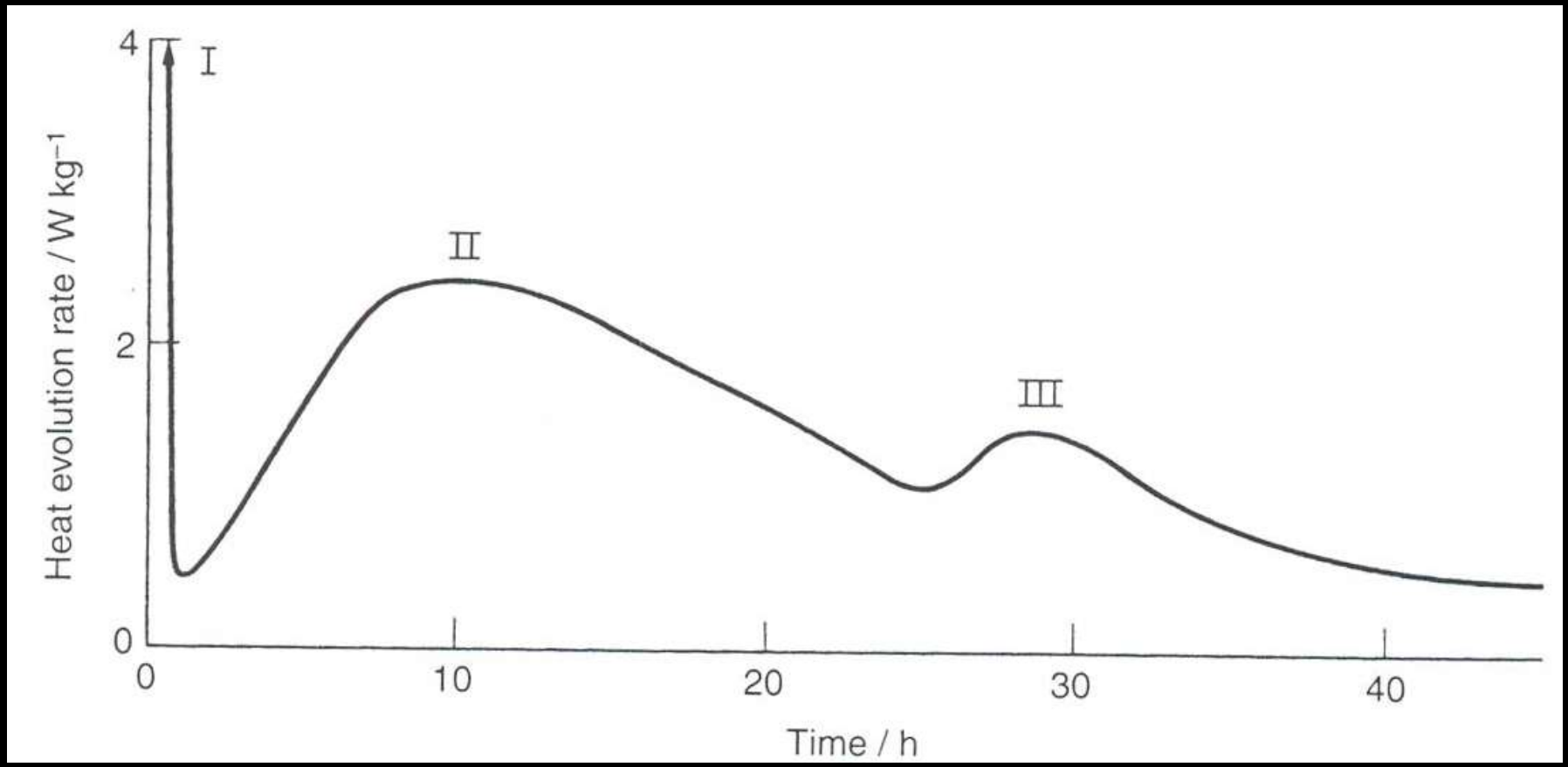
About 10-15% of Heat Energy input at Cement Plant returned to Contractor (at no extra charge)



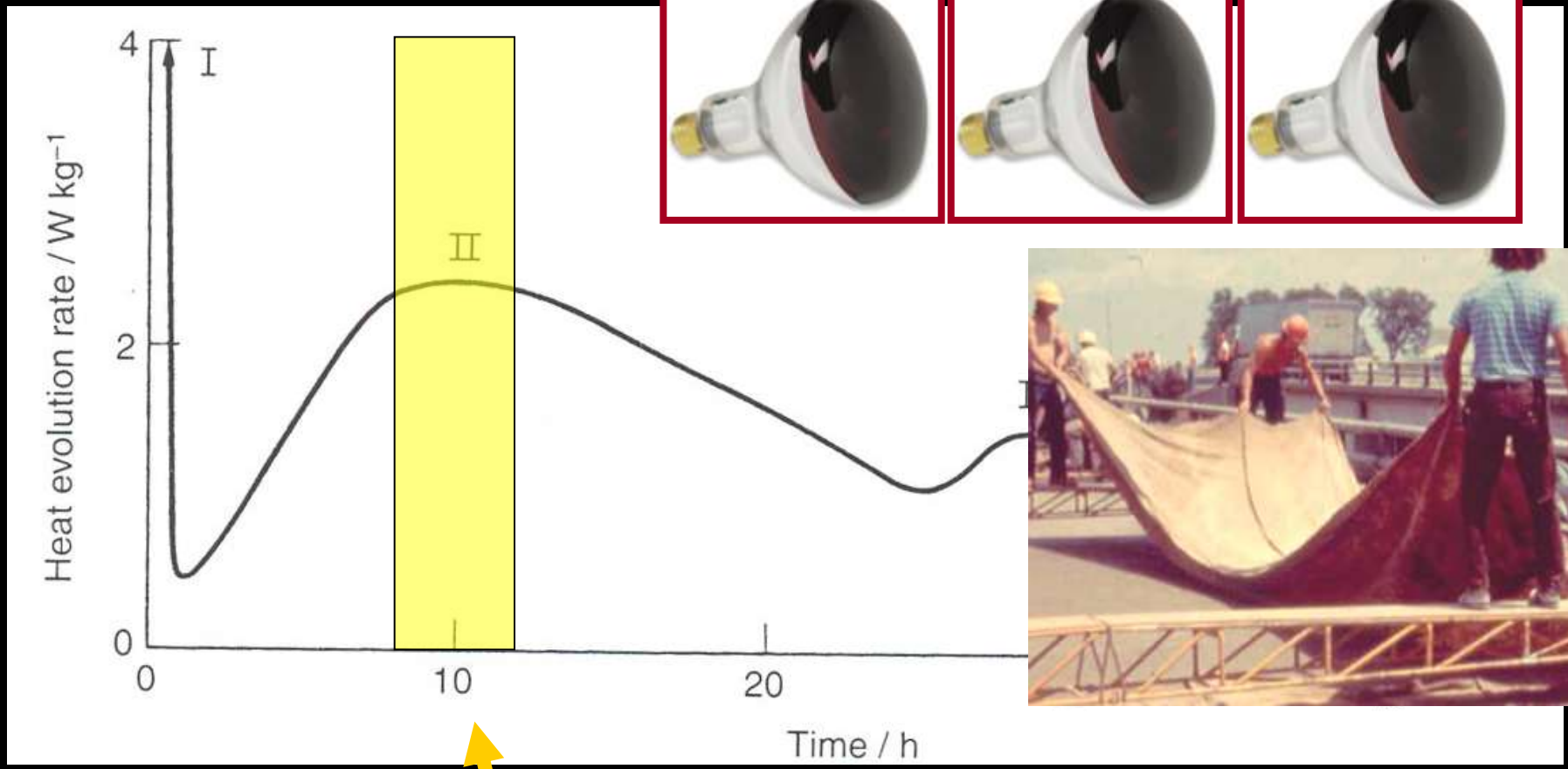



MUNICIPAL
PARKING

How fast is this heat of hydration produced?

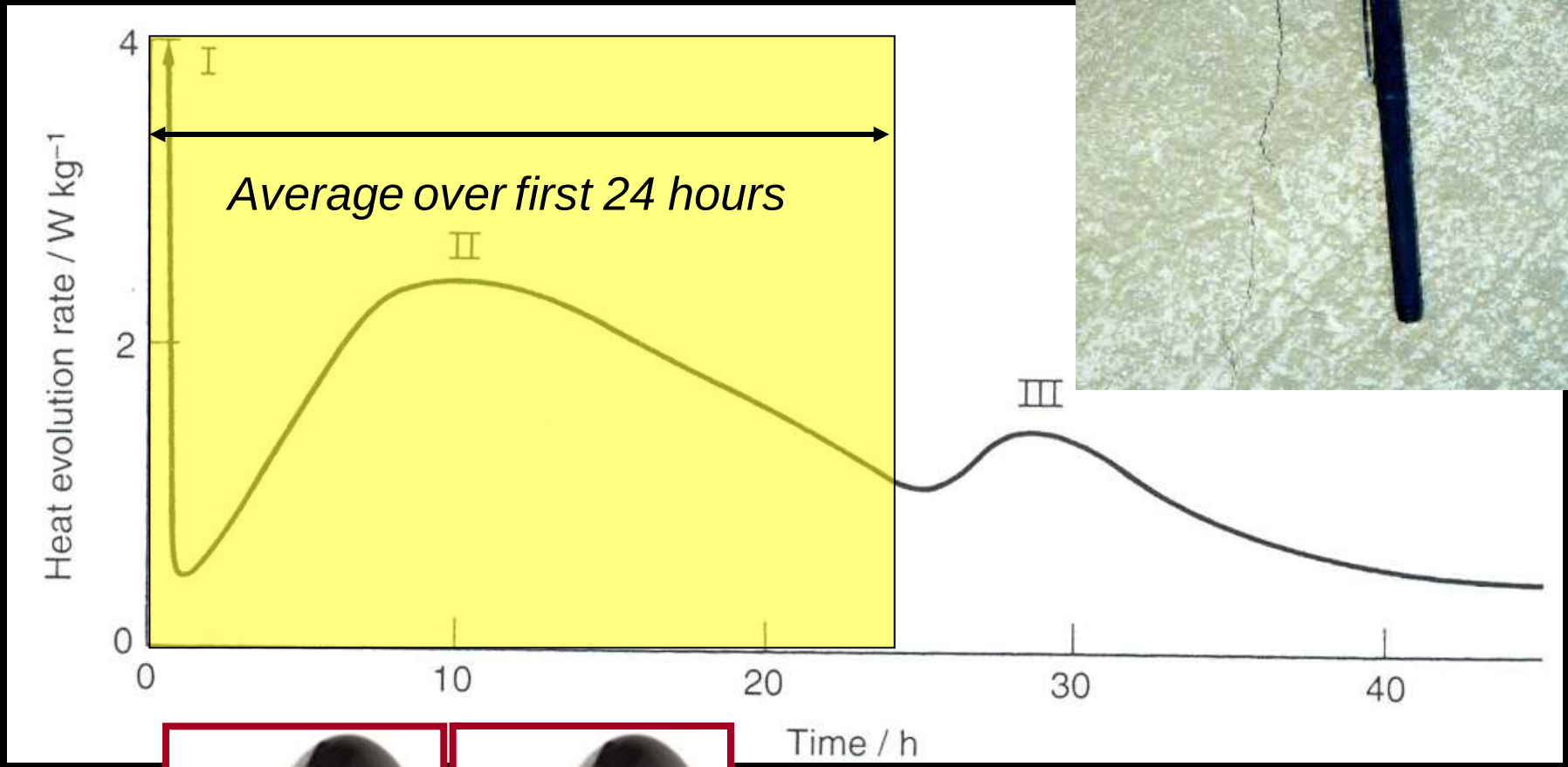


Contractor's Heat Bonus



333 kg Cement / m^3

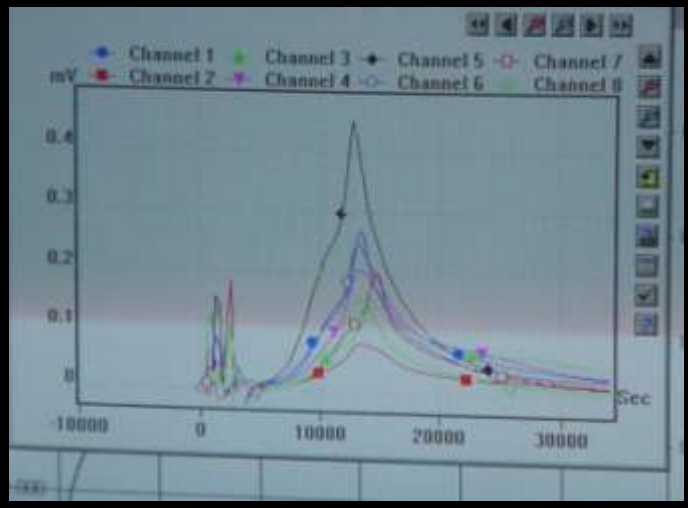
3 - 250 Watt Heat Lamps / m^3



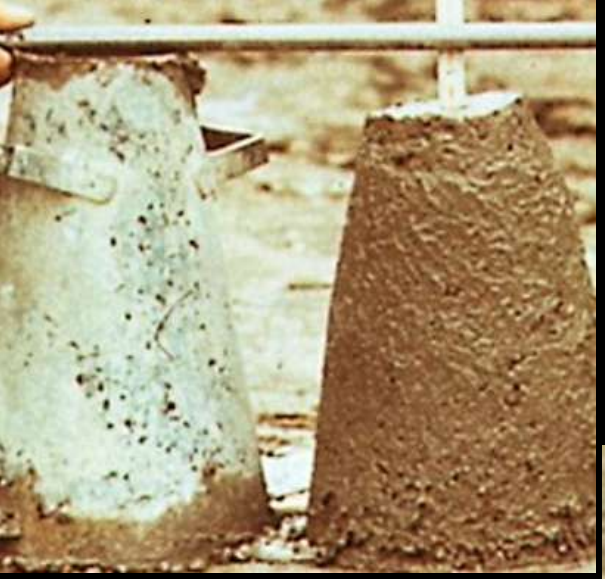
333 kg Cement / m^3

2 - 250 Watt Heat Lamps / m^3

Isothermal Calorimetry



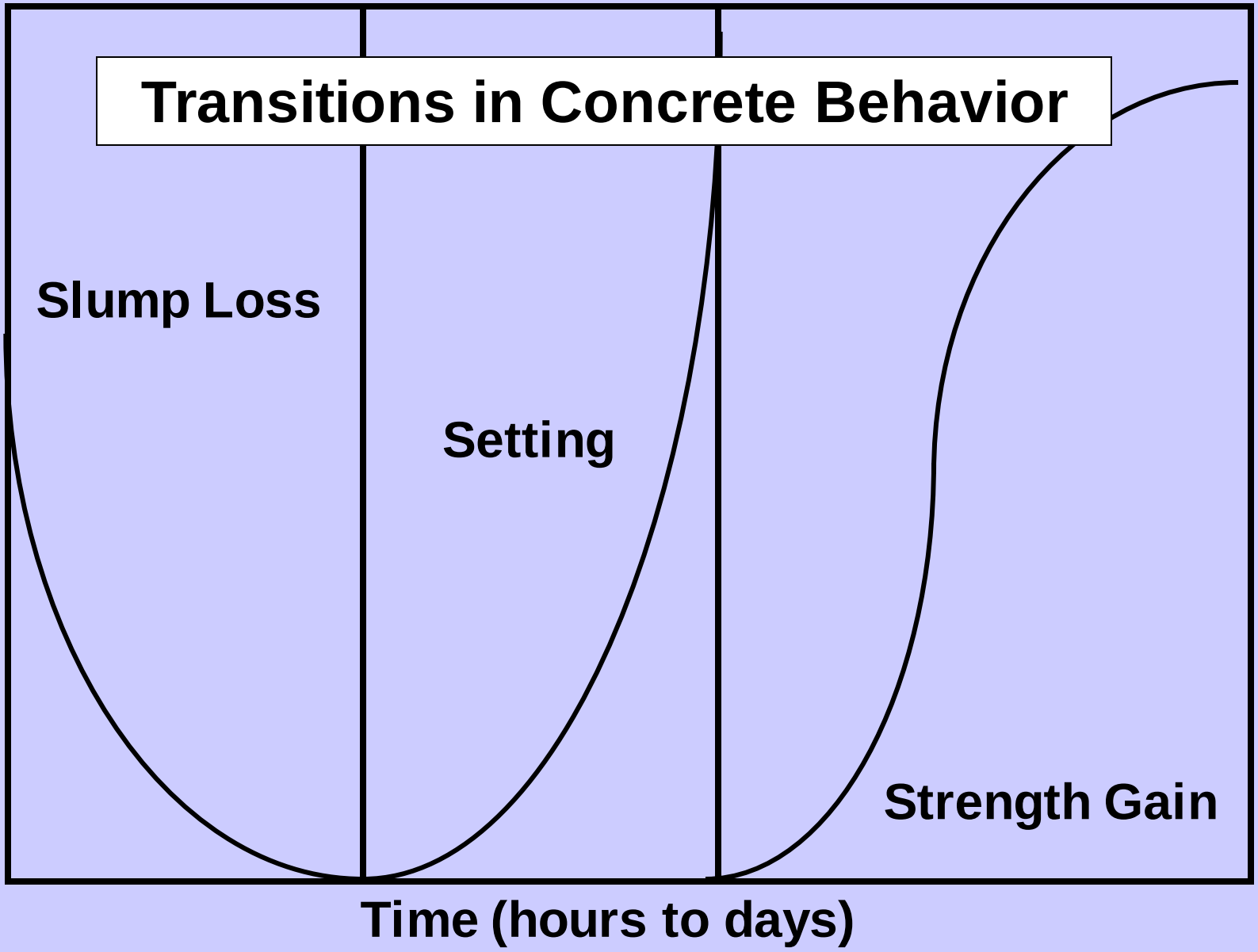
Field Calorimeter



3-Stages in the Early Life of Concrete

Crudely

As defined by our ability to track changes


Transitions in Concrete Behavior
Slump Loss
Setting
Strength Gain
Time (hours to days)

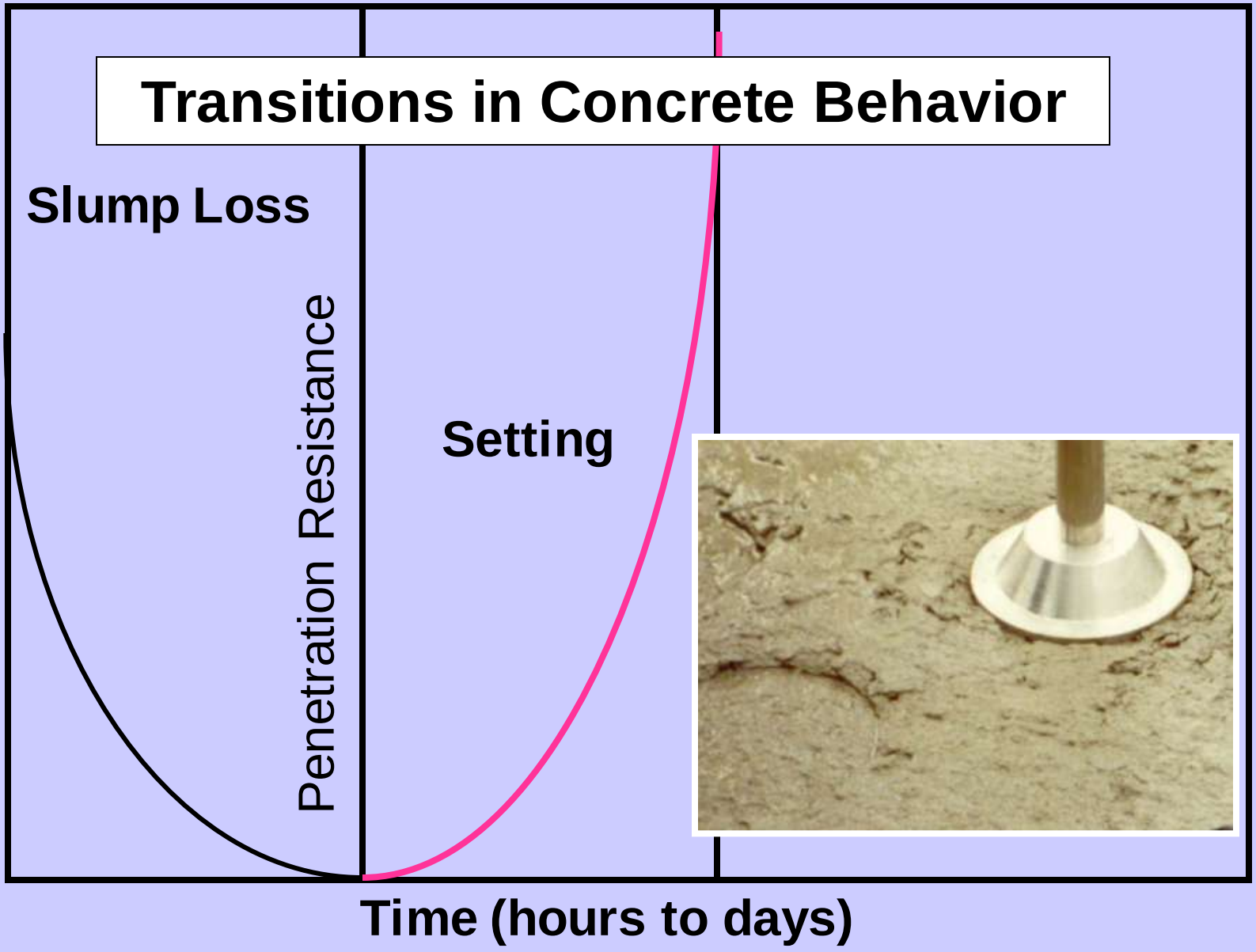
Transitions in Concrete Behavior

Slump Loss

Slump

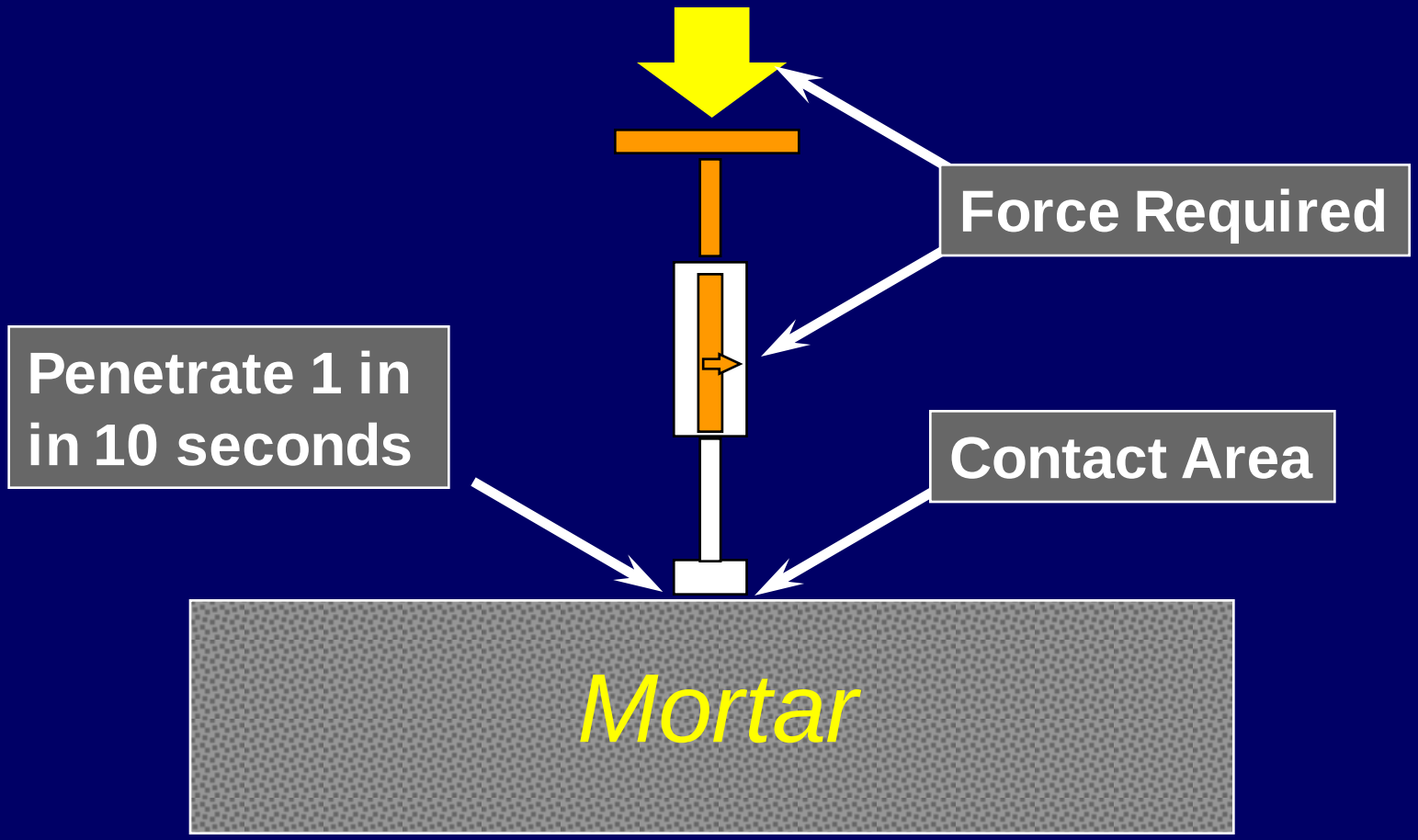
Time (hours to days)

Transitions in Concrete Behavior




~ 6 mm footprint
~ 0.03-0.04 MPa foot pressure

Measuring Penetration Resistance



ASTM C403 Setting Time

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U.F.S.C.

