Test and Evaluation of Calcium Magnesium Acetate–Sodium Chloride Mixtures in Sweden

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Together with plowing and sanding, chemical deicing and deicing agents are important tools for highway snow and ice control. The most commonly used deicing agent is sodium chloride (NaCl), which is effective, easy to handle, and inexpensive. Many negative and often costly side effects, have, however, been recognized over the years. Extensive research has therefore been conducted to find alternatives. Calcium magnesium acetate (CMA) is an alternative deicing agent that has given very promising results in laboratory and field tests. The most significant impediment to its use is its high price, which is more than 20 times that of NaCl. To reduce the cost but maintain the benefits of CMA, tests have been conducted with CMA-NaCl mixtures. In 1993 the Swedish National Road and Transport Research Institute initiated a research project to test and evaluate a mixture of 20 percent CMA and 80 percent NaCl. The field evaluation was conducted on Highway E4 and included both friction measurements and corrosion tests. The laboratory testing, mainly done at the Swedish National Testing and Research Institute, included corrosion tests and freeze-thaw testing on cement concrete. The laboratory tests showed that the addition of CMA to NaCl does reduce the corrosion of steel and the scaling of concrete. The field tests also indicated reduced corrosion of steel, but not to the same extent as the laboratory tests. Furthermore, the same deicing could be obtained with the CMA-NaCl mixture as with NaCl.

The Swedish National Road and Transport Research Institute (VTI), in cooperation with the Swedish National Road Administration, has conducted research projects to test and evaluate salting methods and alternative deicing agents for many years. From 1985 to 1990 the Swedish MINSALT program, "minimizing the adverse effects of salt," was carried out with the aim of finding more effective ways to improve skid resistance without the negative effects of salt (NaCl). The results from the MINSALT projects have been reported in various reports and summarized in a final report (*1*).

Chemical deicing (salting) spreading methods have progressed from the earlier use of dry salt to the use of prewetted salt and saline solutions. The results from the MINSALT projects have led to a proposed strategy to reduce salt consumption and make salting more effective. This has been accomplished by working more with anti-icing measures, before the icy conditions occur, and less with deicing. Prewetted salt or brine is used.

A number of different chemical alternatives to NaCl have been tested. In particular, calcium magnesium acetate (CMA) has been studied closely for ice-melting capacity, corrosiveness, and effect on concrete. Studies of alternatives have also included chemicals suitable for runway purposes. Potassium acetate, a liquid deicer, has been tested and is now used at some Swedish airports (*2,3*).

Since CMA is very expensive, more than 20 times more costly than NaCl, tests have been conducted with CMA-NaCl mixtures. In the United States very promising results regarding the corrosive effect have been obtained by mixing NaCl and CMA. Tests conducted in Minnesota with a mixture of 20 percent CMA and 80 percent NaCl by weight showed that this mixture can give a significant reduction of the corrosion rate (*4*).

In 1993 the Swedish National Road Administration commissioned VTI to start a research project to test and evaluate a mixture of 20 percent CMA and 80 percent NaCl by weight. The evaluation included a field study of the operational effects under varying weather and road surface conditions and laboratory testing of deicing properties, corrosive effects, and the effect on cement concrete. The latter two tests were made by the Swedish National Testing and Research Institute (SP). The corrosion tests were conducted with steel plates in a climate chamber under simulated field conditions, and the effect of various mixtures of CMA and NaCl on cement concrete was investigated by freeze-thaw testing.

METHOD

Laboratory Tests

Ice Melting Rate

The melting capacity of the 20/80 CMA-NaCl mixture was tested on blocks of ice at three temperatures, –2, –6, and –10°C. For comparison, pure NaCl and CMA also were included in the test. The deicer was evenly spread over the surface of the 114-cm^2 ice block in two amounts, 10 and 20 g. The melted ice or brine that formed on the surface of the block of ice was decanted at specified time intervals and weighed.

Corrosion

The corrosive effect of the CMA-NaCl mixture on steel plates was investigated by SP (*5*). A spray test was performed in a climate chamber under simulated field conditions. The chamber is divided into two sections to allow two deicers to be tested at the same time under identical conditions. In one of the sections a 3 percent aqueous solution of the 20/80 CMA-NaCl mixture was sprayed onto the steel plates, and for comparison a 3 percent aqueous solution of NaCl was used in the other section.

