Antifreezing admixtures

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21.1 Introduction

Despite the fact that antifreeze admixtures are currently used in Russia, Finland, Poland and China for placing concrete without any special protection under temperature as low as $-15 \, ^\circ C$, antifreeze admixtures are not used in Canada, Alaska and the northern parts of the United States, or elsewhere in Europe (besides Finland and Poland). Presently in Finland, it is possible to buy on the market prepacked sacks of concrete and mortars in which an appropriate dosage of calcium nitrite has been included. These prepacked mixtures can be used under temperatures as low as $-10 \, ^\circ C$ without any special protection against such a very low temperature. Very little English literature can be found on the subject except one comprehensive article written by Ratinov and Rozenberg in Ramachandran’s book on concrete admixtures (Ramachandran, 1995).

The basic idea of using an antifreeze admixture is very simple: it consists of incorporating in the mixer a soluble salt that lowers the freezing temperature of water. Lowering the freezing temperature of water by adding a soluble salt is a well-known phenomenon. Fahrenheit used it when he selected the origin of his temperature scale: The temperature $0 \, ^\circ F$ corresponds to the minimum temperature at which a saturated solution of calcium chloride freezes. Seawater freezes around $-1.8 \, ^\circ C$ according to its salinity.

21.2 Winter concreting in North America

When facing the first low temperature at the beginning of winter season, Canadian concrete producers start to heat the mixing water in order to increase the temperature of the fresh concrete. As the temperature continues to decrease, they start heating the coarse aggregates and the sand with steam.

In the field, when night temperature is decreasing close to $0 \, ^\circ C$, contractors protect the freshly poured concrete with insulating blankets. When it freezes harder, they build temporary polyethylene heated shelters to protect concrete against freezing. Of course, there is a price associated to the application of all these measures: on average, they charge 25% more for winter concreting.

When the ambient temperature is lower than $-10 \, ^\circ C$ in Canada, concrete is delivered only for inside applications. At $-15 \, ^\circ C$, ready-mix plants stop producing concrete until the ambient temperature goes up. Currently, antifreeze admixtures are not used at all in Canada.
21.3 Antifreeze admixtures

According to Ratinov and Rosenberg, nitrites, nitrates, calcium chloride, sodium chloride, ammonia, etc. have been used as antifreeze admixtures in Russia (Ramachandran, 1995). Usually, a combination of some of these chemicals is used. In practice, the most popular formulations are the ones based on nitrites. In China and Finland, a mixture of sodium nitrite (NaNO₂) and sodium sulphate (Na₂SO₄) is used, as well as a mixture of sodium nitrate and calcium nitrite, Ca(NO₂)₂. Pedro Hernandez (1989), during his master’s thesis, used essentially calcium nitrite as an antifreeze admixture.

As calcium nitrite is currently available in North America to provide an additional protection against the corrosion of reinforcing bars, the use of calcium nitrite as an antifreeze admixture should become an interesting alternative for winter concreting. Of course, the dosage of calcium nitrite that has to be added as an antifreeze admixture is much higher than the one used as a corrosion inhibitor. A saturated solution of Ca(NO₂)₂ freezes at a temperature of about −20 °C.

21.4 The construction of high-voltage power lines in the Canadian North

The anchors of the power lines erected in the Canadian North could benefit from this technology. In the Canadian North, high-voltage power lines are erected in winter because it is very easy to transport on the snow all the materials needed to erect the lines as well as the personnel. The frozen rivers and lakes are no longer obstacles for the progression of the construction of the lines. The only negative point is that the rock in which the anchors have to be fixed is totally or partially frozen, depending on the latitude at which the power line is located. In both cases, it is necessary to heat the rock around the anchorage hole in order to create an unfrozen zone around it before injecting the grout that will fix the anchor. In fact, the rock has to be unfrozen deep enough so that when the heating stops there is enough time for the grout to harden and get enough strength before the rock comes back to its initial frozen temperature.