Performed
on mortar
sieved
from concrete

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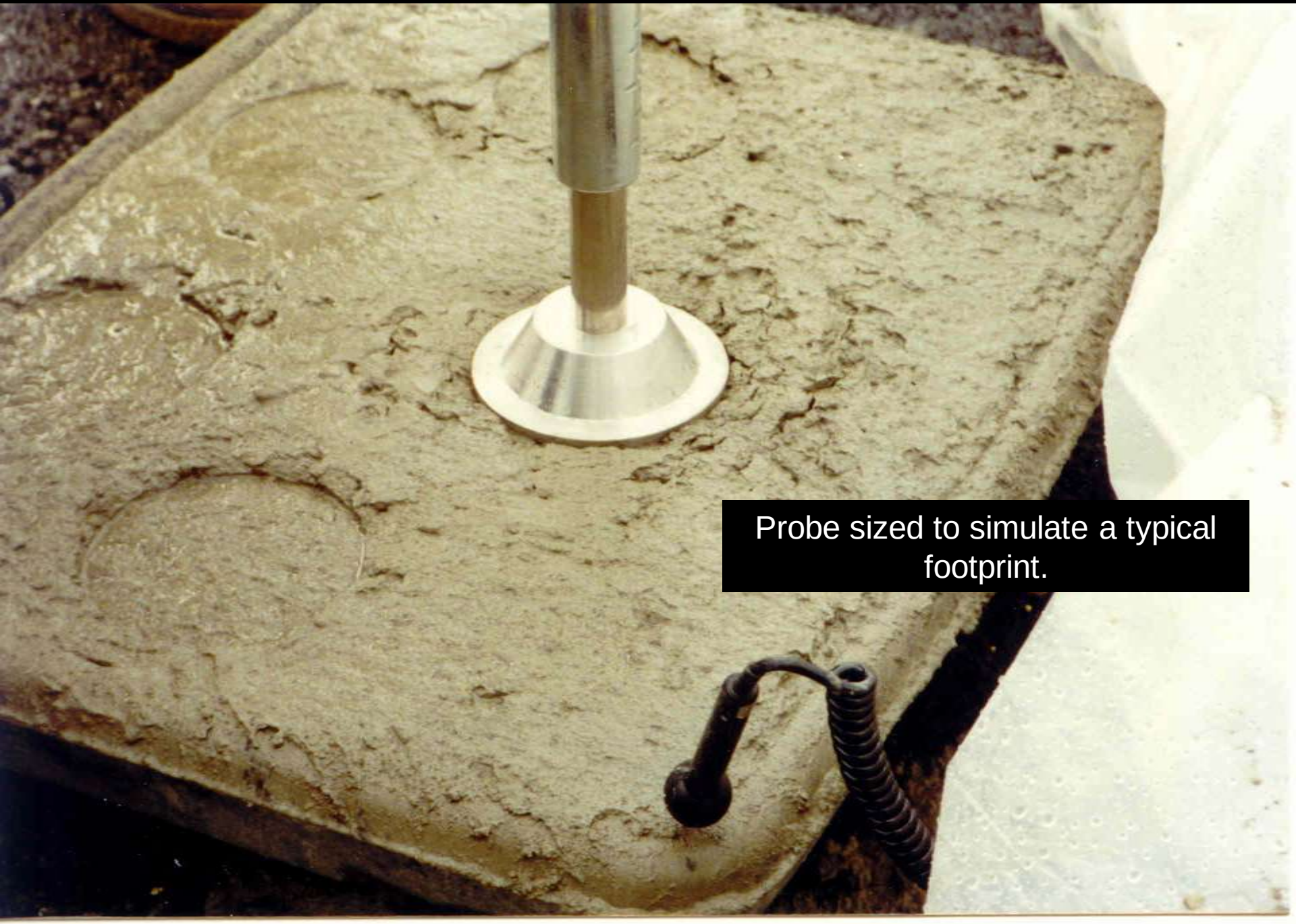
U.F.S.C.

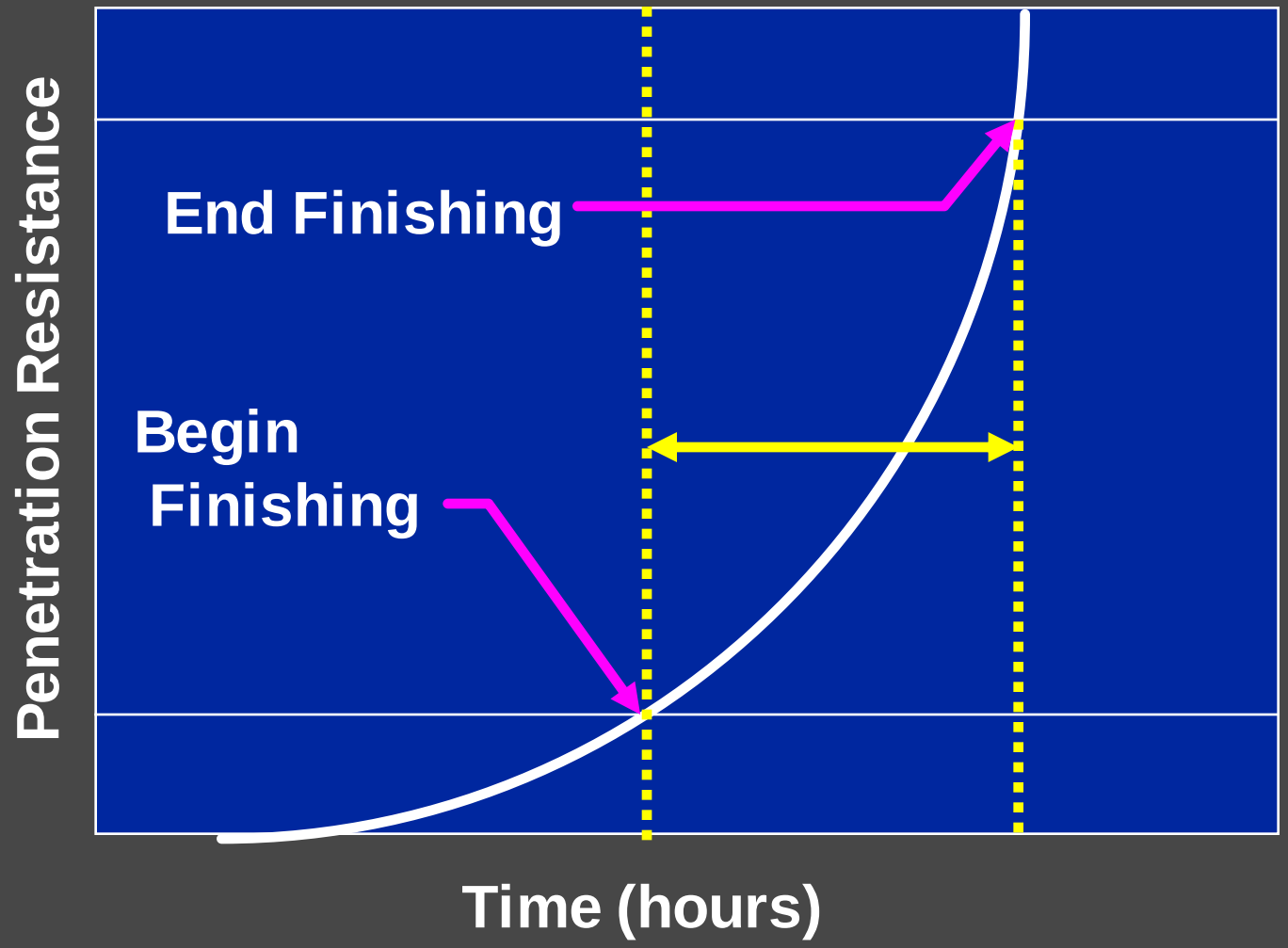
Penetration Test in concrete


Probe sized to simulate a typical footprint.

~ No footprint

6 mm @ ~ 0.1 MPa concrete pressure

Window of Finishability



Transitions in Concrete Behavior

Slump Loss

Setting

Strength Gain

Time (hours to days)

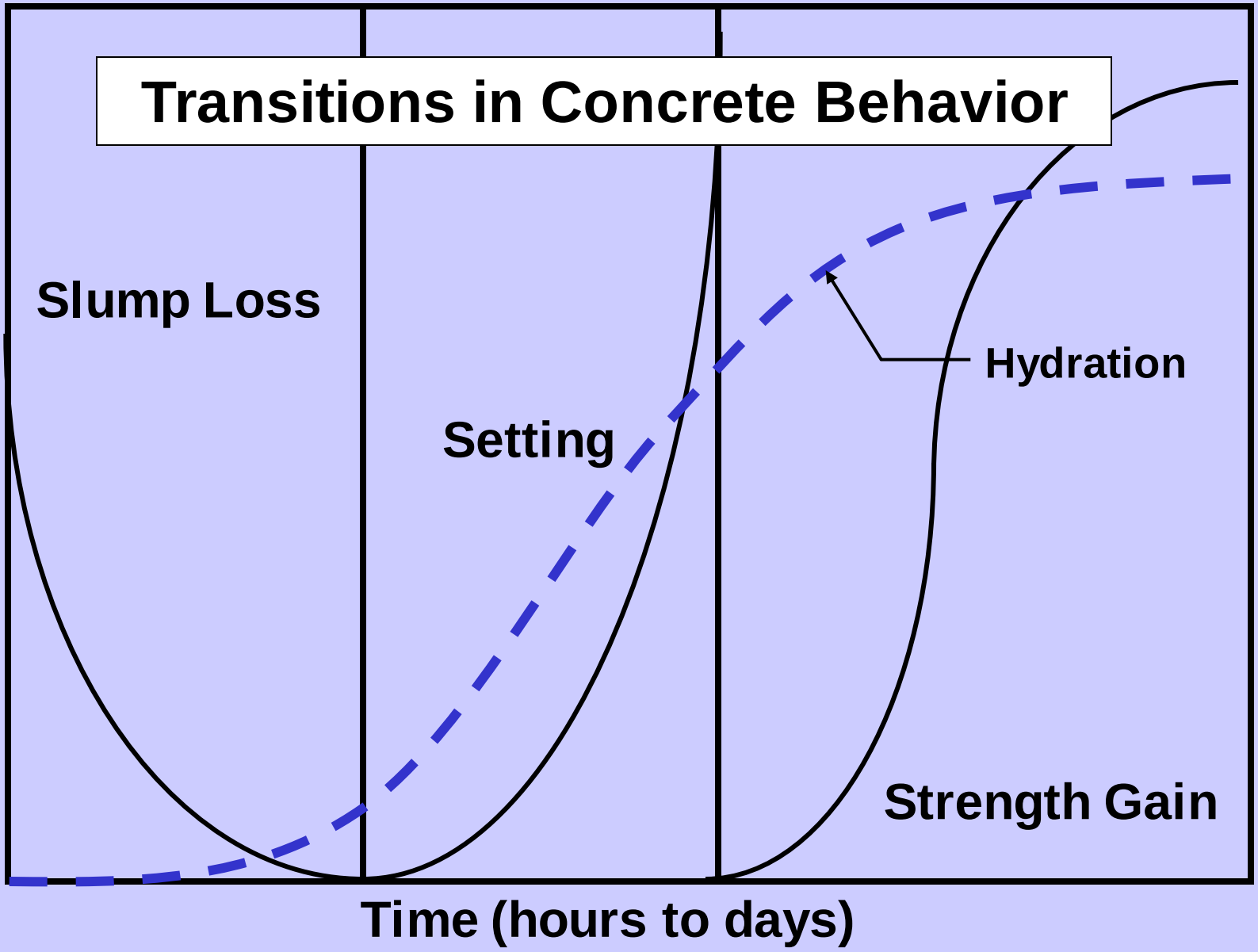
Transitions in Concrete Behavior

Slump Loss

Setting

Strength Gain

Time (hours to days)


Transitions in Concrete Behavior
Slump Loss
Setting
Hydration
Strength Gain
Time (hours to days)

A Single Case History

- 28 MPa mix
- Air Entrained
- 333 kg cem/m^3
- 13 cm slump @45 min
- 19 mm stone
- Ready-mixed (Dry Batch Plant)
- Summer


MACK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U.F.S.C.


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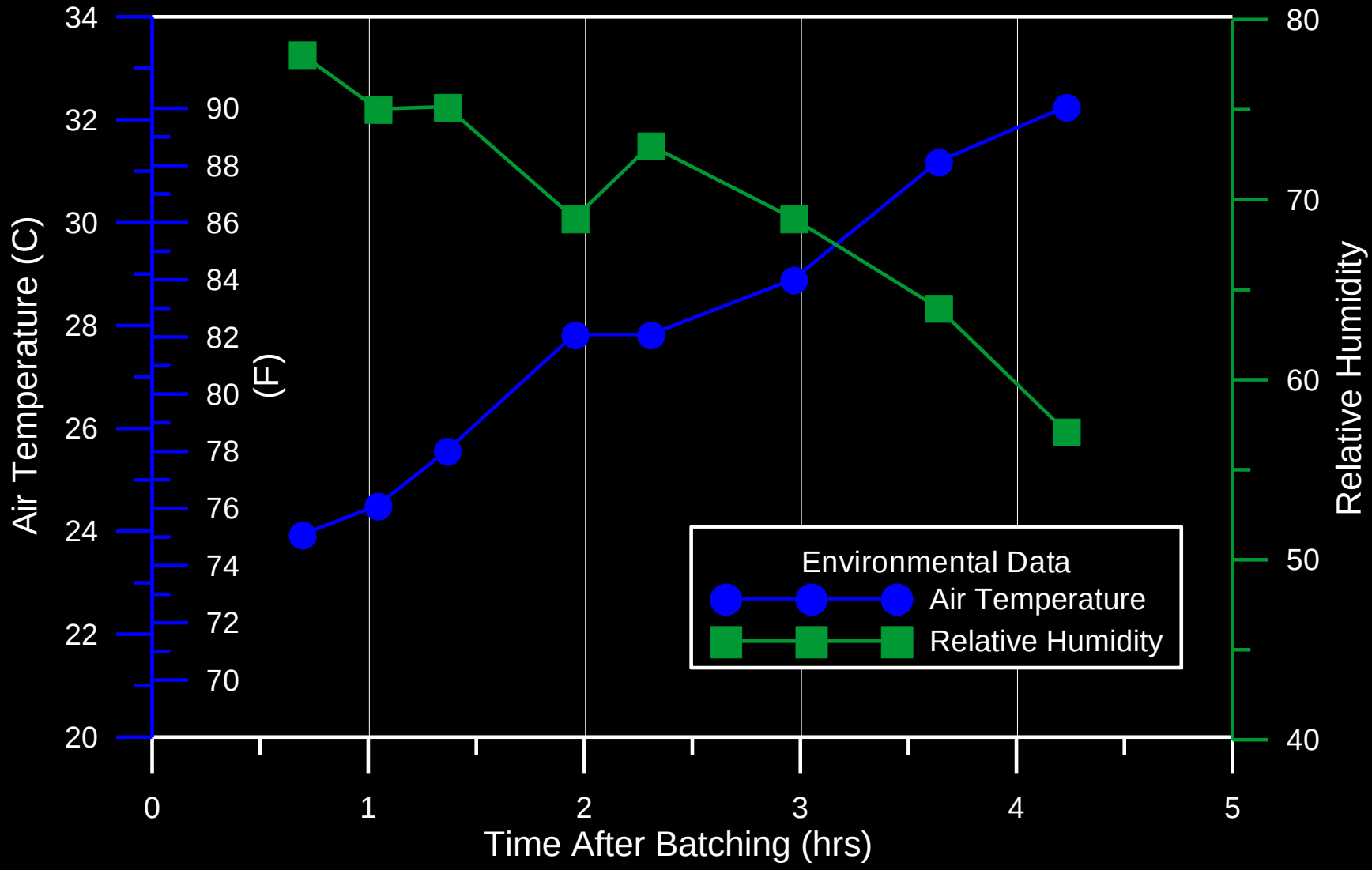
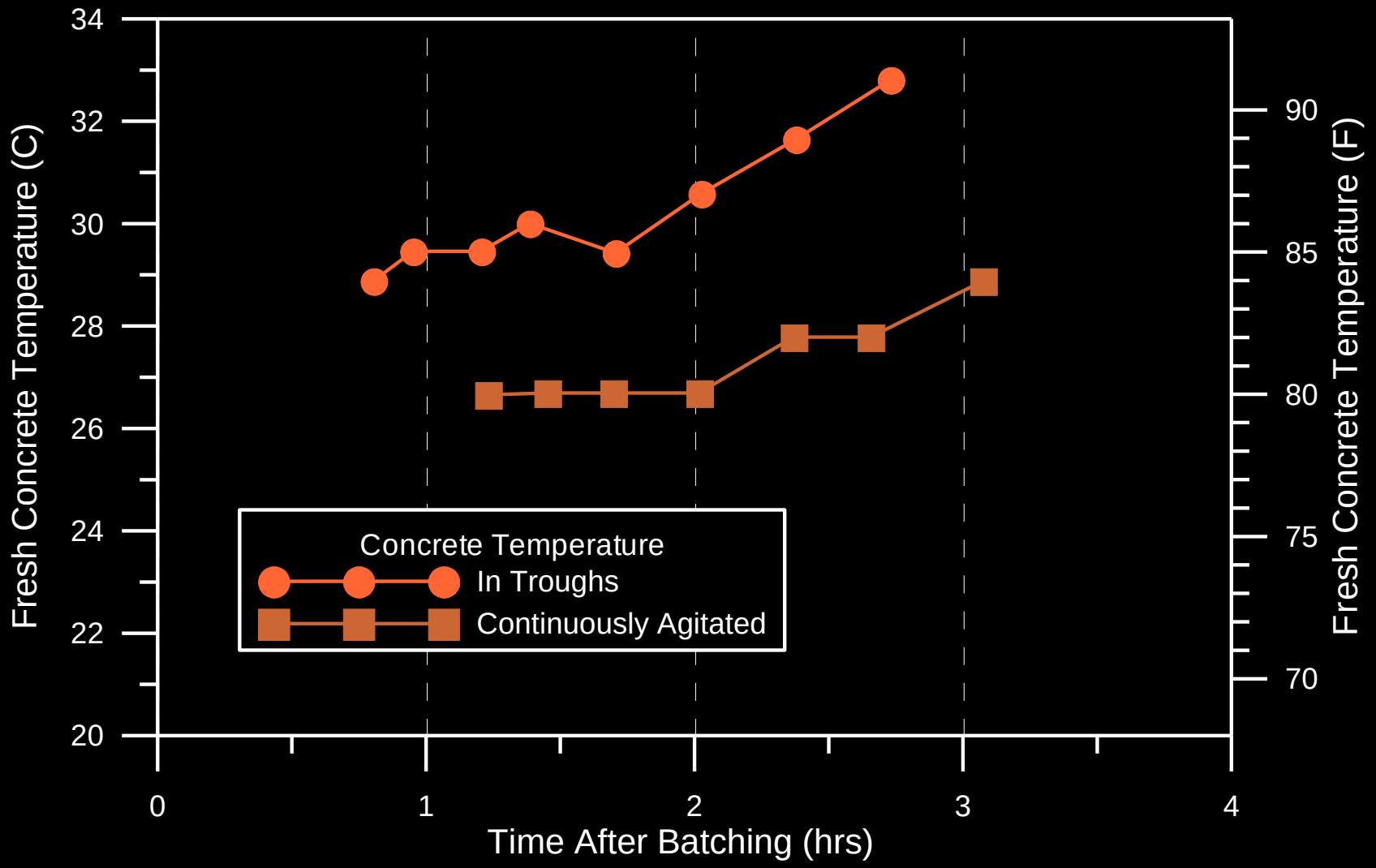
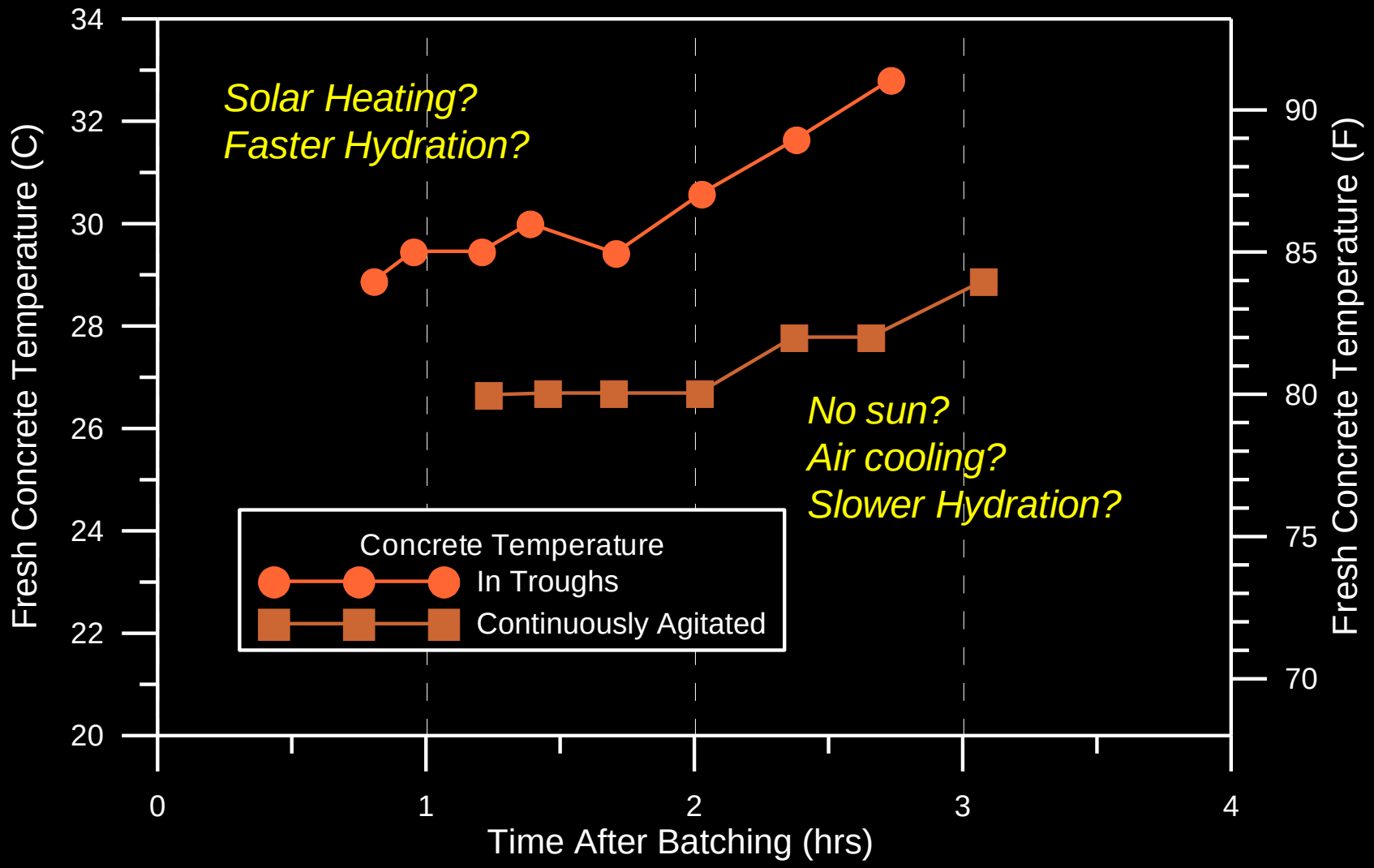
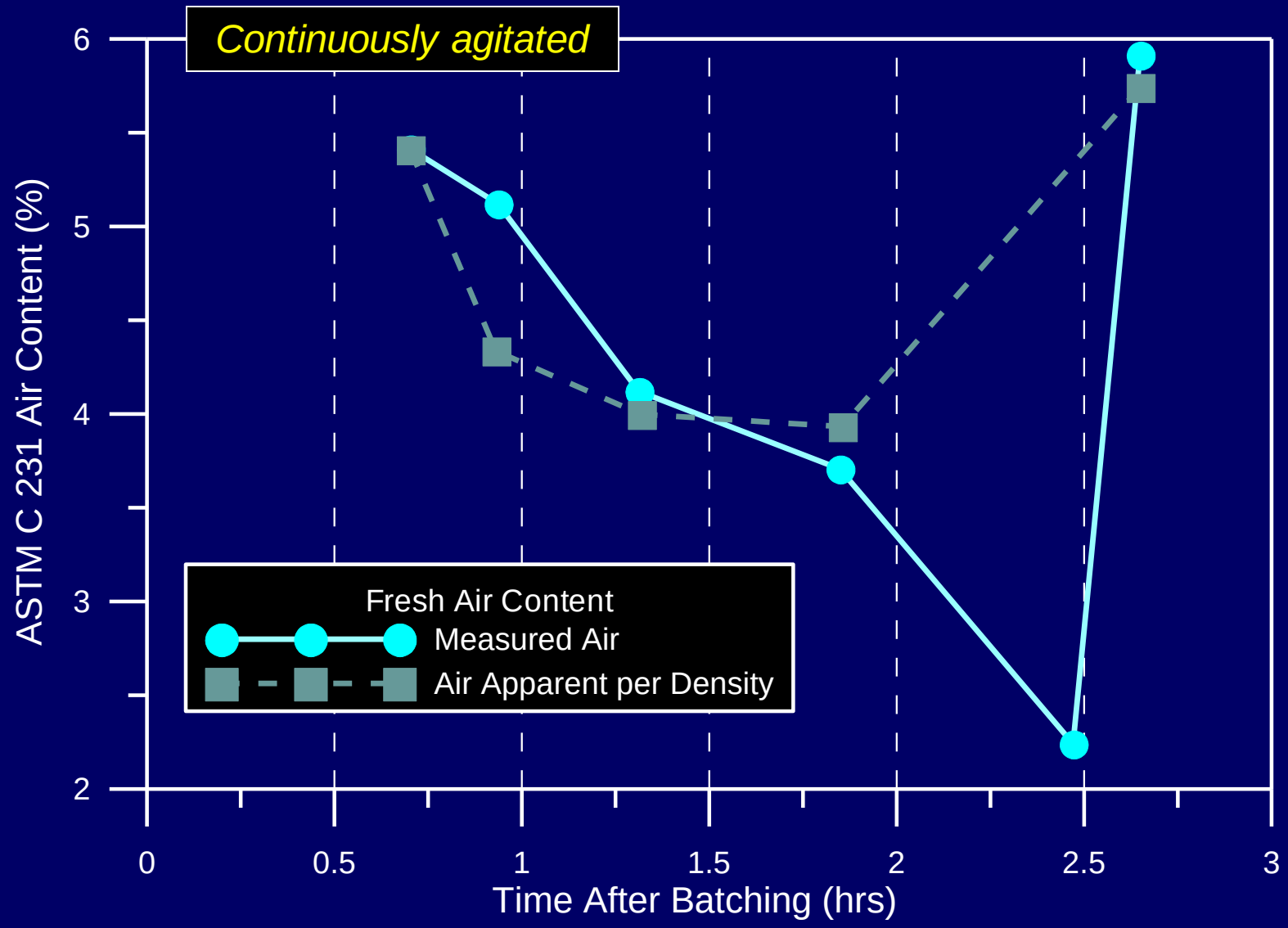
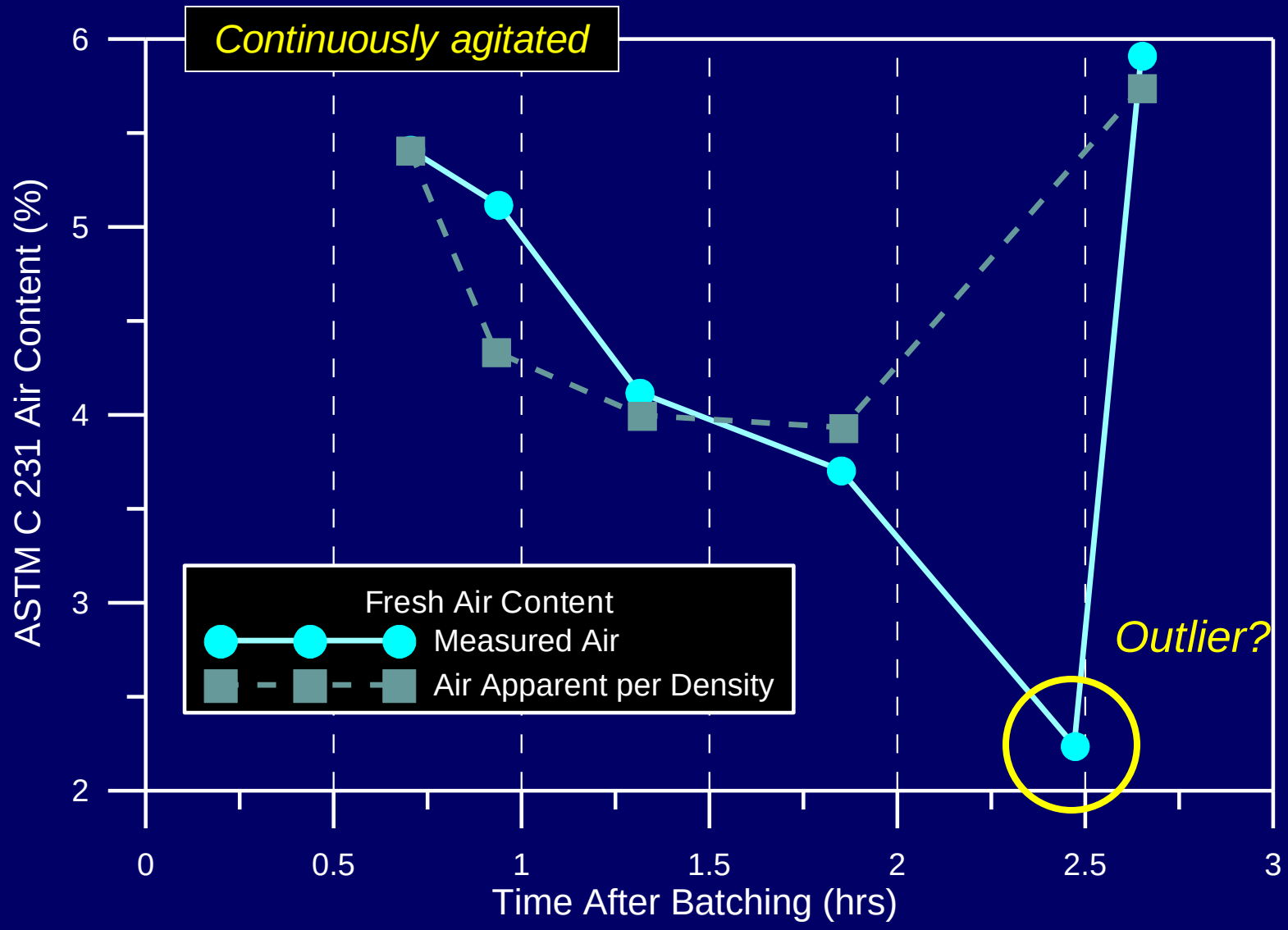
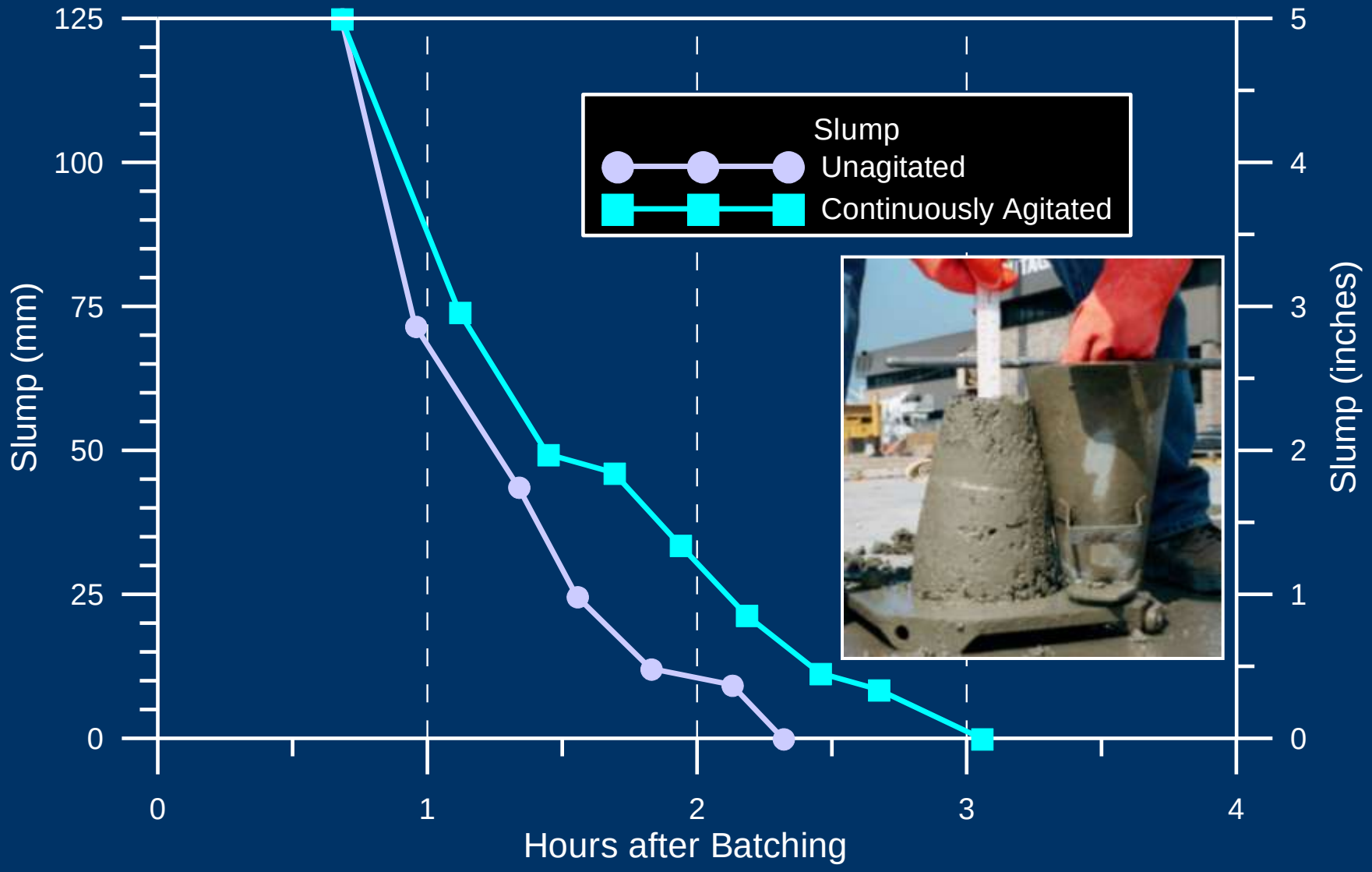

