Effectiveness of Calcium Nitrate as a concrete corrosion inhibitor according to ASTM G109-07 (2013)

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Abstract

In the present work the influence of calcium nitrate as corrosion inhibitor for reinforced concrete structures exposed to aqueous chloride induced solutions was studied.

To study this subject the ASTM C1582/C1582M standard, method G 109-07, was applied. Portland cement, sand, gravel, super plasticizer, air-entraining agent and calcium nitrate as 0-3-4% by weight of cement were used to produce 3 different concretes. In the presence of 3% of calcium nitrate a significant reduction in the corrosion process was recorded with respect to the control mixture without admixture. No significant improvement was found in the performance of calcium nitrate when the percentage was increased from 3% to 4%.

Keywords: Calcium nitrate, Corrosion inhibitor, ASTM C1582

Introduction

Corrosion is one of the biggest issues for concrete structures. Especially for housing and infrastructure, repair work is either very costly or impossible. Therefore inhibiting or slowing down the corrosion rate is target for such projects.

Among different types of corrosion, chloride ingress is counted as one of the major types. It can affect facilities and infrastructure whenever built in a an environment prone to corrosion, for instance high relative humidity and sources of chloride ions such as sea water.

Using calcium nitrate as corrosion inhibitor has been studied for several years. Long term test [1], laboratory models [2], as well as the theory behind and simulation [3], [4] have been studied. All studies demonstrated the effectiveness of calcium nitrate in inhibiting chloride ingress. However tests according to ASTM standards have been missing yet. Such tests are documented within this study.

Methods and Materials

The standard ASTM C1582/C1582M-11 covers the specifications and requirements of materials to use as chloride corrosion inhibiting admixtures for concrete [5]. Accordingly the evaluation tests can be conducted according to method ASTM G109-07. This test method can provide information for predicting the inhibiting effect or corrosive property of the concrete admixture [6].

There are two groups of requirements stated in ASTM C 1582: general requirements (chapter 4 of the standard) and corrosion inhibitor performance (chapter 5 of the standard; to be performed according to ASTM G109 method).

General requirements: ASTM C1582/C1582M-11 states requirements for the setting time and compressive and flexural requirements.. According to the requirement initial and final setting time should not be altered more than 3.5 hours. The compressive and flexural strength of the concrete with corrosion inhibitor should be at least 80% of the reference sample without corrosion inhibitor admixture at all times, especially 3 days, 7 days, 28 days, 6 month and 1 year.

Chemical shrinkage of calcium nitrate is similar to calcium Nitrite, however not dosages as high as 4% have been investigated. [11]

Corrosion inhibiting performance: In addition to general requirements, the corrosion inhibitor must show the following performance regarding corrosion inhibition according to table 2 of the ASTM C1582:

- Test of the admixture shall be done according to method ASTM G109.
- Integrated macro cell current should be less than or equal to 50 C (Coulomb).
- Corroded area should be less or equal to 1/3 of the corroded area of the reference.

Within method ASTM G109 the requirement for the corrosion current is 10 µA. [6]

In line with ASTM G109 requirements CEM I 42.5R (EN 197/1) with W/C ratio of 0.5 and 6±1 percent entrained air was used. The density of fresh concrete was 2192 kg/m3, casted and reinforced with three embedded bars D = 12 mm [5]. Figure 1 shows the specification of concrete beams with details.

