Concrete behavior under simultaneous freeze-thaw cycles and sulfuric acid attack

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1. Introduction

The freeze-thaw deterioration of concrete frequently occurs in cold regions, during wintertime [1]. A recently emphasized problem with an important impact on concrete durability is the sulfuric acid attack on concrete, usually met in sewage systems and facilities [2]. The case of sewage facilities, exposed simultaneously to freeze-thaw cycles and sulfuric acid attack was investigated in this paper.

2. Materials

The study was performed on concrete specimens with W/C ratio of 35% and 65%. Ordinary Portland cement (Blaine surface 328 kg/m^2), pit sand (ρ=2.60g/cm^3; absorption coefficient 2.05%) for fine aggregates, crushed stone aggregate (ϕ_{max}=25mm, ρ= 2.86g/cm^3, absorption coefficient 1.06%) for coarse aggregate, superplasticizer and air entraining agents, were used as mixing materials.

The concrete specimens (dimensions: 10x10x40cm) were cured 2 weeks in water at 20˚C and then tested to freeze-thaw (FT), sulfuric acid attack (S) or combined freeze-thaw and sulfuric acid attack (FTS).

Freeze-thaw experiments, in accordance with JIS A 1148-2001, used water or H_2SO_4 (0.5% and 3.0%) as freezing solutions. Mass loss was measured at each 30 cycles (5 days).

In order to discriminate the effect of H_2SO_4, the sulfuric acid attack on concrete, at constant temperatures (0˚C and 5˚C), was investigated. In experiment were used In the case of the sulfuric acid (concentrations: 0.5% and 3.0%) exposure at constant temperatures, the mass loss was measured weekly.

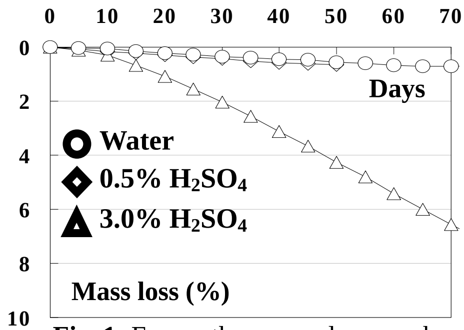

Fig. 1: Freeze-thaw mass loss graph, W/C = 35%

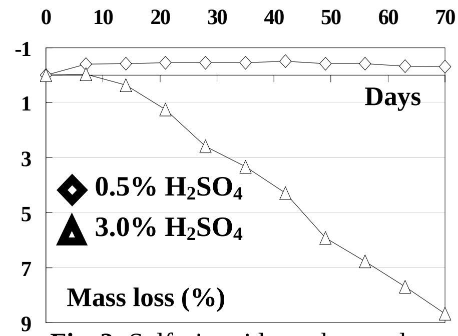

Fig. 2: Sulfuric acid attack mass loss graph at 5˚C, W/C = 35%

3. Results and discussions

Due to the performed experiments, data from exposure only to freeze- thaw (FT), from exposure to sulfuric acid attack (S) and data from simultaneous freeze-thaw in sulfuric acid (FTS) were obtained. Relationships between these sets of data were sought.

Mass losses due to freeze-thaw cycles are presented in Fig.1. Both freeze-thaw in water (FT) and in H_2SO_4 (FTS) show linear mass loss patterns. Therefore, these mass losses can be modeled through linear trend lines and will be characterized by the slopes of these lines.

The sulfuric acid exposure at constant temperature (S) shows by the other hand, non-linear mass loss patterns (Fig.2): an initial increase in mass followed by almost constant values of mass for small (0.5%) sulfuric acid concentrations and a linear mass loss for higher (3.0%) sulfuric acid concentrations. The initial mass increase suggests that these curves describe not a real deterioration but an apparent one.

In order to obtain the real deterioration, the curve for W/C=35% at T=5˚C was set as no-deterioration curve due to the fact that no mass loss was observed through 10 weeks period in this case.

Then, the difference curves were calculated subtracting the no-deterioration curve from the apparent deterioration curves.

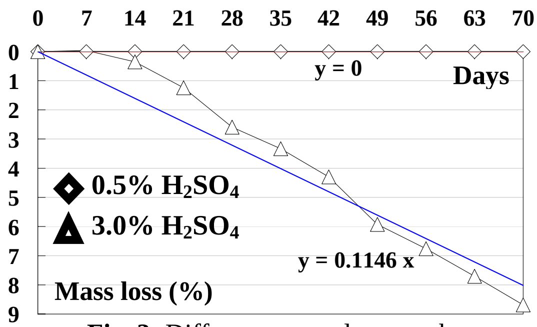

Fig. 3: Difference mass loss graph at 5˚C, W/C = 35%

In Fig. 3 the difference curves for the case of W/C = 35% at T=5˚C are presented. The real deterioration lines show that there is a period of time in which the concrete resists to sulfuric

Key Words: *durability, freeze-thaw, sulfuric acid*
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acid attack; after this non-deterioration period, the mass loss is linear and will be characterized by a deterioration slope as in the case of freeze-thaw model.