Air Temperature (C)
34
32
30
28
26
24
22
20
90
88
86
84
82
80
78
76
74
72
70
(F)
80
70
60
50
40
Relative Humidity
0
1
2
3
4
5
Time After Batching (hrs)
Environmental Data
Air Temperature
Relative Humidity

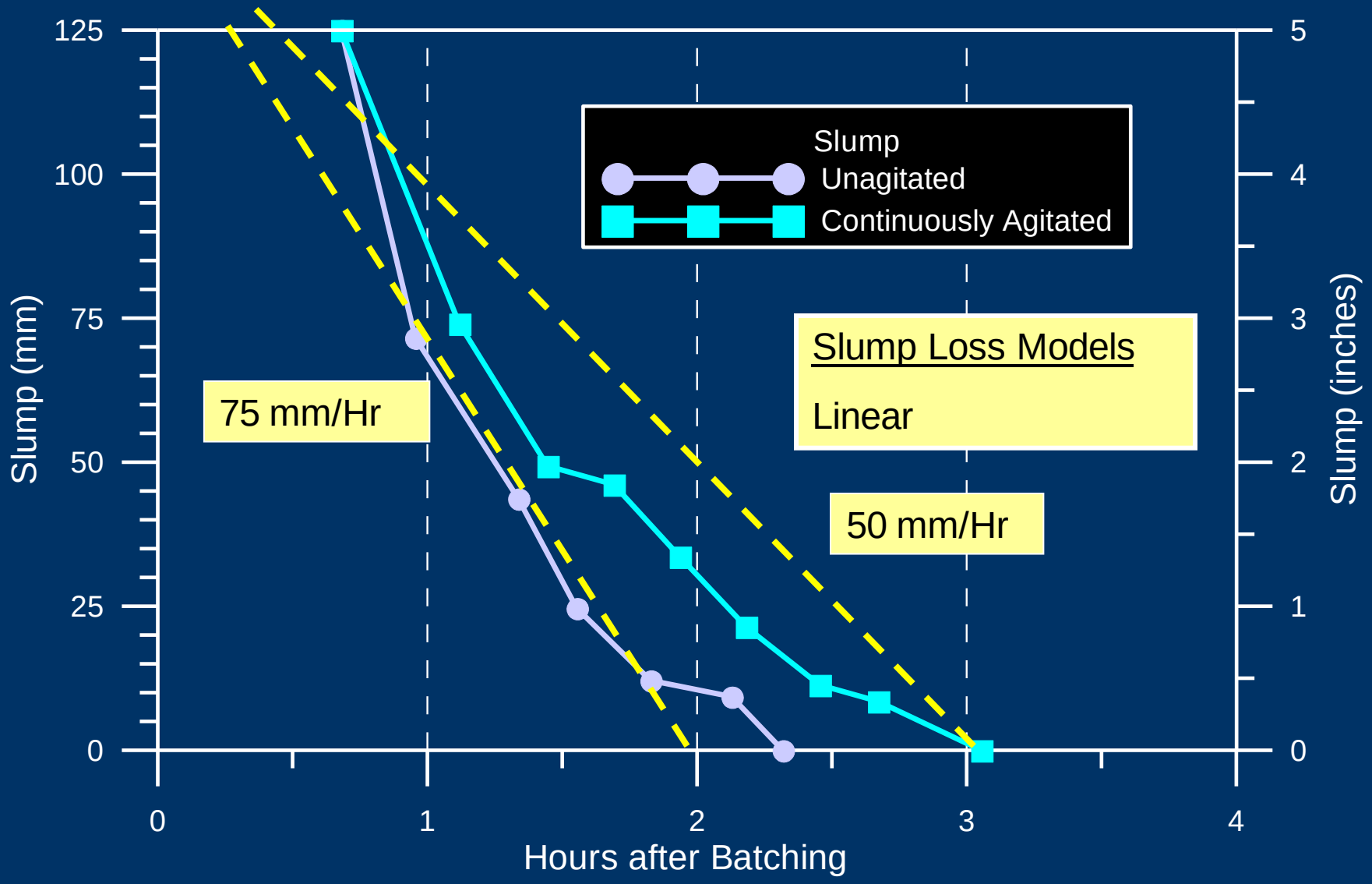

Fresh Concrete Temperature (C)
34
32
30
28
26
24
22
20
Fresh Concrete Temperature (F)
90
85
80
75
70
0
1
2
3
4
Time After Batching (hrs)
Concrete Temperature
In Troughs
Continuously Agitated

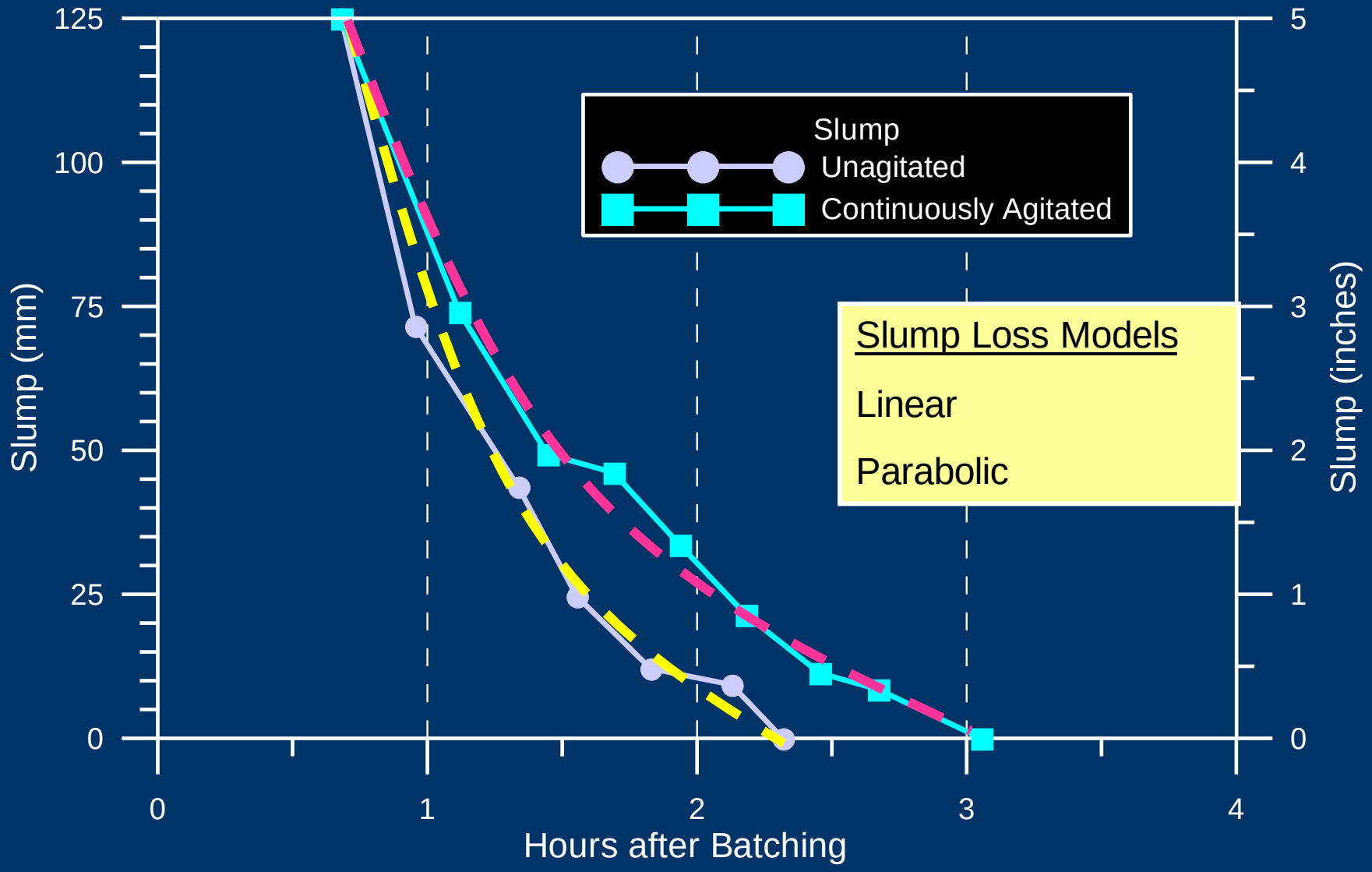

Solar Heating?
Faster Hydration?
No sun?
Air cooling?
Slower Hydration?
Concrete Temperature
In Troughs
Continuously Agitated
Fresh Concrete Temperature (C)
Fresh Concrete Temperature (F)
Time After Batching (hrs)
34
32
30
28
26
24
22
20
90
85
80
75
70
0
1
2
3
4

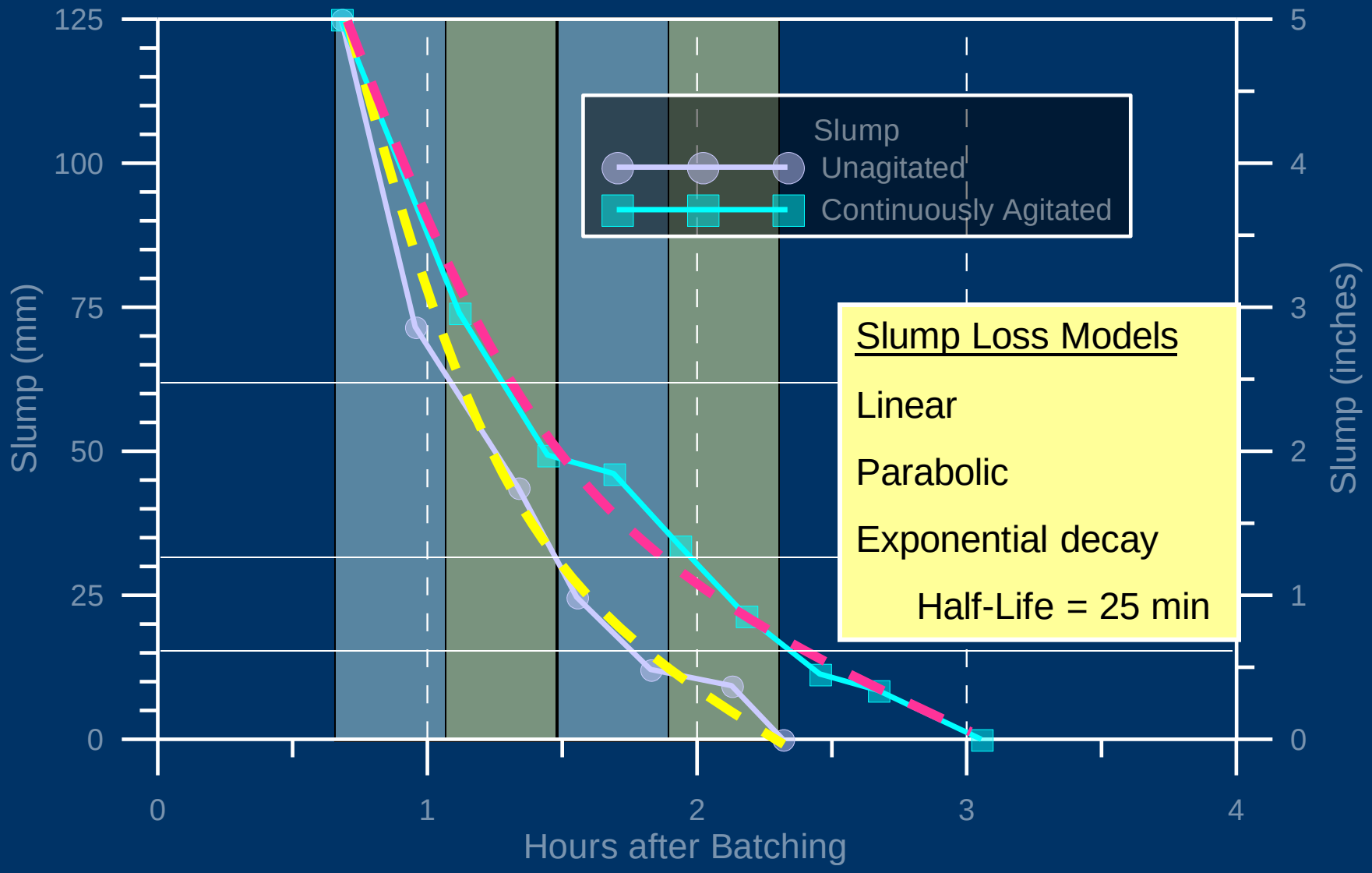

Continuously agitated
ASTM C 231 Air Content (%)
6
5
4
3
2
0
0.5
1
1.5
2
2.5
3
Time After Batching (hrs)
Fresh Air Content
Measured Air
Air Apparent per Density

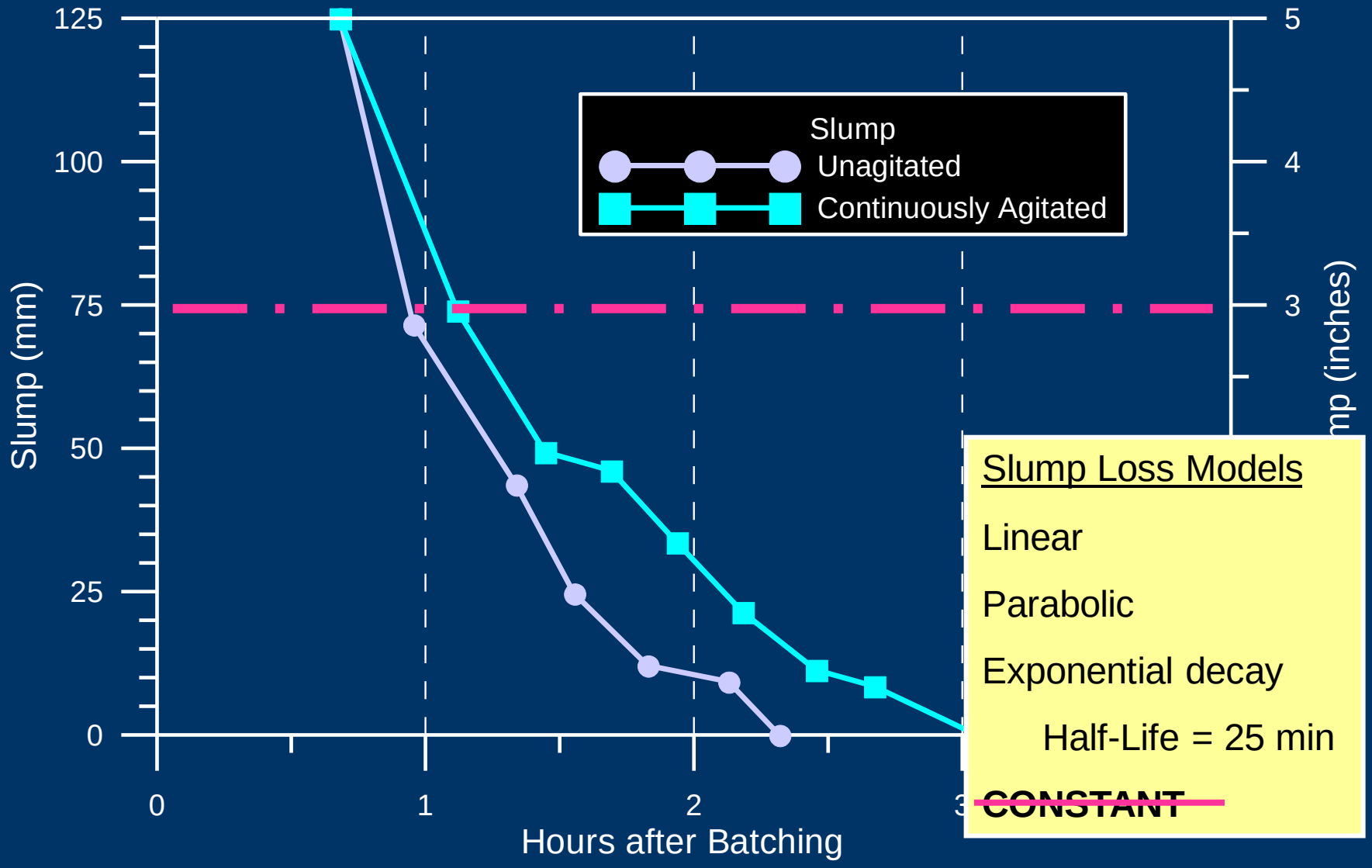

Continuously agitated
ASTM C 231 Air Content (%)
6
5
4
3
2
0
0.5
1
1.5
2
2.5
3
Time After Batching (hrs)
Fresh Air Content
Measured Air
Air Apparent per Density
Outlier?