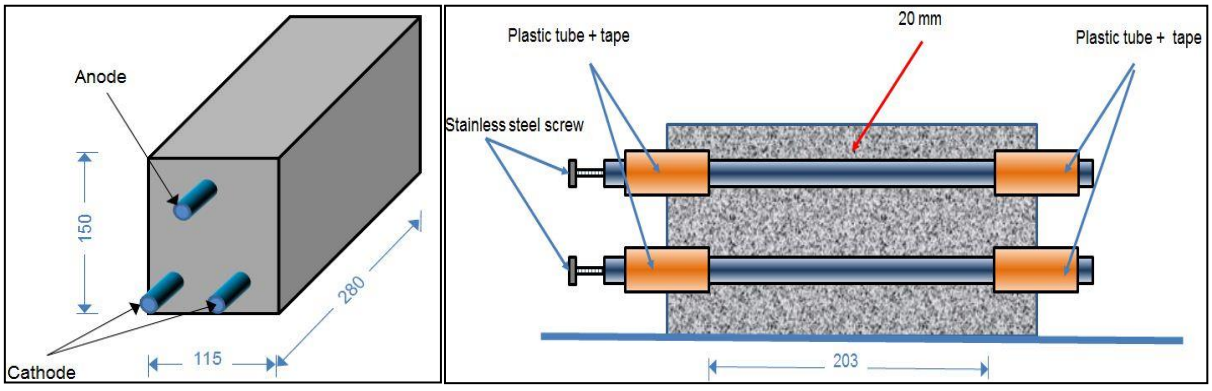

Figure 1: Sketch of the concrete beams according to ASTM G109 [6]

Three different concrete mix were manufactured in order to assess the effect of calcium nitrate on chloride-induced corrosion:

- control concrete, without any corrosion inhibitor.
- concrete equivalent to the control but containing, in addition, 3% of calcium nitrate.
- concrete equivalent to the control but containing, in addition, 4% of calcium nitrate.

In total 9 concrete beams were prepared (three specimen for each concrete mix). The beams have been cured at 20 °C and 95% RH for 28 days. Afterwards they have been treated on the surface with epoxy resin, except for the bottom surface and a 152 mm x 76 mm rectangular area on the top face for plastic wall [7] (as prescribed in ASTM G109) .

Results and discussion

The evaluation of the general requirements is based on literature references. In a first study by SINTEF [8] three types of cements were tested. Setting time for CEM I 52.5R white, CEM II/A-V 42.5 and CEM III/B 52.5 altered 3, 2, and 3.5 hours respectively. CEM I 52.5 R, CEM IV/A 42.5R, CEM II/A-LL 42.5R also tested [9] and the setting time altered 3 hours and ten minutes at the highest with CEM I 52.5 R. Therefore setting time criteria is expected to be fulfilled. [10]

Compressive strength was investigated and tested with CEM I 52.5R white, CEM II/A-V 42.5 and CEM III/B 52.5 [8]. The lowest remaining compressive and flexural strength reported are 83% and 84% respectively with CEM II/A-V 42.5. This level stays above the required 80%.

According to ASTM G109 method, one of the requirements is to reach corrosion current of 10 µA. The control sample reached a current of 10 µA in average at 97 days. [7]

Figure 2, illustrated that 3% CN treated samples reached that current in average at 150 days and the 4% CN treated samples have not reached this current in average within 180 days. According to this criteria testing might have stopped already after 150 days, as the reference started to fail at 90 days and completely failed at 120 days. [7]

