An introduction to Extreme Weather Concreting

by

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There are two major extreme weather conditions:-

- Hot weather concreting
- Cold weather concreting

EXTERME WEATHER CONCRETING:-

- In countries which experience extreme weather condition during a year, special problems are encountered in preparation, transporting, placement and curing of the concrete.

- Pakistan has regions of extreme hot weather (hot –humid and hot-air) as well as cold weather, so, measures need to be considered while concreting under such environment.

COLD WEATHER CONCRETING

Cold weather concreting:-

- Concrete can be placed safely without damage from freezing throughout the winter months in cold climates if certain precautions are taken.

- Cold weather is defined by ACI Committee 306 as a period when for more than 3 successive days the average daily air temperature drops below 5°C (40°F) or when there is a probability of it falling below 5°C within 24 hours of placing —

When suitable preparations to build enclosures and insulate equipment have been made, cold weather is no obstacle to concrete construction.

Cold weather concreting:-

- BS 8110 notes that concrete may suffer permanent damage if its temperature falls below 0°C before it is mature enough to resist disruption by freezing. Also the temperature of the concrete should at no point, fall below 5°C until it reaches a strength of 5 N/mm^2.
- However, there can be some benefits from low initial temperature. Concrete which is placed at low temperatures, but which is not allowed to freeze and receive good curing, may develop higher ultimate strength.
- Under cold weather, all materials and equipment needed for adequate protection and curing must be on hand and ready for use before concrete placement is started. Normal concreting practices can be resumed once the ambient temperature is above 10°C (50°F) for more than half a day.

Cold weather concreting:-

- During cold weather, the concrete mixture temperature should be adapted to the construction procedure and ambient weather conditions.
- The enclosures, windbreaks, portable heaters, insulated forms, and blankets should be ready to maintain the concrete temperature.
- Forms, reinforcing steel, and embedded fixtures must be clear of snow and ice at the time concrete is placed.
- Thermometers and proper storage facilities for test cylinders should be available to verify that precautions are adequate.

Problems at different stages:-

Table 5.3 Problems resulting from cold weather at various stages in the life of concrete

Stage	Effect
Production	Incorporation of frost-bound material
Transit	Cooling of mix
Placing, finishing and curing	Formation of ice crystals in concrete Increased thermal gradients/increased tendency to thermal cracking Delayed formwork removal Slower gain in strength Greater chance of formwork stripping damage Bleed water may remain on surface
Long-term	Slower setting Slower gain in strength Freeze–thaw damage Variable appearance

Main Problems associated with cold weather are:

- Frost damage to immature concrete
- Slow gain in strength leading to later stripping times and
- The possibility of increased damage when the shutters are removed.

➢ Concrete is vulnerable to freezing temperatures both before and after it has stiffened. There are two stages:

1. Expansion of water as it freezes in plastic concrete causes such severe damage that the concrete becomes unusable.

Main problems associated with cold weather are:

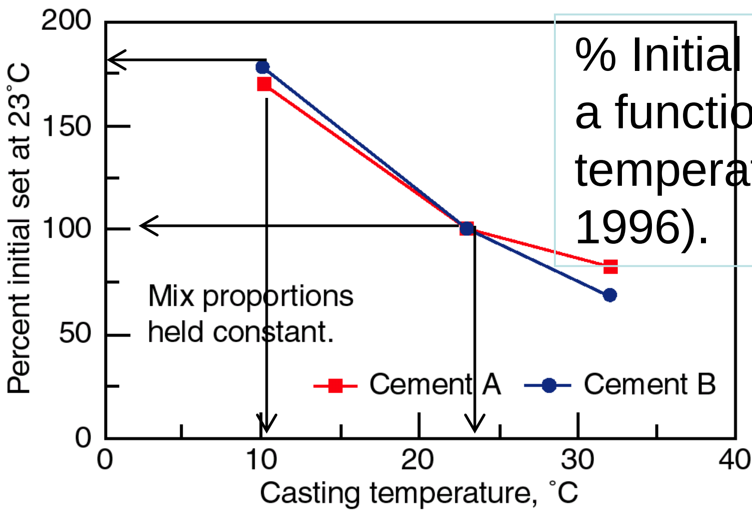
2. Concrete can be permanently damaged by the pressures exerted by ice crystal growth if this occurs after the concrete has stiffened but before it has gained adequate maturity. After stiffening but before gaining strength

   This weakens the paste–aggregate bond and may reduce strength by up to 50 per cent. The porosity of the concrete may be adversely affected causing a loss of durability.

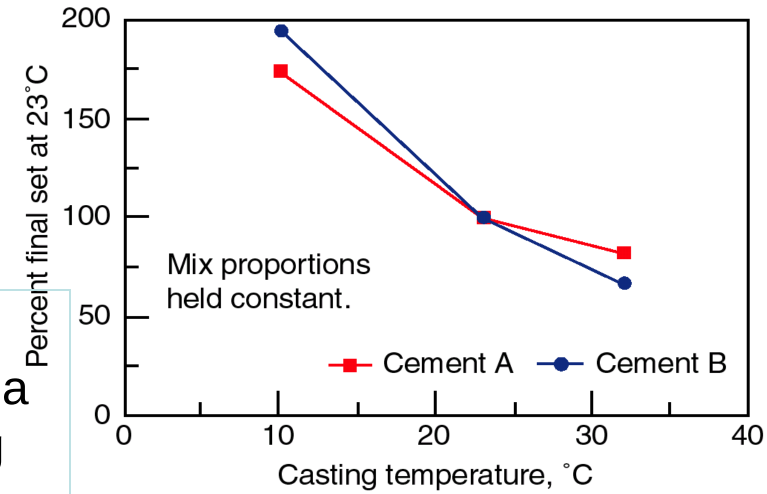
Approximate Setting Times at Different Temperatures

Rule of Thumb:

- "For every 10°C (18°F) reduction in concrete temperature, the time of setting of the concrete almost doubles... thus increasing the amount of time that the concrete is vulnerable to damage due to freezing."



% Initial setting time as a function of casting temperature (Burg 1996).

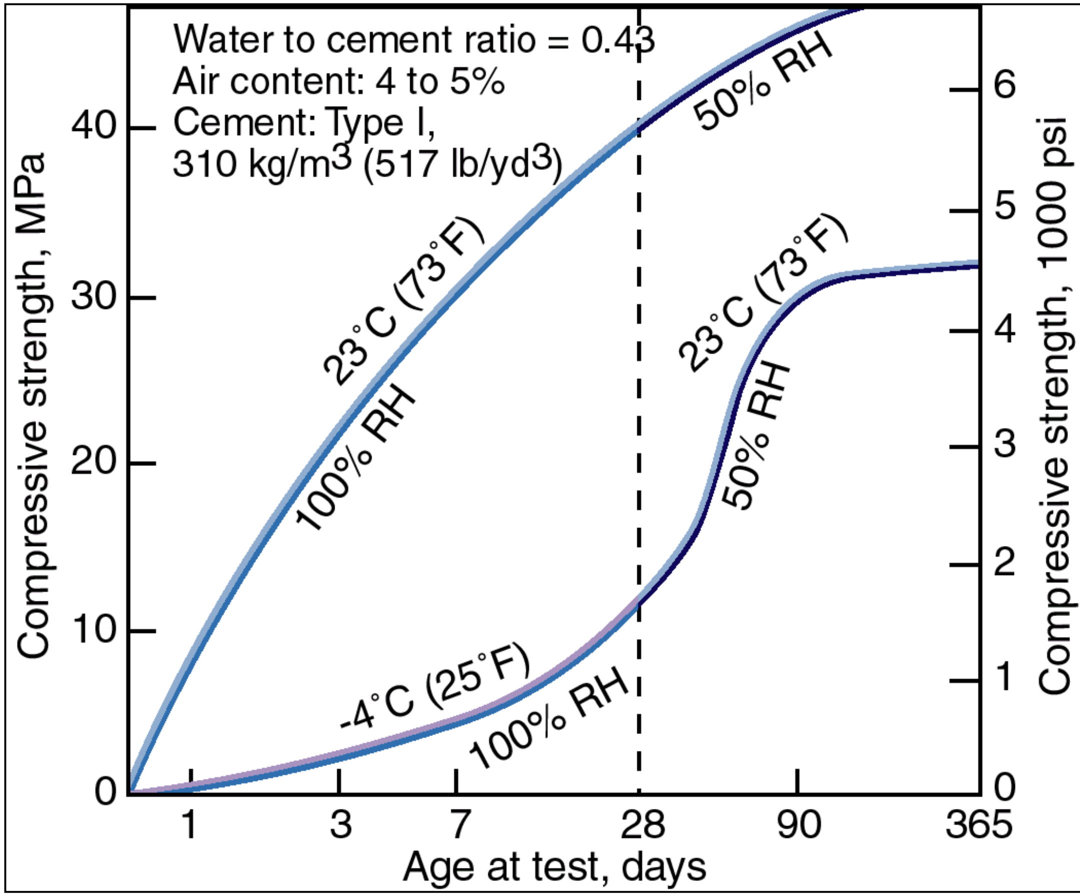


Final set characteristics as a function of casting temperature (Burg 1996).

