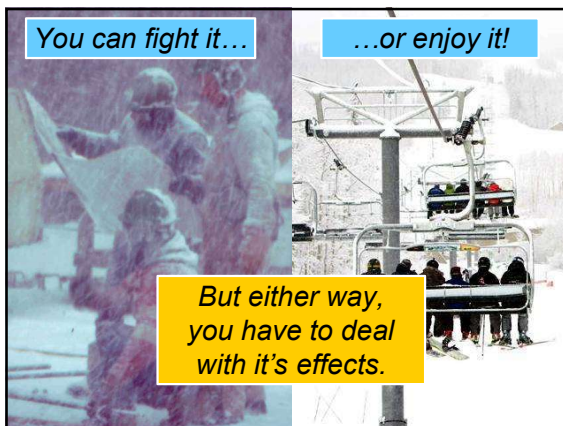
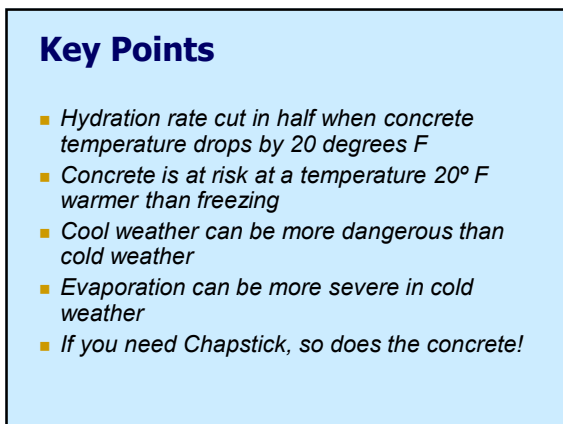




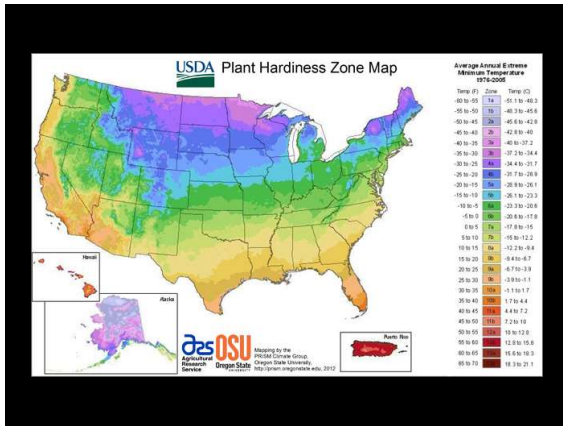
1



18



19



21

Potential Advantages of Cold Weather Concrete

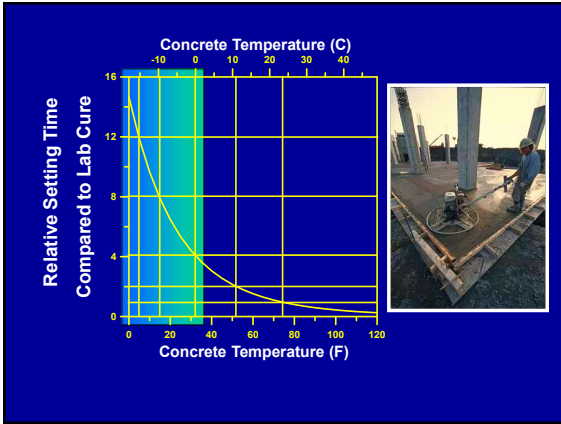
- Higher long-term in-place strength
- Higher cylinder strength
- Slower rate of slump loss
 - More time to transport and place
 - More tolerance to delays

25

More Potential Advantages of Cold Weather Concrete

- Slower setting time
 - More time to finish
- Cooler cement
- More predictable materials temperatures


26



27

Potential Disadvantages of Cold Weather Concrete

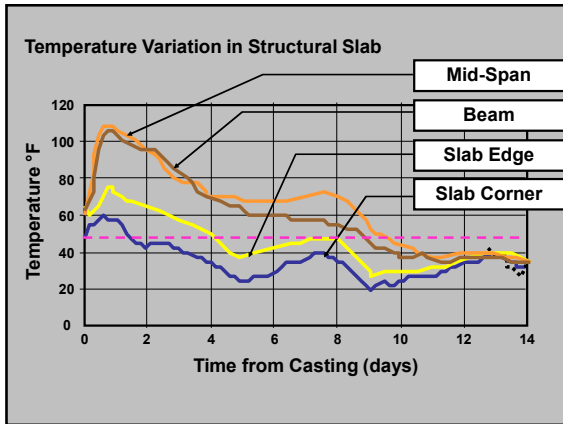
- Slower *rate* of strength gain
 - Delayed form & shore removal
- Slower setting time
 - Delayed finishing
- Edge vs. interior temperature difference
 - Thermal cracking
 - Variable strength due to variable temperature



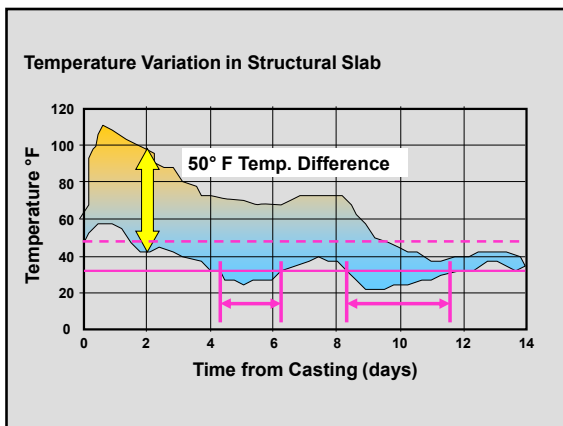
28



29



30



31

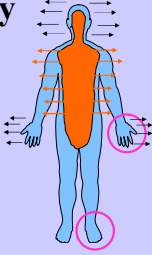
Potential Disadvantages of Cold Weather Concrete

- Logistics of plant & equipment in cold/freezing weather
- Evaporation more severe but wet-cure more difficult
- Concrete freezing
- **Personnel risk of cold injury**

32

Cold Injury


- Drying, Chapping
- Frost Bite
- Hypothermia (“Exposure”)
 - Reduction in core body temperature



33

Cold Injury

- Drying, Cracking
- Delayed setting
- Delayed strength-gain
 - Fatal mismatch between lab and field
- Localized early freezing

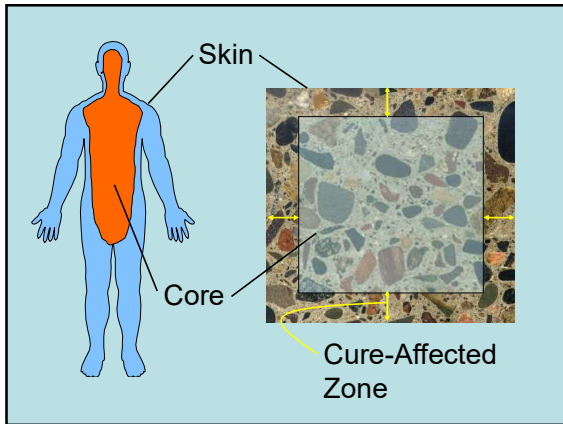


34

Basis for Comparison

People	Concrete
Metabolism	Hydration
Temp. controlled	Temp. controlled
Water-based	Water-based
Drying	Drying
Freezing	Freezing
Wide range of exposure conditions	Wide range of exposure conditions
Narrow range of optimum conditions	Narrow range of optimum conditions

35




36

How do humans define
Cold Weather?
How "Cold" is "Cold?"

37

But the real issue is:
Will the weather conditions impair
the comfort, health, or safety of the
person?



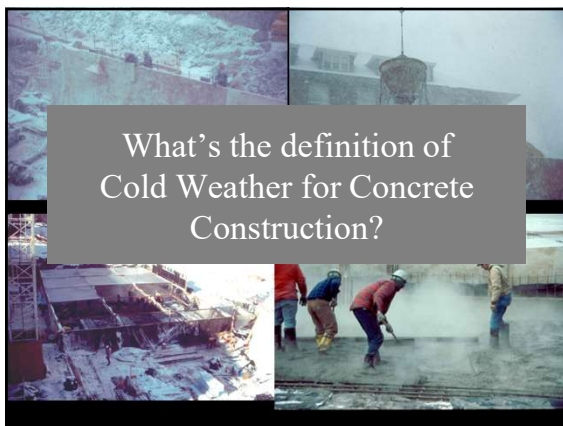
41

A Functional Definition of Cold Weather for People

When Weather is	To Cause
<ul style="list-style-type: none">• Cold enough• Wet enough• Dry enough• Windy enough• For Long enough	<ul style="list-style-type: none">• <i>Discomfort</i>• <i>Seek protection of clothing or shelter</i>• <i>Chapped lips, dry, cracked skin</i>• <i>Numbness or burning</i>• <i>Frostbite</i>• <i>Hypothermia</i>



42



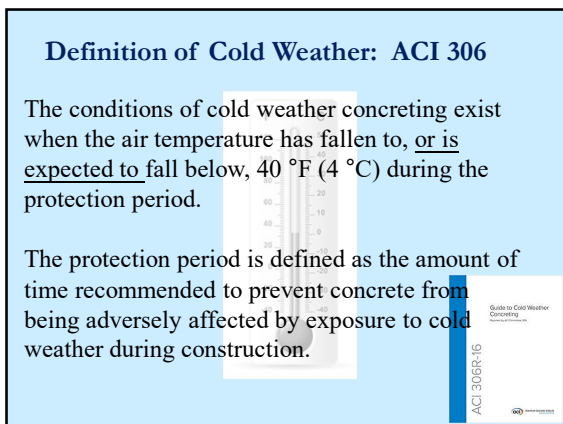
What's the definition of Cold Weather for Concrete Construction?

