Frost Salt Scaling of Concrete

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ABSTRACT

The project will address the mechanism(s) of deterioration in frost salt scaling (FSS) including the potentially protective effect of entrained air voids and the performance of low-clinker blends. Frost deterioration of concrete is an important durability issue for concrete structures exposed to high humidity, frost and deicers (exposure classes XF1-4 in EN206). Today when the variety of binder compositions is rapidly increasing it is more important than ever to understand the mechanism behind the deterioration to define a reliable test method to obtain frost durable structures.

Key Words: Frost Action, Concrete, Supplementary Cementitious Materials, Durability, Modelling, Cement.

1. INTRODUCTION

The combination of high degree of saturation and low temperatures can result in both surface scaling and internal cracking. Frost damage can lead to loss of concrete cover and thus reduced protection of the reinforcement and possible loss of bearing capacity. Frost damage in form of cracking facilitates ingress of aggressive substances and thus also other deterioration mechanisms.

The degree of deterioration depends on the surrounding environment (such as temperature, precipitation, deicers, relative humidity) and the materials properties (such as permeability, pore size distribution, air void structure, and mechanical properties).

2. BACKGROUND

Long-term experience shows that concrete structures with high amounts of Portland clinker and various air entraining admixtures (AEA) can be durable. Field exposure investigations confirm that the existing test methods can usually predict the performance of Portland cement concrete [1]. However, with the increasing substitution of Portland clinker, problems with production (e.g. air entrainment, curing) and ageing (e.g. carbonation) of hardened concrete can lead to reduced protection. There are indications that low clinker concretes are less robust than PC concrete regarding placing and curing [2]. To solve these challenges improved understanding of basic mechanisms is needed.

Valenza and Scherer presented the Glue Spall theory explaining the mechanisms behind FSS [3]. The main features of this theory are that weak salt solutions on the concrete surface gives a weak ice layer during freezing depending on salt concentration. The ice has a larger thermal expansion coefficient than the concrete. Weak salt solutions will create a crack in the ice that will propagate into the concrete surface, causing the surface to be spalled off. The concrete can be protected by a proper air void system since this allows pore liquid to be sucked into and freeze in the air voids creating an additional contraction of the concrete surface as explained by Powers and Helmuth [4] and later described in a quantitative theory by Coussy [5]. This offsets the strain mismatch between the surface ice and concrete, hence reducing damage. Glue Spall theory tells us also that the higher the tensile strength of the concrete surface, the longer it can sustain the strain mismatch, and the lower the temperature the more cracking. If the concrete is not properly air entrained the thermal mismatch will cause spalling earlier, particularly in combination with internal frost damage [6]. The Glue Spall theory is the only model quantitatively explaining the pessimum effect of salt concentration and the impact of thickness of water layer on the surface. However, cycles, which could induce progressive air voids saturation and subsequent increased damage, are not considered. It indicates that positive effects of pozzolana are rather due to improvement of surface strength properties than improvement of transport properties and this has puzzled several researchers.

Fagerlund presented the theory of critical degree of saturation [7]. If a concrete has water content giving an actual degree of saturation higher than the critical degree of saturation and is exposed to freezing temperatures it will be severely damaged. Entraining air voids normally gives a reduced actual degree of saturation since the voids mainly stay dry. The critical degree of saturation is a material parameter individual for each concrete. Therefore, to make a prediction of the future service life possible one has to be able to predict the long term absorption into the air void system. Fagerlund presented a model of this long-term absorption based on dissolution and diffusion of entrapped air which will be replaced by water [8]. The model applies when the concrete is submerged. The main conclusion from Fagerlund’s approach is that we have to consider air voids’ size distribution, the smallest bubbles being rapidly saturated as air dissolution is fast. However, large air voids are almost never saturated. We should have in mind that the spacing factor is defined considering all the entrained air voids but progressive saturation starting with the smallest one, has the same consequence as increasing the spacing factor. Then even if we don’t reach the critical spacing factor proposed by Fagerlund, as the spacing factor should exceed a certain limit, then the classical hydraulic pressure could build up again and generate expansion and damage even if the critical spacing factor proposed by Fagerlund is not reached. Fagerlund

[9] has also proposed that pessimum salt concentrations can be due to a combination of osmotic pressure (increasing with salt concentration) and hydraulic pressure (reducing with salt concentration).

Lindmark [10] applied the theory of frost heave [11], on the surface of concrete – and could account for the same type of deterioration as Powers and Helmuth [4], [12]. This was called the theory of micro ice lens growth and when the critical degree of saturation was transgressed, the surface spalled off. If the concrete has an air void system with good spacing the ice in the air voids attracts the water and the resulting suction in the water offsets the tensile stresses created by ice lenses in the mesopores of the cement paste. Again this theory could be used to consider progressive air void saturation during cycles, taking into account permeability and other material properties. It is also interesting to notice that several researchers have established experimental correlation between FSS and surface sorption [13] which appears as another evidence of the impact of surface permeability, pore size distribution and their connectivity towards critical degree of saturation.

It is essential to recognize that more than one mechanism can contribute to surface damage and they can be more or less dominant under certain climatic conditions for materials with different properties. Another question lies in the mechanism at the origin of the potential beneficial effect of entrained air voids since Liu [13] found opposite results of Sun and Scherer [14].

To be able to obtain frost durable structures with a wider variety of binder compositions, we need a basic understanding of the FSS mechanism of concrete and an understanding why low clinker systems under some circumstances are more susceptible to FSS than PC. This information can be used to create improved experimental protocols to access sensitivity of low clinker systems to FSS.

3. SCOPE AND ACTIVITIES

The four main objectives of this research is first to model the key mechanisms involved in FSS covering the Glue Spall theory, water uptake by cryosuction, critical degree of saturation and repetitive cycles. The second objective is to define which material properties are decisive for resistance to FSS. The third objective is to determine the requirements for a protective air void structure, and the last objective is to establish an understanding of the impact of hydration and aging on FSS.

The main part of this project will be to extend the poroelastic model of cryosuction developed by Fen-Chong et al. [15] based on work by Coussy [5] to include influence of salt solutions and progressive air voids saturation during cycles as well as thermal contraction and surface properties related to the Glue Spall theory. A review of existing theories and parametric studies will be performed to identify the key parameters for frost scaling in the progressive saturation and Glue Spall theories.

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