Freeze-Thaw Test on Cement Concrete

Freeze-thaw tests were conducted by SP to determine the effect of various CMA-NaCl mixtures on cement concrete (*6*). The method used was based on the Swedish Standard SS 13 72 44 according to which a sawed concrete surface is exposed to a 3 percent NaCl solution during 56 freeze-thaw cycles. Four proportions of CMA-NaCl were included in the test: 0/100, 20/80, 40/60, and 100/0, and cement concrete of three qualities was used: (A) an old type of concrete, made before air-entraining agents came into use, (B) a modern type of concrete with air-entraining agents added, and (C) a very dense concrete of high quality, which is used only in certain structures but which is expected to be more common in the future; this concrete is air-entrained and also contains 5 percent silicon dust. An investigation of the effect of higher concentrations of CMA on cement concrete was also conducted.

Field Tests of CMA-NaCl Mixture on Highway E4

Deicing Performance

Field studies were undertaken during the winters of 1993–1994 and 1994–1995 on a section of Highway E4, which is a four-lane divided highway with bituminous surfacing. To compare the performance of the CMA-NaCl mixture and NaCl as deicing agents, skid resistance measurements and pavement surface observations were conducted on a test (CMA-NaCl) section and a control (NaCl) section. Each section was about 20 km long and included both north- and southbound lanes. Within the test and control sections were a number of 400-m-long sampling sections, in both the driving and the passing lanes, in which the skid resistance measurements were conducted. The sampling sections were selected to be uniform for pavement cross section, flatness, traffic, and other conditions. This segment of Highway E4 does not experience the effects of peak hour or commuting traffic.

Friction measurements and pavement surface observations were made at each of the sampling sections during a number of situations with slippery conditions. The friction measurements were made using a SAAB Friction Tester. The skid resistance monitoring and pavement surface observations were usually made before the spreading operation, 10 to 30 min after spreading, and then at intervals of 45 to 60 min until a stable or bare pavement condition was reached. In addition, the atmospheric conditions and pavement temperatures were monitored by using two road weather information system stations, which were located in the test and control sections. The time of application and the application rate were reported by the operators of the spreading vehicles.

The mixture used in the field testing was 20 percent CMA and 80 percent NaCl by weight. The mixture was prepared by using a small double hopper with a conveyor belt (Figure 1). The accuracy of the mixture was checked

FIGURE 1 Mixing CMA-NaCl by using a small double hopper with conveyor belt.

FIGURE 3 Panel with steel plates for corrosion test, placed between northbound and southbound lanes of Highway E4.

by taking a sample of the mixture and then separating and weighing the salt and CMA compounds.

Corrosion

To study the corrosive effect of the CMA-NaCl mixture under more realistic and varying conditions, field experiments were conducted by placing steel plates in the median of the road between the northbound and southbound lanes (*5*). Five painted and five unpainted steel plates were mounted on a stand (Figure 2). The painted steel plates were provided with a scratch to be used for evaluating the formation of cracks and scaling caused by corrosion. Two stands were placed at the test and control sections, one stand facing the northbound lane and the other facing the southbound lane (Figure 3). The atmospheric corrosion rate was monitored with five unpainted plates placed far from the road at each section (Figure 4). By subtracting the atmospheric corrosion from that of the specimens at the road side, the corrosive influence from the road environment could be evaluated.

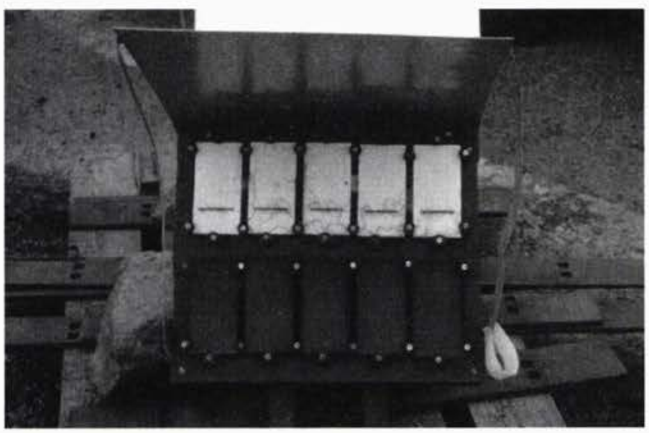


FIGURE 2 Steel plates, five painted and five unpainted, for corrosion test.