Effect of Temperature on Strength Development:-

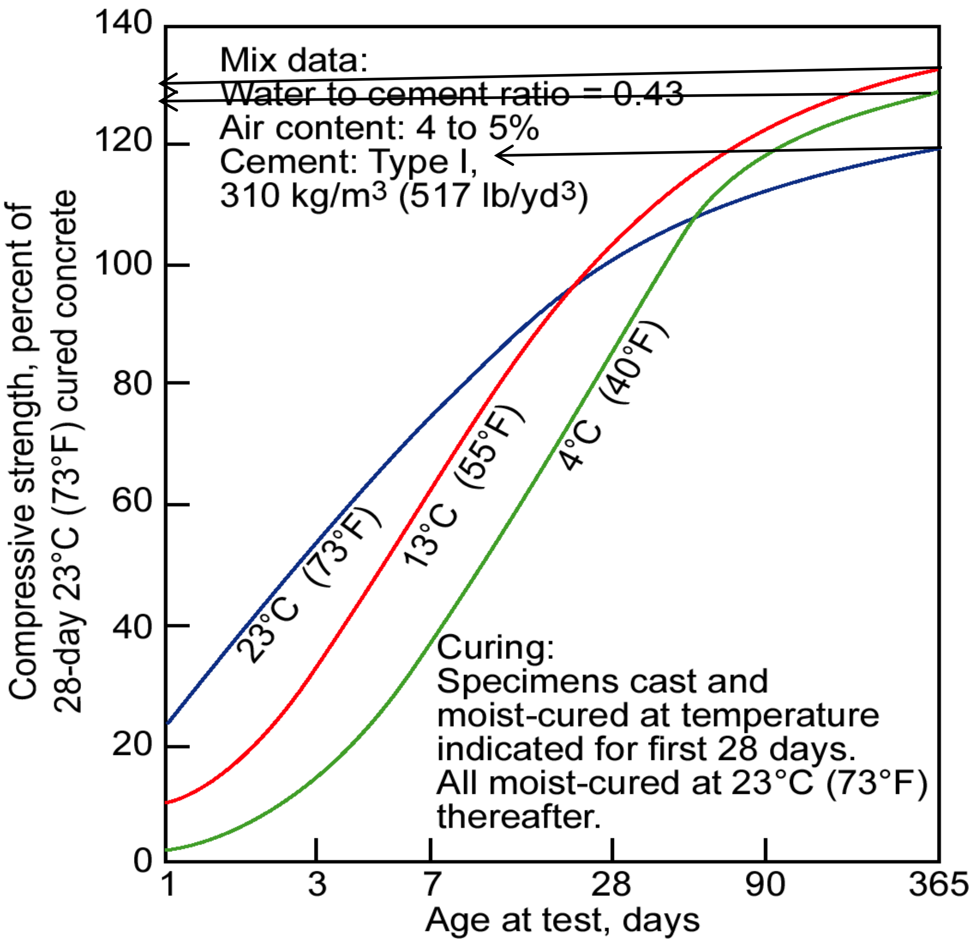
- Here the concrete for the lower curve was cast at 4°C (40°F) and placed immediately in a curing room at -4°C (25°F).

- Both concretes received 100% relative-humidity curing for first 28 days followed by 50% relative-humidity curing (Klieger 1958).

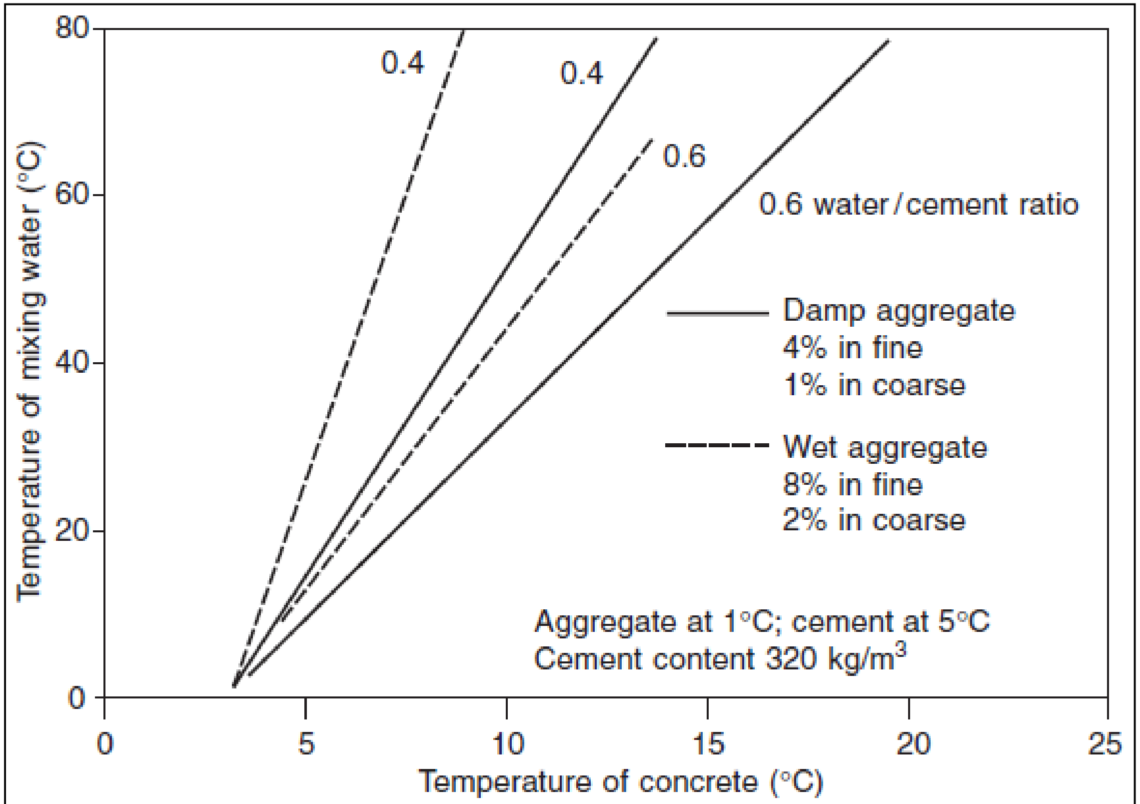


Favorable temperature for long term Strength development at various ages:

- Here for the same particular mixture made with Type I cement, the best temperature for long-term strength (1 year) is 13°C (55°F) (Klieger 1958).

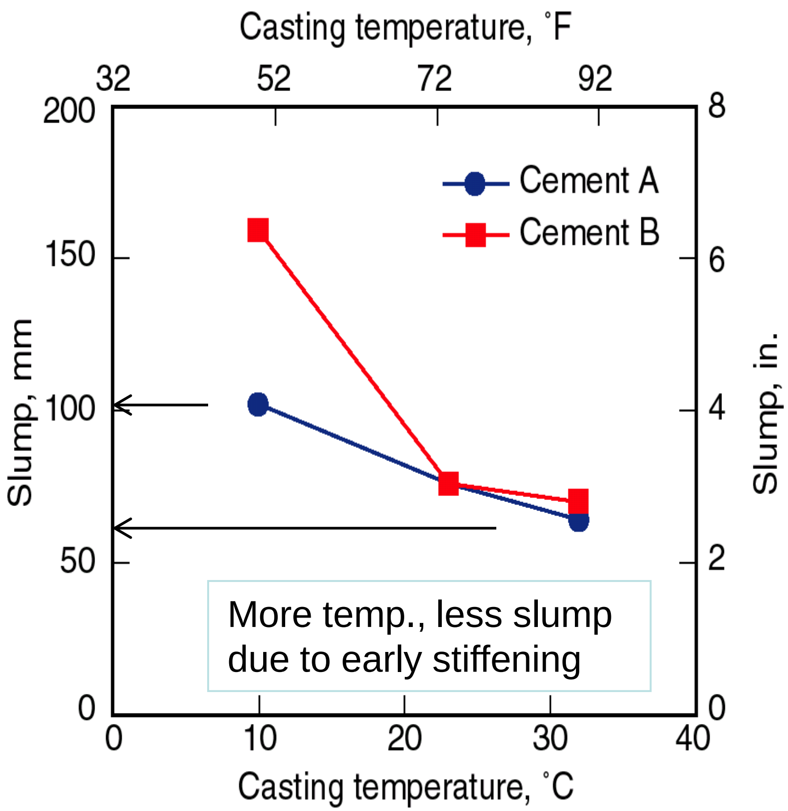


The C & CA publication *Winter Concreting* (Pink, 1967) gives charts for estimating concrete temperature when mixed with heated water.

