# The use of concrete with fly ash or slag in constructions exposed to de-icing salt-frost scaling

During the winter, with temperatures below 0 °C, any water on the roads or bridges that have come from snowfall or rain can freeze. This ice results in a risk for vehicles to slip, crash, and cause personal and structural damages. In order to solve this problem, one common solution is to use a de-icing agent (e.g. sodium chloride, NaCl) in order the thaw and remove the ice. With no ice on the roads, this can seem like a perfect solution to the problem. Unfortunately, the use of de-icing salts increases the corrosion on vehicles and results in a risk of damage to concrete structures like bridges. This project has been about the latter problem.

When a salt-based de-icing agent has caused the water to thaw, the product is a solution of water and salt. If the salt concentration is low, the freezing point is relatively high. For example, pure water freezes at 0 °C, a solution with 6% NaCl and 94% water freeze at approx. -4 °C, which is not a very low temperature; a solution with >23% NaCl and <77% water freezes at approx. -21 °C. After the first application of salt on the ice, the salt solution concentration will most likely be high and therefore the freezing point will be low, however, if there is some snowfall (added water) the salt solution concentration will decrease and therefore the freezing point increase. During a normal winter in Sweden it is common for the temperatures to be somewhere between -5 and -15 °C. Therefore, a salt solution with a low concentration of salt will be able to freeze. If a solution with a low salt concentration freezes on top of a concrete surface (e.g. bridge, pavement, balcony) this can cause a superficial damage where concrete flakes scale off.

The above phenomenon has been studied since the beginning of the 20th century. Harry Arnfelt, a researcher at the Swedish road institute, was one of the first to study this phenomenon. He published a paper 1943 where he had varied the concentrations of the salt solutions and tested a wide variety of de-icing agents (urea, NaCl, ethyl alcohol and five others). The results showed that low concentrations caused the largest damages and all of the de-icing agents caused damages. Another researcher that studied this phenomenon is Treval Clifford Powers. He published an early important theory regarding the underlying mechanism based on measurements and results which showed that entrained air voids reduce the scaling damage. Another important factor to consider when studying this superficial damage is what happens to concrete properties when the concrete surface has carbonated. Carbonation is a spontaneous chemical reaction where concrete binds carbon dioxide, which exists in the atmosphere. This has also proven to influence the de-icing salt-frost scaling according to results presented by Stefan Jacobsen and Peter Utgenannt among others.

Earlier researchers focused on the damage in ordinary concrete which contain aggregates, cement and water. The cement and water result in a hardened paste that binds to the aggregates. However, the production of cement results in a large release of carbon dioxide to the atmosphere. Due to the immense world-wide usage of concrete, the production of cement and concrete is responsible for approx. 5% of the man-made carbon dioxide release. One way to reduce this carbon dioxide release is to reduce the cement usage. One way to reduce the cement usage without reducing the net concrete usage is to replace some of the cement in the concrete recipes with other materials. Two examples of replacement materials that are used are the waste products from coal power plants and the steel industry, which are fly ash and slag. When fly ash or slag is added to the cement, the reaction with the water and products from these reactions change. This results in a change to the microstructure and therefore a change to the material properties. Changes to the material properties infer a change to the resistance to destructive mechanisms such as the de-icing salt-frost scaling.

This PhD project has studied the de-icing salt-frost scaling in concrete that contain various fractions of fly ash or slag. In addition to testing the effect to the de-icing salt-frost scaling resistance from adding fly ash or slag, the air void content was varied. The effect from drying and carbonation has also been studied. To test the de-icing salt-frost scaling, a method was developed at the beginning of the project. The results showed that air void content, and the drying and carbonation have a significant impact on the de-icing salt-frost scaling. The results also indicate that it is possible to replace some of the cement with fly ash or slag without decreasing the de-icing salt-frost scaling resistance. Therefore, in an effort to reduce the carbon dioxide emissions, it would most likely be preferable to allow fly-ash or slag to be used in concrete structures that are exposed to de-icing salt-frost scaling. However, a problem with laboratory testing of salt-frost scaling is that it is difficult to find correlations between laboratory results and constructions exposed to ordinary weather. There have been some researchers that have pointed out these differences in results for concrete containing either fly ash or slag. Some of the results presented in the thesis show that the preconditioning of the samples is very important to the results. Putting these two last mentioned factors together, in order to get a better correlation between the laboratory and the field results, one way would be to adjust the preconditioning process to calibrate the laboratory results to the field studies.

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