Slump
Unagitated
Continuously Agitated
Slump (mm)
Slump (inches)
Hours after Batching
125
100
75
50
25
0
5
4
3
2
1
0
0
1
2
3
4

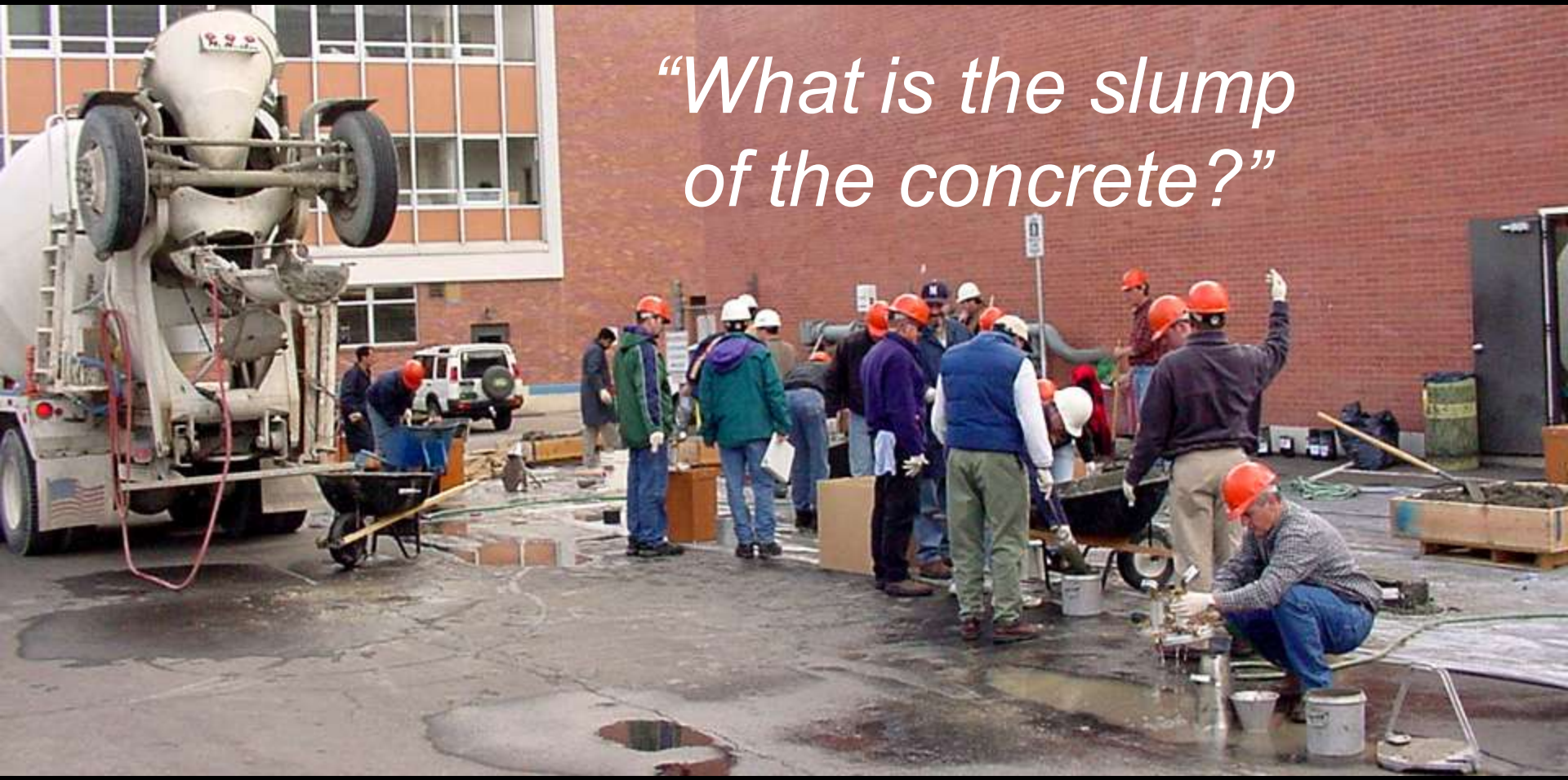

Slump (mm)
125
100
75
50
25
0
Slump (inches)
5
4
3
2
1
0
0
1
2
3
4
Hours after Batching
Slump
Unagitated
Continuously Agitated
Slump Loss Models
Linear
75 mm/Hr
50 mm/Hr


Slump (mm)
125
100
75
50
25
0
Slump (inches)
5
4
3
2
1
0
0
1
2
3
4
Hours after Batching
Slump
Unagitated
Continuously Agitated
Slump Loss Models
Linear
Parabolic

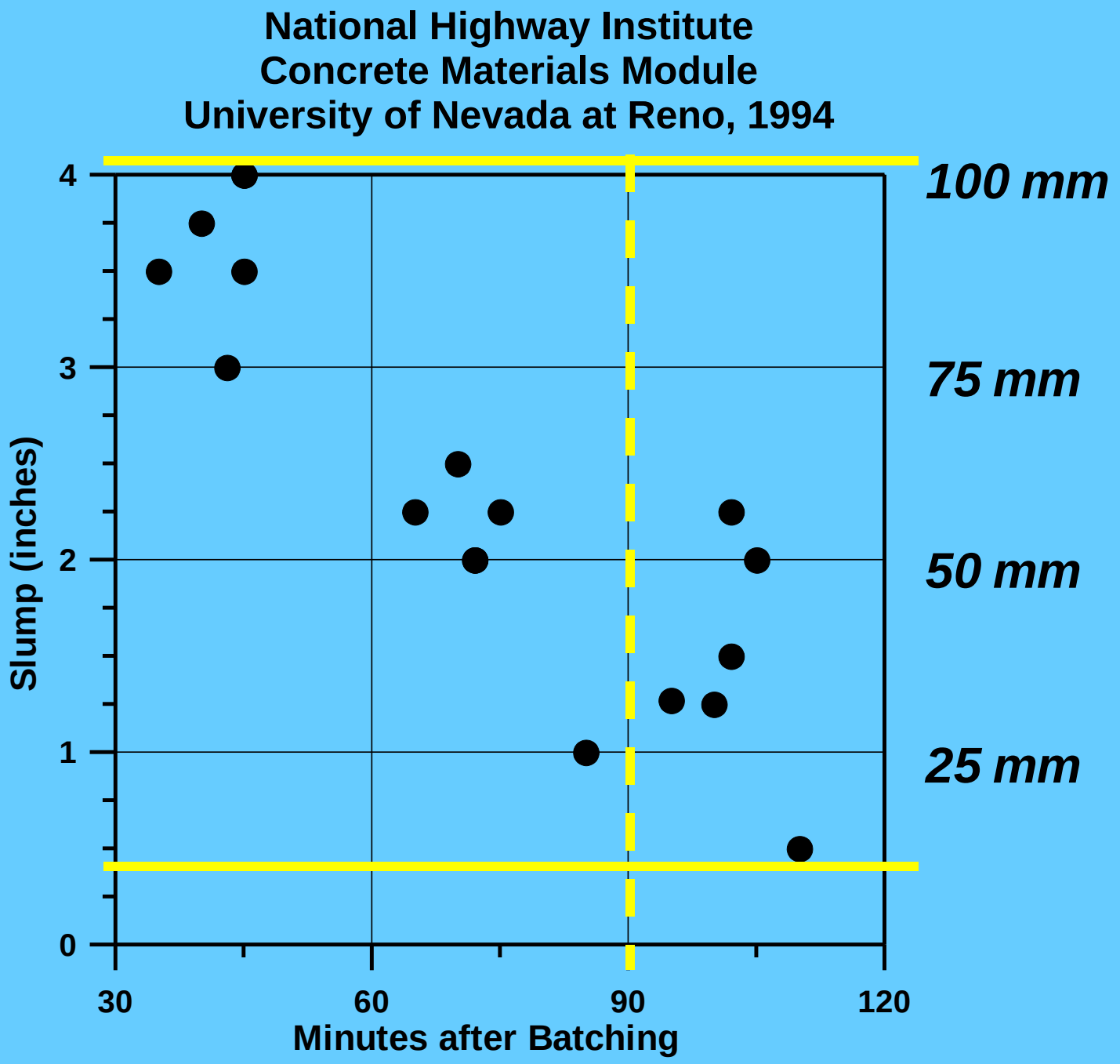

125
100
75
50
25
0
Slump (mm)
5
4
3
2
1
0
Slump (inches)
0
1
2
3
4
Hours after Batching
Slump
Unagitated
Continuously Agitated
Slump Loss Models
Linear
Parabolic
Exponential decay
Half-Life = 25 min

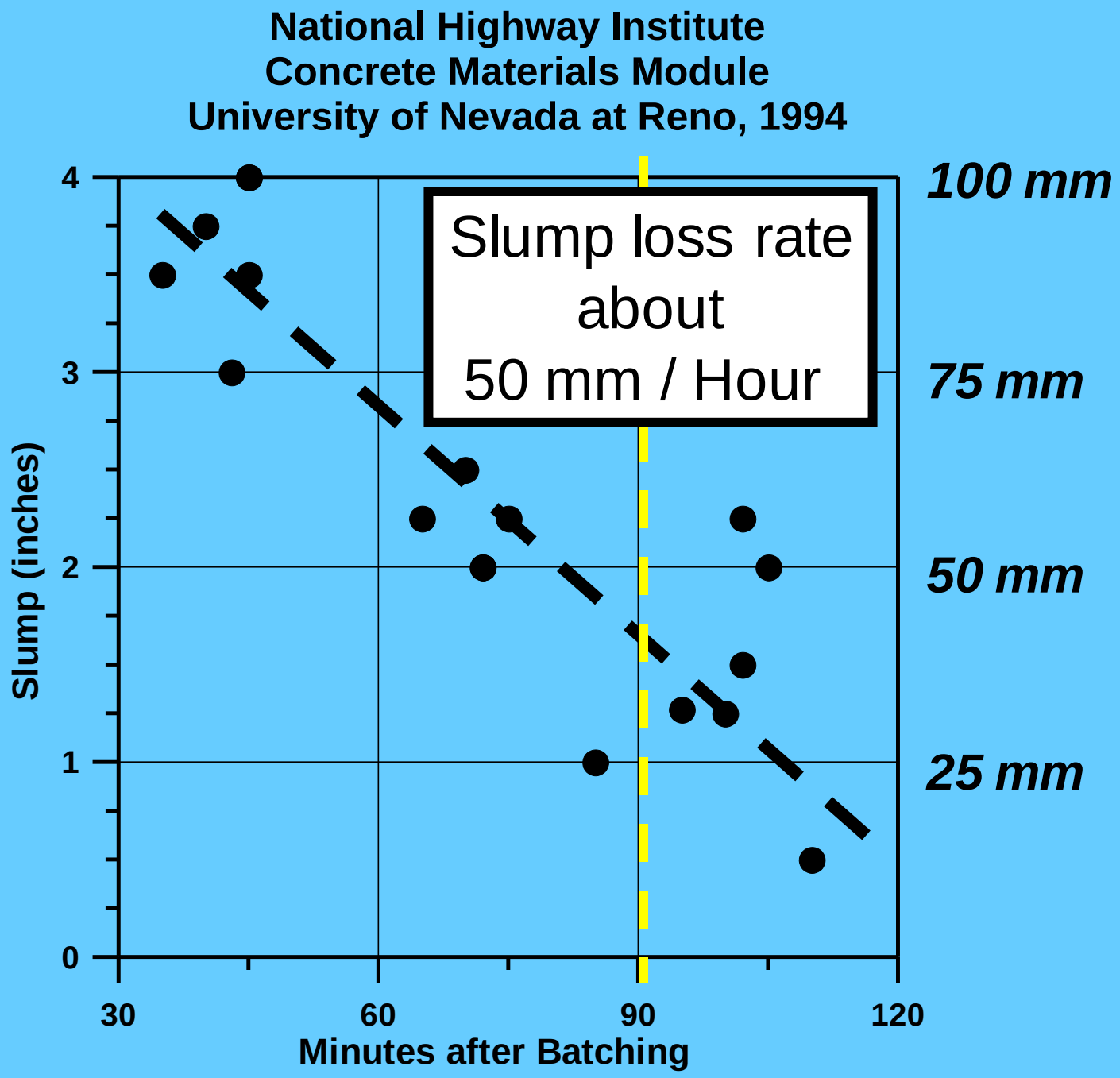

125
100
75
50
25
0
Slump (mm)
5
4
3
mp (inches)
0
1
2
Hours after Batching
Slump
Unagitated
Continuously Agitated
Slump Loss Models
Linear
Parabolic
Exponential decay
Half-Life = 25 min
CONSTANT

30 State & Federal Highway Engineers



vs. 1 Truckload of Concrete


National Highway Institute
Concrete Materials Module
University of Nevada at Reno, 1994
Slump (inches)
0
1
2
3
4
30
60
90
120
Minutes after Batching
100 mm
75 mm
50 mm
25 mm


National Highway Institute
Concrete Materials Module
University of Nevada at Reno, 1994
Slump loss rate about 50 mm / Hour
100 mm
75 mm
50 mm
25 mm
Slump (inches)
0
1
2
3
4
30
60
90
120
Minutes after Batching

Slump & Setting
Un-agitated Slump
Agitated Slump
Setting

Final Set
Initial Set

Penetration Resistance (mPa)
(psi)

5000
4000
3000
2000
1000
0
30
20
10
0
0
2
4
6

Hours after Batching

Slump
ASTM C143

Slump & Setting
Un-agitated Slump
Agitated Slump
Setting

Final Set

Initial Set

Penetration Resistance (mPa)

5000
4000
3000
2000
1000
(psi)

30
20
10

0

0
2
4
Hours after Batching

Penetration Resistance
(Setting)
ASTM C403

Slump & Setting
Un-agitated Slump
Agitated Slump
Setting

Final Set

Initial Set

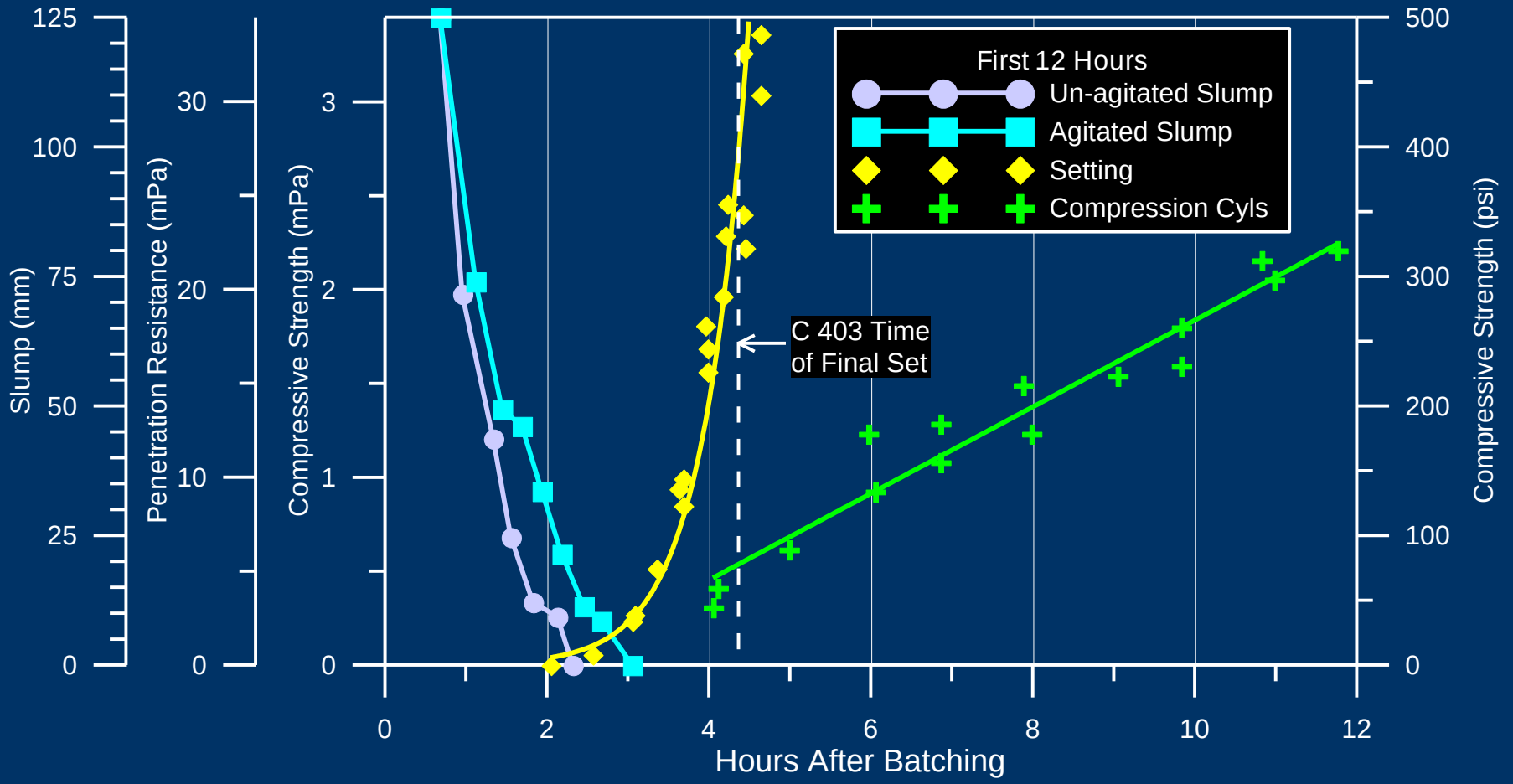
Penetration Resistance (mPa)

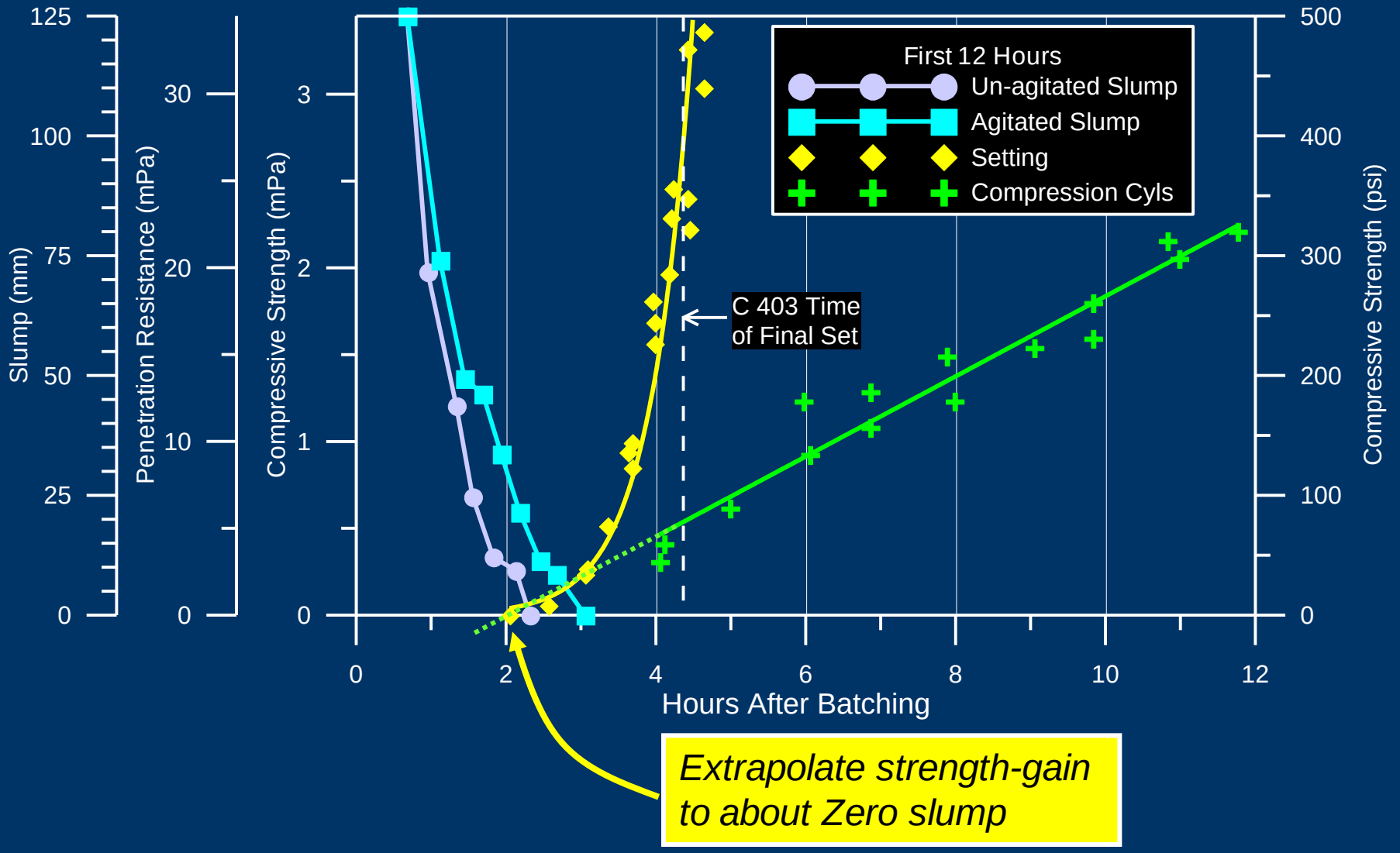
5000
4000
3000
2000
1000
0
(psi)