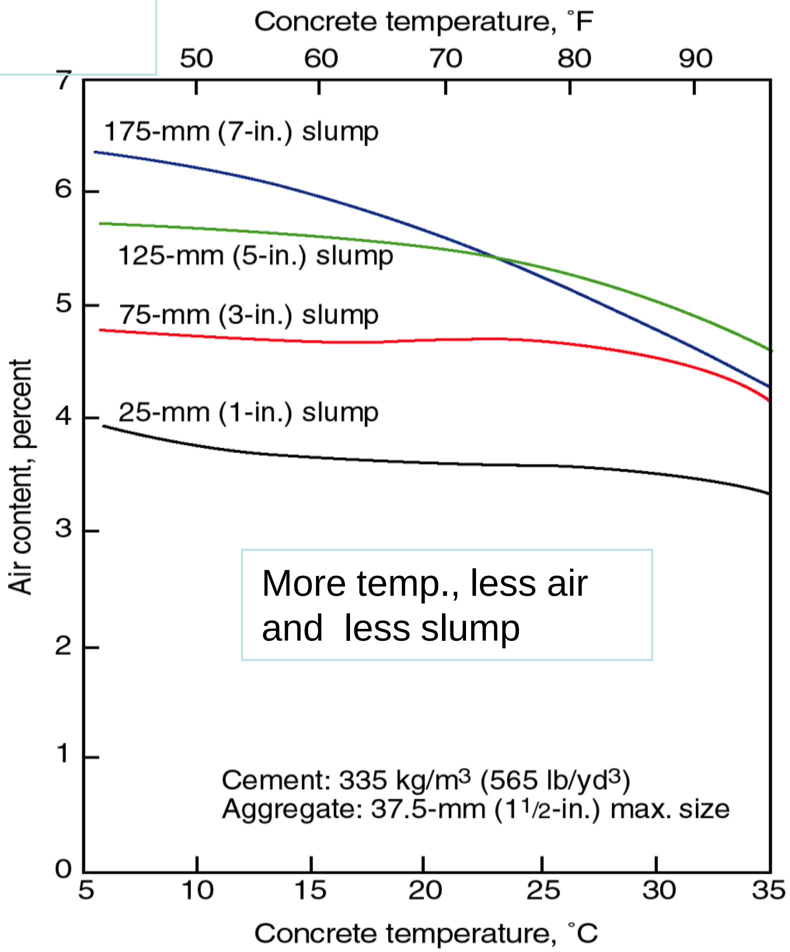


Relationship between mixing water temperature and concrete temperature under cold conditions (after Pink, 1967).

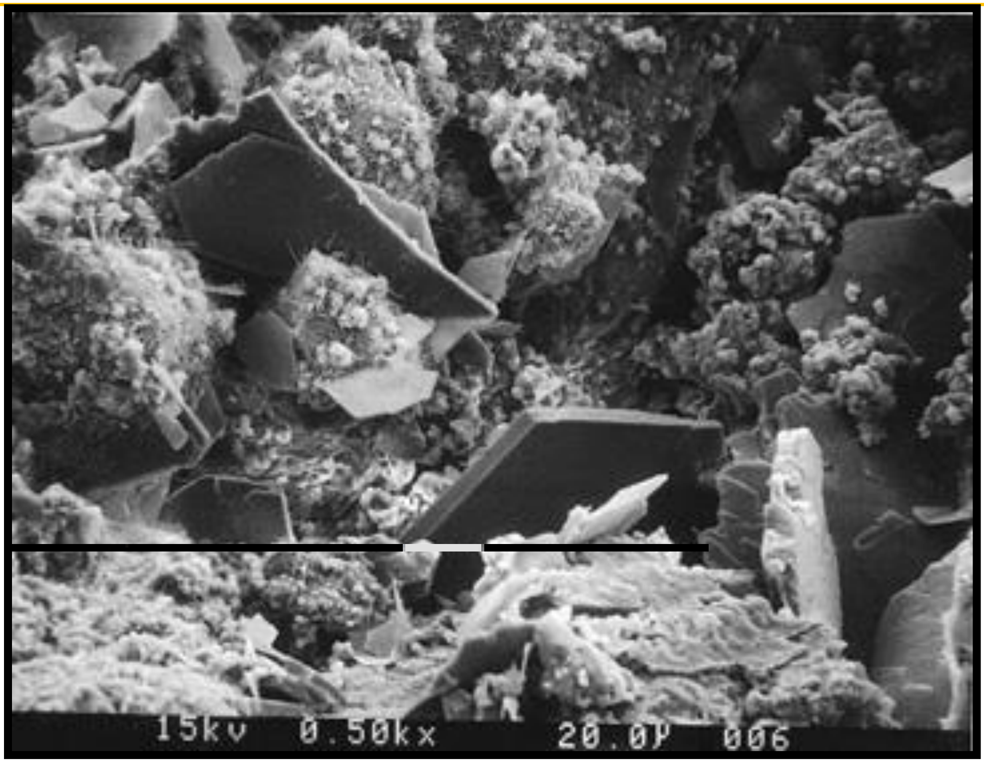
Effect of Casting Temperature on Slump



Relationship b/w Temperature, Slump and Air Content:



Hydration Ceases at… “-10 °C” (14 ºF);



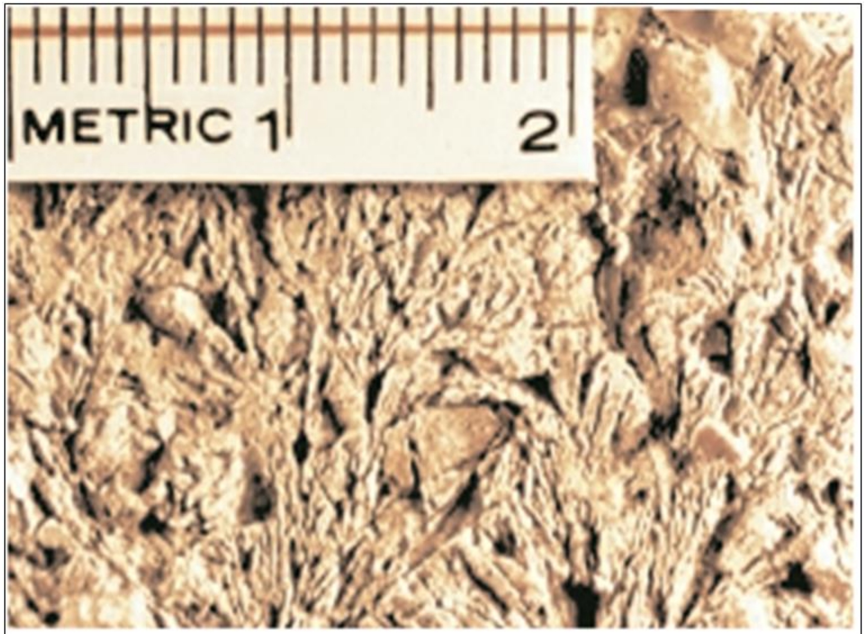


Fig. 14-2. Closeup view of ice impressions in paste of frozen fresh concrete.

The ice crystal formations occur as water in unhardened concrete freezes. They do not occur in adequately hardened concrete. The disruption of the paste matrix by freezing can cause reduced strength gain and increased porosity.

EFFECT OF FREEZING FRESH CONCRETE:-

- Concrete gains very little strength at low temperatures. Freshly mixed concrete must be protected against the disruptive effects of freezing until the degree of saturation of the concrete has been sufficiently reduced by the process of hydration. The time at which this reduction is accomplished corresponds roughly to the time required for the concrete to attain a compressive strength

- Concrete that has frozen at an early age just once can be restored to nearly normal strength by providing favourable subsequent curing conditions.