Until now, it has been shown that one parameter (deterioration slope) can characterize freeze-thaw deterioration and that the sulfuric acid attack can be described through two parameters (a non-deterioration period and a deterioration slope). Any model connecting freeze-thaw (FT) and sulfuric acid attack (S) with the combined exposure (FTS) must consider these parameters in such a way that the predicted values equal the experimental data. As a first approximation, the law of combination between the individual effects was considered to be a simple addition. Due to the fact that the description of the non-deterioration period requires data regarding the concrete porosity, this parameter was ignored.

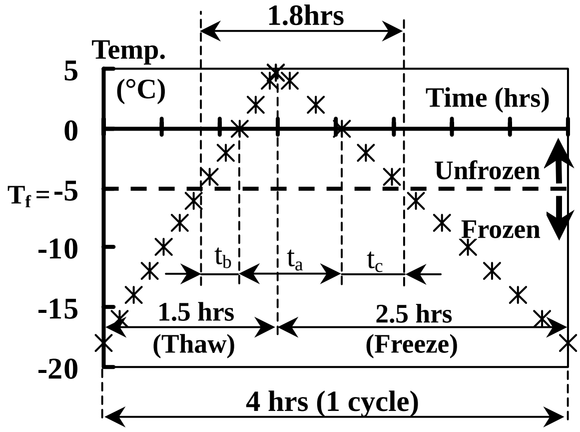

Fig. 4: Characteristics of freeze-thaw cycles

When it comes to discuss the combination of freeze-thaw and acid attack effects, the period in which these processes occur simultaneously should be considered. During one freeze-thaw cycle, there is a period of time in which the H_2SO_4 is frozen, and practical no acid attack takes place. In this experiment, the freezing point (T_f) was observed at –5˚C; for this temperature, in one freezing cycle lasting 4 hours, only 1.8 hours were available for sulfuric acid attack (Fig. 4). Another aspect to be considered is that during a freeze-thaw cycle, temperature varies from -18˚C to 5˚C and backward; therefore the rate of the sulfuric acid attack varies too (Fig. 5). An average rate of deterioration must be considered as shown in Fig. 6.

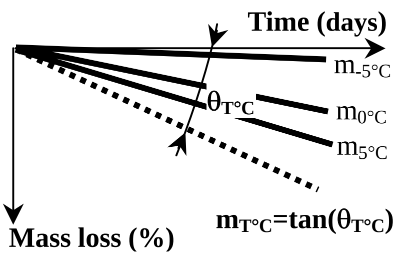

Fig. 5: Sulfuric acid attack deterioration rate (slope) variability

With the aspects regarding the simultaneous exposure solved, the addition of the individual effects was performed for each of the tested W/C (35% and 65%) and sulfuric acid concentration (0.5% and 3.0%). Then, the modeled data [(FT) + (S)] were drawn against the corresponding values from the combined exposure [(FTS)] as is shown in Fig.7.

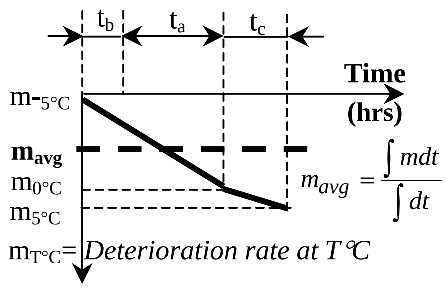

Fig. 6: Average rate of deterioration

The accuracy of the proposed model will be determined by the closeness of the drawn points to the line (FT) + (S)= (FTS). It can be seen that the for high H_2SO_4 concentrations (3%), the previous simplified model should be refined considering the non-deterioration period and maybe more elaborated law of combination.

4. Conclusions

Freeze-thaw mass loss is linear in time, regardless of the freezing solution. The sulfuric acid attack at low temperatures occurs only after a non-deterioration period. This non-deterioration should be considered in modeling the simultaneous freeze-thaw and sulfuric acid exposure. The characteristics of this non-deterioration period must be further studied.

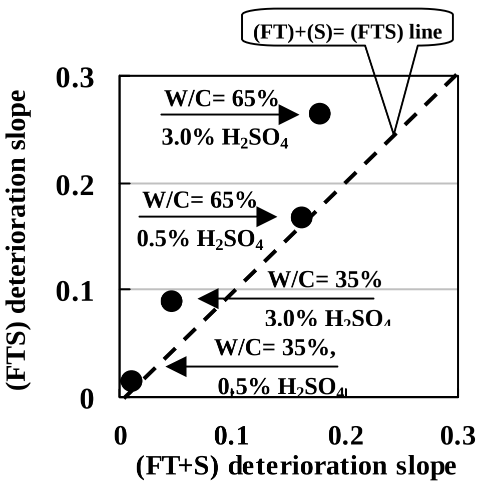

Fig. 7: Modeled data [(FT)+(S)] versus experimental data [(FTS)]

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