After the first winter the steel plates were taken down, the rust was removed, and the weight loss of the plates was determined. The test was repeated with new steel plates the second winter.

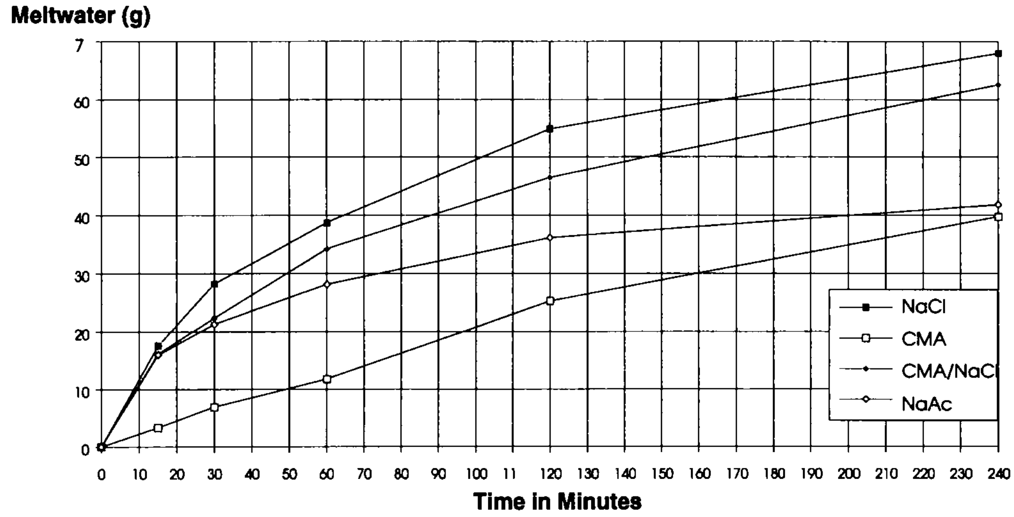
RESULTS

Laboratory Tests

The ice-melting rates at –6°C for NaCl, CMA, a 20/80 mixture of CMA and NaCl, and sodium acetate (NaAc) are shown in Figure 5. It can be noted that CMA has a considerably lower melting rate than NaCl. Especially, CMA has a very slow initial melting effect compared with NaCl. The melting rate for the CMA-NaCl mixture is, however, not very much lower than that for NaCl. The same relationships are found at lower temperatures, but under those conditions the slower melting effect of CMA is even more pronounced.

According to the results of the corrosion test in the climate chamber, the CMA-NaCl mixture reduced the

FIGURE 4 Steel plates for monitoring atmospheric corrosion.



Note: 10 g deicer spread on blocks of ice.

FIGURE 5 Ice-melting rate at –6°C for various deicers.

corrosion rate of steel by 45 percent compared with NaCl. The results from the laboratory tests are presented in Figures 6 and 7, together with the results from the field corrosion tests.

The concrete scaling obtained after 56 cycles of freezing and thawing is shown in Table 1. As expected, the scaling of the old type of concrete (A) caused by NaCl is very extensive. The concentration of the solutions used in the test was chosen to be 3 percent since earlier experiments had shown that the degradation caused by NaCl has a peak at this concentration (7). When NaCl is partly replaced by CMA in the solution, the scaling is significantly reduced. The scaling caused by NaCl on modern, air-entrained concrete (B) is very small, but even here a reduction can be observed when NaCl is partly or fully replaced by CMA.

Field Tests

During winter 1993–1994 approximately 10 percent more applications of deicing agent were made and about 17 percent more material was spread on the control section with NaCl than on the test section with CMA-NaCl.