EFFECT OF FREEZING FRESH CONCRETE:-

- The critical period after which concrete is not seriously damaged by one or two freezing cycles is dependent upon the concrete ingredients and conditions of mixing, placing, curing, and subsequent drying.

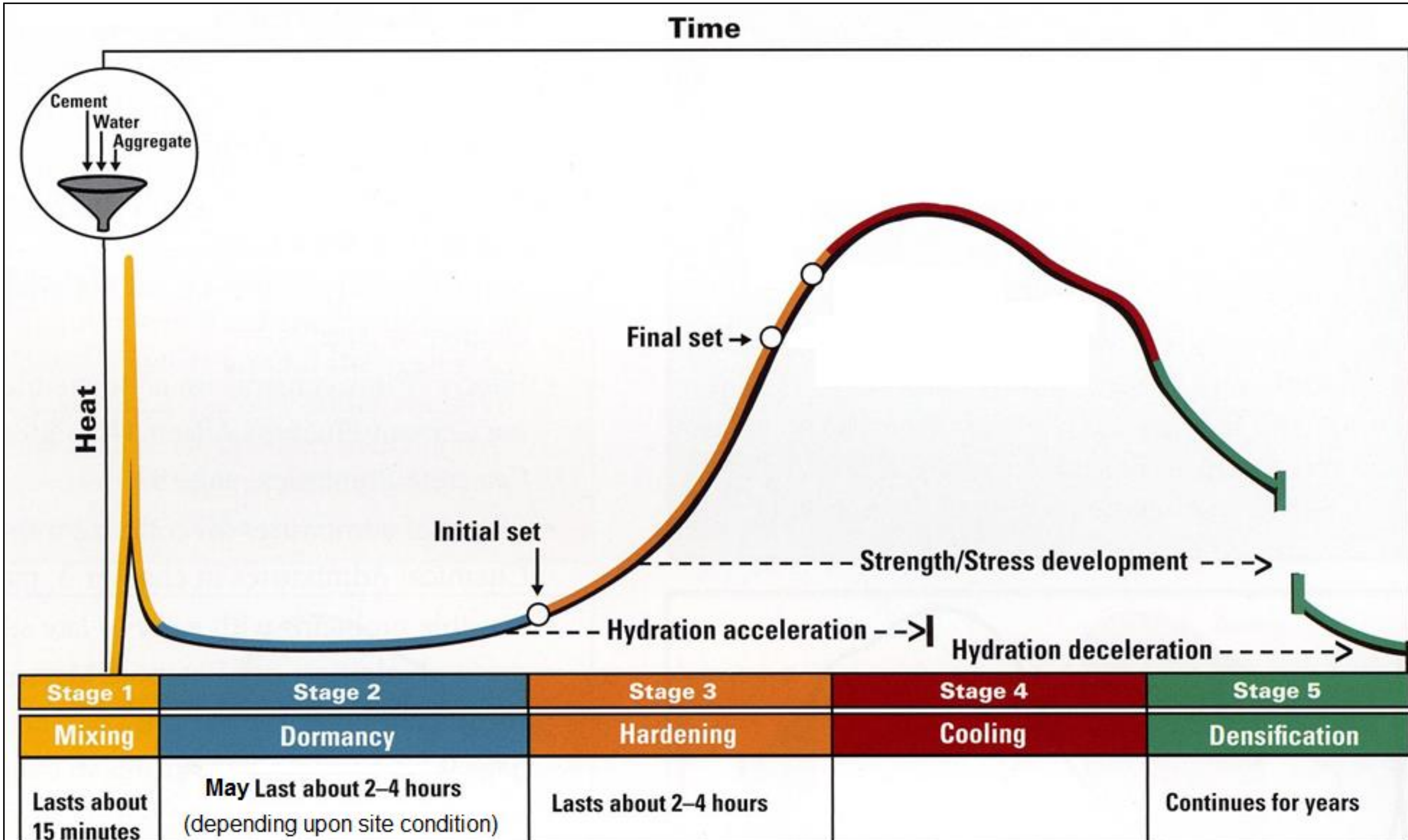
- For example, air-entrained concrete is less susceptible to damage by early freezing than non-air-entrained concrete.

Effect of Freezing Fresh Concrete:

- Up to 50% reduction of ultimate strength can occur if frozen -
  - Within a few hours
  - Before reaching a strength of 3.5 MPa (500 psi)

- Frozen only once at an early age -
  - Nearly all strength can be restored with curing
  - Less resistance to weathering
  - More permeable

Hydration Stages (at 23°C):



Heat of hydration:- Advantage

- Concrete generates heat of hydration by which cement reacts with water to form a hard, stable paste.
- The heat generated varies in amount and rate for different cements. Dimensions of the concrete placement, ambient air temperature, initial concrete temperature, water- cement ratio, admixtures, composition, fineness, and amount of cementitious material, all affect heat generation.
- Heat of hydration is useful in winter concreting as it contributes to the heat needed to provide a satisfactory curing temperature; often without other temporary heat sources, particularly in more massive elements.

Retaining Heat of Hydration

- Fig. shows a concrete pedestal being covered with a tarpaulin just after the concrete was placed.
- Tarpaulins and insulated blankets are often necessary to retain the heat of hydration more efficiently and keep the concrete as warm as possible.

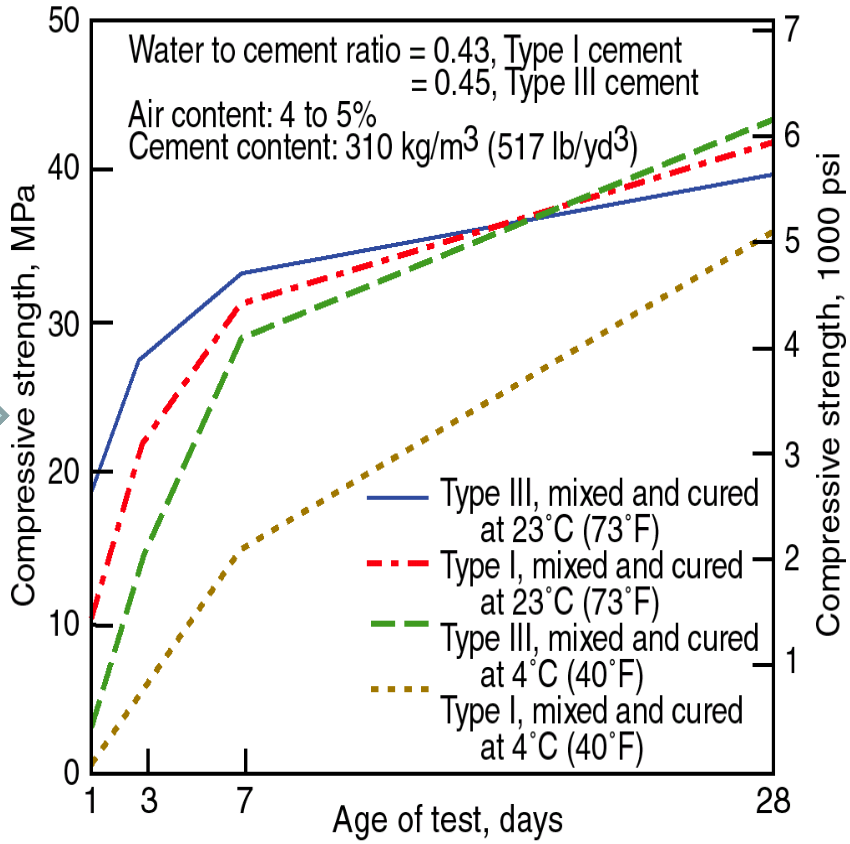
Methods to accelerate strength gain:-

- High strength at an early age is desirable in winter construction to reduce the length of time for maturity.

- High-early-strength concrete can be obtained by using one or a combination of the following:

1. Use Type III or high-early-strength cement

2. Use additional Portland cement (60 to 120 kg/m3 or 100 to 200 lb/yd3)



Early-age compressive-strength relationships for Type I and Type III portland cement concretes mixed and cured at 4°C (40°F) compared to 23°C (73°F)

Methods to accelerate strength gain:-

3. Chemical accelerators (ASTM C 494 or AASHTO M 194, Type C)

- Small amounts of an accelerator such as calcium chloride (at a maximum dosage of 2% by weight of Portland cement) will:
    - Accelerate the hydration (setting) and
    - Gain early-age strength in concrete in cold weather.