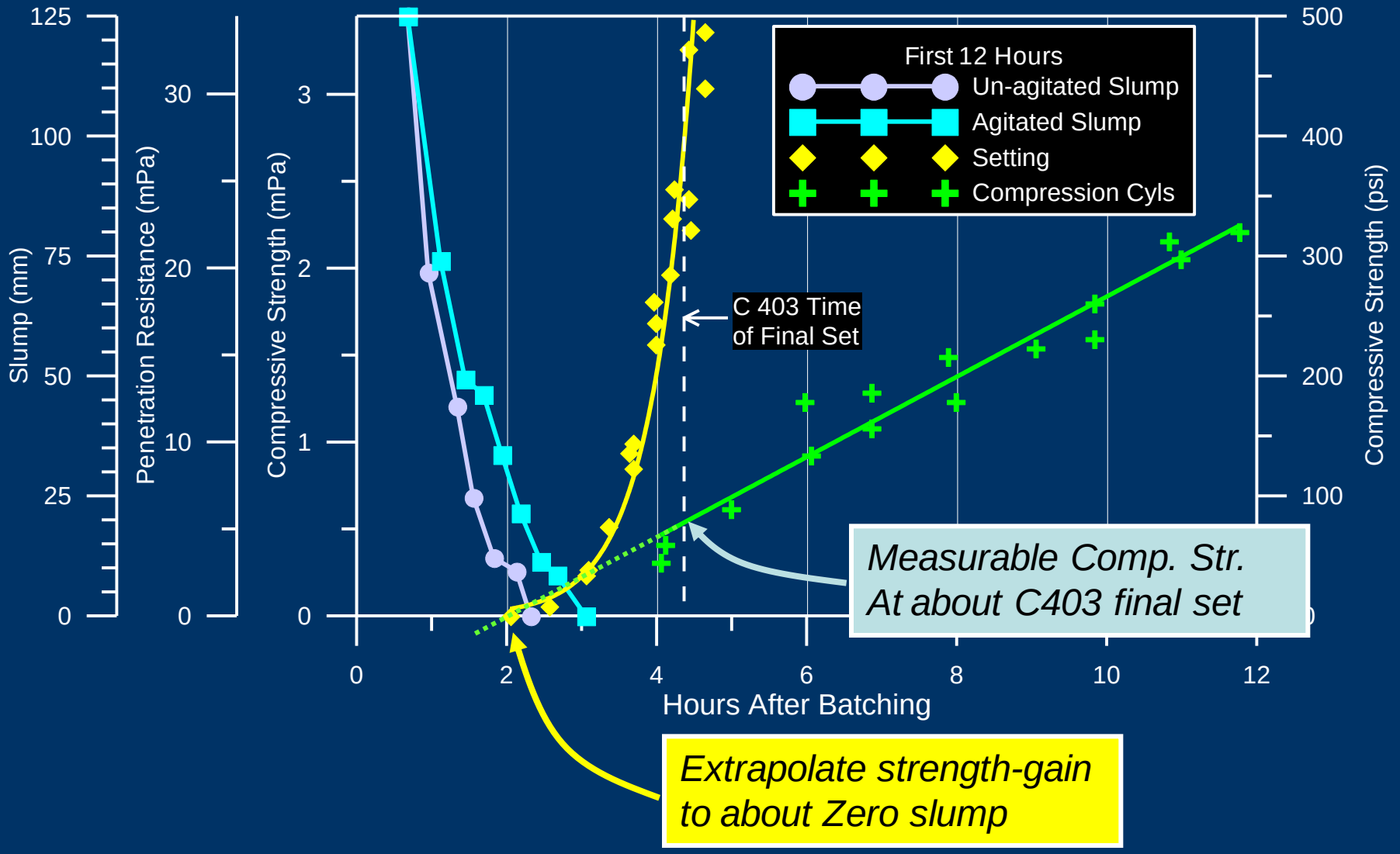
30
20
10
0

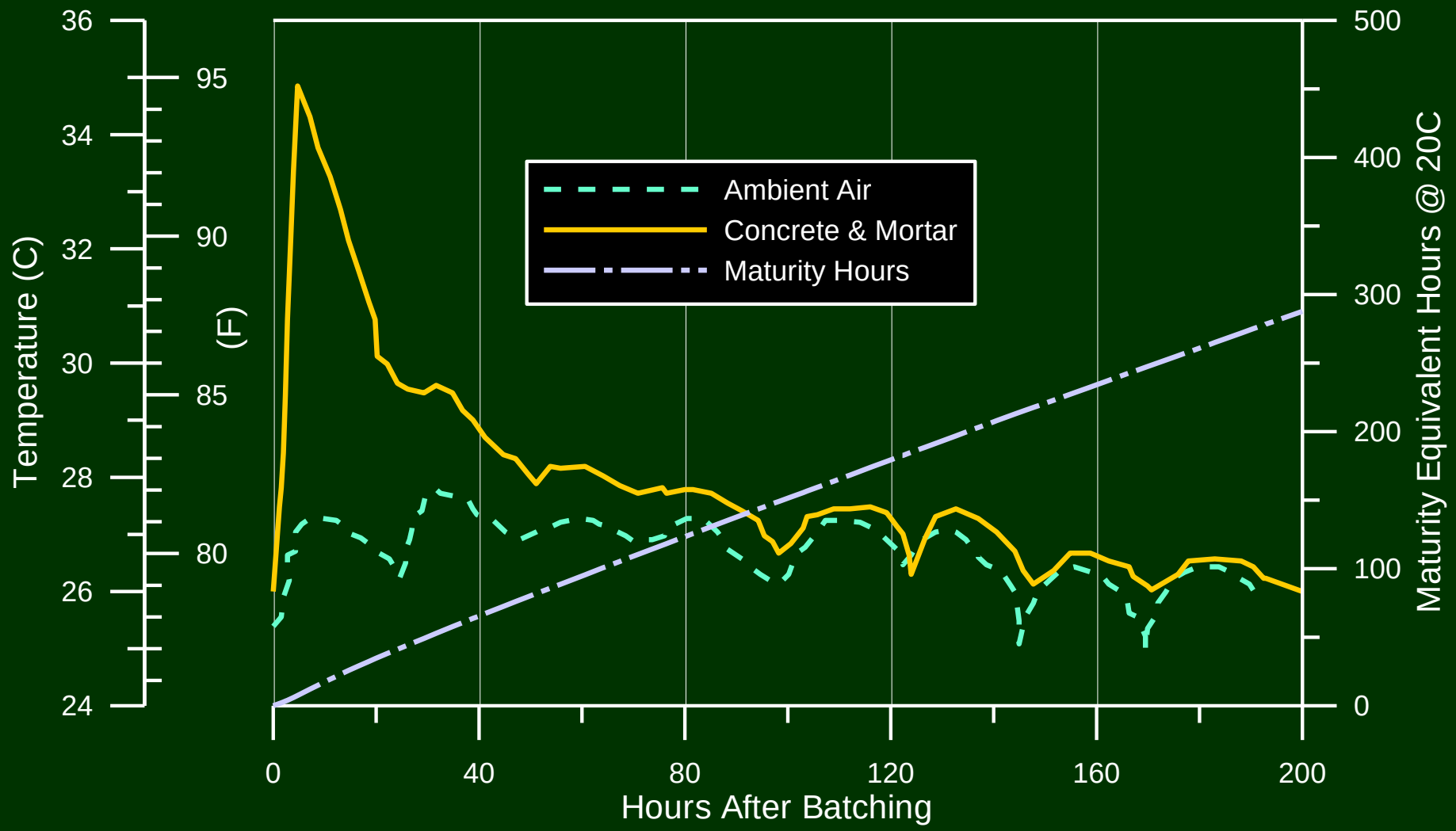
2
4
6
Hours after Batching

Measurable Penetration Resistance at about zero slump


First 12 Hours
Un-agitated Slump
Agitated Slump
Setting
Compression Cyls
C 403 Time
of Final Set
Slump (mm)
Penetration Resistance (mPa)
Compressive Strength (mPa)
Compressive Strength (psi)
Hours After Batching
0
25
50
75
100
125
10
20
30
1
2
3
100
200
300
400
500
2
4
6
8
10
12


First 12 Hours
Un-agitated Slump
Agitated Slump
Setting
Compression Cyls
C 403 Time
of Final Set
Slump (mm)
Penetration Resistance (mPa)
Compressive Strength (mPa)
Compressive Strength (psi)
Hours After Batching
0
25
50
75
100
125
10
20
30
1
2
3
100
200
300
400
500
4
6
8
10
12
Extrapolate strength-gain
to about Zero slump

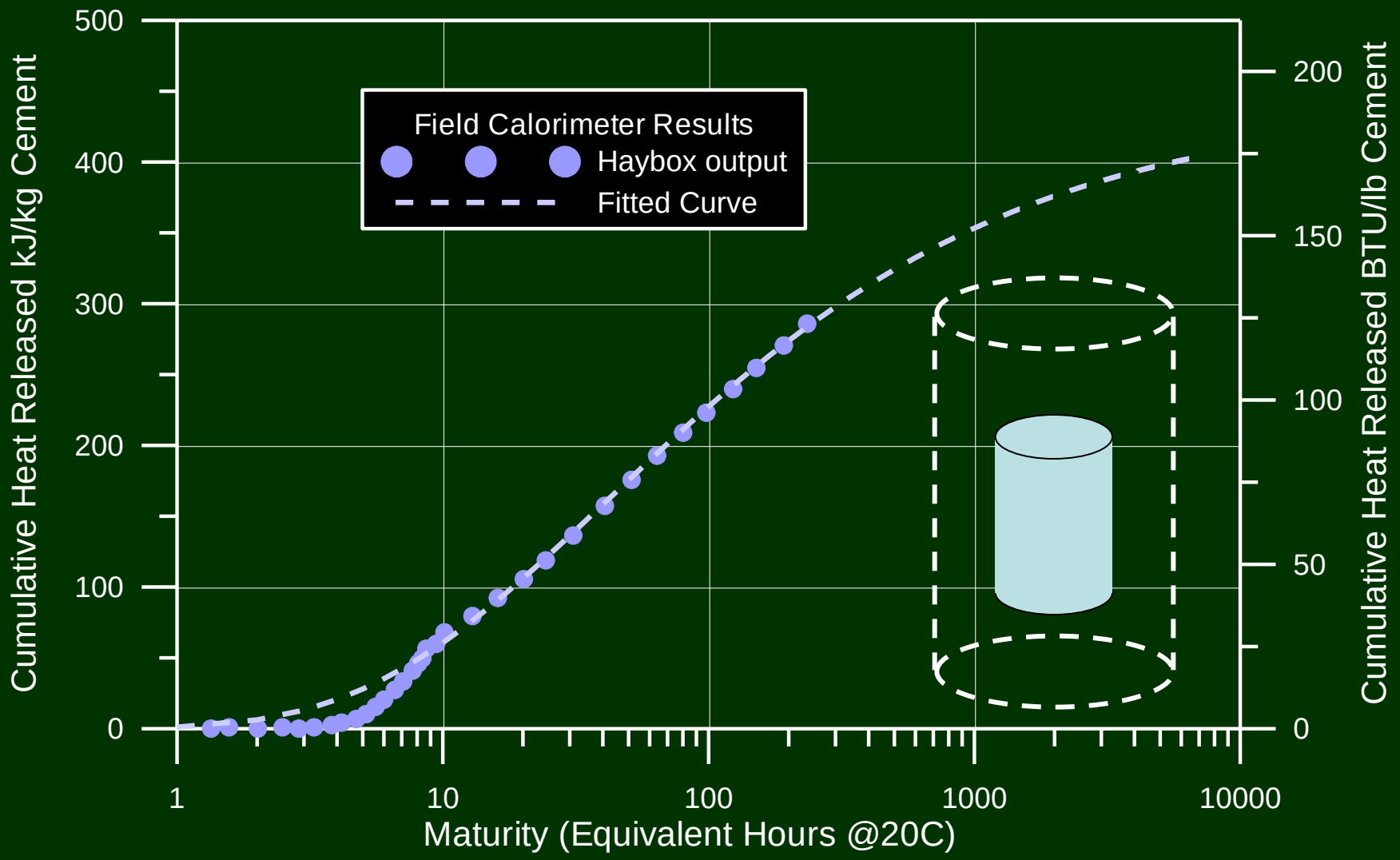

First 12 Hours
Un-agitated Slump
Agitated Slump
Setting
Compression Cyls
C 403 Time
of Final Set
Measurable Comp. Str.
At about C403 final set
Extrapolate strength-gain
to about Zero slump
Slump (mm)
Penetration Resistance (mPa)
Compressive Strength (mPa)
Compressive Strength (psi)
Hours After Batching
0
25
50
75
100
125
10
20
30
1
2
3
100
200
300
400
500
4
6
8
10
12

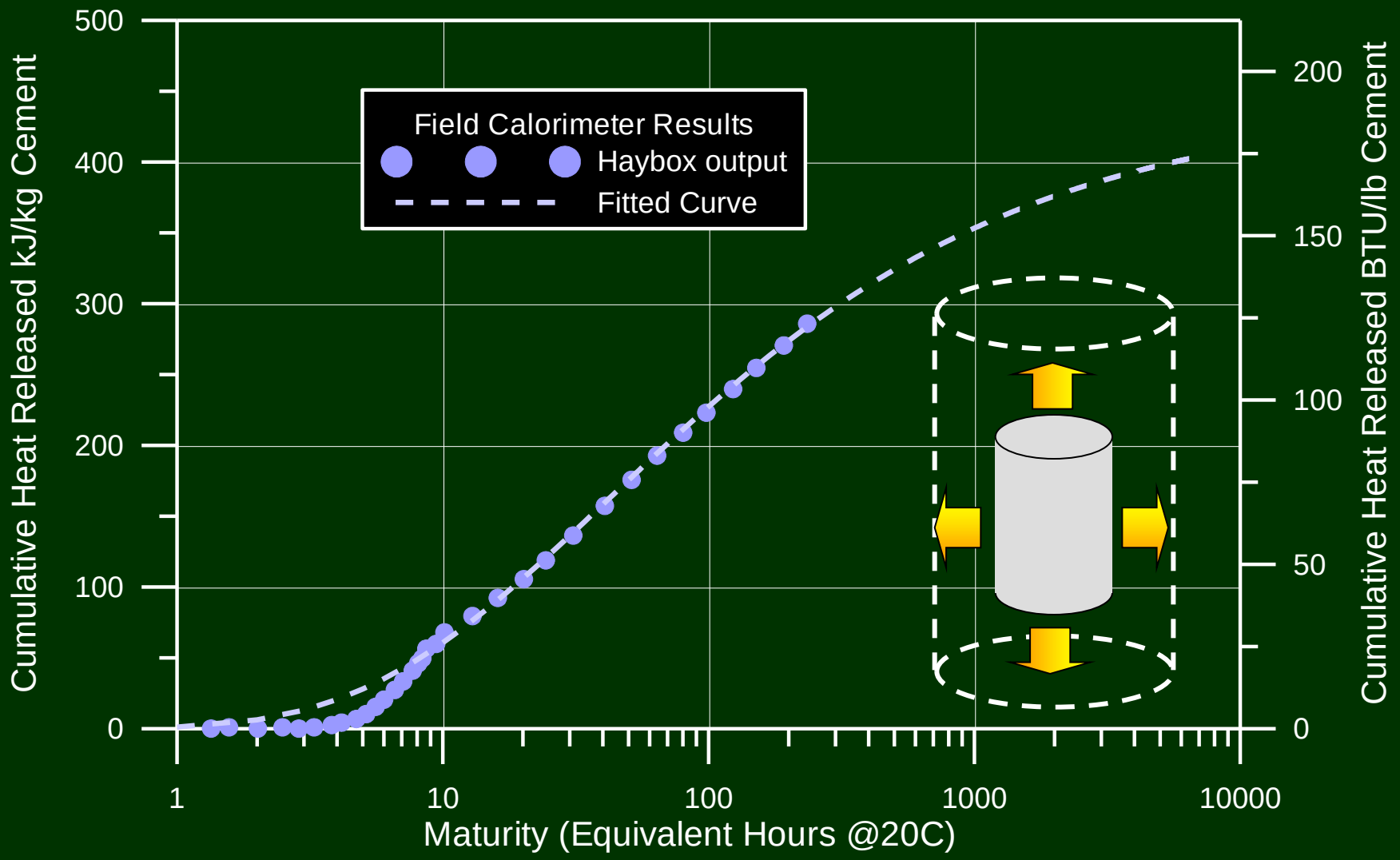


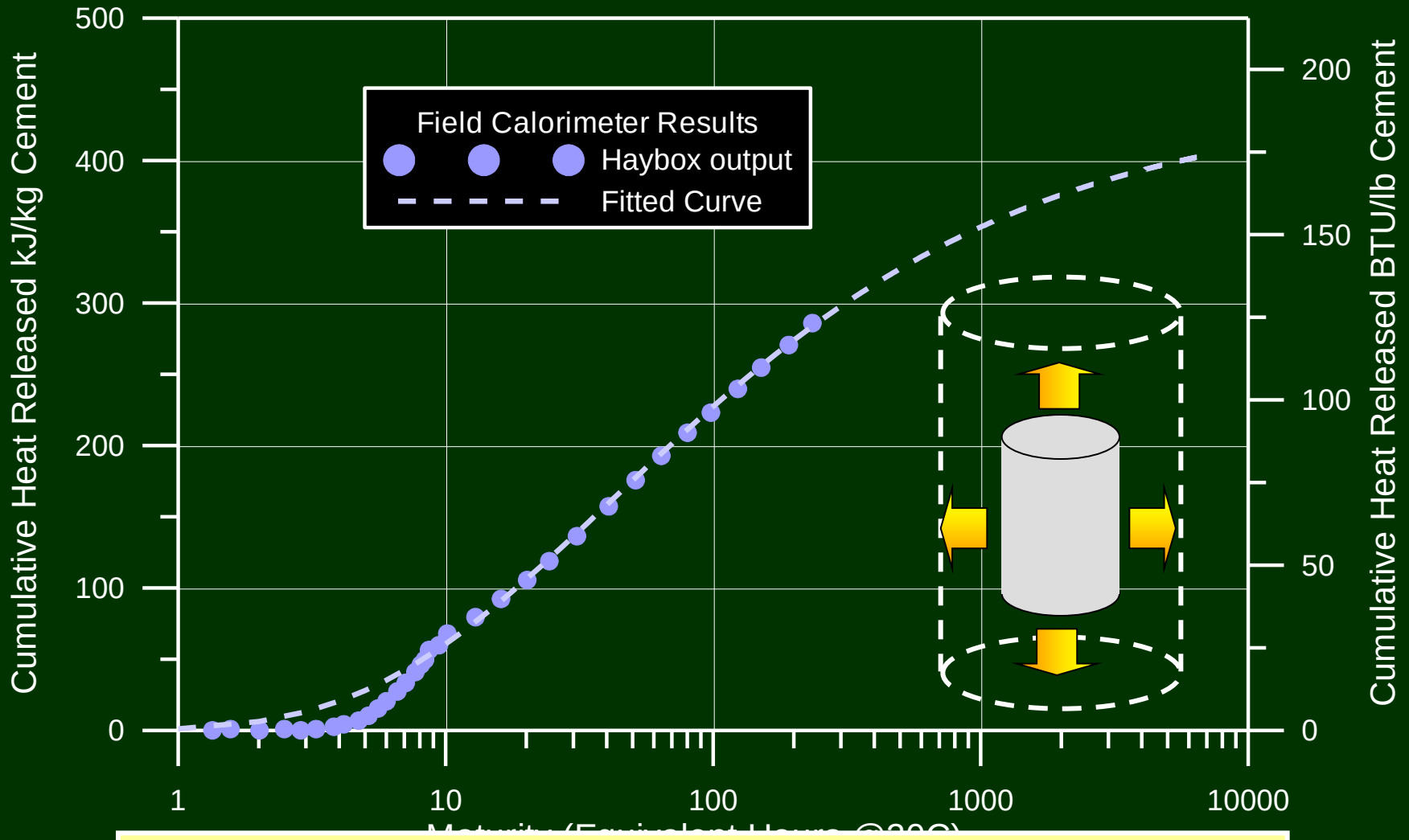
Arrhenius-Type Maturity, T_{ref} = 20C (68F), E_a = 33.5 kJ/mol


HayBox


F
B
1
2

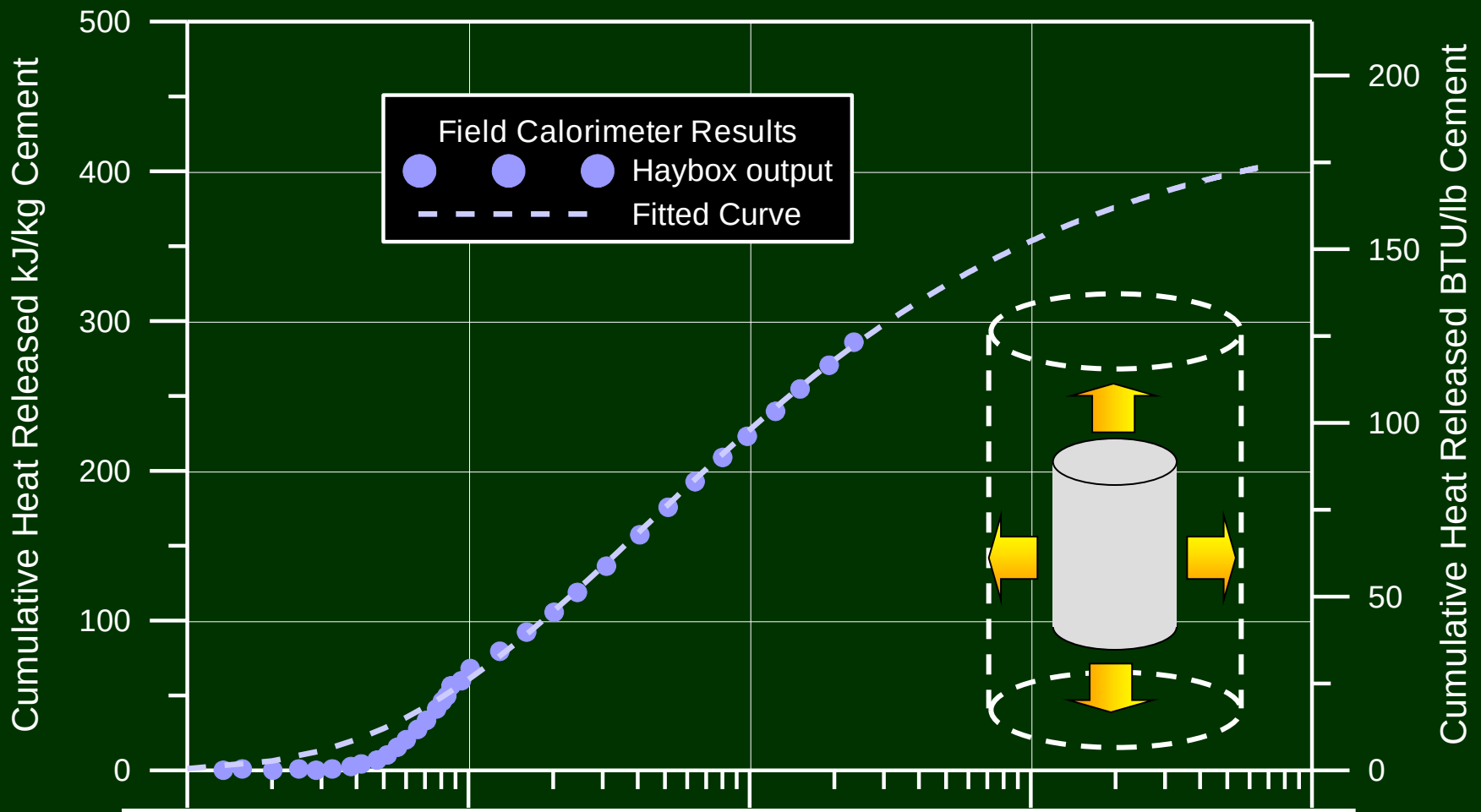

Field Calorimeter Results
Haybox output
Fitted Curve
Cumulative Heat Released kJ/kg Cement
Cumulative Heat Released BTU/lb Cement
Maturity (Equivalent Hours @20C)
500
400
300
200
100
0
200
150
100
50
0
1
10
100
1000
10000


Field Calorimeter Results
Haybox output
Fitted Curve
Cumulative Heat Released kJ/kg Cement
Cumulative Heat Released BTU/lb Cement
Maturity (Equivalent Hours @20C)
500
400
300
200
100
0
200
150
100
50
0
1
10
100
1000
10000



[Time, Concrete T, E_a] → Maturity

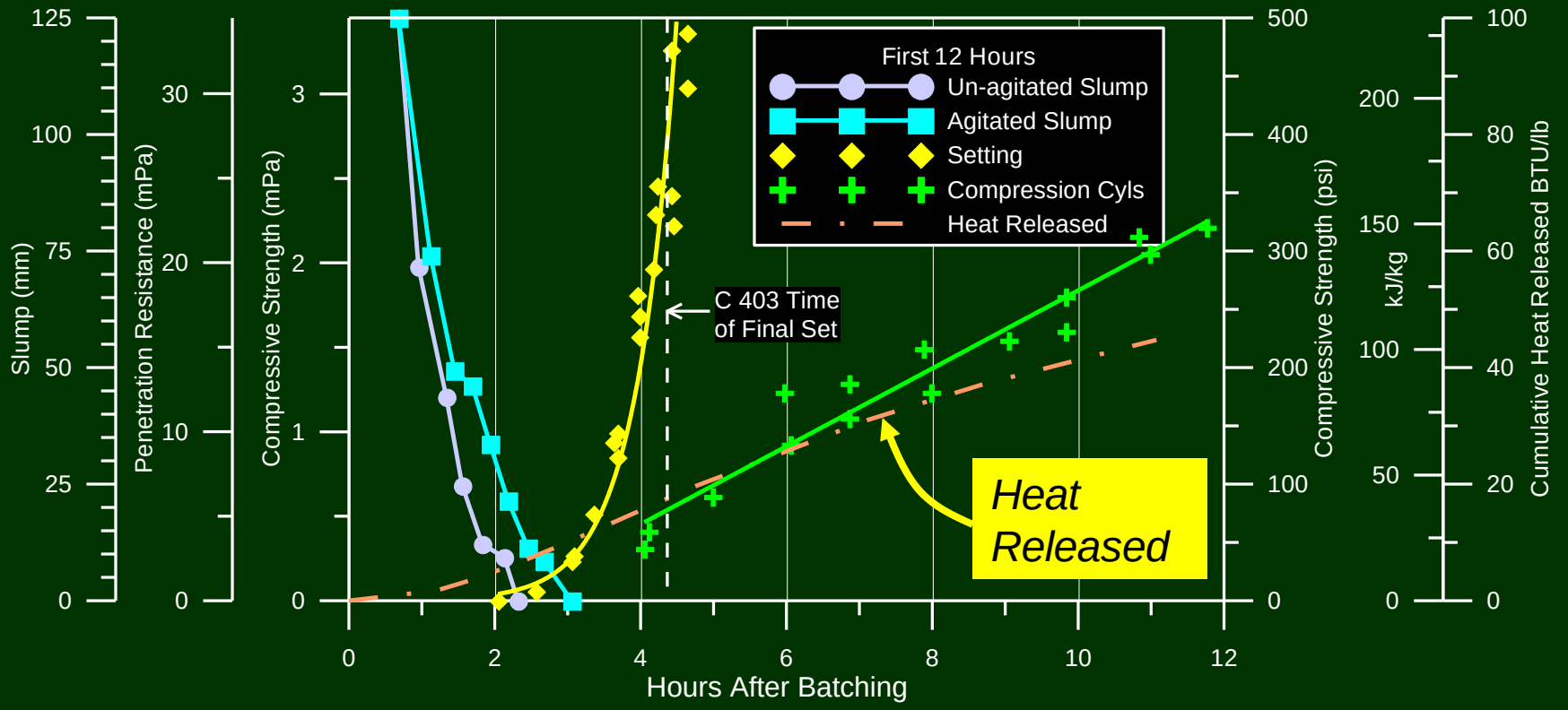
[Maturity and Calorimetry] → Heat release = f(Maturity)