43

Definition of Cold Weather: ACI 306

The conditions of cold weather concreting exist when the air temperature has fallen to, or is expected to fall below, 40 °F (4 °C) during the protection period.

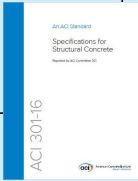
The protection period is defined as the amount of time recommended to prevent concrete from being adversely affected by exposure to cold weather during construction.



45

**Definition of Cold Weather:
ACI 301**

When the average of the highest and lowest ambient temperature from midnight to midnight is expected to be less than 40°F for more than three successive days

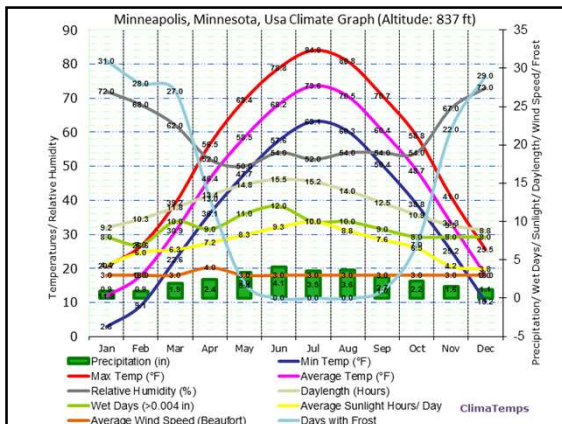


46

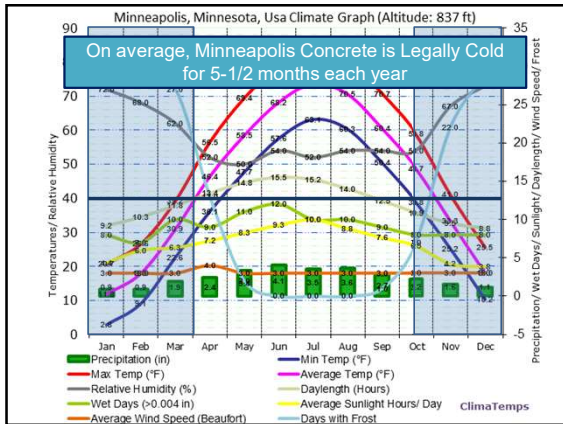


On whose authority are we "Expecting" cold weather?

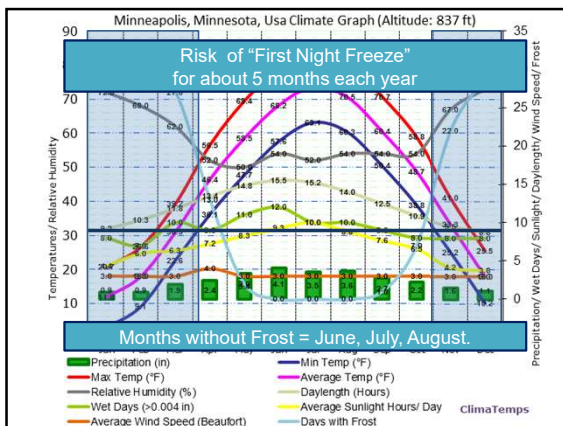
47



48



49



50


But the real issue is:

Will the weather conditions impair the behavior of the fresh or hardened concrete?

52


A Functional Definition of Cold Weather for Concrete

When Weather is	To Cause
<ul style="list-style-type: none">• Cold enough• Wet enough• Dry enough• Windy enough• For Long enough	<ul style="list-style-type: none">• <i>Delayed setting</i>• <i>Early cracking or crazing</i>• <i>Early Freezing</i>• <i>Reduced early-age strength</i>• <i>Reduced later-age strength</i>



53

How does cold weather affect people and concrete?



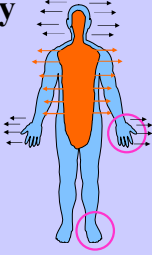
54

Drying,
Chapping,
Cracking

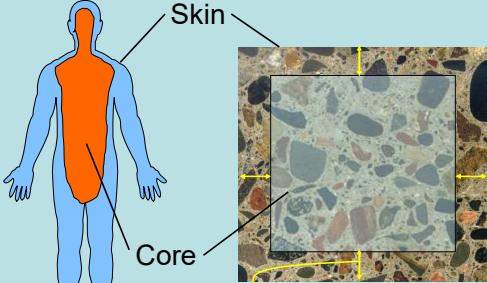
55

Cold Injury

- Drying, Chapping
- Frost Bite
- Hypothermia (“Exposure”) Reduction in core body temperature



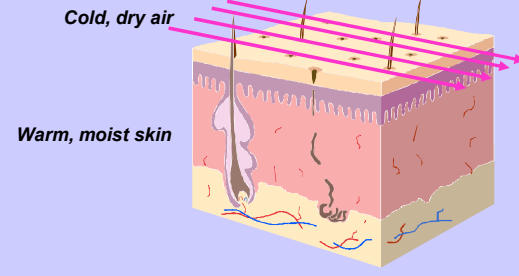
56



Labels: Skin, Core, Cure- and Cold-Affected Zone

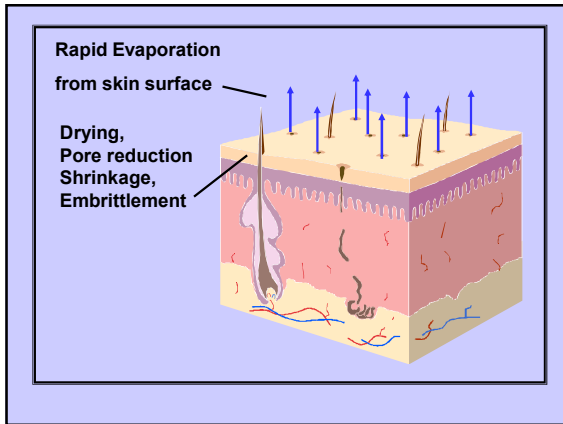
57

Skin Response to Cold Weather

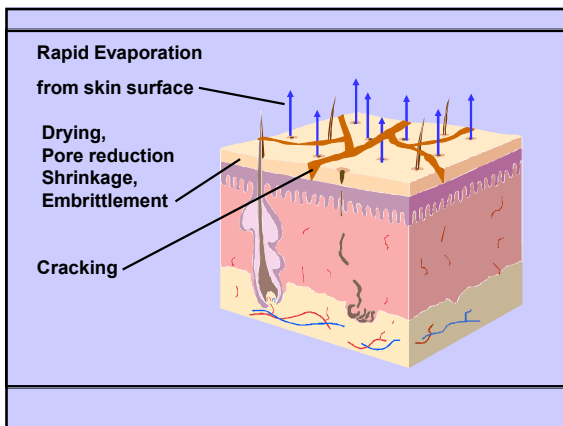


Labels: Cold, dry air, Warm, moist skin

58



59



60



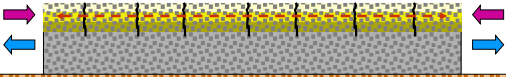
61




62

Early-Age Shrinkage Cracking

- 1.) Bleed water appears on concrete surface
- 2.) Rate of evaporation exceeds bleed rate
- 3.) Concrete surface dries....
- 4.) Concrete surface tries to shrink....



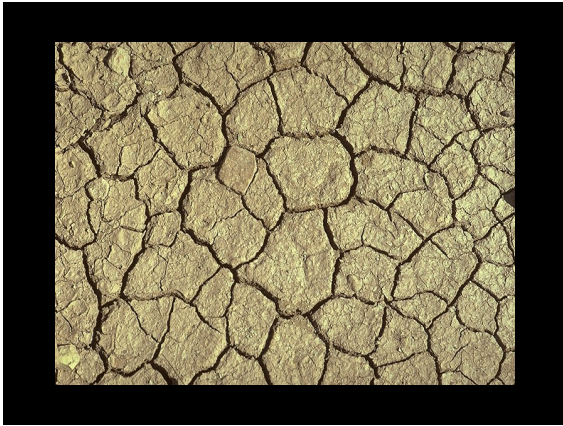
- 5.) Moist concrete resists shrinkage.
- 6.) Stress develops in soft "plastic" concrete.
- 7.) "Plastic" shrinkage cracks form



63



65



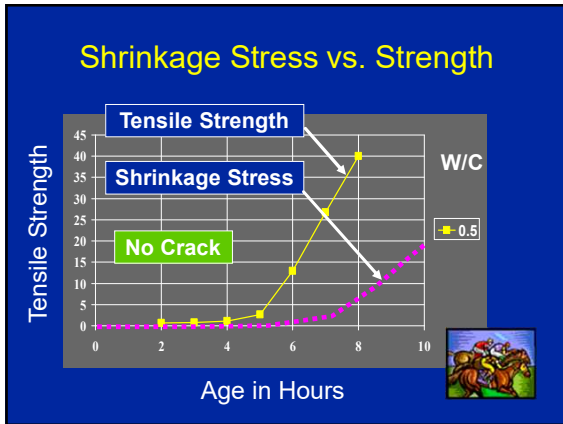
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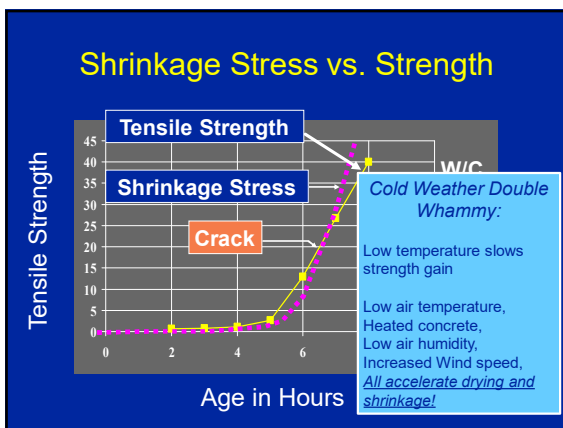
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68