But, calcium chloride accelerators has potential for :

- Increasing drying shrinkage,
- reinforcement corrosion and concrete scaling
- Darkening concrete

Methods to accelerate strength gain:-

- Specially designed accelerating admixtures allow concrete to be placed at temperatures down to -7°C (20°F).
- The purpose of these admixtures is to reduce the time of initial setting, but not necessarily to speed up strength gain. Covering concrete to keep out moisture and to retain heat of hydration is still necessary.

Finishing the concrete flatwork can proceed because a windbreak has been provided, there is adequate heat under the slab, and the concrete has low slump.

Finished surface

Example of Accelerator Effect on Set Time

Mix @ 10 °C (50 °F)	Initial Set (h:min)	Difference (h:min)
Plain concrete (without accel.)	13:44	REF
Concrete using Accel. @ 1300 mL/100 kg	7:11	- 6:33 (reduction)
Concrete using Accel. @ 2600 mL/100 kg	6:05	- 7:39 (reduction)

Permissible Concrete Temperatures at Placing:

As per CSA A23.1 [Cement association of Canada]

Thickness of Section, m	Temperature, °C	
	Minimum	Maximum
Less than 0.3	10	35
0.3-1	10	30
1-2	5	25
More than 2	5	20

Chapter14-Cold Weather Concreting-EB101 – Design and Control of Concrete Mixtures—7th Canadian Edition, 2002.

Air entrainment is important against freez-thaw

AIR-ENTRAINED CONCRETE:- Air Entrainment for Safety

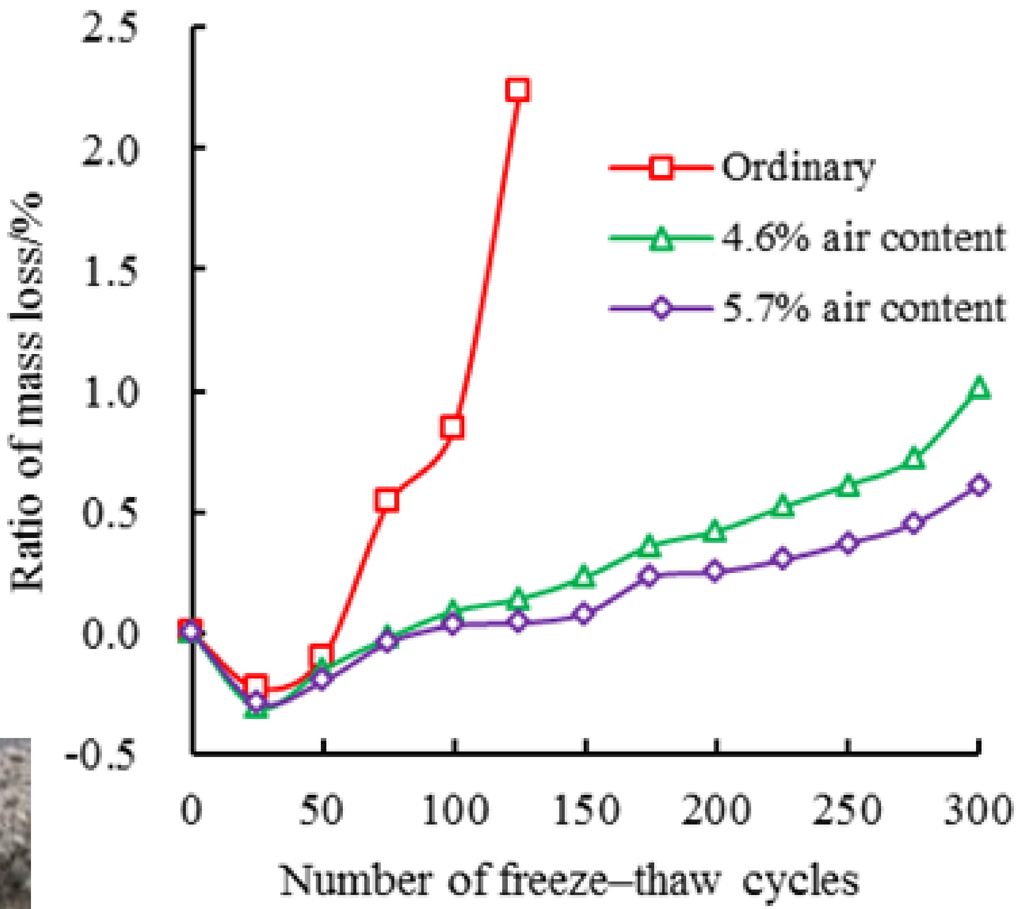
- Entrained air is particularly desirable in any concrete placed during freezing weather. Concrete that is not air entrained can suffer strength loss and internal as well as surface damage as a result of freezing and thawing .

- Air entrainment provides the capacity to absorb stresses due to ice formation within the concrete.

Concrete floor saturated with rain, snow, or water and then frozen, showing the need for air entrainment

Effect of F/T cycle on mass loss of Concrete:

Effect of freezing and thawing on mass loss of concrete with and without entrained air



Effect of Material Temperature on Concrete Temperatures:-

$$T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa}}{0.22(M_a + M_c) + M_w + M_{wa}}$$

Factor of 0.22 with Aggregate and Cement and No factor on added free water and water in aggregates.

T = temperature of the freshly mixed concrete, °C (°F)

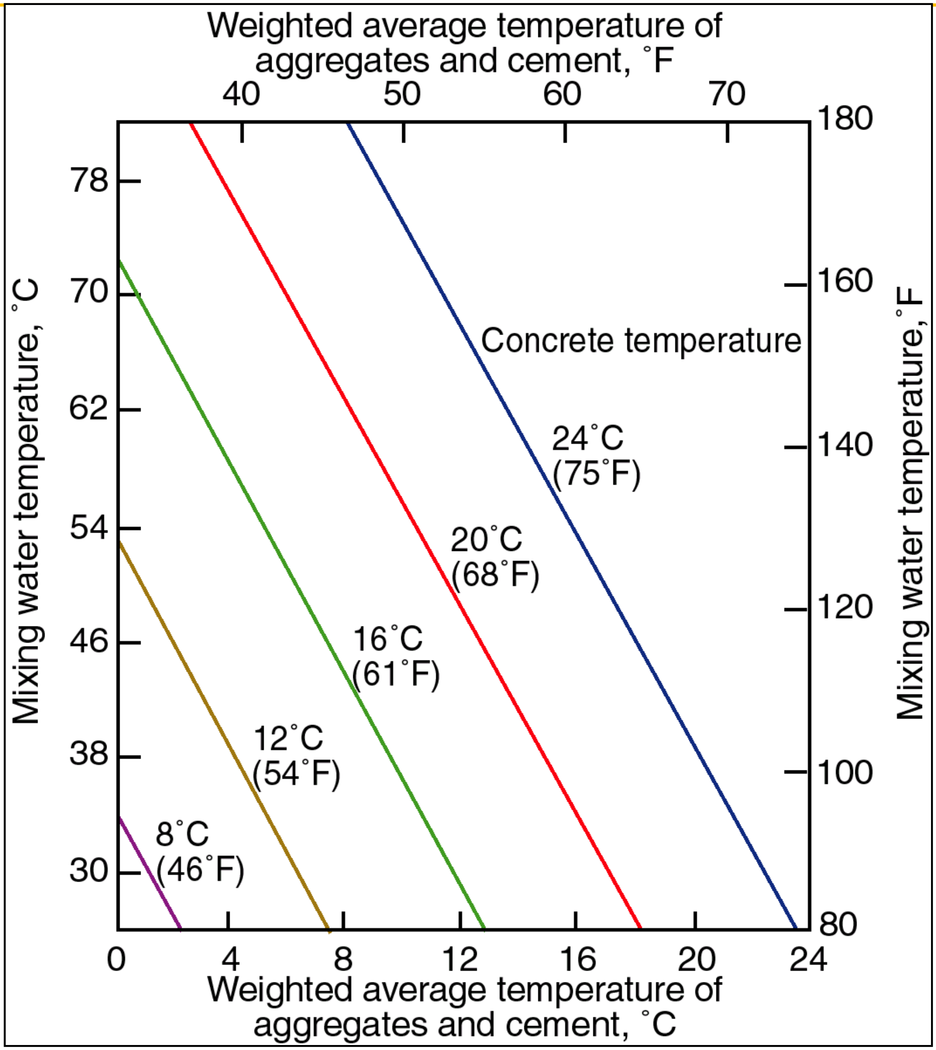
T_a, T_c, T_w, and T_{wa} = temperature in °C (°F) of aggregates, cement, added mixing water, and free water on aggregates, respectively

M_a, M_c, M_w, and M_{wa} = mass, kg (lb), of aggregates, cementing materials, added mixing water, and free water on aggregates, respectively