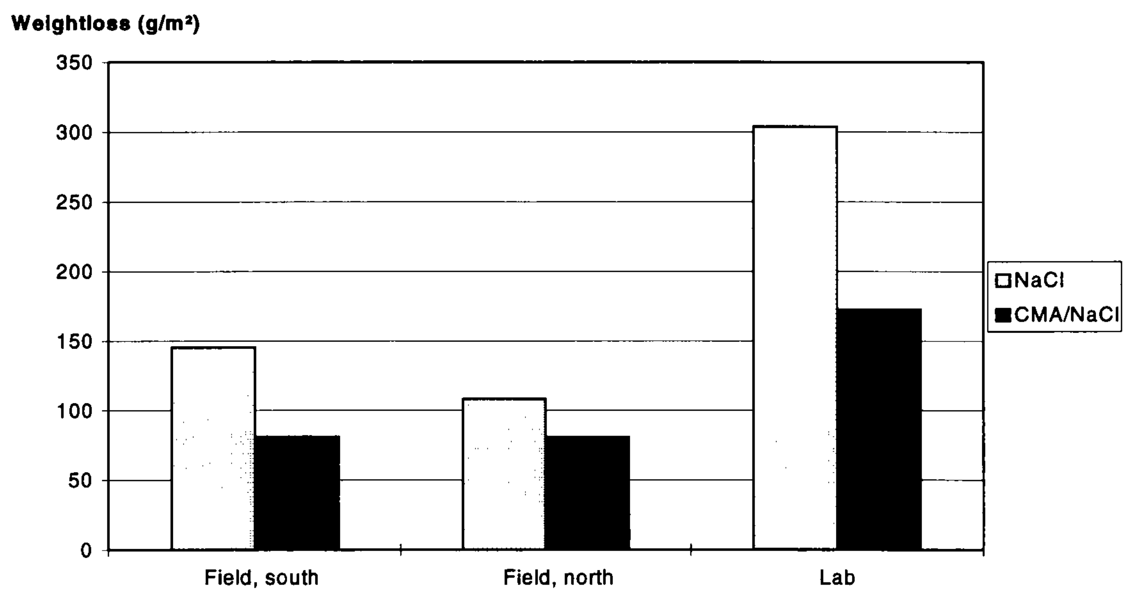


FIGURE 6 Corrosion tests performed during winter of 1993–1994. Histogram shows results from field exposures at both southbound and northbound lanes. For comparison, results from laboratory experiments performed in climate chamber are presented.

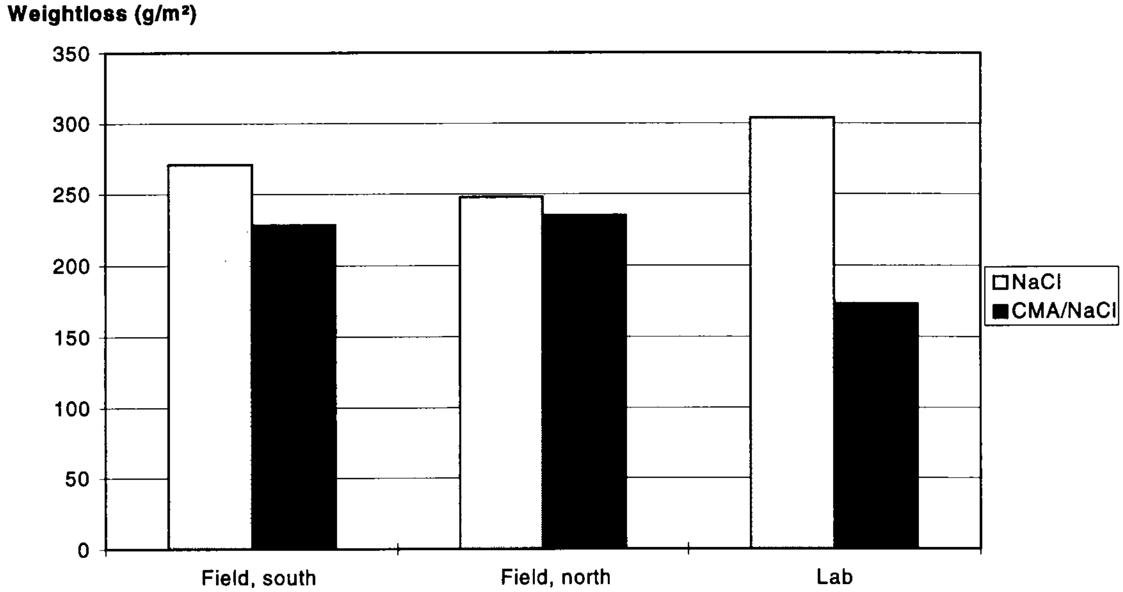


FIGURE 7 Corrosion tests performed during winter of 1994–1995. Histogram shows results from field exposures at both southbound and northbound lanes. For comparison, results from laboratory experiments performed in climate chamber are presented.