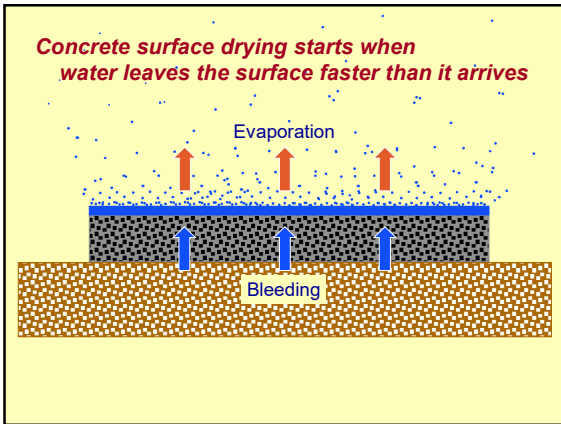
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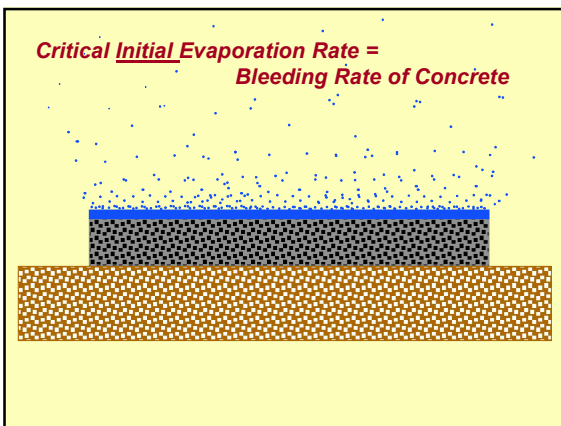
70

Conditions that increase drying & shrinkage

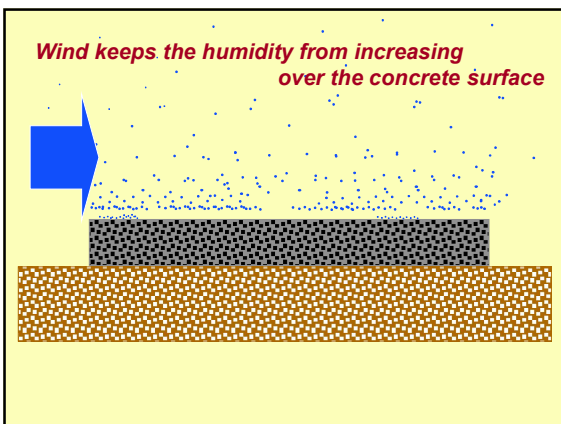
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72



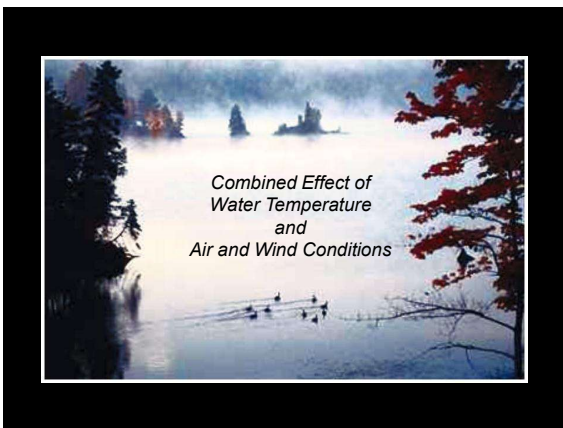
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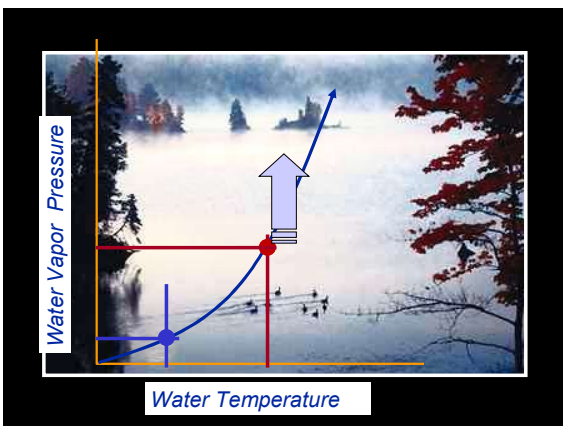
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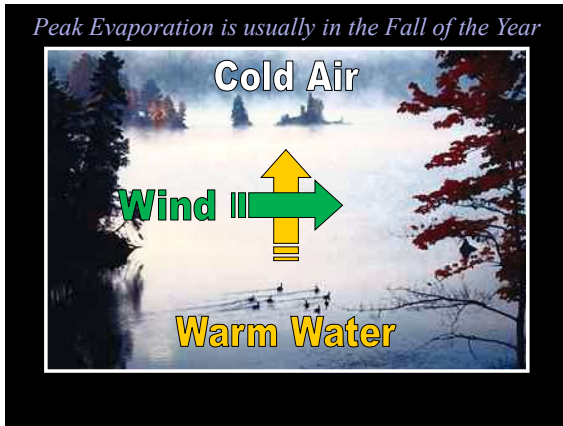
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76



77



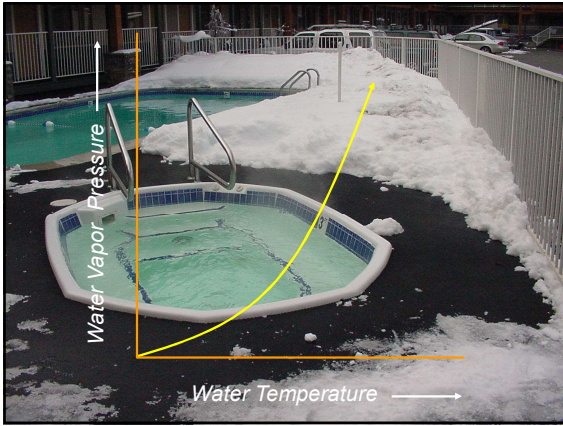
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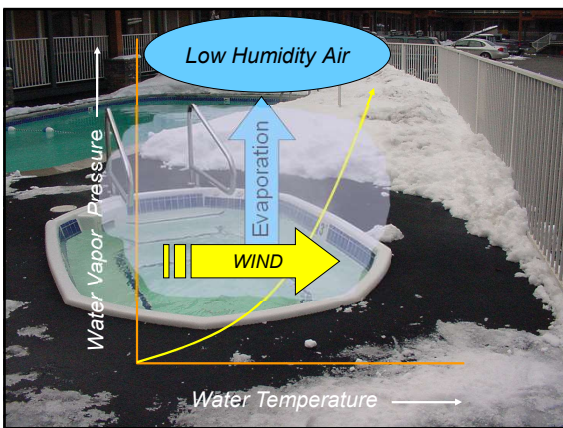
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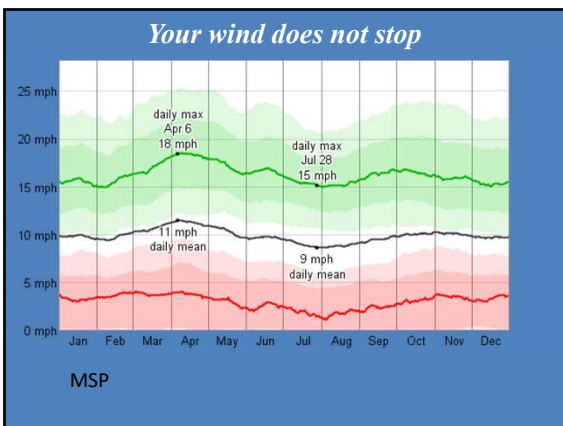
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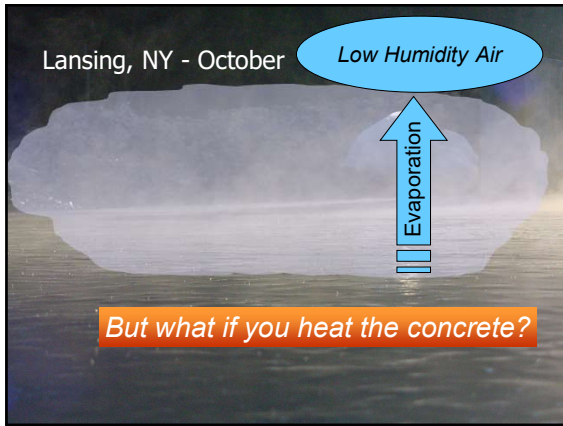
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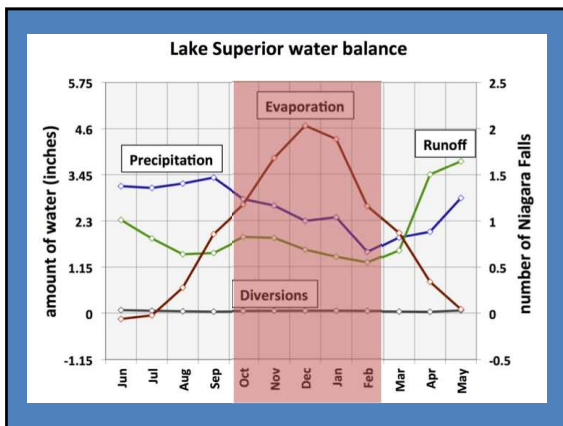
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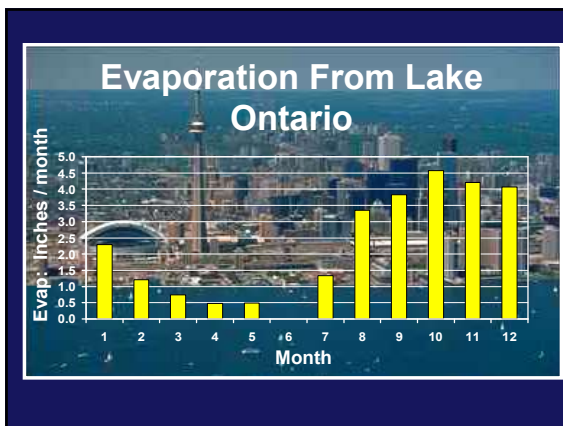
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85