Heating Mix Water and aggregate:-

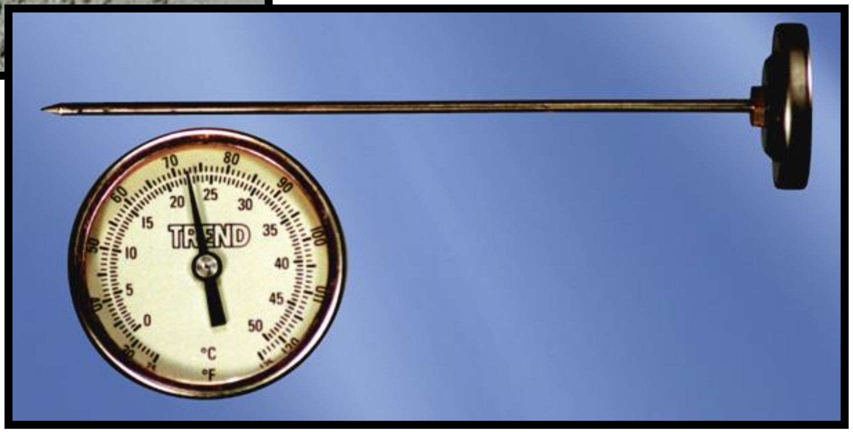
Temperature of mixing water needed to produce heated concrete of required temperature.
Temperatures are based on the mixture shown but are reasonably accurate for other typical mixtures.

Mix data:
Aggregate = 1360 kg (3000 lb)
Moisture in aggregate = 27 kg (60 lb)
Added mixing water = 108 kg (240 lb)
Portland cement = 256 kg (564 lb)



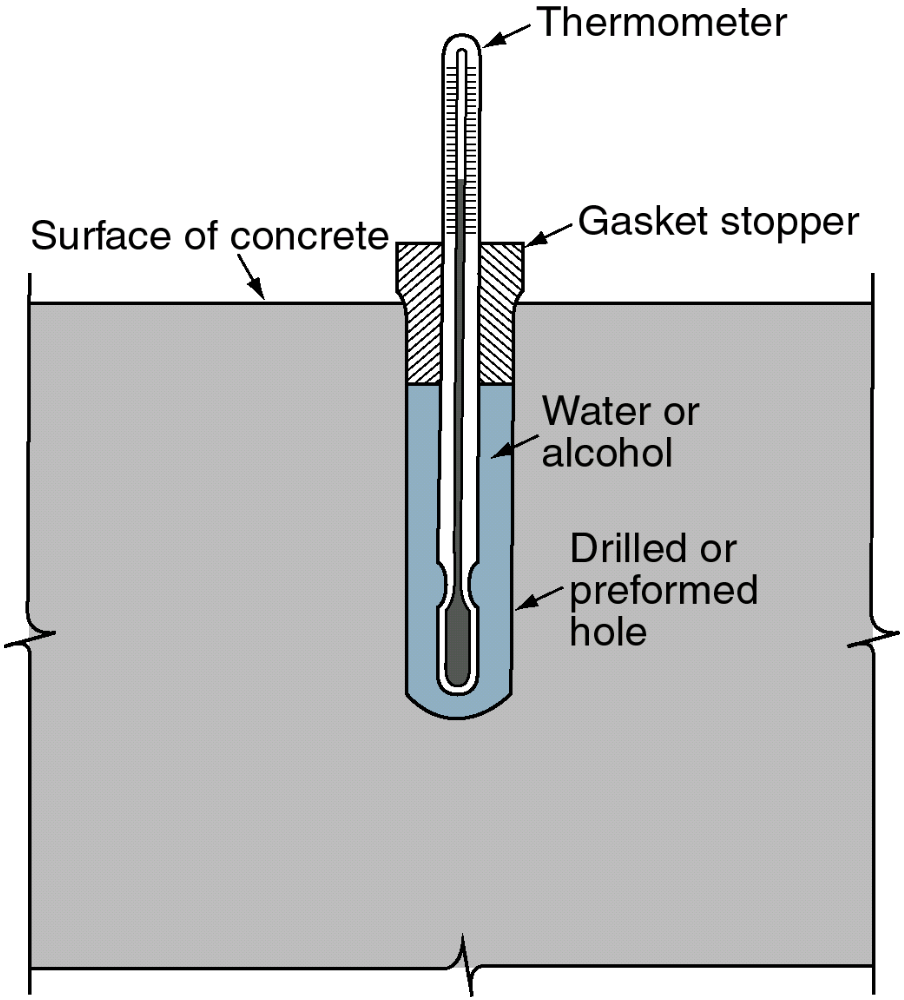
Checking Fresh Concrete Temperatures:

A bimetallic pocket thermometer with a metal sensor suitable for checking fresh concrete temperatures



Checking Hardened Concrete Temperature:

Scheme for measuring concrete temperatures below the surface with a glass thermometer.



Temperature of Test Cylinders

Insulated curing box with thermostat for curing test cylinders. Heat is supplied by electric rubber heating mats on the bottom. A wide variety of designs are possible for curing boxes.

Heating Materials:-

- Water
- Aggregates

SUMMERY OF THE MEASURES:-

Table 5.4 Summary of measures to reduce the adverse effects of cold weather

Stage	Measure
Production	Build up stockpiles Use warm water Use more reactive cementitious materials Increase concrete grade Reduce slump Shelter batching plant Insulate aggregates Heat aggregates Use accelerating admixtures
Transit	Minimize transit times Reduce truck revolutions Match production rate and delivery rate to placing r
Placing and curing	Shuttering and reinforcement frost-free Subgrade thawed Insulated formwork Heated enclosure Provide protection to completed work

Insulating Blankets:-

Thermal resistance of mineral fibre blanket (50 to 70-mm thick)	1.2 $(m^2 \cdot °C)/W$

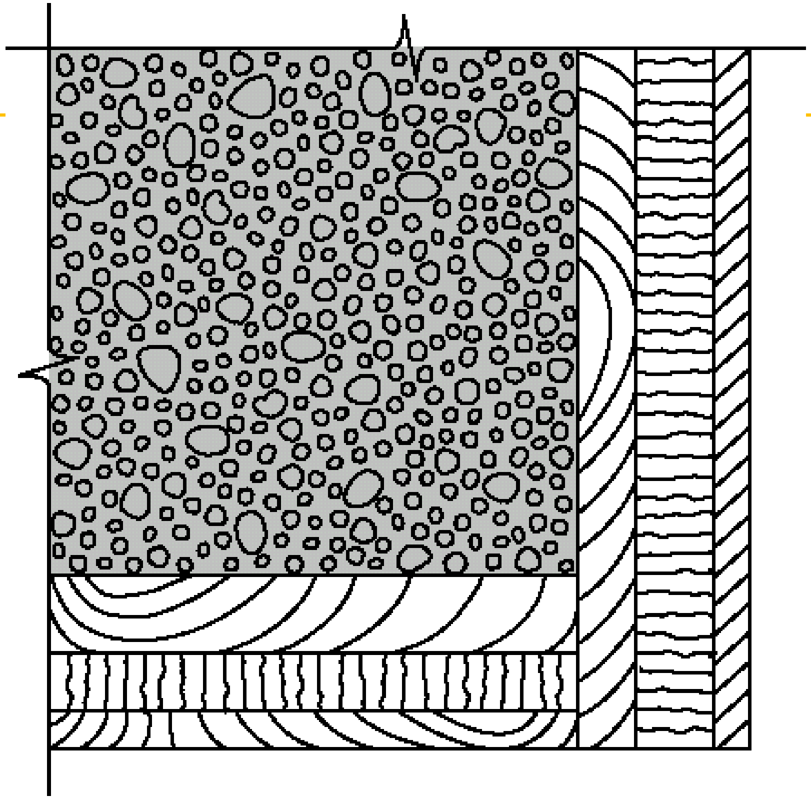
R is capacity to resist heat flow.
Increase of 1K temperature through 1 unit area by 1 watt.

- Stack of insulating blankets. These blankets trap heat and moisture in the concrete, providing beneficial curing

Insulating Concrete Forms (ICF):

Insulating concrete forms (ICF) permit concreting in cold weather.

Insulated Column Forms:



With air temperatures down to -23°C, concrete cast in the insulated column form made of 19-mm high-density plywood inside, 25-mm rigid polystyrene in the middle, and 13-mm rough plywood outside. R value: 1.0 $m^2 \cdot °C/W$.