Maintenance personnel explained the difference by saying that when they applied NaCl to the control section, they sometimes judged that compared with the NaCl, the CMA-NaCl was having a longer-lasting effect and did not need to be applied again to the test section. Nine storms and approximately three times as many applications of chemicals were followed closely by monitoring the skid resistance. According to the friction measurements, the CMA-NaCl mixture worked as well as, and in some cases even better than, NaCl in situations with slippery conditions. There were also situations in which NaCl worked better but these were not as frequent.

For the winter of 1994–1995 the locations of the test and control sections were switched and results almost opposite to those of the first winter were obtained. Approximately 10 percent more applications were made and as much as 28 percent more material was spread on the test section. This result led to the conclusion that the difference in application rate and amount of chemicals on the test and control sections was due mainly to different local climates along the sections. In 1994–1995 the operational effects were studied during six storms, and the friction measurements also showed that it was possible to obtain the same deicing with the CMA-NaCl mixture as with NaCl. As an example, the skid resistance monitoring performed during one storm in March 1995 is shown in Figure 8.

The results for corrosion from the field test the first winter pointed in the same direction as the results from the laboratory test, indicating that the corrosion rate is reduced by adding CMA to NaCl (Figure 6). The reduction was not as large as in the laboratory test, however. There was also a difference between the northbound and the southbound directions. The reduction of the corrosion rate for the CMA-NaCl mixture was approximately 45 percent on the plates facing the southbound lanes and 20 percent on the plates facing the northbound lanes. The difference in the two directions may have been caused by wind direction or traffic influence. The difference in corrosion rate for the CMA-NaCl mixture and NaCl not only is explained by the materials, but depends also to some extent on the difference in number of applications and amount of material spread. During the first winter more applications were made and a larger amount of material was spread on the control section where the highest corrosion rate was also obtained.

During the second winter, when the test and control sections had been switched, the situation for the number of applications and amount of material was reversed. Although more chemicals were spread on the test section, the corrosion rate was lower than at the control section (Figure 7). The reduction of the corro-

TABLE 1 Scaling of Three Qualities of Concrete After 56 Freeze-Thaw Cycles

Alt.	Solution	Scaling (kg/m²) A	B	C
1	NaCl 3 %	13.78	0.03	
2	CMA/NaCl 20/80 weight-%	10.84	0.01	0.03
3	CMA/NaCl 40/60 weight-%	3.79	0.01	0.01
4	CMA 3 %		0.01	0.01
5	CMA 10 %		0.01	
6	CMA 20 %		0.01	

Note: A is an old type of concrete, B and C are two different modern types of concrete with air-entraining agents added.