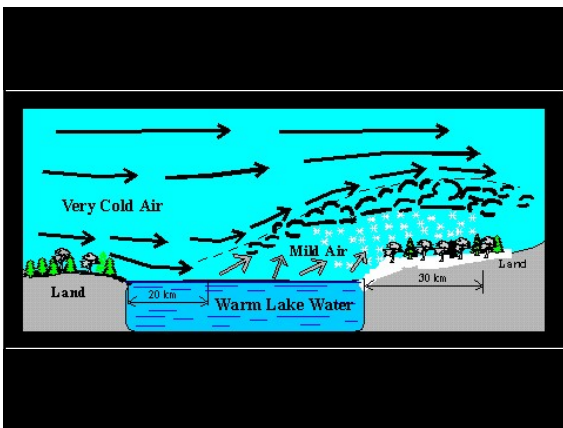
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91



92



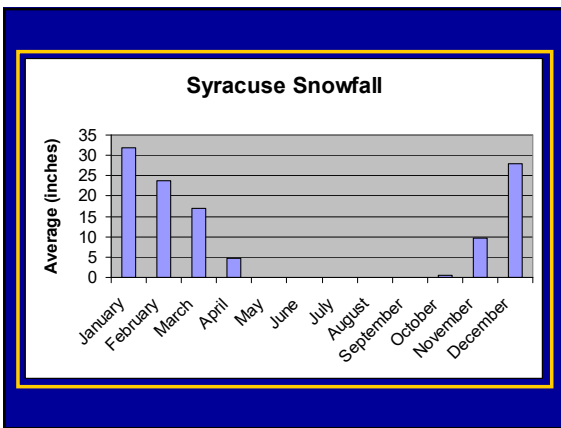
93



94



95



96

Temperature Effects

Concrete

- Localized Freezing
- Rate of Hydration
- Rate of Setting & Slump-loss
- Rate of Strength Gain
- Long-Term Strength

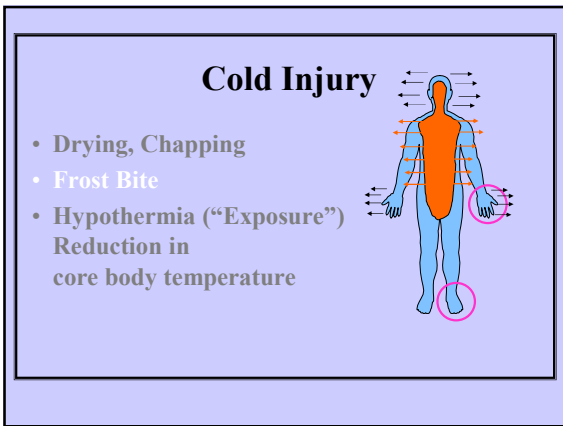
People

- Localized Freezing (Frostbite)
- Rate of Metabolism
- Hypothermia

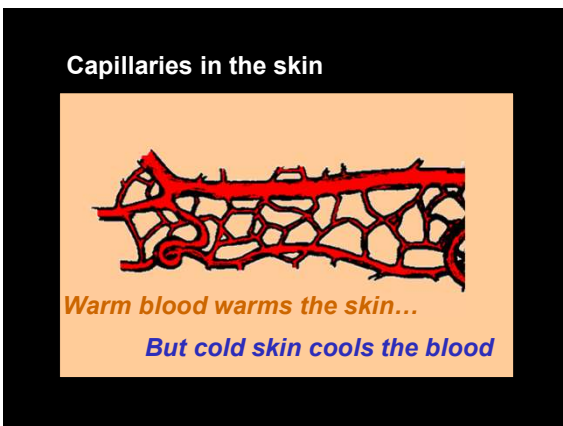
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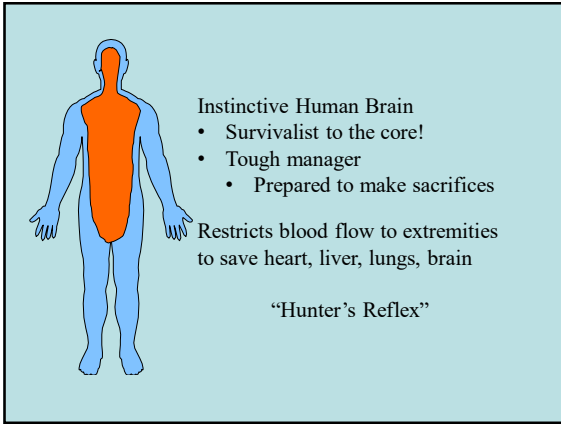
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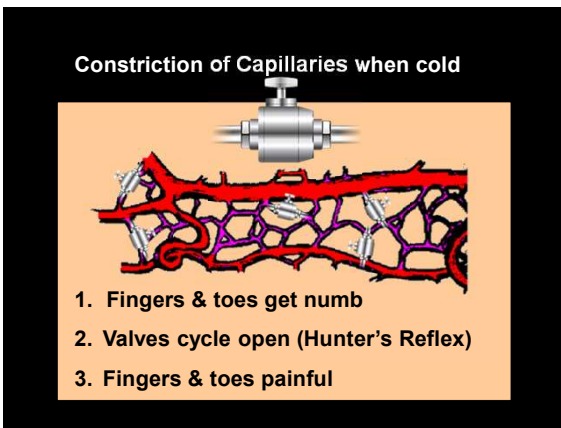
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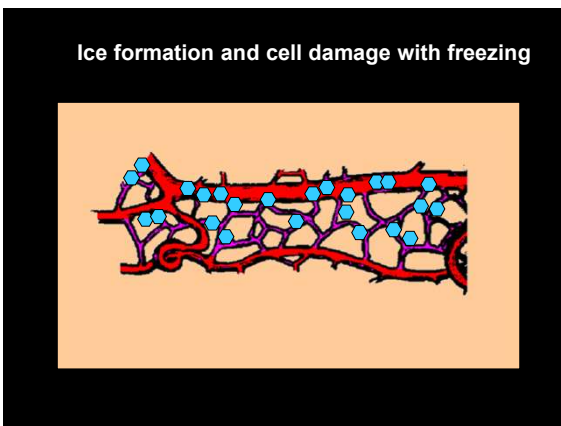
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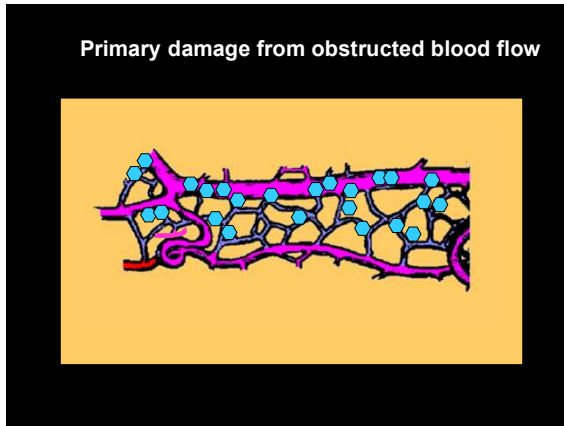
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102