R is capacity to resist heat flow.
Increase of 1K temperature through 1 unit area by 1 watt.

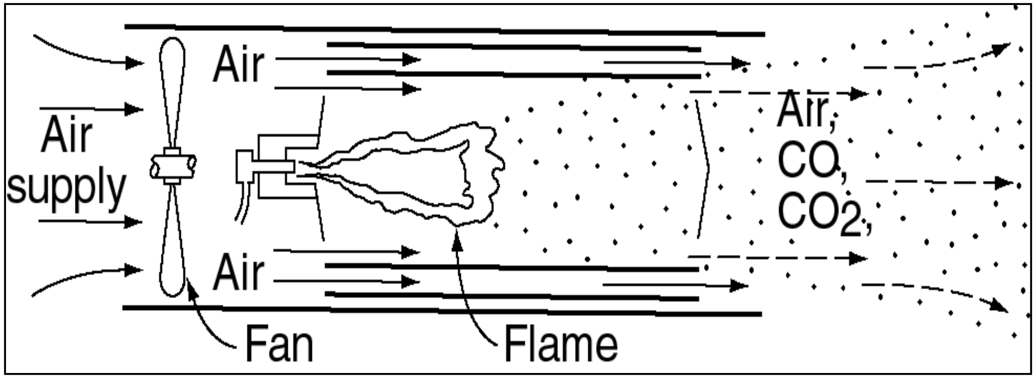
Enclosures:-

- Wood
- Canvas
- Tarpaulins
- Polyethylene Film

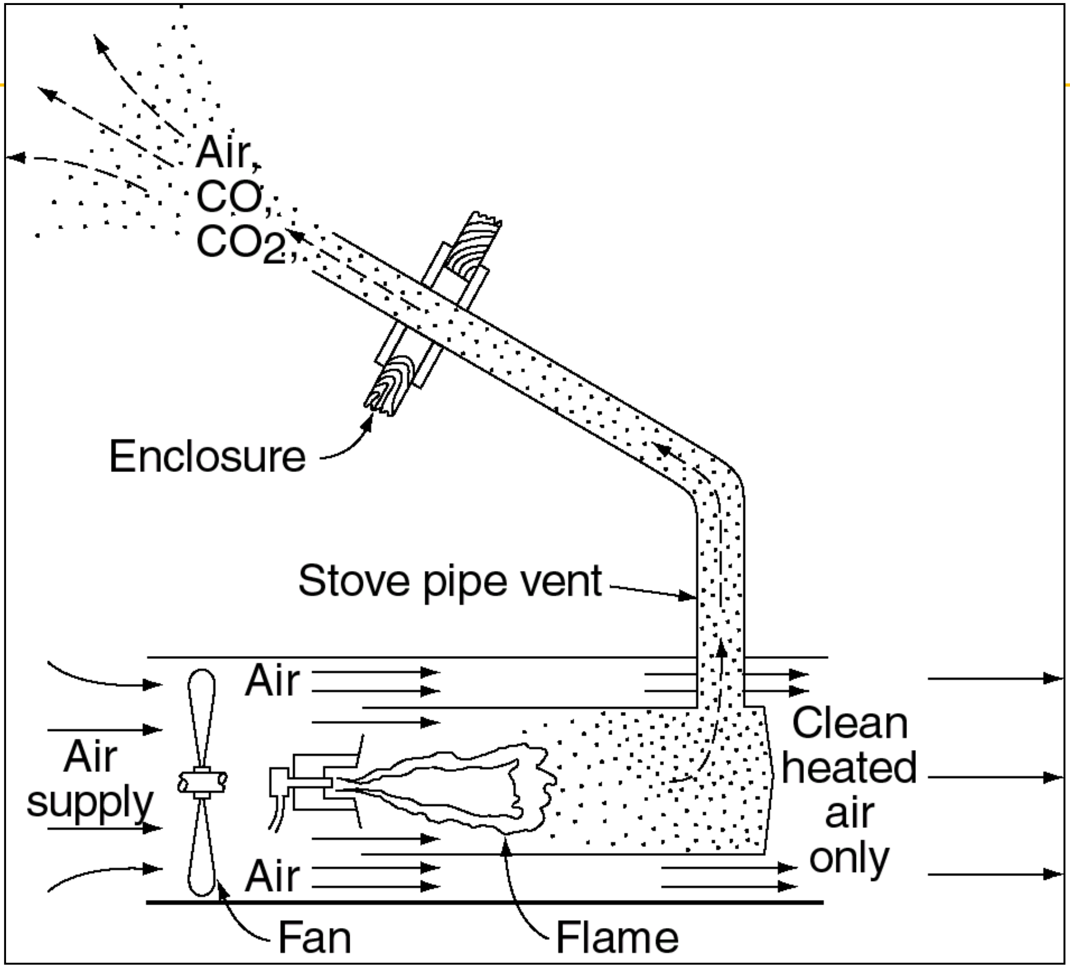
✓ (top) Tarpaulin heated enclosure maintains an adequate temperature for proper curing and protection during severe and prolonged winter weather.

✓ (bottom) Polyethylene plastic sheets admitting daylight are used to fully enclose a building frame. The temperature inside is maintained at 10°C with space heaters.

Direct-Fired Heater:-



Indirect-Fired Heater:-



An indirect-fired heater. Notice vent pipe that carries combustion gases outside the enclosure.

Hydronic Systems:

(**Hydronic Heating** heats water at its source via super energy efficient Gas Boilers. Once used the water is returned to be reheated via reticulating **system**.)

Hydronic system showing hoses (left) laying on soil to defrost subgrade and (right) warming the forms while fresh concrete is pumped in.

MATURITY CONCEPT:-

- The concept of maturity is important in relation to cold weather concreting.
- It is based on the principle that strength gain in concrete is a function of curing time and temperature.
- Maturity is the mathematical product of temperature and time. It has been found that concretes from the same mix which have the same maturity, whatever combination of time and temperature make up that maturity, have approximately the same strength.
- Concrete gains practically no strength at a temperature of –10°C and this has been used as the baseline for temperatures used in maturity calculations.

MATURITY CONCEPT:-

- The maturity is given by the equation

$$\text{Metric: } M = \Sigma\,(C + 10)\,\Delta t \quad \text{or}$$

$$\text{Inch-Pound: } M = \Sigma\,(F - 14)\,\Delta t$$

where

- M = maturity factor
- Σ = summation
- C = concrete temperature, degrees Celsius
- F = concrete temperature, degrees Fahrenheit
- Δt = duration of curing at temperature C (F), usually in hours

MATURITY CONCEPT:-

There are other suggested formulae for calculating maturity. For example Sadgrove (1975) developed a formula for concrete cured below 20°C:

$$M = (T + 16)^2 \times t$$

Using the same example as before (20°C for 72 hours) gives a maturity $(20 + 16)^2 \times 72$ = 93312 °C^{2}h. Likewise if the concrete had been cured at 15°C it would have attached the same strength after

