FROST RESISTANT CONCRETE

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FROST RESISTANT CONCRETE

What happens in a concrete when the temperature falls? When does a concrete freeze? What is obtained by the use of anti-freeze agents? What happens after the thawing of a frozen concrete? What compressive strength can be expected from a once frozen concrete?

First of all, it is essential to separate the terms frost secure and frost resistant concretes. When the term frost secure concrete is used, it is denoting the fact that this concrete has reached a certain development which enables it to withstand freezing once without permanent damage. By the term frost resistant concrete we refer to a concrete with properties that throughout the construction’s expected life will not be deteriorated by any changes in humidity and temperature (e.g. repeated freezing and thawing cycles) that might occur.

What happens in the concrete when temperature falls?

First; the hydration (the chemical reaction between cement and water) is temperature dependent; the lower the concrete’s temperature, the slower the process. See figure 1. Roughly speaking, a factor of 1.5 for each 10 degrees centigrade can be expected. Examples: If the open time of a concrete (the time when the concrete can be compacted), is 4 hours at 20 degrees, the open time at 10 degrees will be 4 * 1.5 hours = 6 hours. If the temperature falls below 10 degrees, the factor can be increased to 2.5. Following the same concrete, and its temperature drops to 0 degrees, it might happen that it will take 10 hours before the concrete sets

Until the concrete has set, logically no strength is developed. The strength starts building up after the concrete has stiffened. The exothermal function – that is, the concrete’s abilities of yielding heat to its surroundings – will not be able to prevent any temperature fall in the concrete due to the ambient temperature.

Figure 1: The temperature function according to the BKI Central (Freisleben Hansen)

Action

Actions to counteract the fall in the concrete’s temperature:
- a more reactive cement type – that is, to change from a normal OPC - cement to a rapid cement (higher Blaine and higher rate of heat development)
- higher temperature of the ready mixed concrete (i.e. warm concrete), by heating the aggregates, by hot water, by steam in the mixer etc.
- more cement, since the cement is the prime source of heat
- use chemical admixtures (accelerators or anti-freeze agents)
- cover the fresh concrete’s surface to take care of the concrete’s temperature and its potential properties

In a massive construction member, and even if the ambient temperature drops to several degrees below freezing point, the concrete’s temperature will most probably be ensured simply by covering it up. But, if the construction is non-voluminous, or if the concrete must be transported through cold air or is in wide contact with a cold substrate, the temperature fall might be substantial, and higher than can be helped by covering alone. Nevertheless, to cover the concrete is always advantageous and is highly recommended.

**Frozen water takes up more space.**
To make concrete, water is needed. The amount of water in a mix will normally be somewhere between 140 to 240 liters to each m³ - that is 14 to 24 % of the volume of the concrete.

When water freezes, ice lenses or ice needles with a volume 9 % higher than water are created. If the freezing happens in fresh concrete, the result can be extremely damaging. One can risk a frozen layer directly beneath the surface, a layer that most probably will crumble when the concrete is thawed at a later stage. Or, one gets a concrete which is frozen all through and will be filled with larger pores left when the ice melts and the water is consumed or evaporated. A loss of compressive strength of as much as 80 % is registered after only one freezing.

Rapid water transport + slow freezing speed  $\Rightarrow$ creation of **ice lenses**  
$\Rightarrow$ crumbling of surface

Slow water transport + rapid freezing speed  $\Rightarrow$ creation of **ice needles**  
$\Rightarrow$ reduced bonding between paste and aggregates  
$\Rightarrow$ loss of mechanical strength

When the concrete stiffens, contraction forces in the concrete will increase gradually and the possibilities of the formation of ice needles will be reduced. As the hydration process continues, water is consumed and less water is available for freezing. In the event that all water in the concrete is instantly frozen, the volume of the concrete will increase by 1.2 to 2.1 %. This expansion can normally happen without resistance, since the concrete hasn’t yet any strength. If the hydration process has established some kind of strength before the water is allowed to freeze, the amount of available water will be reduced, and the concrete’s tensile strength will reduce the expansion significantly.

**Required minimum compressive strength: 5 N/mm²**
Both tests and practical applications show that for most normal concrete mixes, no harmful longtime deteriorating effects can be observed on a concrete if it has gained the strength of 5 N/mm² when it freezes. New studies even suggest that this acceptable lower limit can be reduced to 2 N/mm². See figure 2.
In Norwegian Norm (NS-3465) it is stated that no concrete is allowed to freeze (notably that the temperature in no part of the concrete construction falls below zero) until the concrete has reached a mechanical strength of 5 N/mm². How this achieved, is entirely up to the contractor.