103



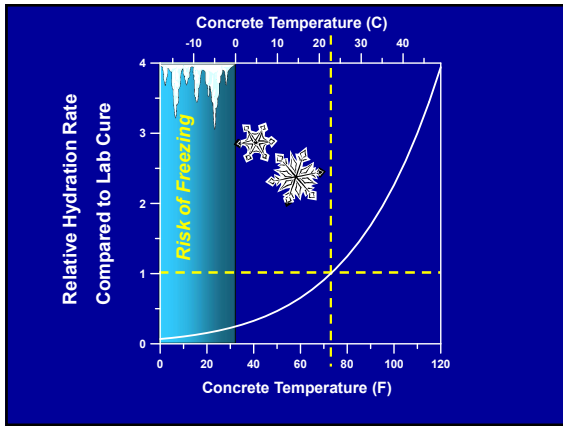
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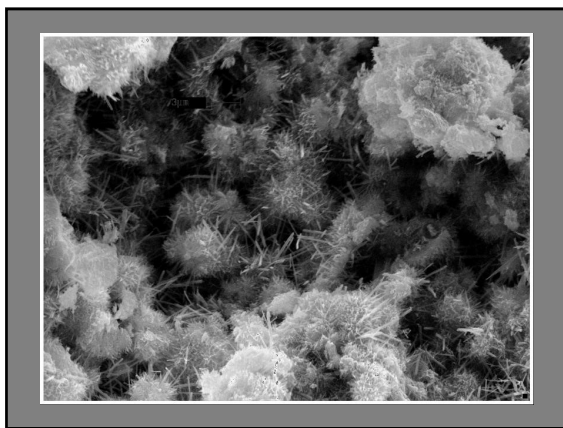
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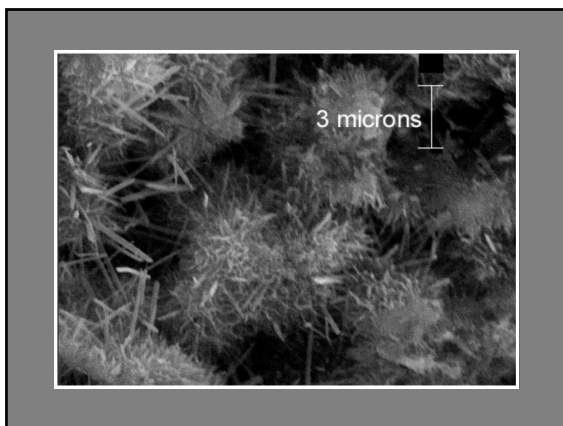
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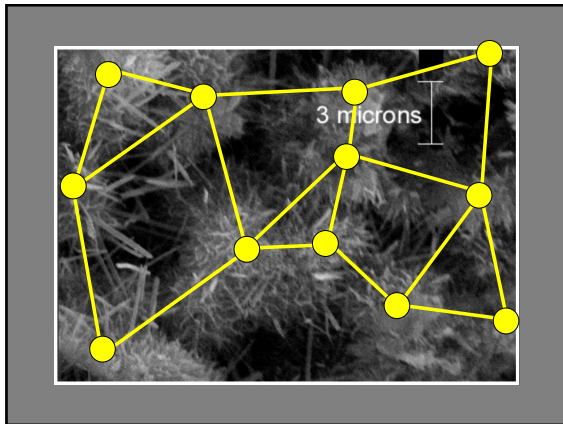
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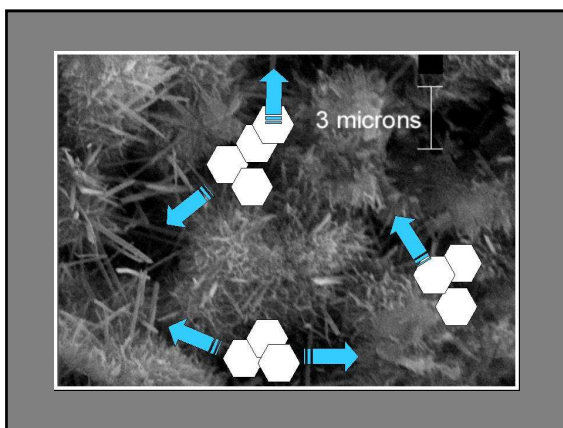
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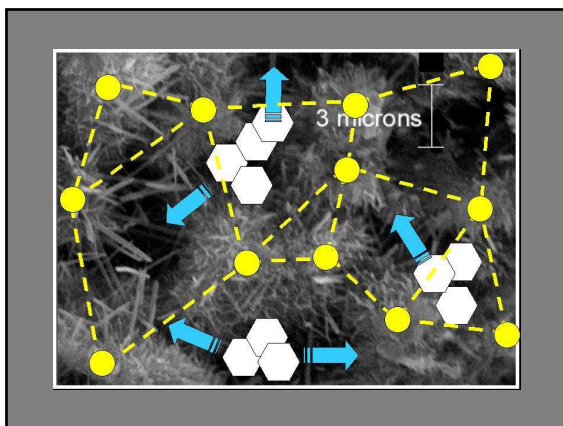
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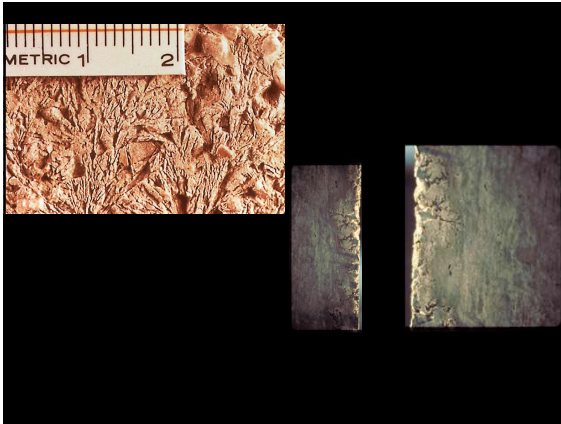
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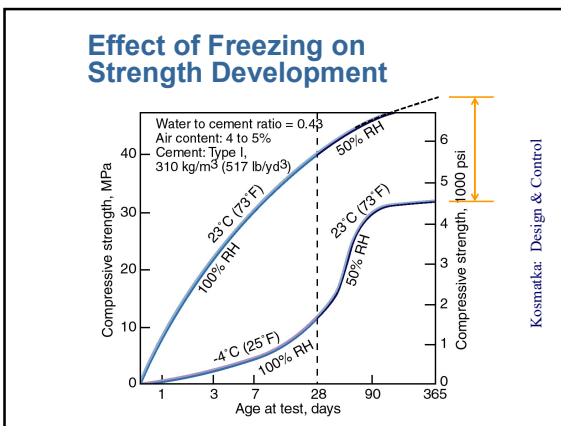
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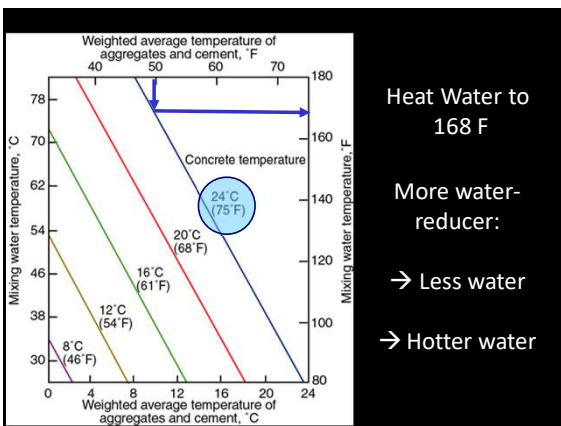
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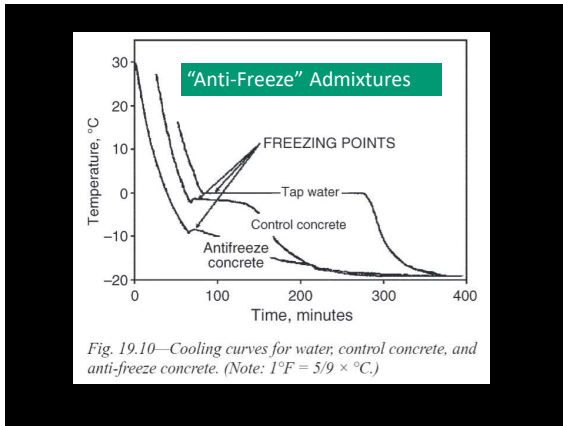
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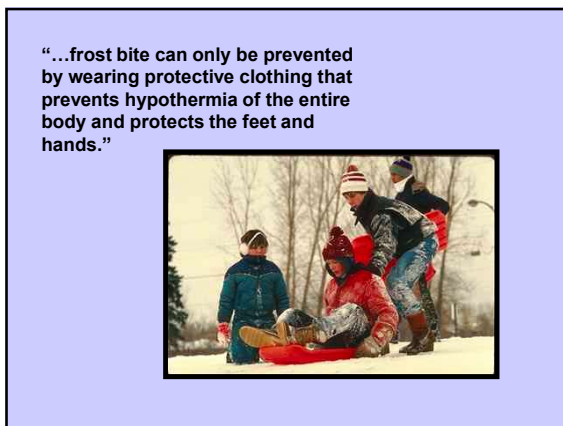
114



115



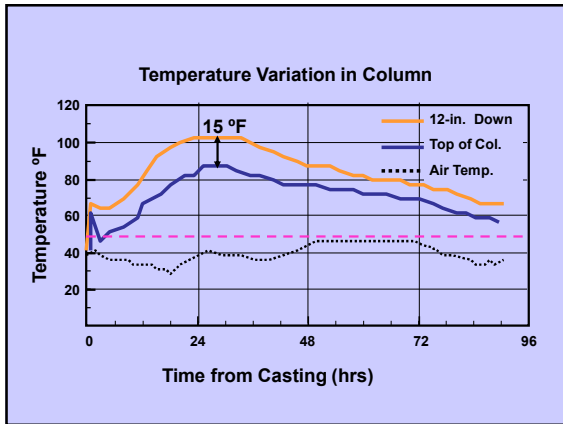
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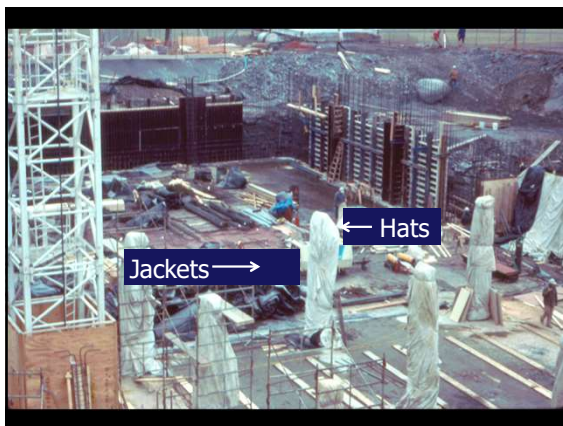
117



118



119



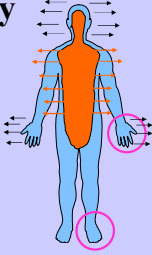
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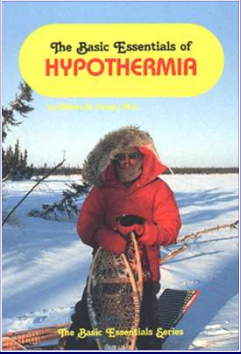
122

Cold Injury

- Drying, Chapping
- Frost Bite
- Hypothermia (“Exposure”) Reduction in core body temperature



123

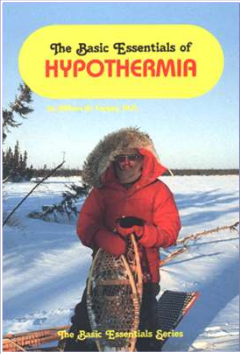


Hypothermia
Number One Killer of Outdoor Recreationalists
“Exposure”