$$\frac{93\,312}{(15 + 16)^2} \text{ hours}$$

i.e. 97 hours

MATURITY METER

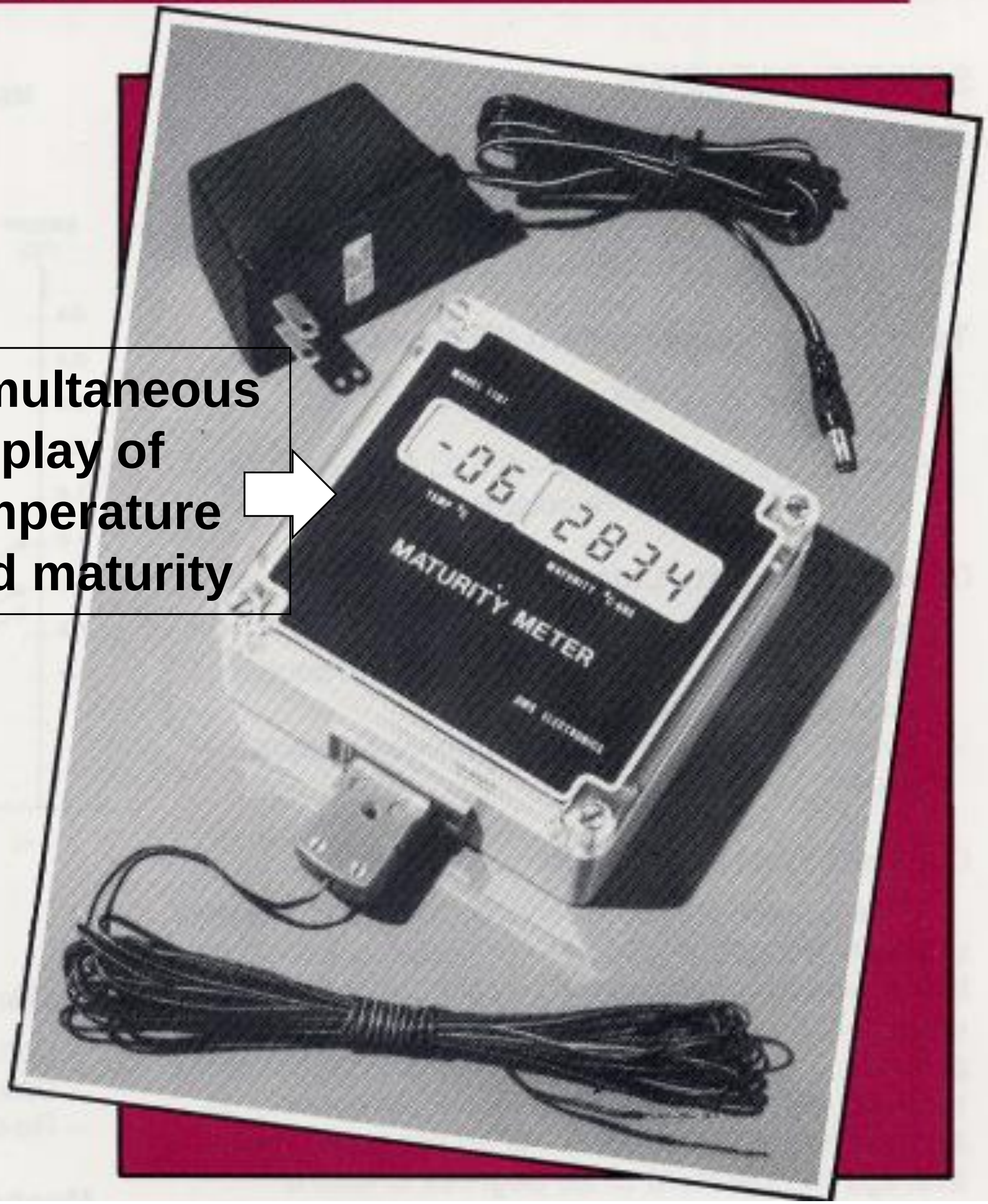
APPLICATIONS

- Accurate, Predictable Concrete Strength Determination
- Form and Shoring Removal Time Prediction
- Loading and Post-Tensioning Time Prediction
- Control of Winter Heating and Insulation Requirements
- Accelerated Construction Scheduling

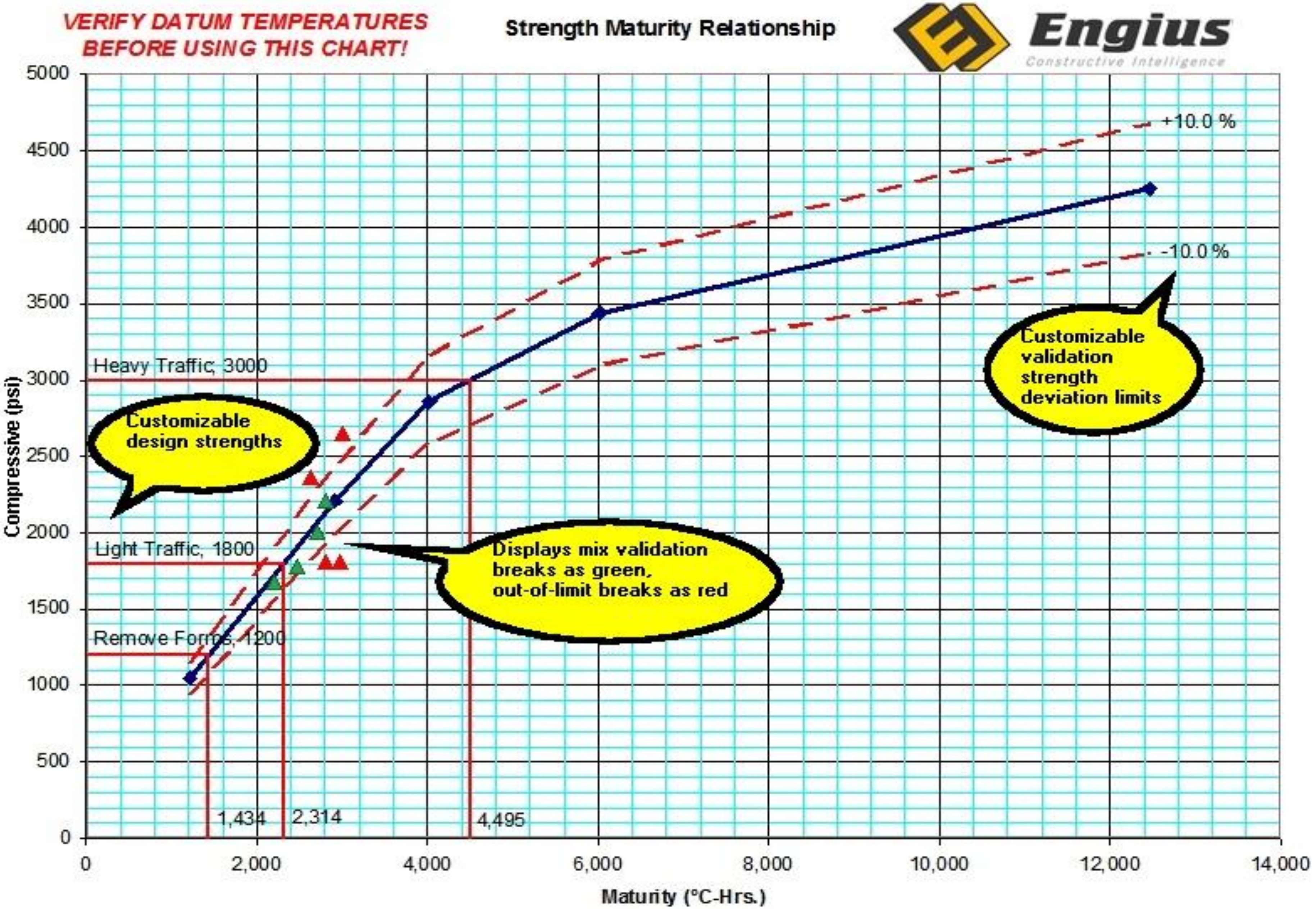
FEATURES

- Water-Tight, Impact Resistant Enclosure
- Low Power CMOS Design
- Built-in Rechargeable Batteries
- 2½ Months of Continuous Operation
- Low Battery Indicator
- Thermocouple Temperature Sensing
- Low Cost, High Accuracy Type "T" Thermocouple Wire Used
- High Impedance, Differential Input
- Cold Junction Compensation
- Transducer Linearization
- Open Circuit Indicator
- Over and Under Range Indicators
- Simultaneous Display of Both Temperature and Maturity Values
- Magnetic Power ON/OFF and Reset (No Switches or Buttons)

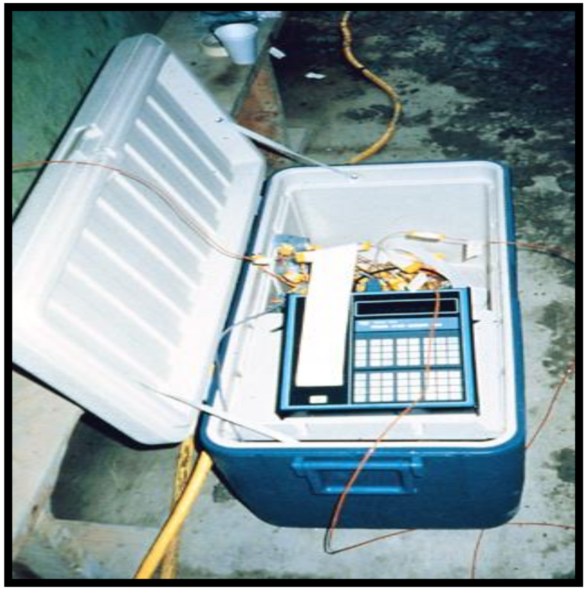
Simultaneous display of temperature and maturity



SAMPLE RELATIONSHIP BETWEEN MATURITY AND STRENGTH OF CONCRETE:



Mix Cal.: P27, Batch Date: 9/8/2004, 7:30am



- (Left) Automatic temperature recorder.
- (Right) Thermocouples and wiring at various depths in a caisson