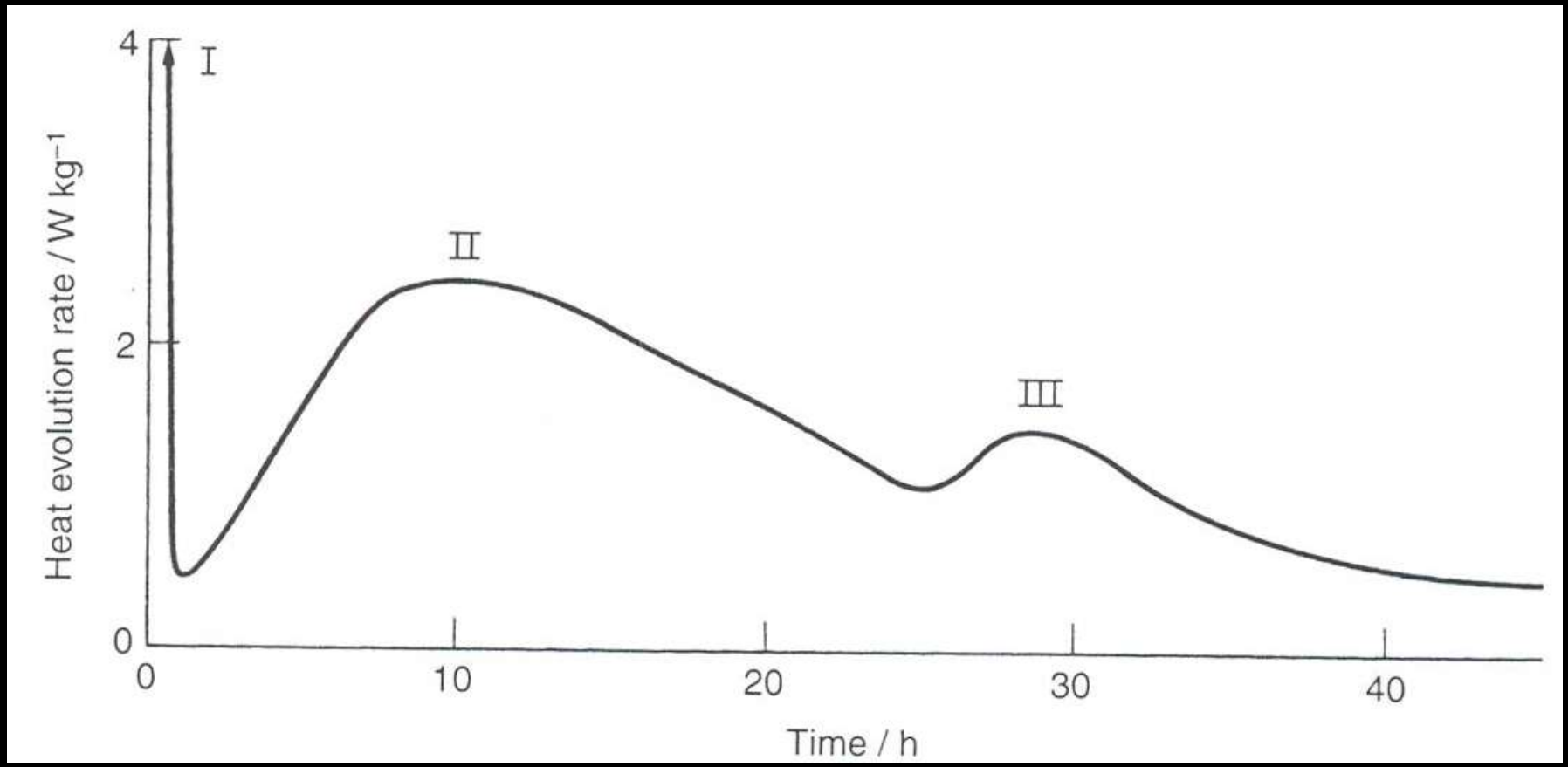


[Time, Concrete T, E_a] → Maturity

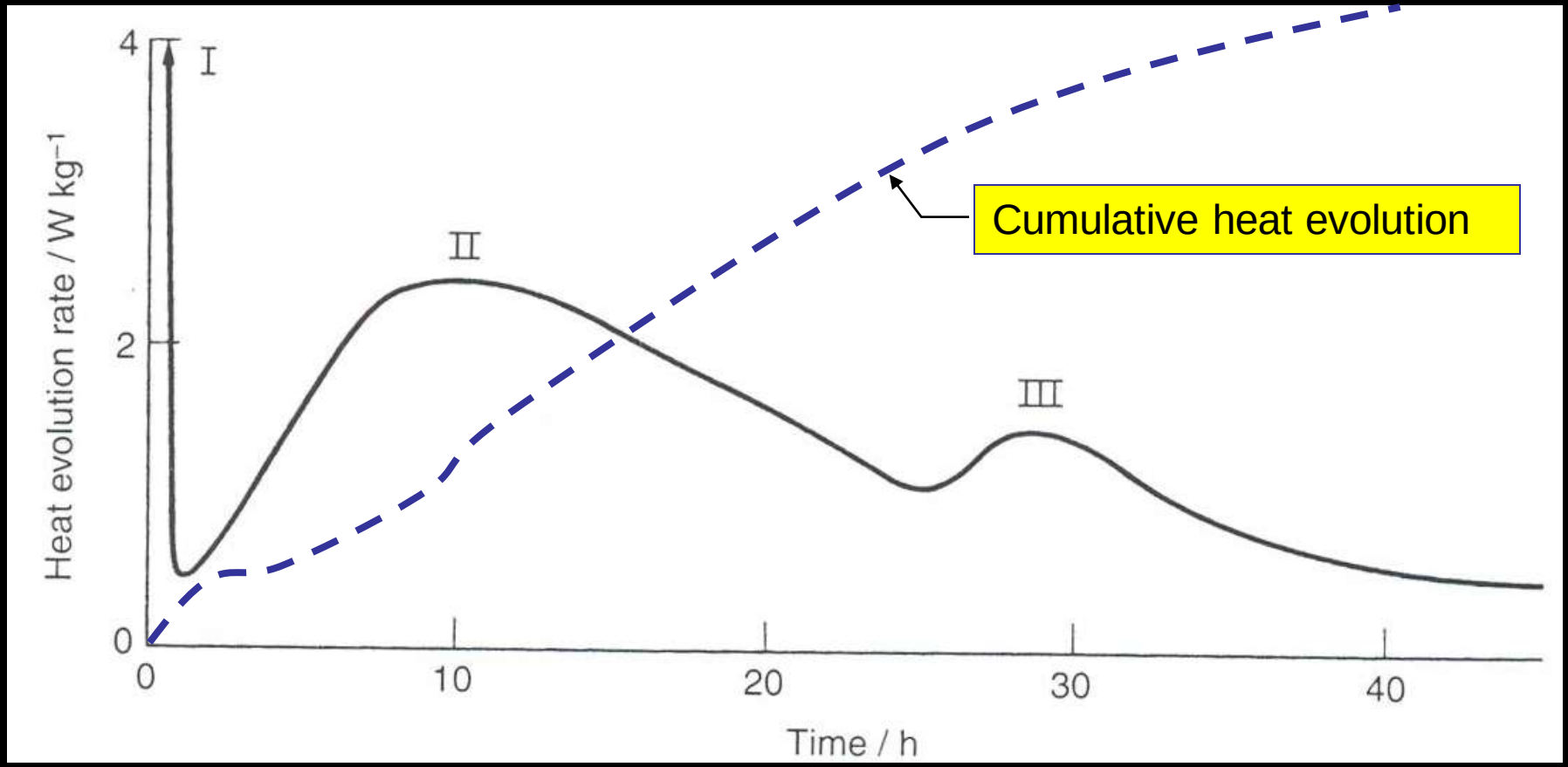
[Maturity and Calorimetry] → Heat release = f(Maturity)

Heat Release = f (degree of hydration)

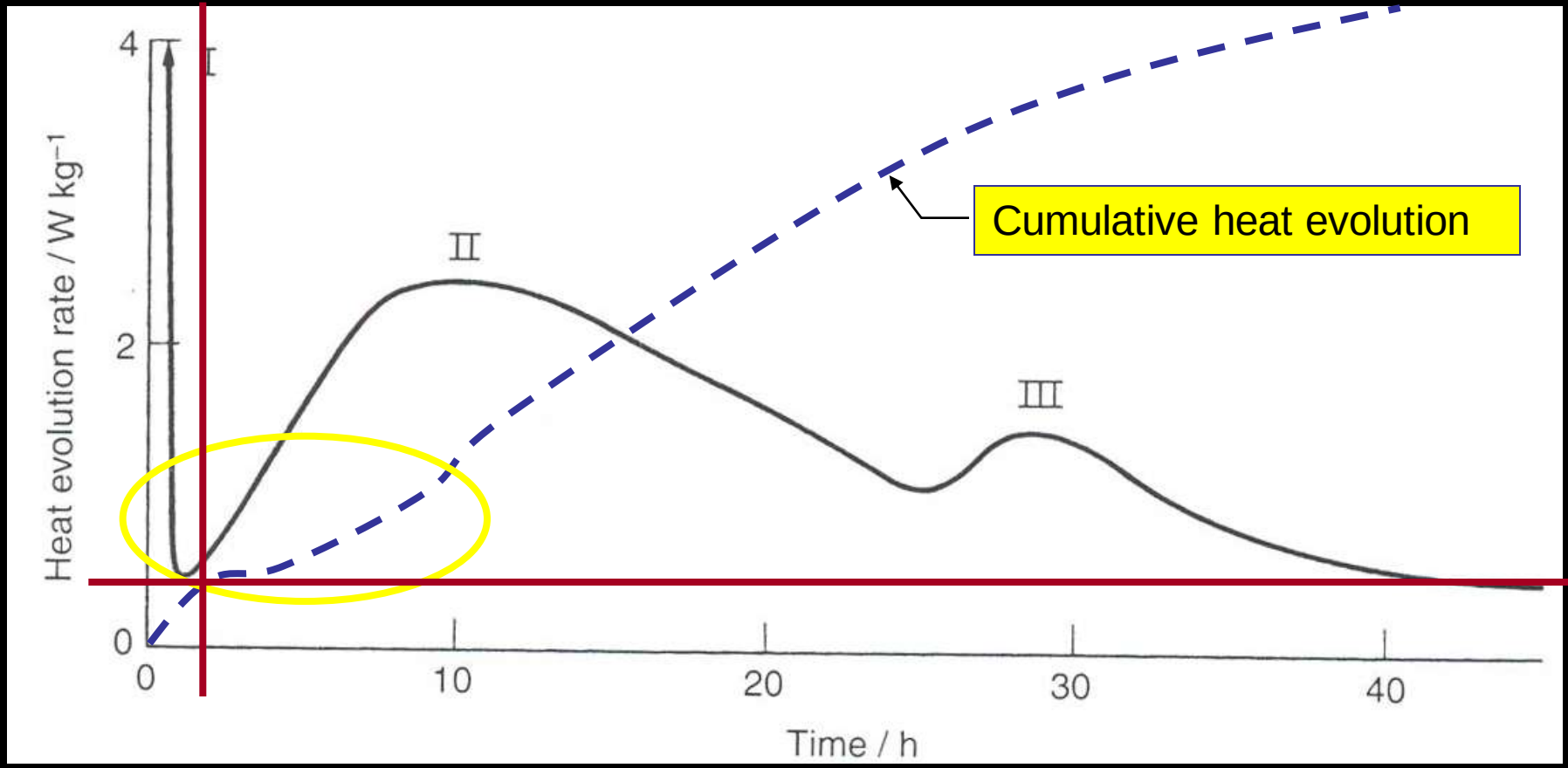

First 12 Hours
Un-agitated Slump
Agitated Slump
Setting
Compression Cyls
Heat Released
C 403 Time of Final Set
Heat Released
Slump (mm)
Penetration Resistance (mPa)
Compressive Strength (mPa)
Compressive Strength (psi)
kJ/kg
Cumulative Heat Released BTU/lb
Hours After Batching
0
2
4
6
8
10
12
125
100
75
50
25
0
30
20
10
0
3
2
1
0
500
400
300
200
100
0
200
150
100
50
0
100
80
60
40
20
0



Typical Heat Evolution with Time

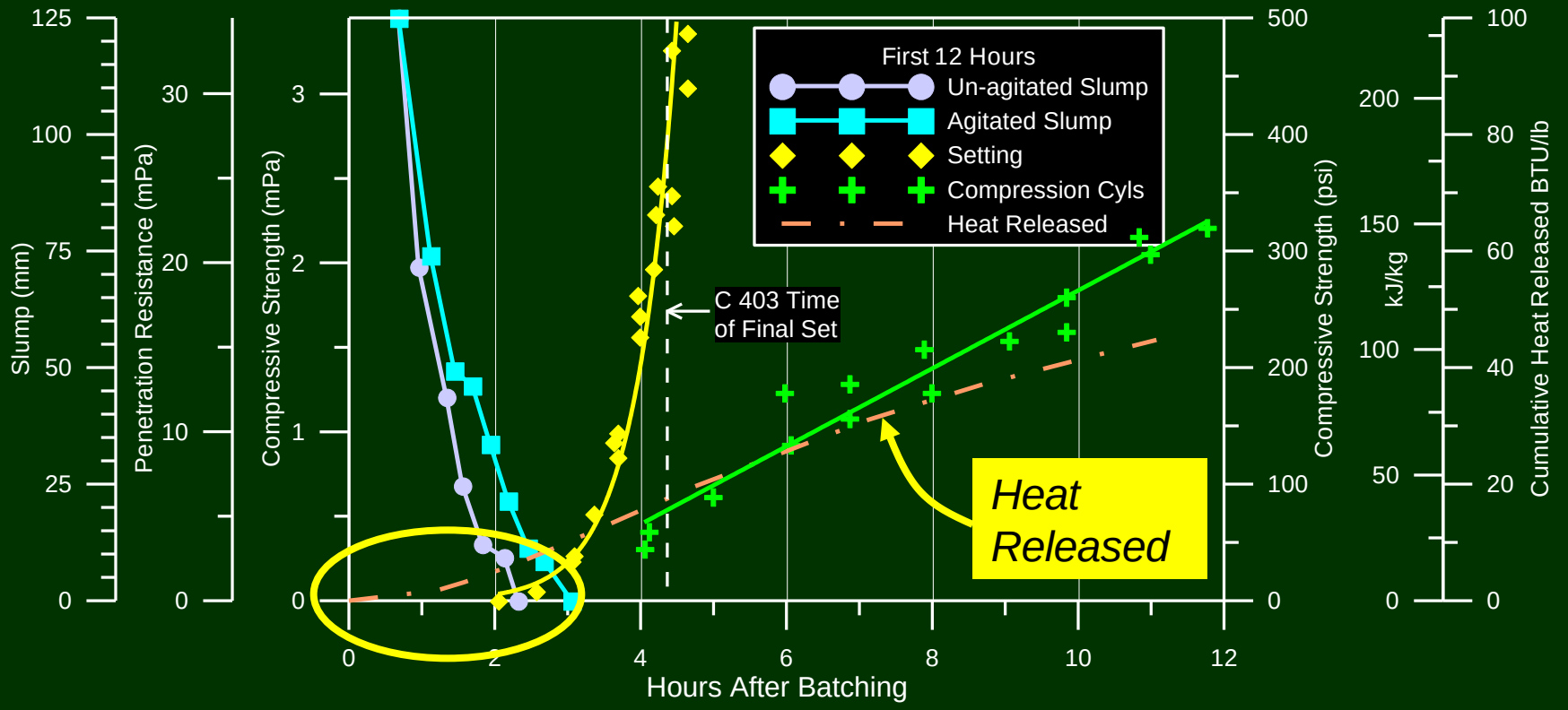


Heat Evolution with Time



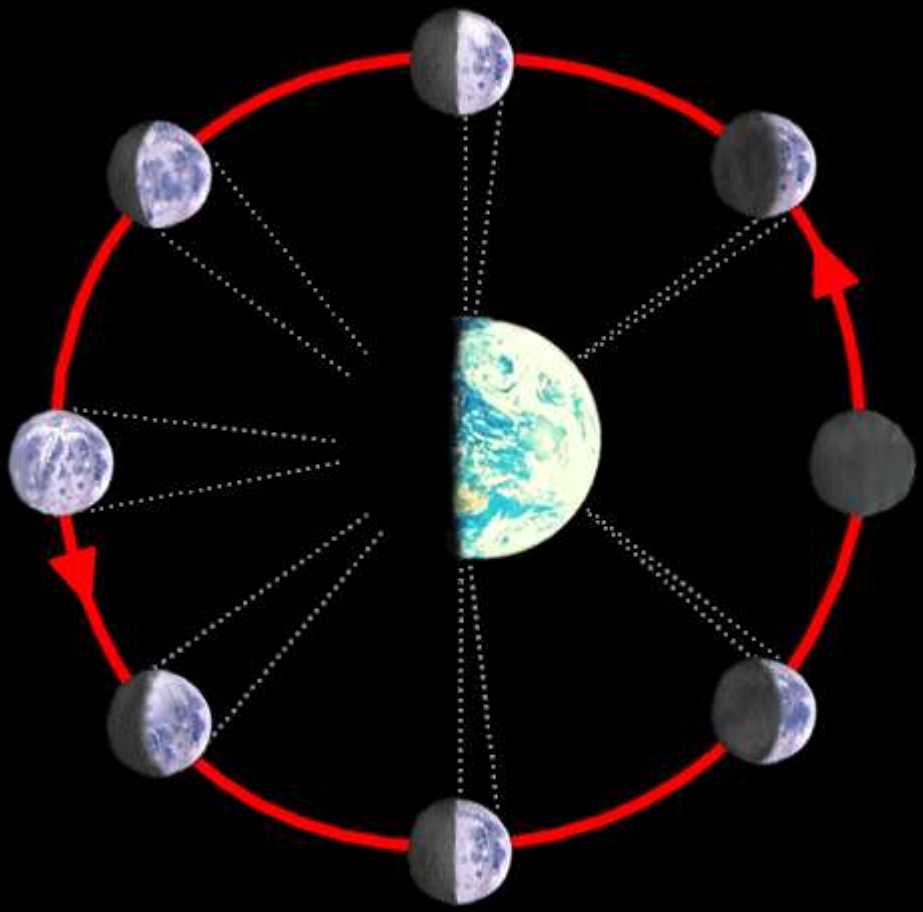
Typical Heat Evolution with Time

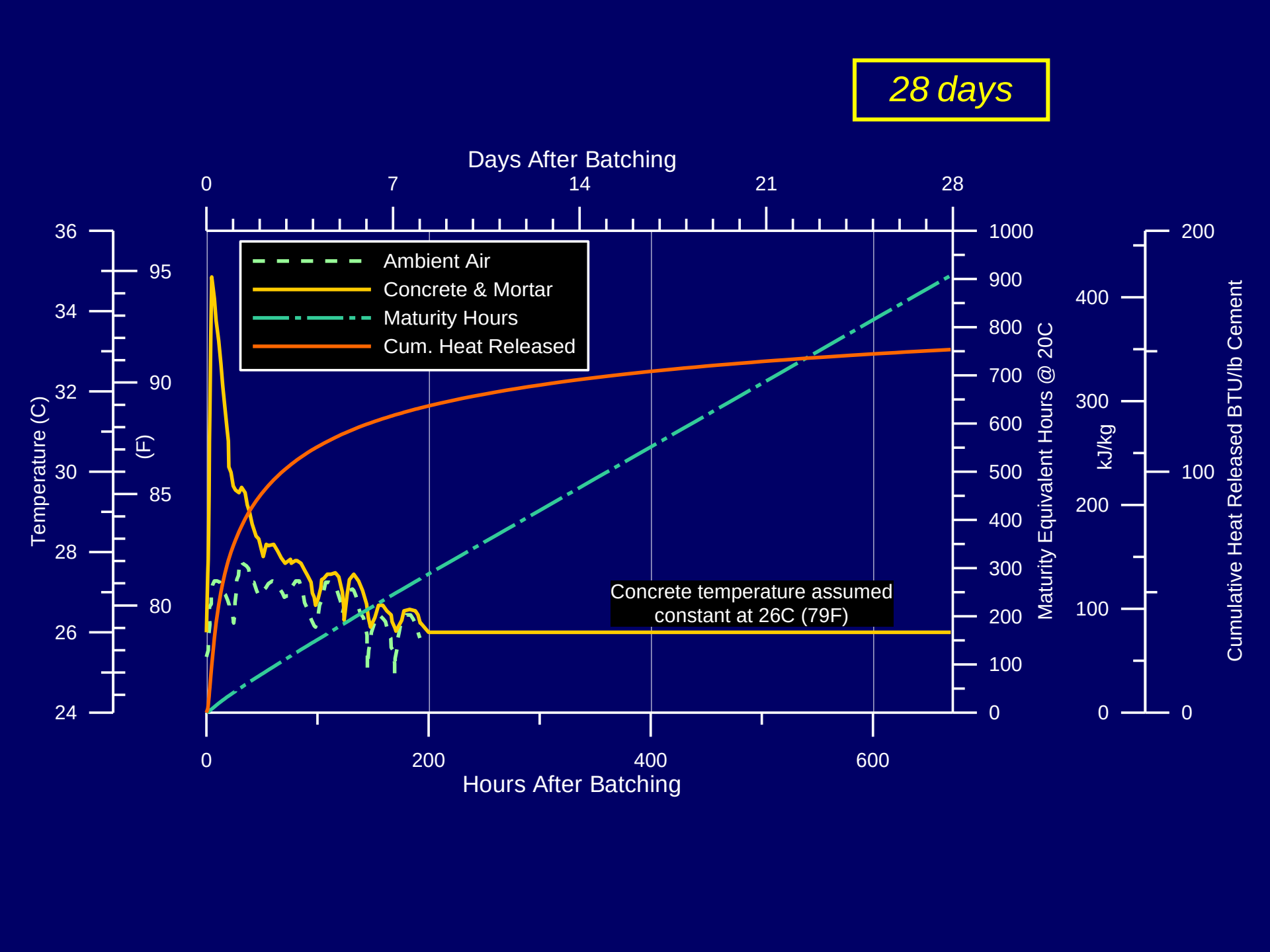
Re-set origin: If expt. begins 1-1/2 hrs after batching