124

Hypothermia
Lowered “Core” Temperature

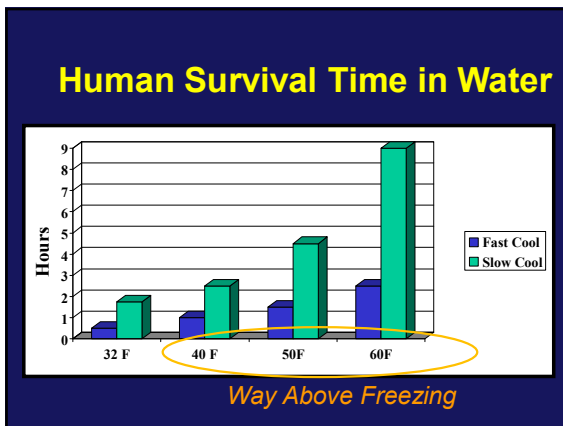
Chronic – core temp drops below **95F**, over 6 hours +
Acute -- drops in less than 2 hours
Profound -- Core temp drops below **90F**



125



126



127

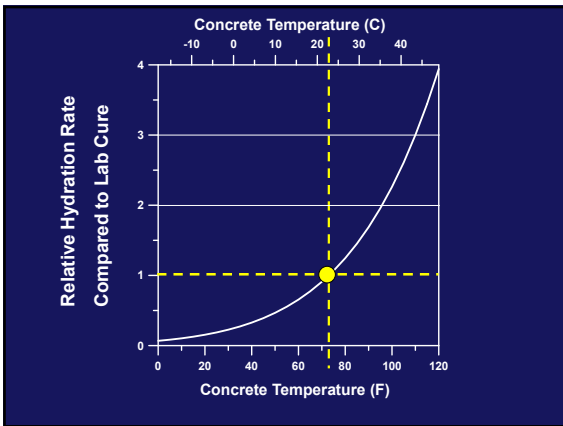
Concrete Hypothermia

Drop in concrete temperature that impairs concrete performance

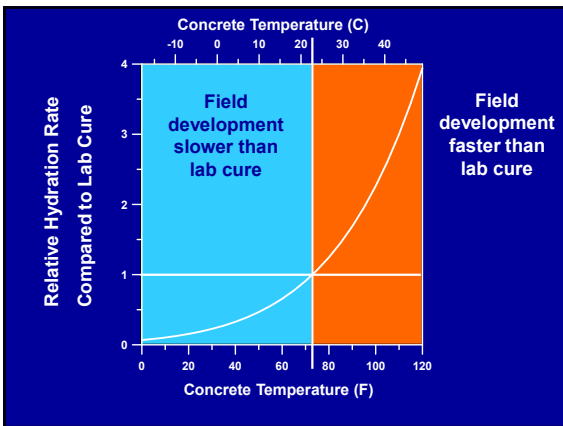
128

Concrete Temperature and Rate of Cement Hydration

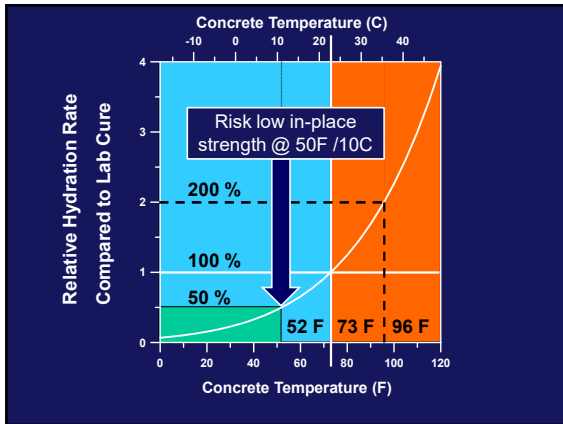
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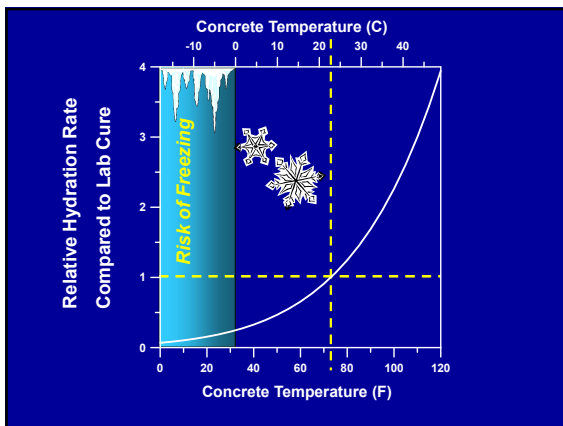
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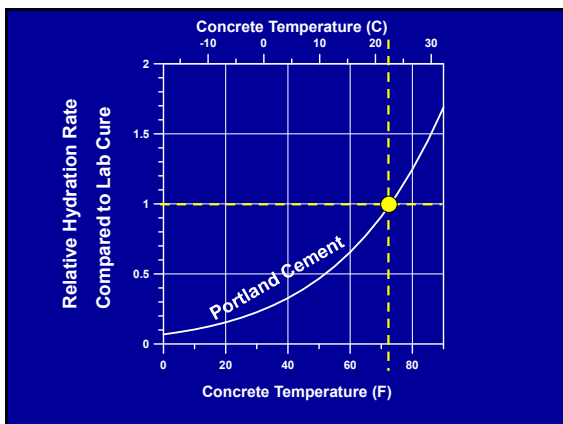
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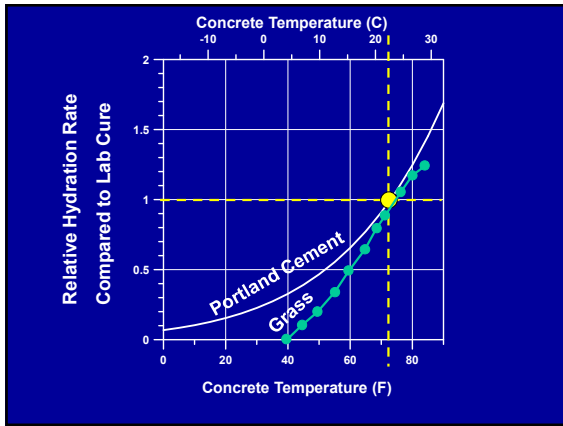
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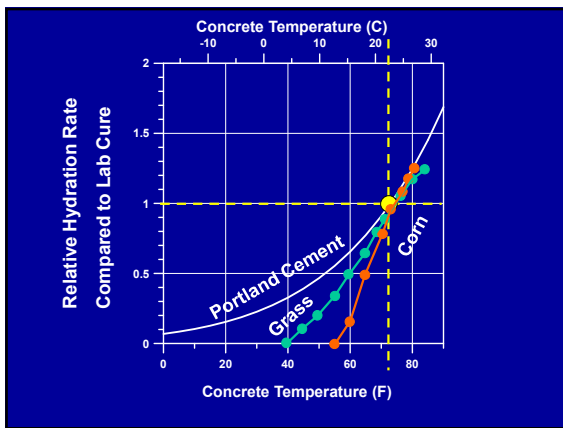
133



134



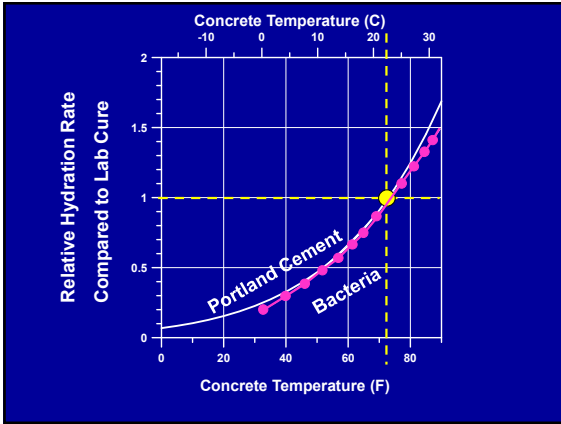
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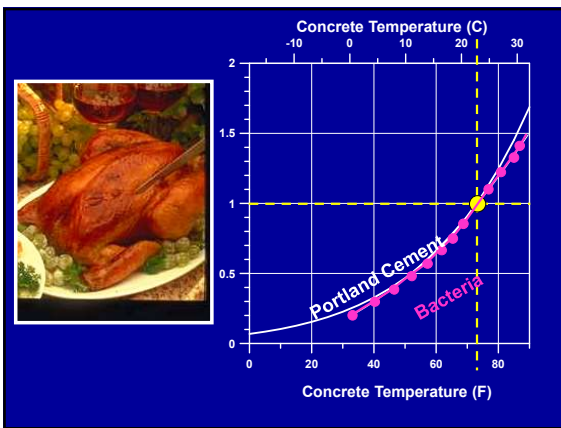
136