The use of an antifreeze admixture could avoid such a long and complicated process. In order to prove the feasibility of such an alternative, experimental anchors were cast in Nanisivik in the extreme north of Baffin Island.

21.5 The use of calcium nitrite in Nanisivik

Nanisivik is a village located in the extreme north of Baffin Island at the 73 parallel where Nanisivik Mines exploits a zinc mine (Figure 21.1). An airport is connected to Ottawa twice a week and a harbour facility exists to ship the extracted zinc ore.

To study the feasibility of using grouts containing calcium nitrite as an antifreeze admixture, it was possible to take advantage of all of the facilities of the mining
company (food and dwelling, drills, transportation, etc.) and establish a temporary small laboratory inside a garage.

Two series of experiments were done: the first one in a cap of rock close to the plant as seen in Figure 21.2 and a second one in a gallery of the mine where the rock and the air were all year round at $-12\, ^\circ \text{C}$ (Figure 21.3).

At 300 mm below its surface, the temperature of the rock was $-12\, ^\circ \text{C}$ for the 12 anchors tested. The ambient temperature was $-15\, ^\circ \text{C}$ when the grouting was done.

The grouts were prepared in a garage using water at $10\, ^\circ \text{C}$ and transported to the site immediately to be poured in the anchor holes. They contained some aluminium powder in order to create a small expansion of the volume of the grout to improve the bonding of the grout with the anchor and the rock. Only the first 300 mm of the anchors were grouted and thermocouples installed at the bottom of the anchor to monitor the temperature of the grout (Figures 21.4 and 21.5). The composition of the grout is shown in Table 21.1.
Dosages are given in proportion of the cement mass. In the case of the superplasticizer and the calcium nitrite, the dosage corresponds to that of their solid content.

On the cap of rock, the anchors were pull out after 14 days. In the frozen gallery of the mine, the anchored bars were supposed to be pulled out 1 year later. A small rectangular base was built around each anchor to support the base of the hollow jack used to pull out the anchors (Figure 21.5).
Figure 21.4 Installation of the 12 anchors.

Table 21.1 Composition of the grout

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>High early strength cement (O)</td>
<td>1</td>
</tr>
<tr>
<td>Water (W)</td>
<td>0.44</td>
</tr>
<tr>
<td>Silica fume (FS)</td>
<td>0.10</td>
</tr>
<tr>
<td>Aluminium powder</td>
<td>$0.7 \times 10^{-4}$</td>
</tr>
<tr>
<td>Superplasticizer</td>
<td>0.03</td>
</tr>
<tr>
<td>Sodium nitrite (N)</td>
<td>0.12</td>
</tr>
<tr>
<td>N/(N + E) ratio</td>
<td>0.21</td>
</tr>
<tr>
<td>W/(C + FS) ratio</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Figure 21.5 The small rectangular base built around each anchor to support the base of the hollow jack used to pull out the anchors. The temperature of each grout was monitored by a thermocouple.
The results obtained on the cap of rock were compared to those obtained in an un-frozen rock in Sherbrooke; they were excellent (Benmokrane et al., 1987). However, in the case of the anchors grouted in the frozen gallery, after a year at $-12 \, ^\circ C$ it was impossible to pull them out because by error the grouted length was too long; the load that had to be developed to extract them was well over the capacity of the jack. It was necessary to cut the anchors with acetylene torches and seal the anchoring hole with a grout to avoid any accident in the gallery.

21.6 Conclusion

This experience of the Université de Sherbrooke in the Canadian Arctic has shown the great potential of using antifreeze admixture in concrete or grouts, as is currently done in Finland, Russia and China. The use of this technology could result in important savings when erecting power lines. Antifreeze admixtures can also be used to increase the length of the concrete season in the Canadian North by adding 2 months to the usual concreting season. Concreting could start 1 month earlier and stop 1 month later, which would be a great advantage in the short concreting seasons of the north.

References