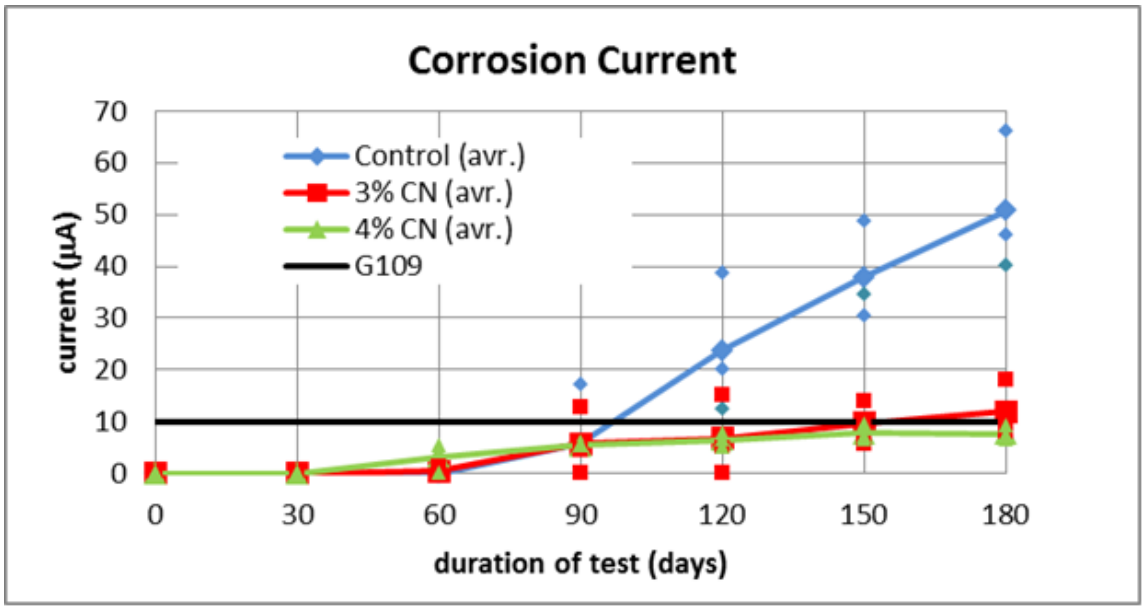

Figure 2: Corrosion current. The 4% CN treated sample does not exceed the corrosion requirement of G109, whereas the reference fails at about 90 days. [7]

The second requirement for final measurement is an integrated charge of 150 C for the reference samples. In the experiment, this alternative criterion of 150 C was reached for the reference at about 156 days, interpolated from the measurement at 150 days and 180 days. This resulted in the end of testing after 180 days (Figure 3).

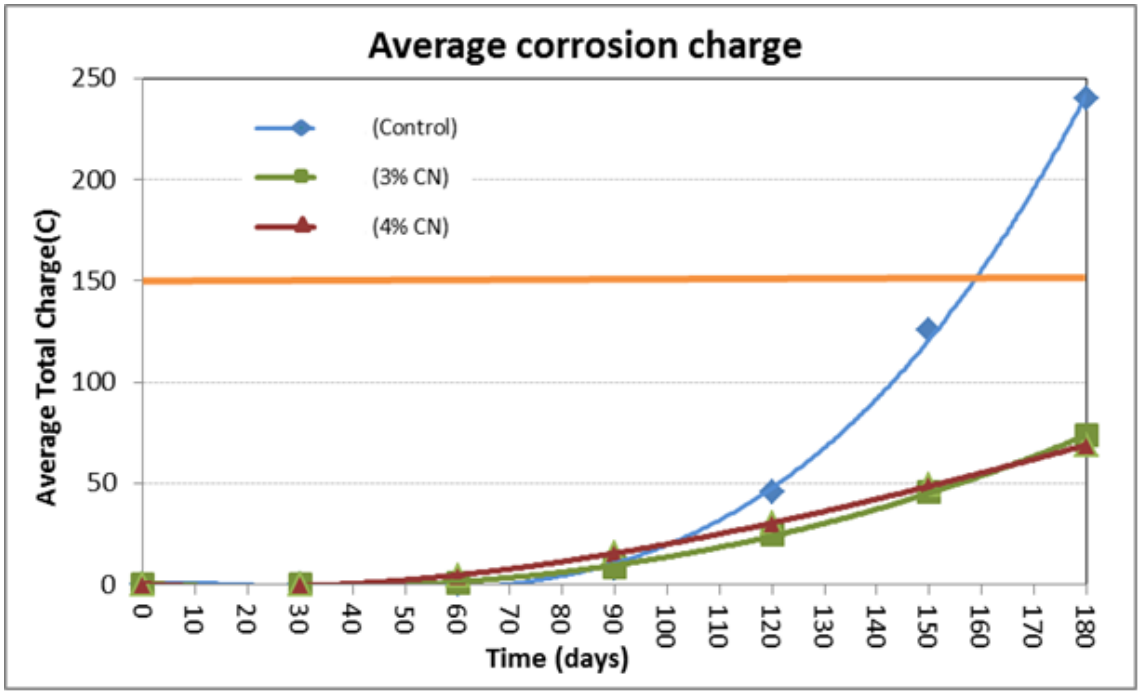

Figure 3: Average corrosion charge increase within the testing period

The third requirement for a corrosion inhibitor is that the macro cell current is less than or equal to 50 C. After 150 days the integrated charges for the treated samples were in average < 50 C, after 156 days (end of experiment according to standard requirement) the integrated charges were about in average 50 C and at 180 days the integrated charge is a bit higher than 50 C but much less than reference sample. The references exceeded 50 C strongly at both 150 days and 180 days.