137



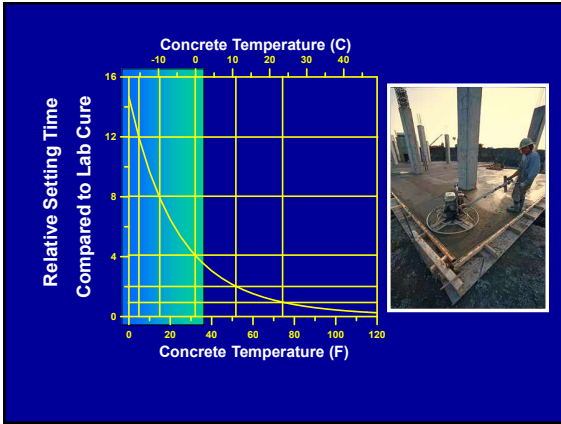
138



139



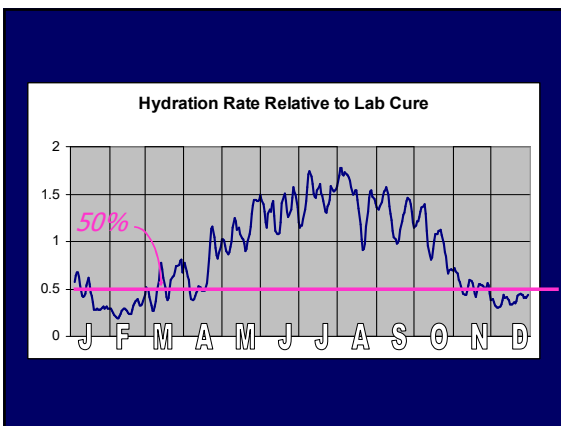
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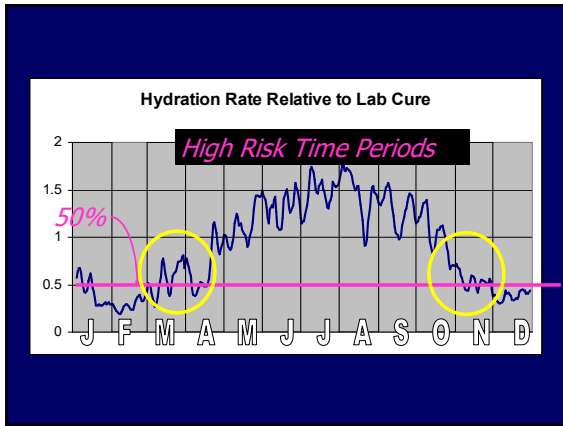
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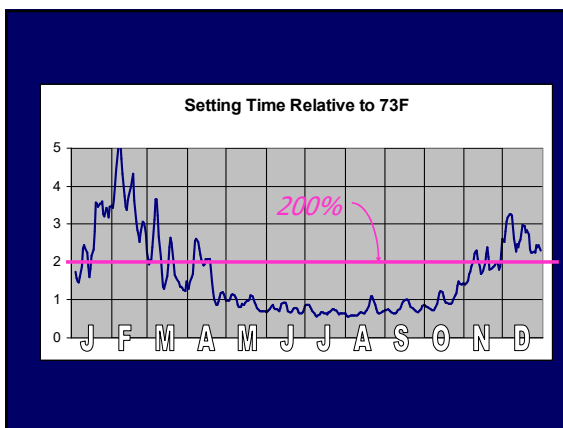
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145



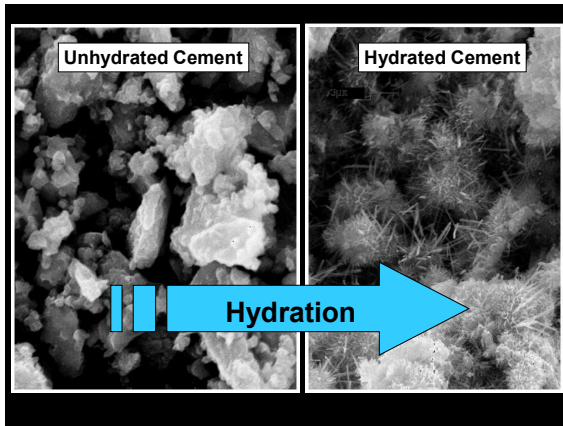
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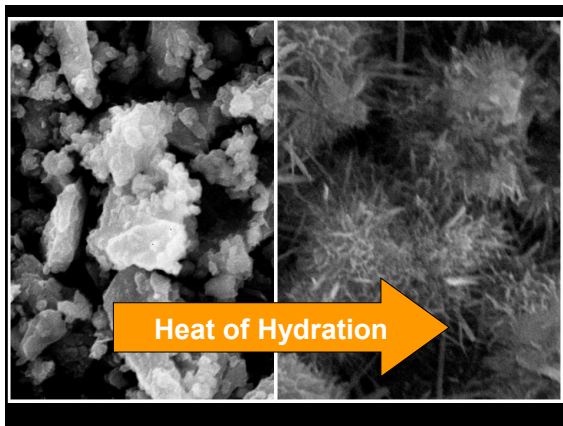
147

People	Concrete
Metabolism	Hydration
Temp. controlled	Temp. controlled
Water-based	Water-based
Drying	Drying
Freezing	Freezing
Wide range of exposure conditions	Wide range of exposure conditions
Narrow range of optimum conditions	Narrow range of optimum conditions

159



161



162

About 70 BTU/lb

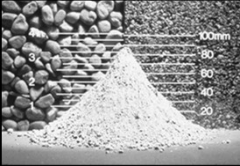

100mm
80
60
40
20
0

About 190 BTU per lb Cement

Slightly Less than 10% of Heat Energy input at Cement Plant returned to Contractor (at no extra charge)