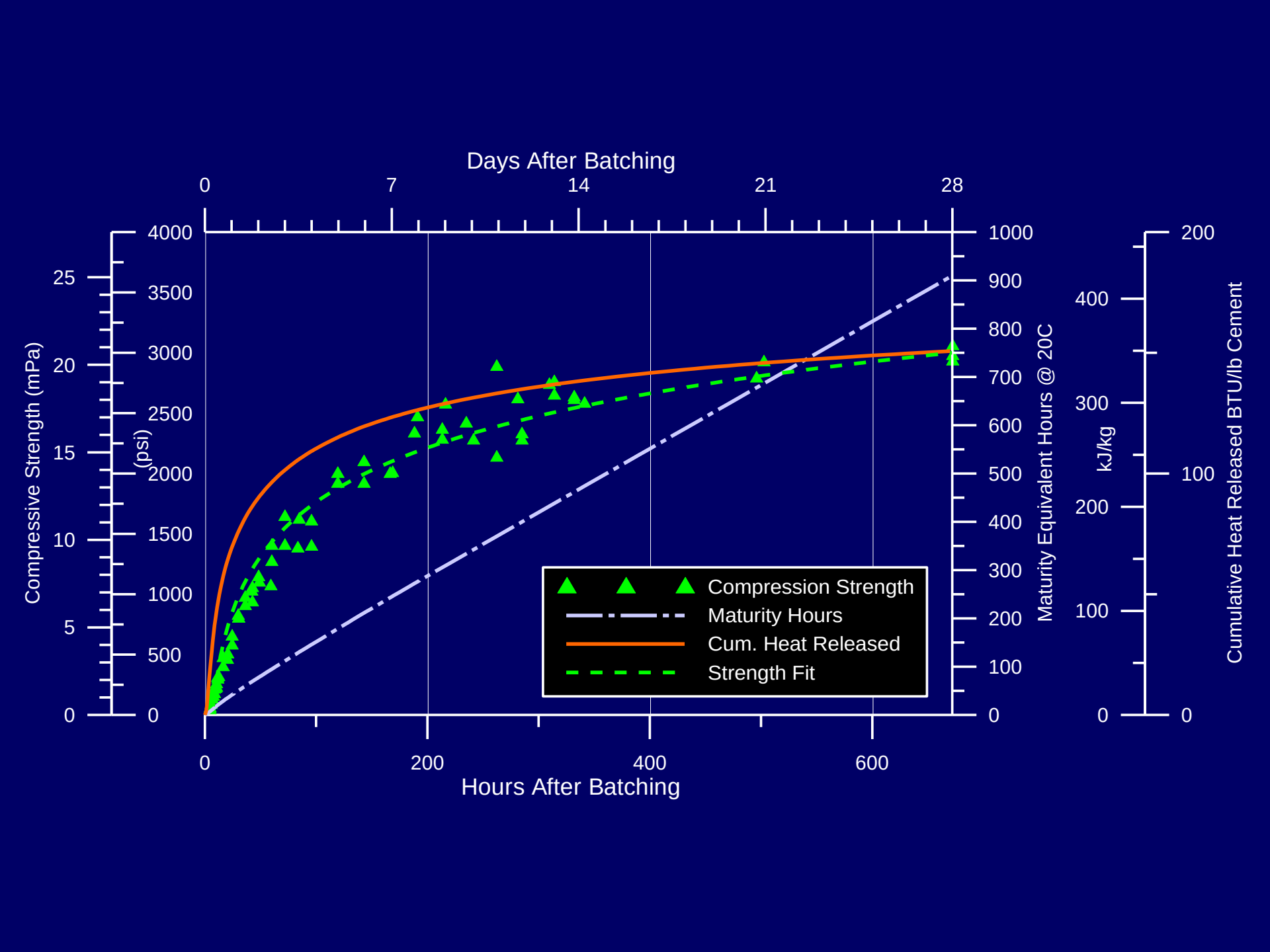


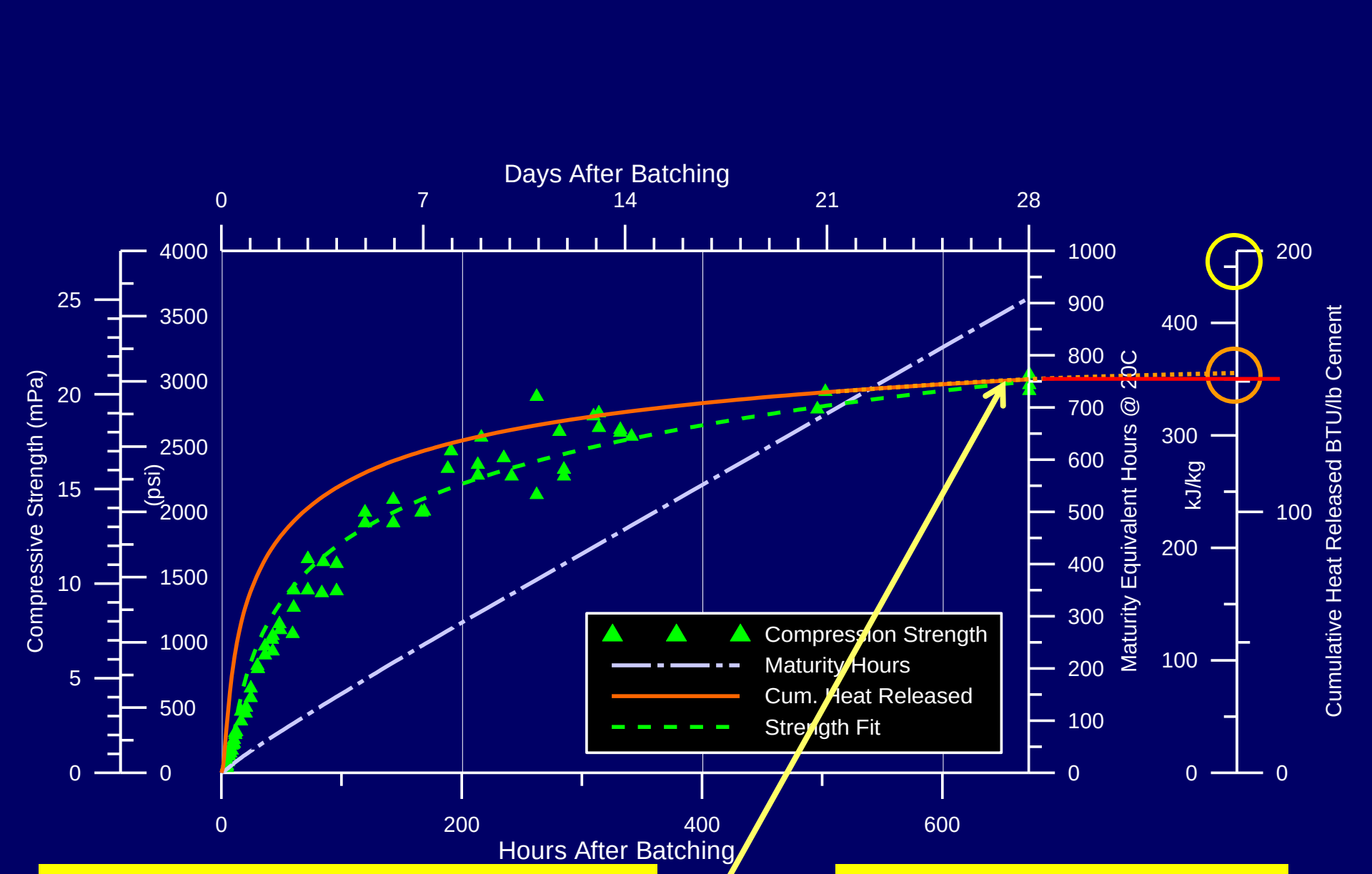
Re-set origin: Expt. begins 1-1/2 hrs after batching

28-Day Properties



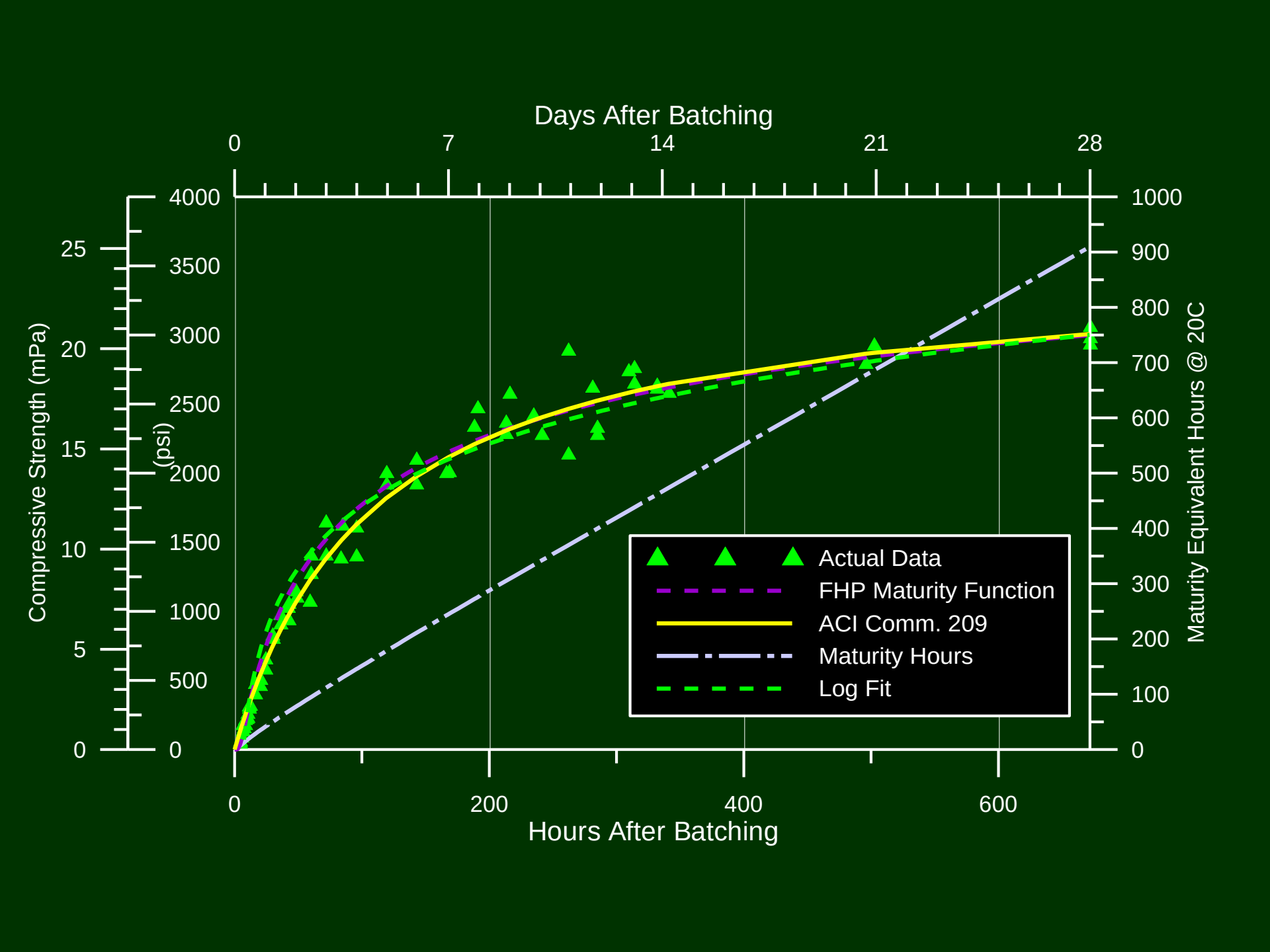

28 days
Days After Batching
0
7
14
21
28
Ambient Air
Concrete & Mortar
Maturity Hours
Cum. Heat Released
Concrete temperature assumed constant at 26C (79F)
Temperature (C)
(F)
Maturity Equivalent Hours @ 20C
kJ/kg
Cumulative Heat Released BTU/lb Cement
Hours After Batching
0
200
400
600
36
34
32
30
28
26
24
95
90
85
80
1000
900
800
700
600
500
400
300
200
100
0
200
400
300
200
100
0
100
0

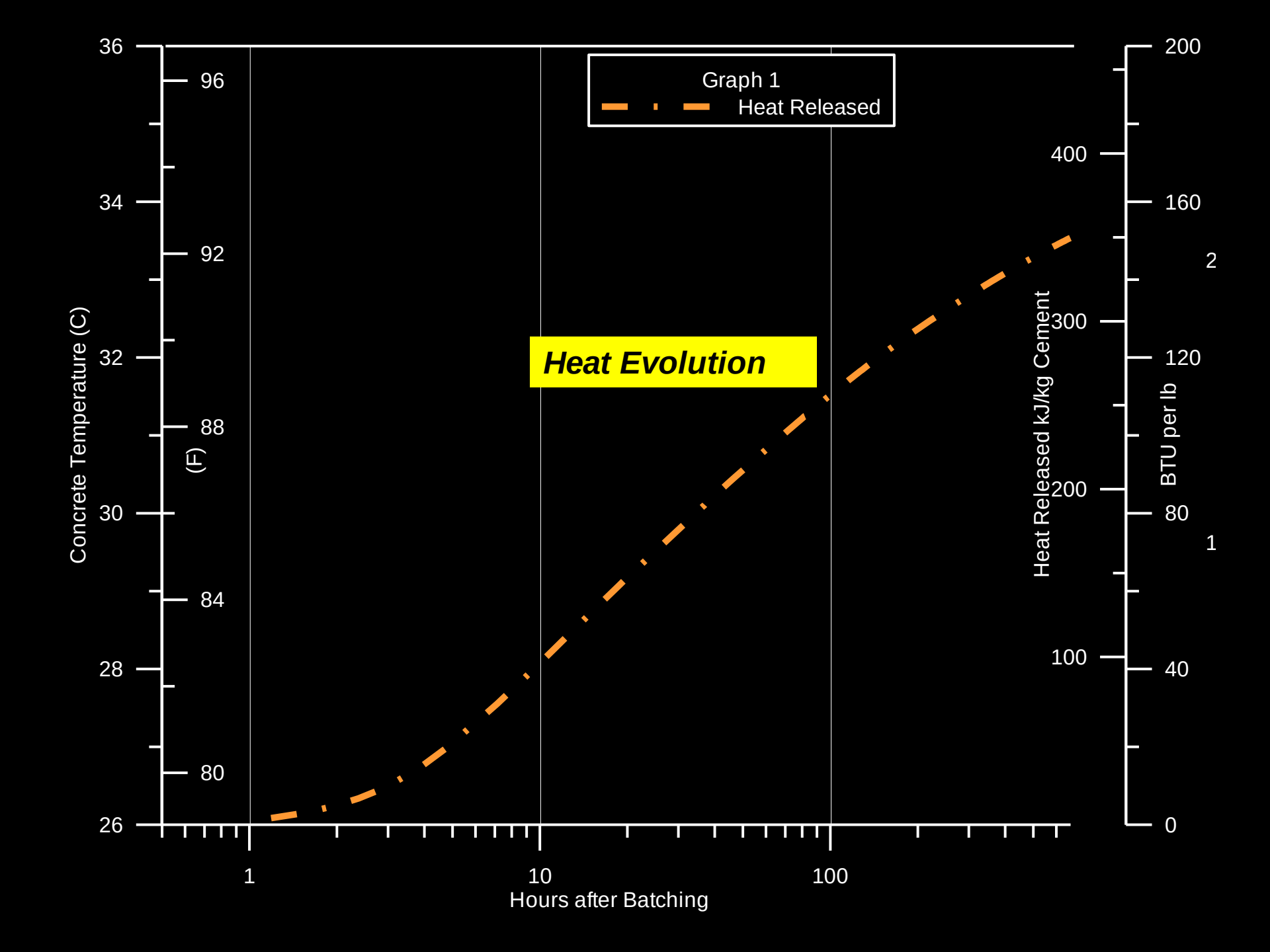

Days After Batching
0
7
14
21
28
Compressive Strength (mPa)
(psi)
Maturity Equivalent Hours @ 20C
kJ/kg
Cumulative Heat Released BTU/lb Cement
Hours After Batching
0
200
400
600
Compression Strength
Maturity Hours
Cum. Heat Released
Strength Fit

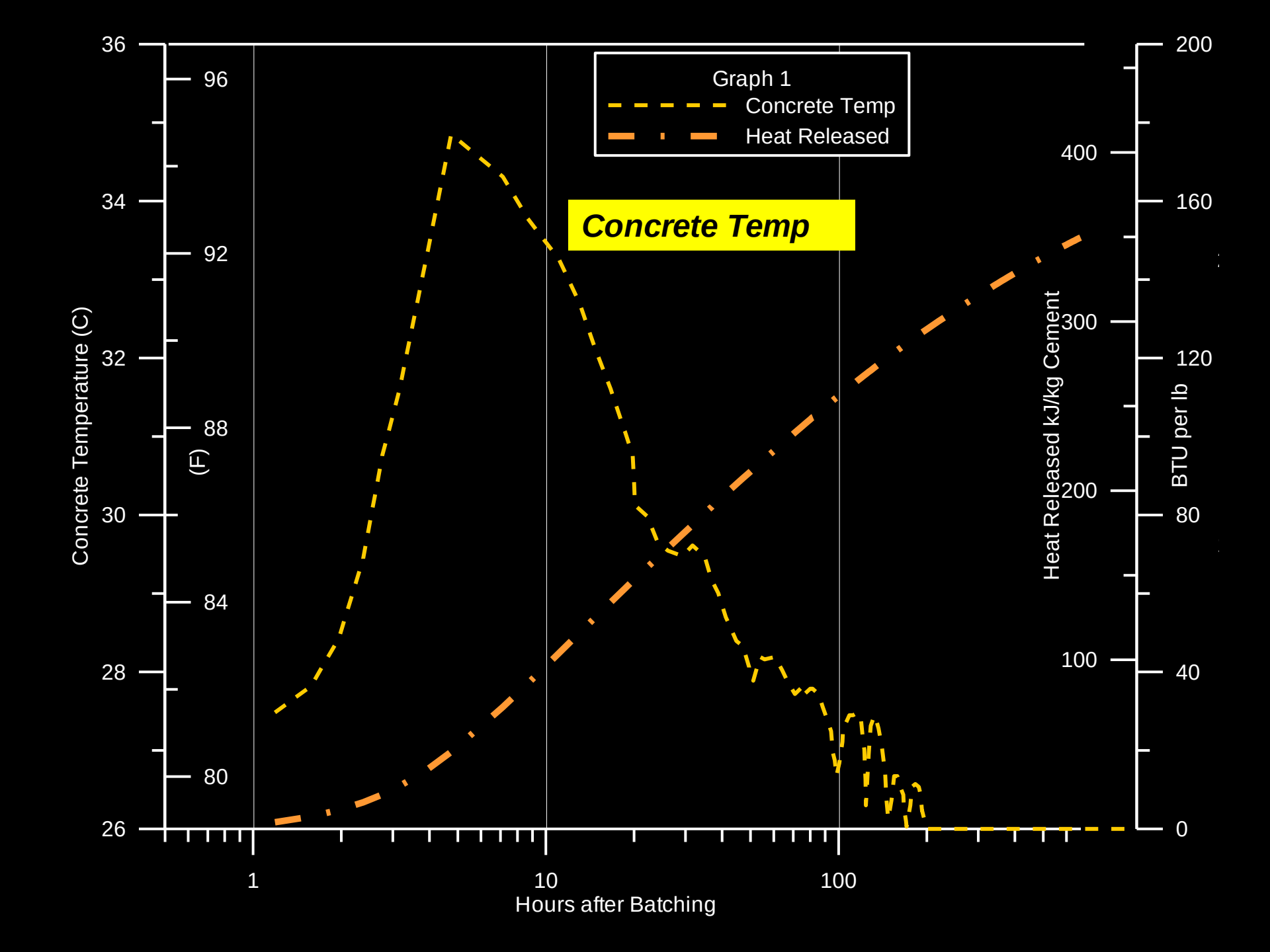


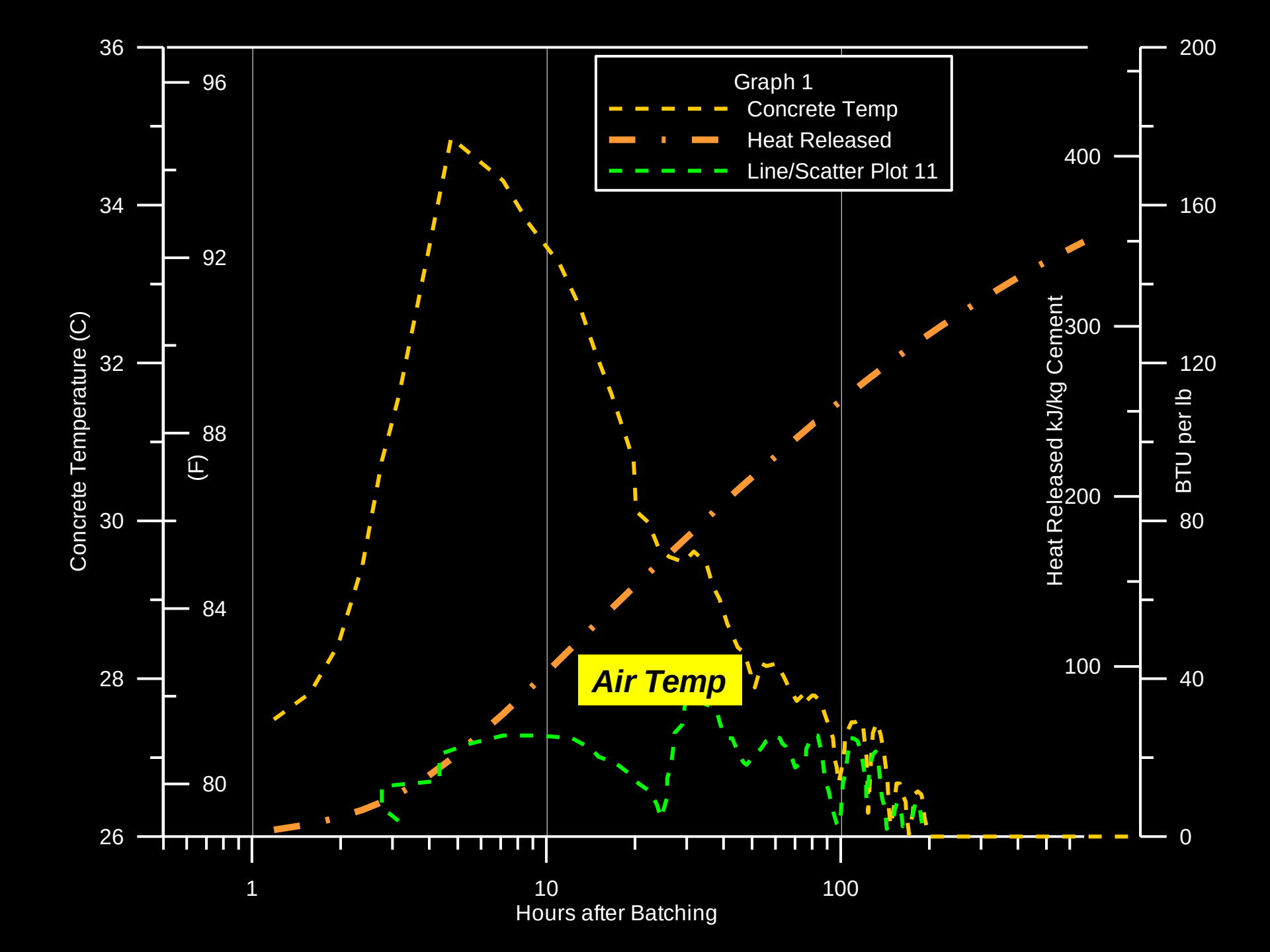
Max Degree of Hydration
= 350 / 450 BTU/lb cement = 80%

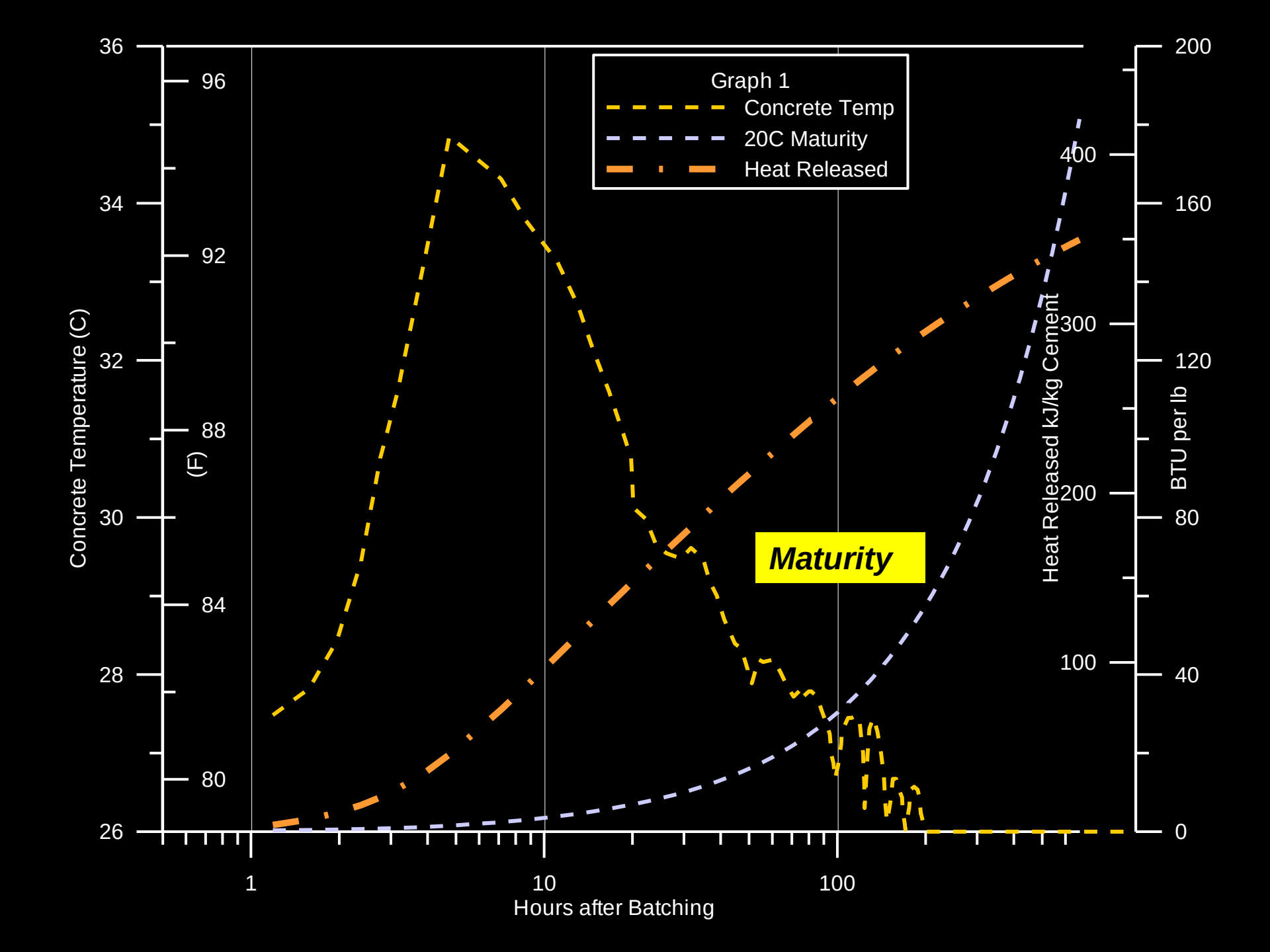
Max Cum. Heat Output
= 350 kj/kg cement

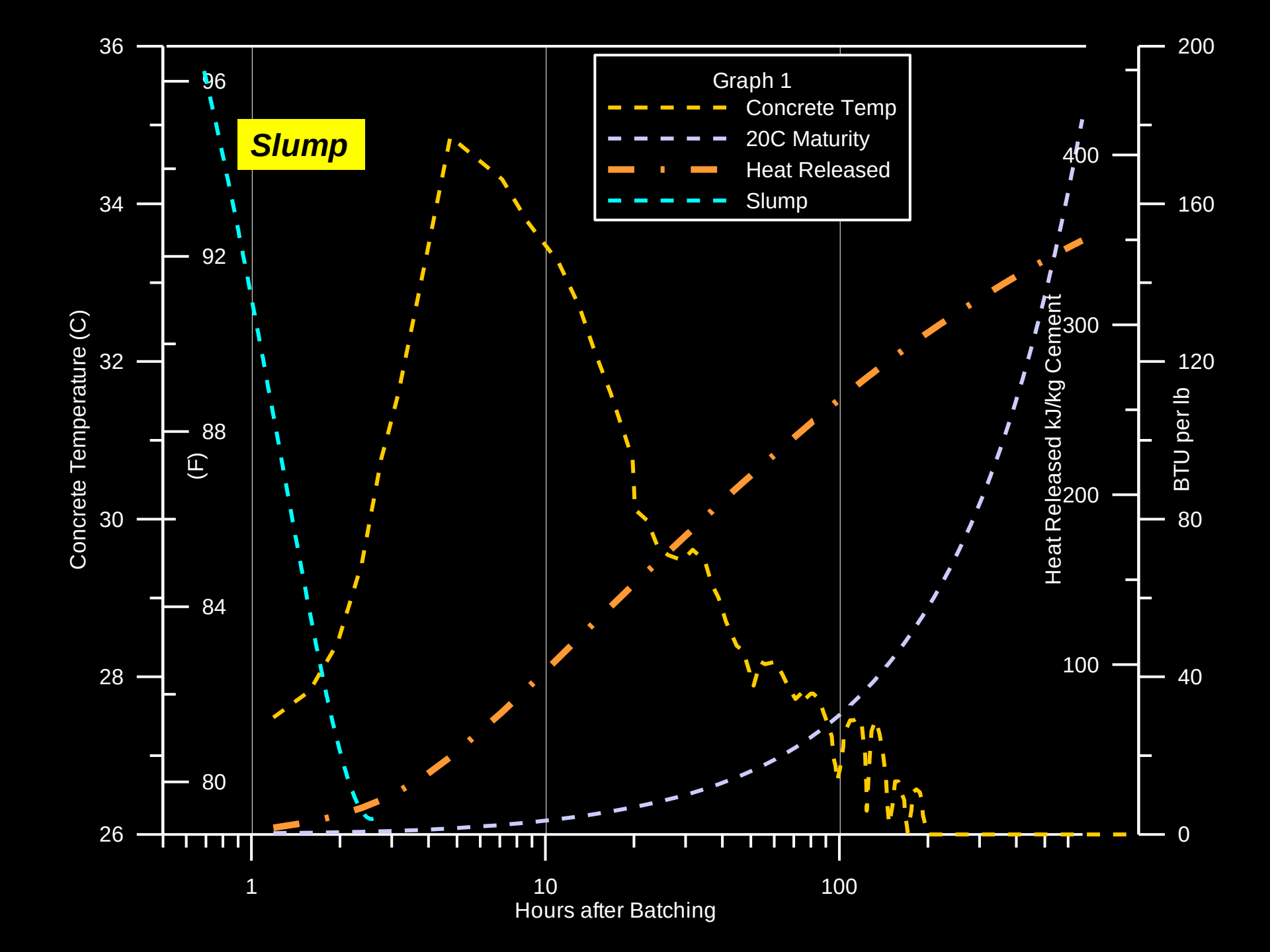

Days After Batching
0
7
14
21
28
Compressive Strength (mPa)
(psi)
Maturity Equivalent Hours @ 20C
0
5
10
15
20
25
0
500
1000
1500
2000
2500
3000
3500
4000
0
100
200
300
400
500
600
700
800
900
1000
0
200
400
600
Hours After Batching
Actual Data
FHP Maturity Function
ACI Comm. 209
Maturity Hours
Log Fit