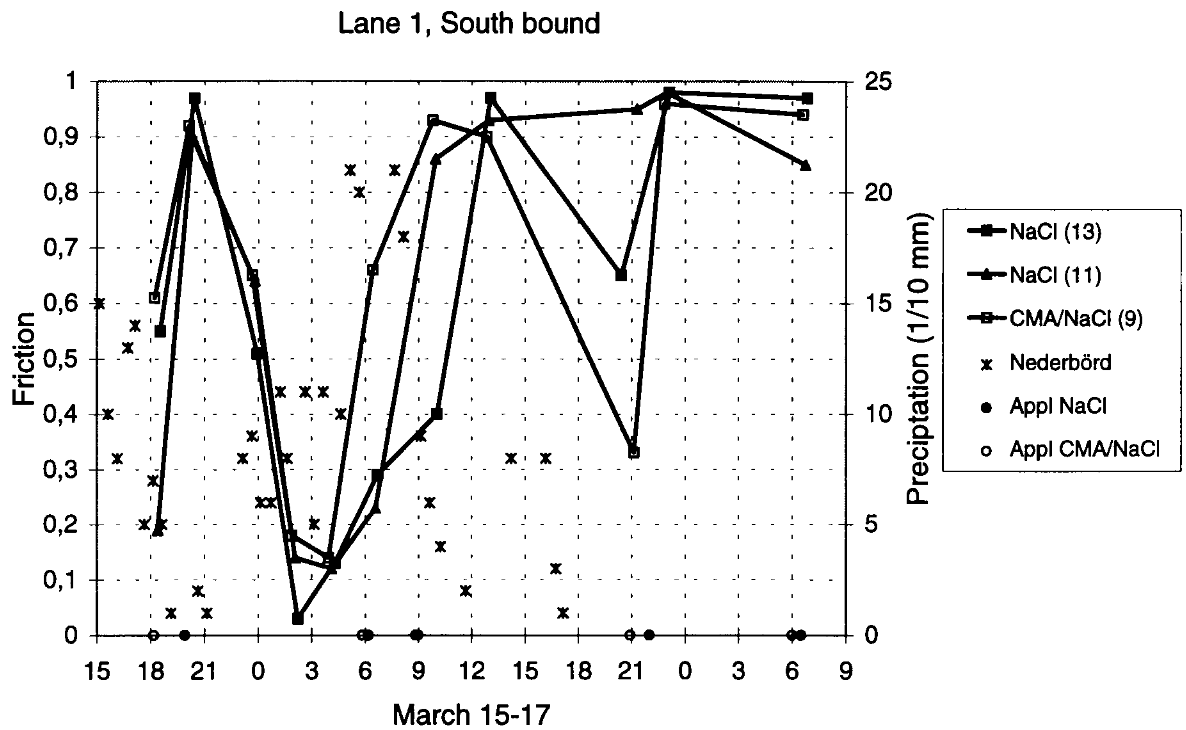


FIGURE 8 **Friction measurements conducted in northbound driving lane during snow storm in March 1995. Numbers in parenthesis refer to sampling sections within test and control sections.**

sion rate for the CMA-NaCl mixture was, however, considerably smaller than that of the first winter. The reduction was approximately 16 percent on the plates facing the southbound lanes and 5 percent on the plates facing the northbound lanes.

Conclusions

During the period 1993–1995 a mixture of 20 percent CMA and 80 percent NaCl by weight was evaluated in laboratory and field tests. The results from the tests are summarized here.

- Deicing properties
  - Laboratory tests showed that the 20/80 CMA-NaCl mixture has an ice melting capacity similar to, but somewhat less than, that of salt.
  - Friction measurements showed that the 20/80 CMA-NaCl mixture works as well as NaCl in most situations with slippery conditions.
  - The effect of the 20/80 CMA-NaCl mixture was not observed to last longer than that of NaCl.
- Corrosion
  - Corrosion tests in a climate chamber resulted in a reduction of the corrosion rate by 45 percent for the CMa-NaCl mixture compared with NaCl.
  - In the field tests, the 20/80 weight-% CMA-NaCl mixture also gave a certain reduction in corrosion rate as compared with NaCl. The reduction was, however, not as large as that in the laboratory tests.
- Concrete
  - On concrete of poor quality, a very large scaling was observed for NaCl in freeze-thaw tests. The scaling was considerably reduced by replacing some of the NaCl with CMA.
  - On modern, air-entrained concrete of good quality, the scaling was very small even for NaCl. A reduction of the damage was observed for the 20/80 CMA-NaCl mixture.

The price for CMA is about 20 times the price for NaCl, which means that the 20/80 CMA-NaCl mixture is about 5 to 6 times more expensive than NaCl. Although a cost-benefit analysis has not been done, it is doubtful if the benefit from the reduced corrosion, in particular, is large enough to compensate for the high price of the CMA-NaCl mixture. Furthermore, the environmental effects of CMA have not been considered in this study. Many studies have shown that CMA is less harmful to the environment than is NaCl. However, when CMA is decomposed, oxygen is consumed.

The decomposition rate is strongly temperature dependent, and low temperatures may lead to the accumulation of nondecomposed acetate in soil and water. A very restrictive use of CMA was recommended in a Finnish study after it had been observed that the infiltration of nondecomposed acetate into deep soil can be rather significant (*8*).

ACKNOWLEDGEMENT

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