164

Heat of Hydration



*6 Sack Mix =
564 lb x 190 BTU =
107,000 BTU / CY*

167

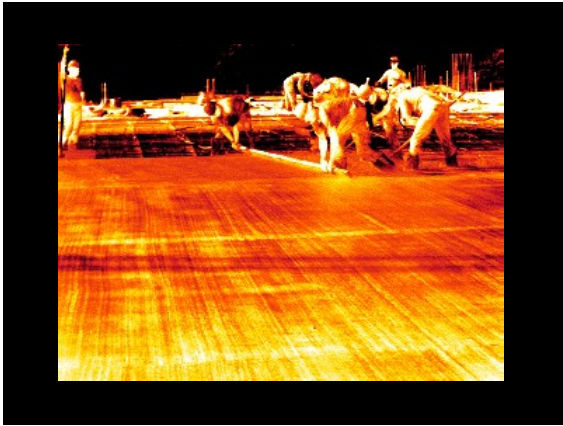


**Heat of Hydration:
13 LP Tanks / 6 Loads**

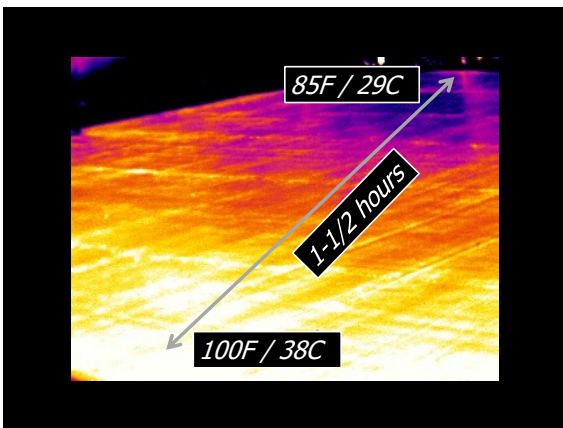
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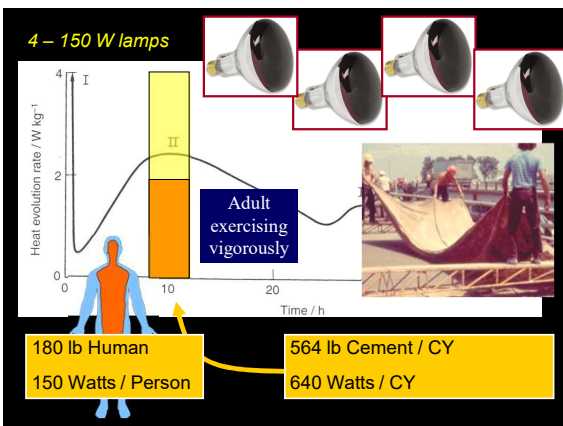
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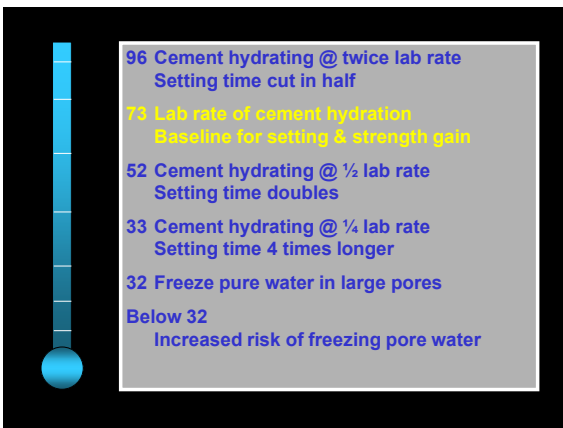
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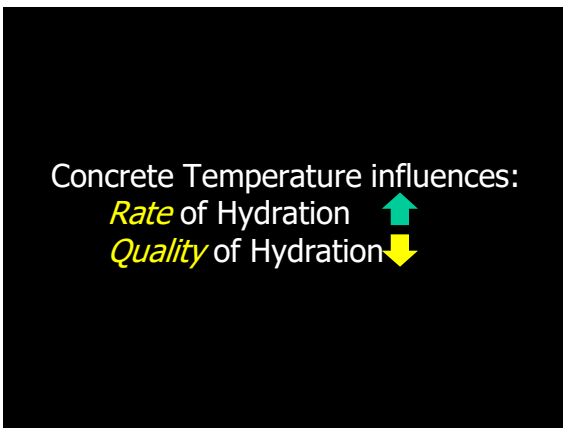
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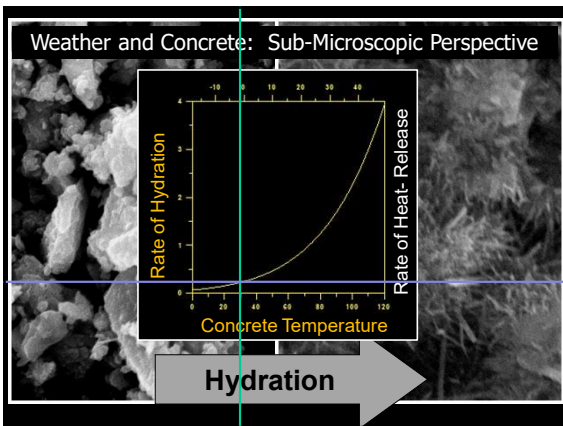
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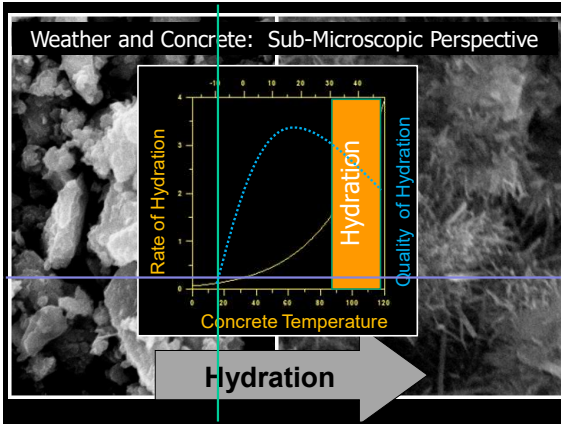
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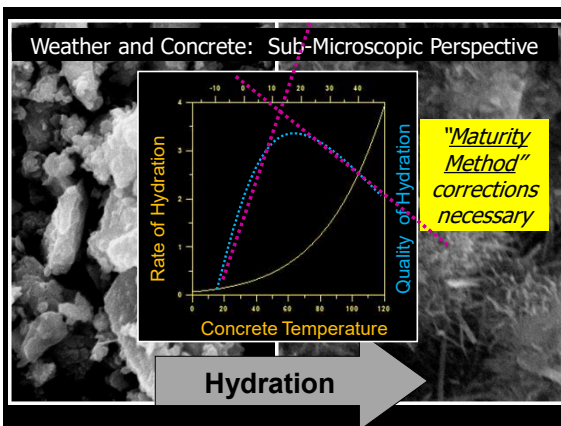
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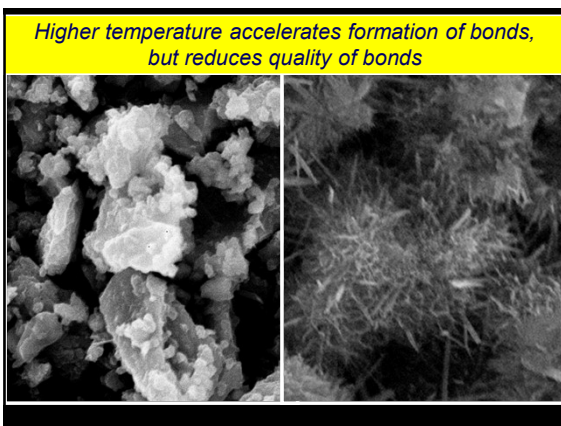
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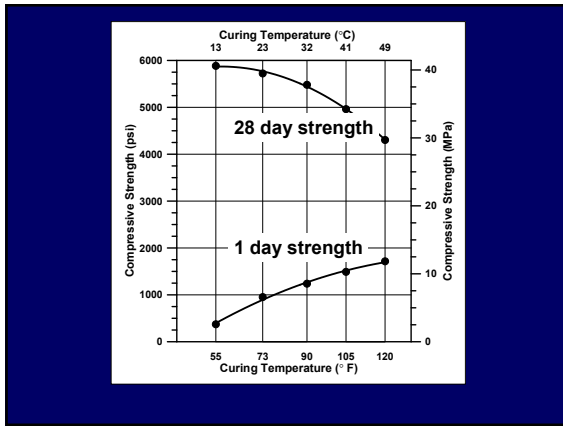
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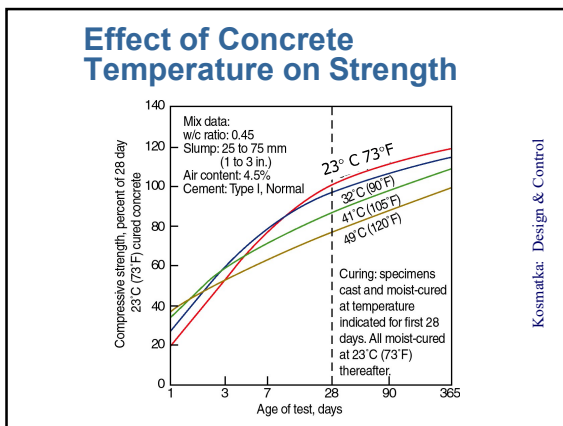
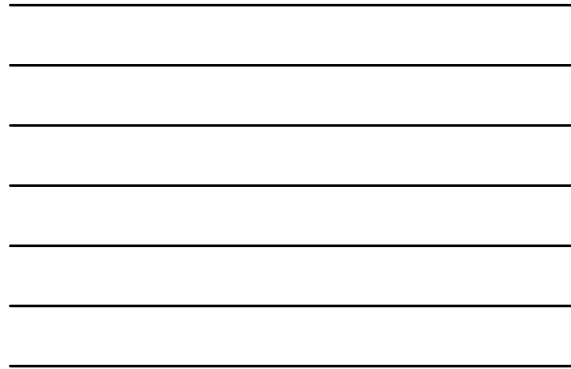
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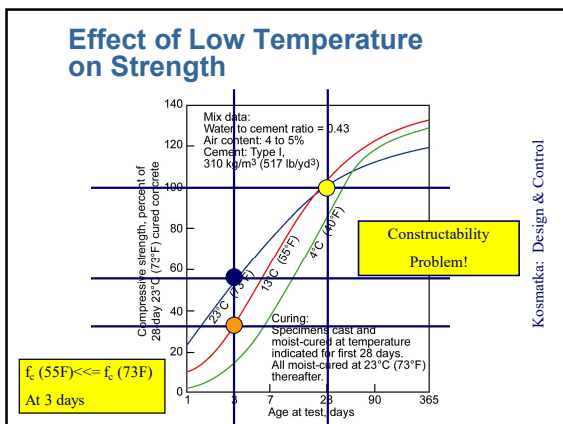
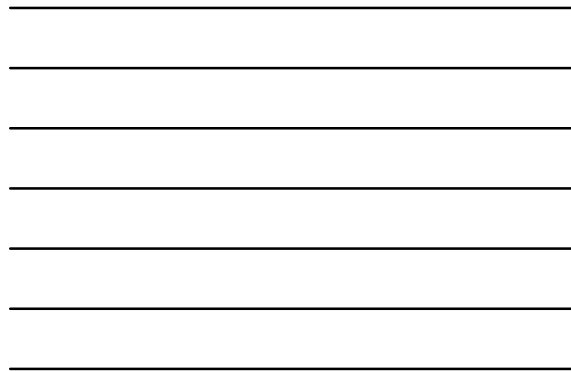
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ASTM C31-Making Cylinders

10.1.2 *Initial Curing*— Immediately after molding and finishing, the specimens shall be stored for a period up to 48 h in a temperature range from 60 and 80 °F [16 and 27 °C] and in an environment preventing moisture loss from the specimens. For concrete mixtures with a specified strength of 6000 psi [40 MPa] or greater, the initial curing temperature shall be between 68 and 78 °F [20 and 26 °C].

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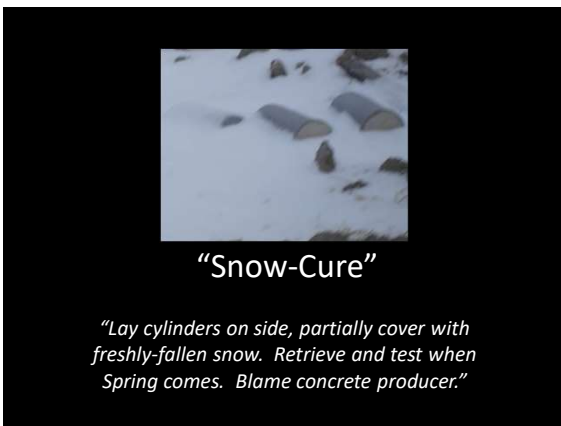
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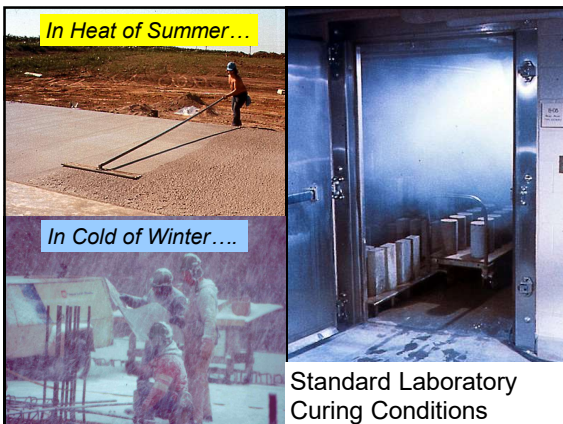
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210



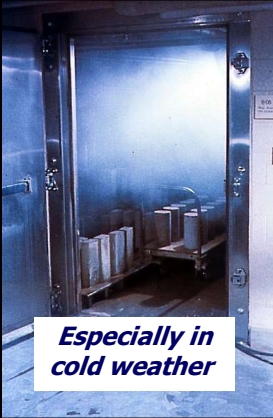
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Lab-cured test specimens evaluate quality of concrete **as delivered,**

Lab Specimens may not represent concrete strength **in-place**



Epecially in cold weather

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But **Field-Cured** specimens represent **neither** the concrete as delivered **nor** the concrete **in-place**

Epecially in cold weather!

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Recommended Practice

- Plan so as to avoid adverse exposure
- Pre-placement conference
- Modify the Micro-climate
- Monitor on site conditions
 - Instrumentation
 - Watch the bleed water
 - Watch the people
- Be prepared for changes in the weather

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Action	People	Concrete
Start Warm!	Hot Soup	Hot Water Warm Aggs
Avoid Drying	Chapstick, Handcream	Curing Windbreaks
Minimize Heat Loss	Dress in layers	Insulation
Watch Extremities	Gloves, scarves, boots	Edges, corners, surface
Stay Alert	Watch yourself & friends	Measure Temp. & <i>in-place</i> <i>strength</i>

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"Avoiding Injury in Cold Weather: for
Humans and for Recently Cast
Concrete," by Ken Hover

Concrete International, Vol. 24, No.
11, November, 2002, pp. 49-54.

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