The fourth and last requirement for a corrosion inhibitor is related the corroded area of the reinforcement. The corroded area of the treated samples shall not exceed 1/3 of the corroded area of the reference samples. After 180 days the corroded area of the treated samples was in average about 1/3 of the reference samples. [7] Results are illustrated in Figure 4.

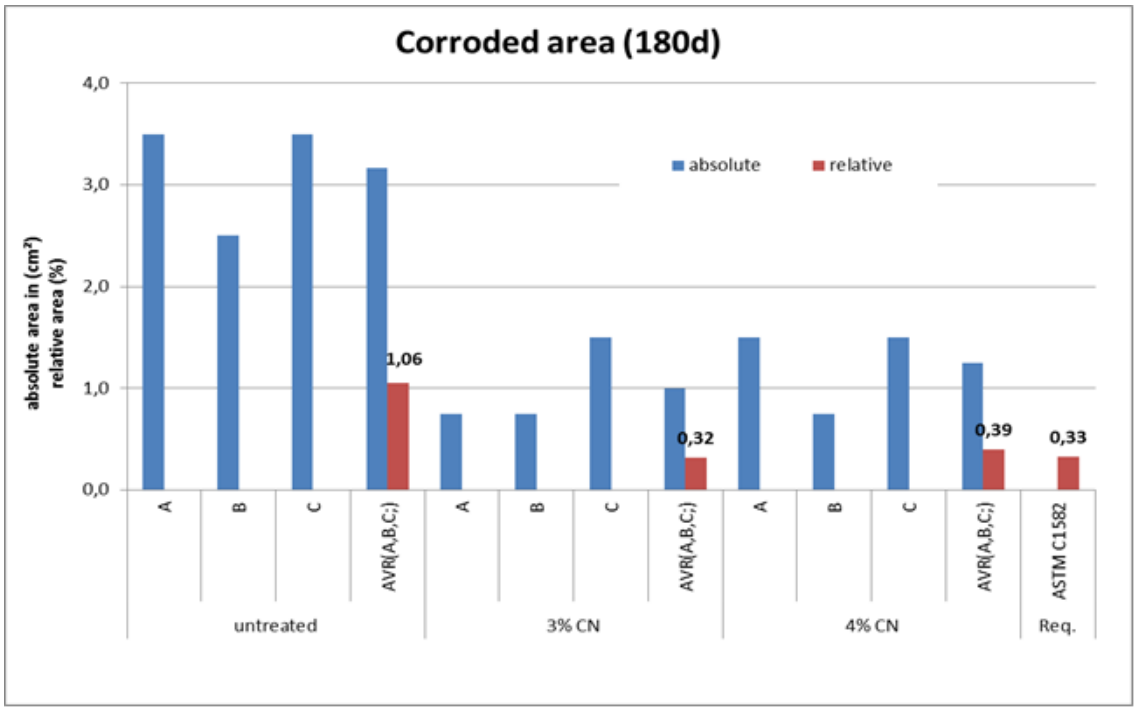

Figure 4: The corroded area of the CN treated samples reached about 1/3 of the area of the untreated sample after 180 days. [7]

Conclusions

With reference to literature it can be concluded that calcium nitrate meets the general requirements of ASTM C1582 regarding setting time and compressive strength. Setting time is usually altered less than 3.5 hours and compressive strength is usually > 80% of the reference at all times.

The here presented results indicate that calcium nitrate, added as 3% and 4% bwoc., matches the corrosion inhibitor requirements of ASTM C1582 with minor deviation (when tested in accordance with test method ASTM G109). The corrosion current stays within the documented tests below 10 µA, the integrated charges stay below 50 C (for 150 days) and the corroded surface is about 1/3 of the reference (180 days). [7]

Except lower corrosion current at 150 and 180 days, no significant improvement was found in the performance of calcium nitrate when the percentage was increased from 3% to 4%.

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