**NS 3465:2002 Concrete construction execution**

#.9.3 (6)
*If the ambient temperature is expected to fall below 0 °C during casting or in the concrete during hardening, necessary action to protect the concrete against potential damaging freezing shall be executed*

#.9.5 (8)
*Action as to ensure that the concrete’s temperature at no place falls below 0 °C before the concrete has gained a compressive strength of 5 MPa, must be taken.*

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**Fig. 2 Practical measurements by Sadgrove /1974/ confirm Kasais frost damage curve as presented in 1967**

**Thawing and renewed hydration**
What happens following the thawing of the concrete? Frozen water – ice – will become liquid again and the hydration process continues. This process will in turn consume water, and consequently, as ice needs larger volume than water, pores or voids will be left in the concrete Green concrete that is allowed to freeze after setting but before having gained any strenght, will as a result of the above mentioned expansion, be considerably weakened, as it no longer can be compacted.

There is one advantage of low concrete temperatures; as long as concrete doesn’t freeze, slow cement hydration gives higher strength in the long run. It seems like the quality of the fibres produced (CSH-fibres) at lower speed is better than those formed rapidly, under higher temperatures. Concrete cured at + 5 °C will normally get at least 20 % higher compressive
strength after 56 days. Even concrete cured at 0 °C will not be damaged, but “final” strength is reached very delayed and certainly a long time after the conventional 28 days. See figure 3.

**STRENGTH DEVELOPMENT OF CONCRETE AT DIFFERENT CURING CONDITIONS**

![Strength Development Graph](image)

**Fig 3: A lower starting point yields higher “final” strengths (from Haram & Helland 1986)**

Water encapsulated in concrete, normally has a freezing point between – 1°C and – 2°C, so even concretes with temperatures sub-zero don’t necessarily freeze. The problem is that the hydration process, which is, as we know, temperature dependent, will be very slow, and the risk of even lower temperatures is imminent. Consequently, the risk of freezing increases.

**Anti-freeze agents.**

As mentioned, concrete will not freeze until it has reached a couple degrees below zero. By using certain anti-freezing agents, this temperature can be lowered even further. Through testing, temperatures as low as –7 to –9 °C is measured in concretes, still with free water available. Even lower temperatures can be obtained, but we recommend that works with cement based materials should not be executed at temperatures lower than –10° C. With, of course, an important exception of casting of concrete structures of some size, when the concrete is covered, and with the use of warmer concrete – these actions will normally be sufficient to keep temperatures in the concrete well above freezing, even if the surrounding temperatures are very low.

As long as free water is available in the concrete, the hydration process will continue. But, since this process is temperature dependent, the use of an anti-freeze agent will only satisfy the need of the existence of available free water, and not influence the speed of the reaction. So, anti-freeze agents for instance based on nitrates or nitrites are efficient means of preventing frost in the mortar/concrete. And, when the temperature in the mortar/concrete increases, the hydration process speeds up again.
The dosages of different types of anti-freeze agents are normally relatively high, which leads to more expensive concrete.

**Solution: Combined action!**

Working in a winterland like Norway, will in shorter or longer periods mean that the temperatures fall far beneath zero degrees. To prevent cement based products from freezing at a too early stage, one has to do “something”. Sometimes, one precautionary measure might be sufficient (heating of the substrate, warmer concrete, a rapid cement, more cement, insulated forms, covering after casting, reduced water to cement ratio, use of superplasticising or freezing-point lowering admixtures, heating in the form or beneath the form). But, what kind of single action that might be sufficient or even optimum, can sometimes be very difficult to predict. More common (and advisable) is combined action. The most important project is to prevent the water from freezing – so to rely entirely on one card is in my opinion more than dubious.

<table>
<thead>
<tr>
<th>Action</th>
<th>People</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start warm!</td>
<td>Hot soup</td>
<td>Hot water</td>
</tr>
<tr>
<td>Avoid drying</td>
<td>ChapStick, handcream</td>
<td>Curing</td>
</tr>
<tr>
<td>Minimize heat loss</td>
<td>Dress in layers</td>
<td>Insulation</td>
</tr>
<tr>
<td>Watch extremities</td>
<td>Gloves, scarves, boots</td>
<td>Edges, corners, surface</td>
</tr>
<tr>
<td>Stay alert</td>
<td>Watch yourself &amp; friends</td>
<td>Measure temp.</td>
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</tbody>
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*Fig. 4: Common sense rules for dealing with cold weather for people and for concrete (from Concrete International 11/2002)*