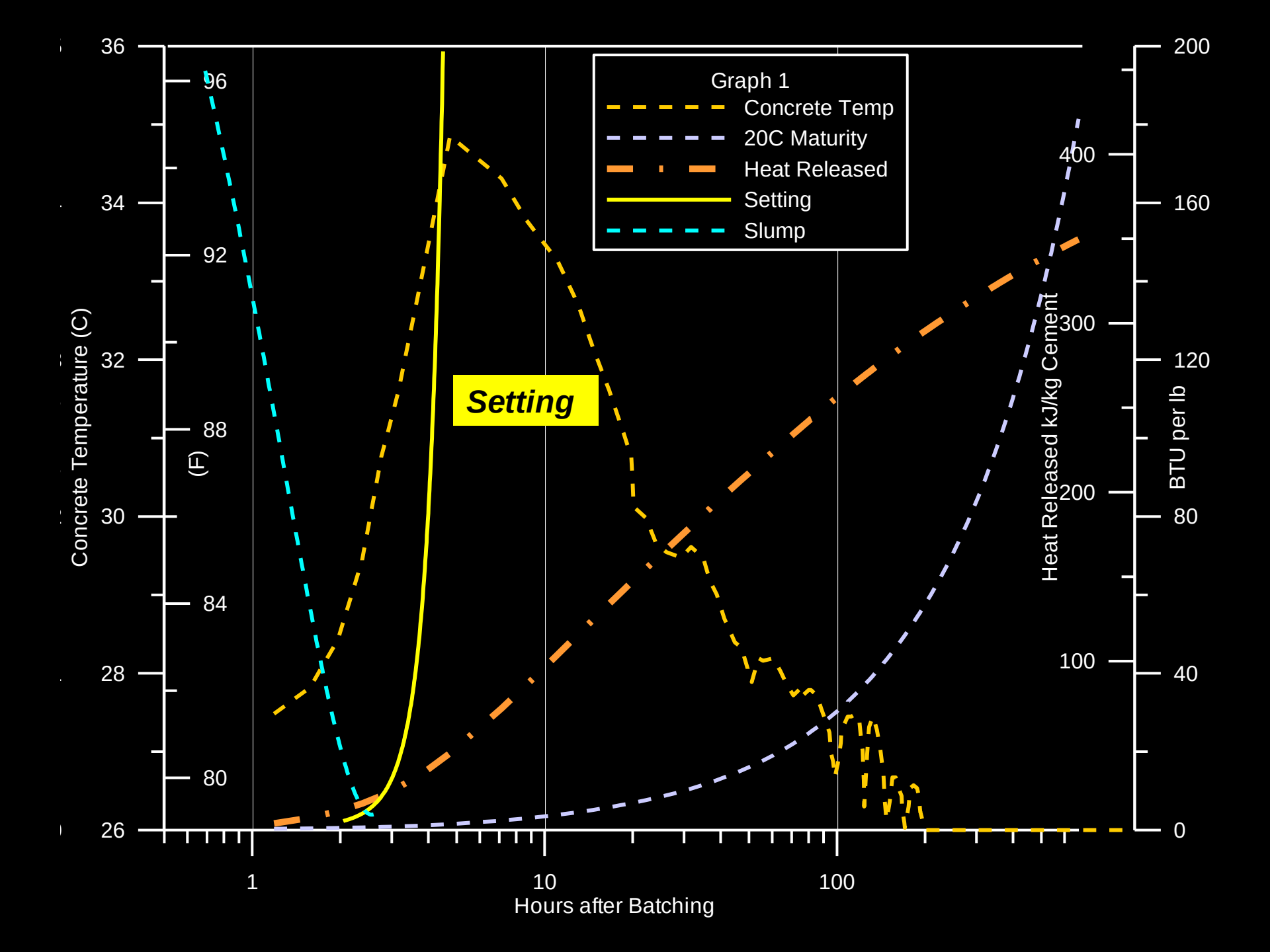

Graph 1
Heat Released
Heat Evolution
Concrete Temperature (C)
(F)
Heat Released kJ/kg Cement
BTU per lb
Hours after Batching
36
34
32
30
28
26
96
92
88
84
80
400
300
200
100
200
160
120
80
40
0
2
1
1
10
100

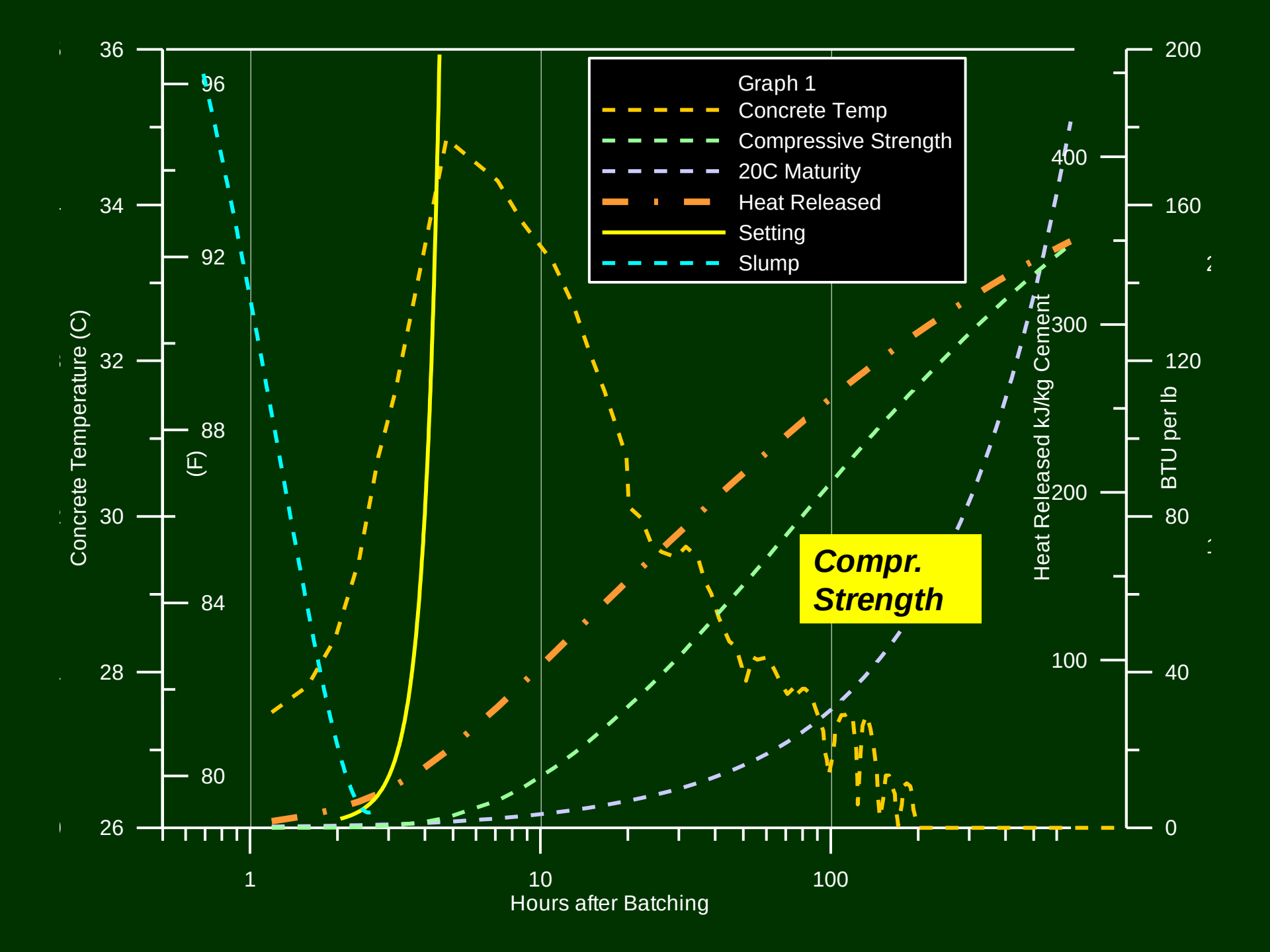

Graph 1
Concrete Temp
Heat Released
Concrete Temp
Concrete Temperature (C)
(F)
Heat Released kJ/kg Cement
BTU per lb
Hours after Batching
36
34
32
30
28
26
96
92
88
84
80
400
300
200
100
200
160
120
80
40
0
1
10
100


Graph 1
Concrete Temp
Heat Released
Line/Scatter Plot 11
Air Temp
Concrete Temperature (C)
(F)
Heat Released kJ/kg Cement
BTU per lb
Hours after Batching
36
34
32
30
28
26
96
92
88
84
80
400
300
200
100
200
160
120
80
40
0
1
10
100


Graph 1
Concrete Temp
20C Maturity
Heat Released
Maturity
Concrete Temperature (C)
(F)
Heat Released kJ/kg Cement
BTU per lb
Hours after Batching
36
34
32
30
28
26
96
92
88
84
80
200
160
120
80
40
0
400
300
200
100
1
10
100


Graph 1
Concrete Temp
20C Maturity
Heat Released
Slump
Slump
Concrete Temperature (C)
(F)
Heat Released kJ/kg Cement
BTU per lb
Hours after Batching
36
34
32
30
28
26
96
92
88
84
80
200
160
120
80
40
0
400
300
200
100
1
10
100


Graph 1
Concrete Temp
20C Maturity
Heat Released
Setting
Slump
Setting
Concrete Temperature (C)
(F)
Heat Released kJ/kg Cement
BTU per lb
Hours after Batching
36
34
32
30
28
26
96
92
88
84
80
200
160
120
80
40
0
400
300
200
100
1
10
100

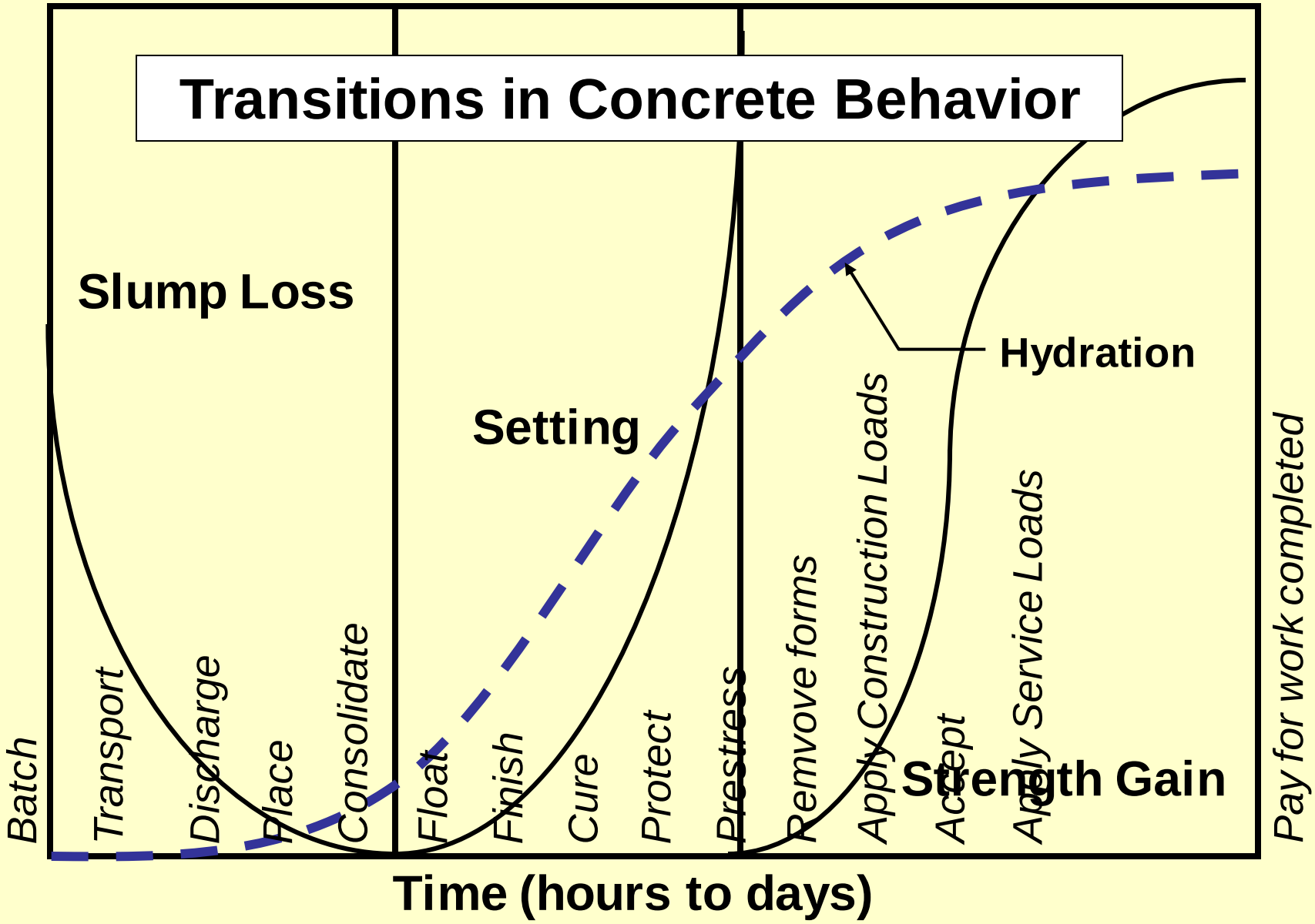

Graph 1
Concrete Temp
Compressive Strength
20C Maturity
Heat Released
Setting
Slump
Compr. Strength
Concrete Temperature (C)
(F)
Heat Released kJ/kg Cement
BTU per lb
Hours after Batching
36
34
32
30
28
26
96
92
88
84
80
400
300
200
100
200
160
120
80
40
0
1
10
100

- Rapid changes in slump & setting
  = early and short-fuse events

- Hydration just getting good start by end of slump-loss & setting periods

- Heat-release and maturity
  = continuous functions over entire period

- Tracking changes requires multiple testing specialists, working quickly.


Transitions in Concrete Behavior
Slump Loss
Setting
Hydration
Strength Gain
Batch
Transport
Discharge
Place
Consolidate
Float
Finish
Cure
Protect
Prestress
Remvove forms
Apply Construction Loads
Accept
Apply Service Loads
Pay for work completed
Time (hours to days)

Allen Face's Dictum:

Allen Face's Dictum:

"...down inside [recently cast] concrete,

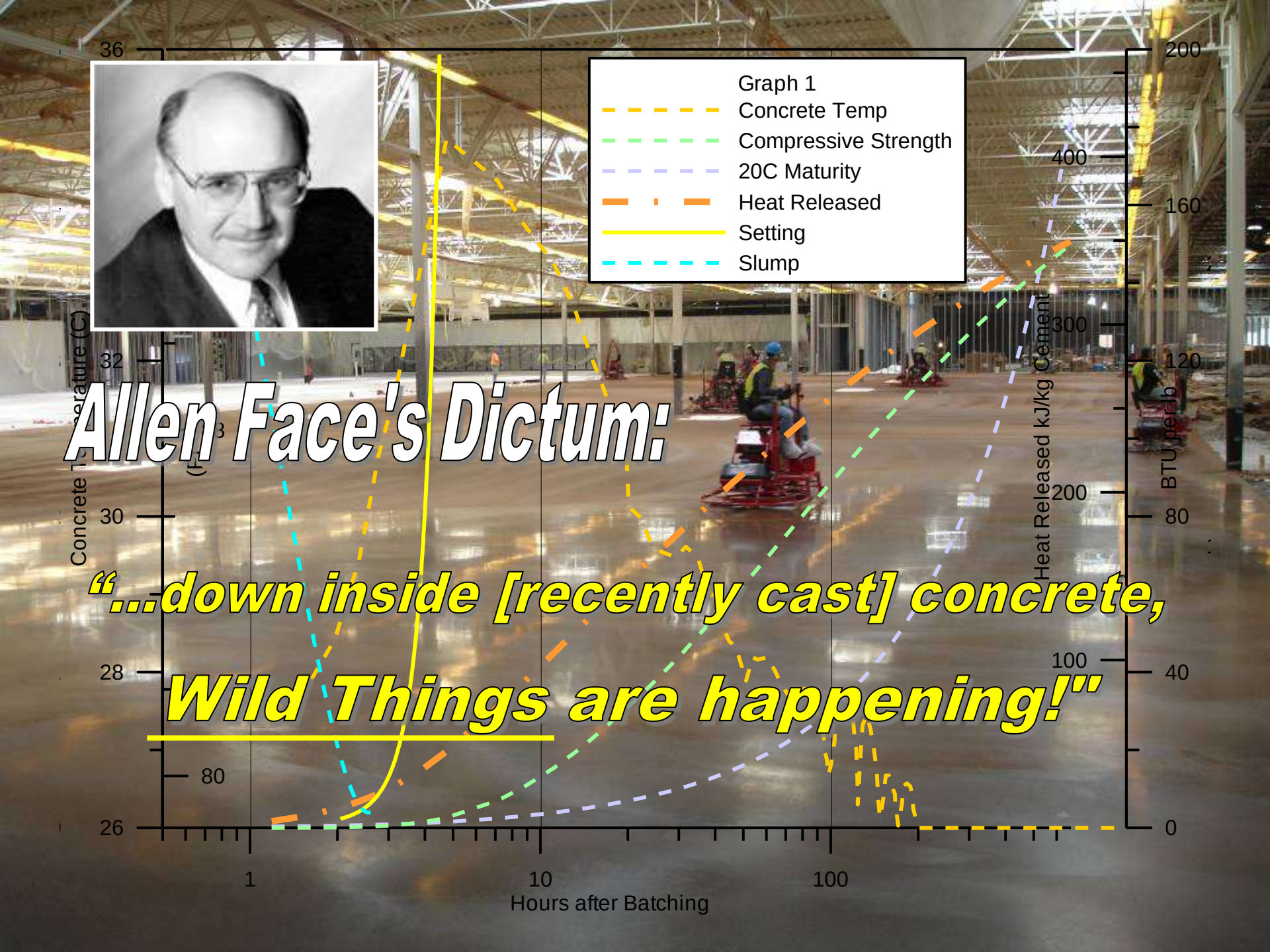
Allen Face's Dictum:

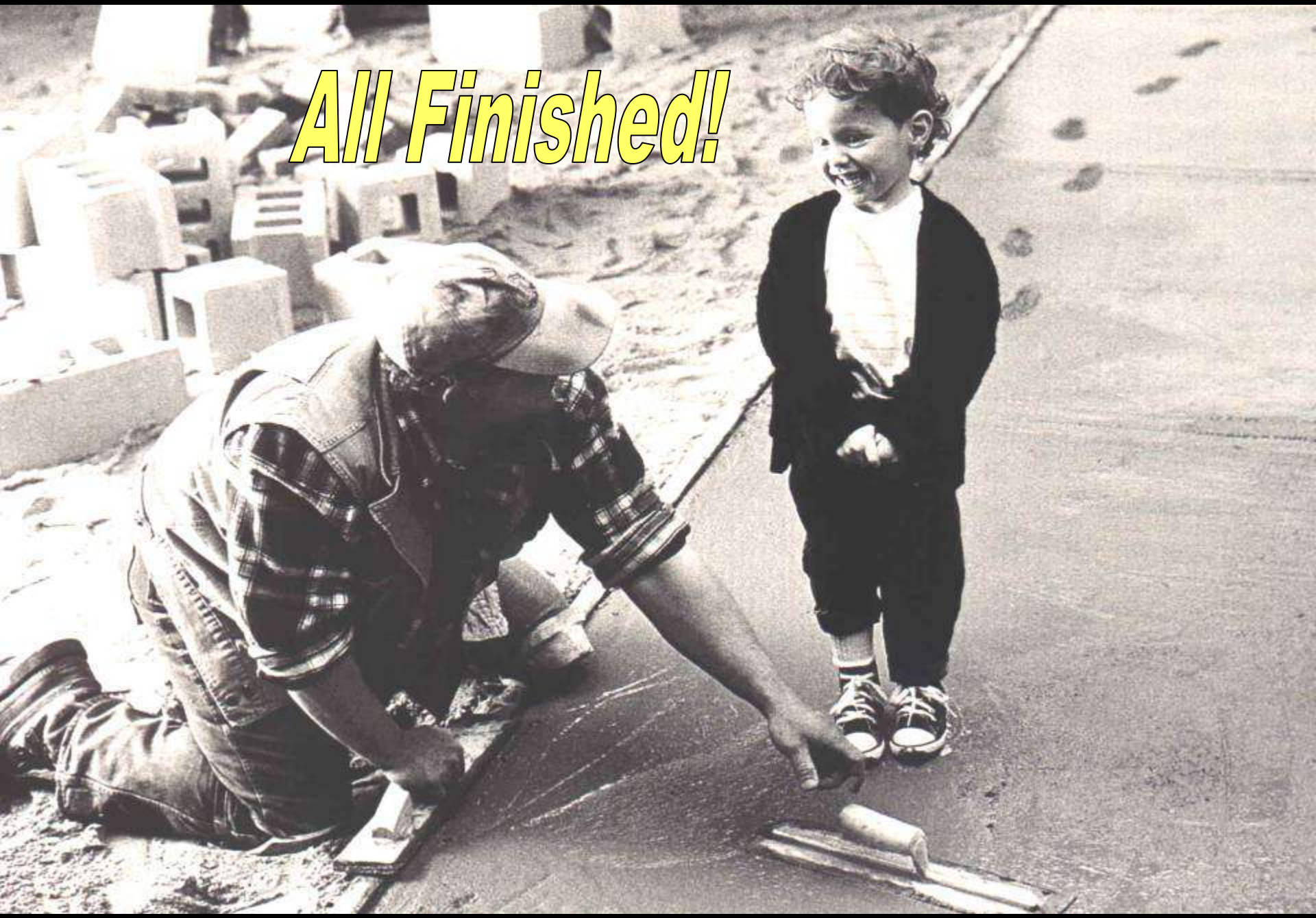
"...down inside [recently cast] concrete,

Wild Things are happening!"

Allen Face's Dictum:

"...down inside [recently cast] concrete, Wild Things are happening!"




All Finished!