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RESEARCH OF SNOW MELTING MATERIALS PERFORMANCE EFFICIENCY FOR ROAD WINTER MAINTENANCE

Alfredas Laurinavičius[1], Donatas Čygas[2], Audrius Vaitkus[3], Tomas Ratkevičius[4], Matas Bulevičius[5], Darjušas Mučinis[6], Andrius Baltrušaitis[7]

[1–4]Dept of Roads, Vilnius Gediminas Technical University, Vilnius, Lithuania
[5–7]JSC 'Problematika', Vilnius, Lithuania

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Abstract. In 2012, the Lithuanian Road Administration initiated a three-year research project 'The study of effective winter road maintenance of national significance roads in Lithuania'. The main purpose of this research was to optimize road maintenance in winter and to determine the most effective means of combating slippery conditions. The research project was carried out by two institutions: the Road Research Institute of the Faculty of Environmental Engineering of Vilnius Gediminas Technical University and JSC 'Problematika'. JSC 'Problematika' conducted exploratory experiments, which were divided into two phases. In the first phase of the experiment, five different snow melting materials (Slipperiness Reducing Materials – SRMs) were investigated in the laboratory. Different test methods were used in this investigation. In the second phase of the experiment, three SRMs with different properties were selected, and experimental road sections were set up to determine the road slipperiness and the change in coating layer thickness over time concerning different environmental conditions, as well as different snow and ice layer thicknesses. An optical remote sensor of Road Condition Monitor (RCM 411) was used for friction measurements on the roads. This report covers the laboratory test results of five different SRMs, road slipperiness measurement results using three selected SRMs and their analysis, comparison of the performance efficiency of the most widely used SRMs in Lithuania and the tested SRMs under different environmental conditions.

Keywords: friction; snow melting materials; road condition monitor; slipperiness.

Introduction

The most significant action in winter road management is to remove snow and ice from the road surface more efficiently and rapidly. In cold and snowy regions, salting is the primary measure against icy road surfaces and an important measure to secure safe and smooth winter road traffic (Zofka *et al.* 2014). However, the excess use of chloride deicer can cause soil and water pollution, corrosion of concrete structures, and spalling of concrete pavement. Based on the increasing requirements in the field of traffic safety, environmental protection and ecology, it is necessary to search for the most effective and less damaging measures to ensure road maintenance in winter (Ružinskas *et al.* 2016; Kazlauskienė *et al.* 2013; Craver *et al.* 2008; Strong, Shi 2008; Ye *et al.* 2009).

Numerous laboratory and field studies have been conducted to evaluate the performance of Snow Melting Materials (Slipperiness Reducing Materials – SRMs) and the resulting friction coefficient of treated pavement. However, laboratory results often do not translate to the field performance due to varying temperatures, wind, traffic, etc. (Muthumani *et al.* 2014; Akin, Shi 2012). In this context, laboratory and field experiments need to be carefully designed to encompass all relevant variables so that better correlations can be developed.

Several test methods are standardized by various consortiums, such as ASTM International, American Association of State and Highway Transportation Officials (AASHTO), Strategic Highway Research Program (SHRP), among other.

Three types of test methods or SRMs performance were created: The SHRP Ice Melting Test (H-205.1 and H-205.2), the SHRP Ice Penetration Tests (H-205.3 and H-205.4) and the third is the SHRP Ice Undercutting Test (H-205.5 and H-205.6). Additional details are available in the *Handbook of Test Methods for Evaluating Chemical Deicers* (Chappelow *et al.* 1992; Muthumani *et al.* 2014).

Standardized test methods were identified as well as laboratory methods developed for individual research

Corresponding author: Tomas Ratkevičius
E-mail: *tomas.ratkevicius@vgtu.lt*

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projects. Mauritis *et al.* (1995) developed a laboratory test of ice undercutting that could be used to screen the effectiveness of solid SRMs. This test is different from the SHRP tests in that the test utilizes Pyrex test tubes and does not incorporate dye. Instead, ice undercutting is detected by the break in an electrical circuit caused by a wire detaching from the test tube coinciding with deicer penetration and undercutting.

However, the scientific literature provides many other tests that have been developed for specific research projects, some of which resemble the standardized SHRP tests while others are more unique (Chappelow *et al.* 1993).

The literature review identified many possible test methods for SRMs performance that could be used to screen potential deicer products and blends. Some of the test methods seem to be more widely used, while others have inherent limitations. A comparison of SRMs in a laboratory setting is only helpful if field applications of the same SRMs results in similar trends of effectiveness. Given that the focus of this project was to develop laboratory test methods that could be used to screen potential deicing products and blends, and the desire for relatively simple and straightforward test methods, a more realistic laboratory method that incorporates pertinent field parameters is highly recommended Muthumani *et al.* 2014).

The purpose of this research paper is to present a series of specification testing procedures that will allow different SRMs to be compared for effectiveness and efficiency to considering in Lithuanian climate and traffic conditions.

Tests were conducted in a laboratory (Cuelho, Harwood 2012; Xu, Tan 2012; Abel'hanova, Borisyuk 2012) and in the field to study five different SRMs: sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), a mixture of sodium and calcium modified chlorides (hereafter referred to as NCMC), and a mixture of sodium acetate and sodium formate (SASF). Test results were obtained for the ice mass losses and efficiency of SRMs. Then, the results were analysed, and three SRMs were selected. Tested road sections were constructed to perform measurements of the change in road slipperiness using a mobile optical sensor called Road Condition Monitor RCM 411 (road friction measuring device).

1. Problem Formulation and Objectives

The friction between pavement surface and a tyre is a major factor in traffic safety. On a slippery road, low friction can lead to a fatal car accident. Accident rates for different friction intervals were assessed and displayed in Table 1 (Wallman, Åström 2001).

When spreading the deicer on the road surface, snow and ice change into liquid state due to solubility and dropping of the freezing point. Where road surface is on icy condition, the deicer solution penetrates into ice and cuts the connection between the surface and ice (Klein-Paste, Potapova 2014).

Every year, considerable quantities of snow and ice melting materials are applied to roads. Environmental and regulatory agencies have questioned the environmental effects of these products (Blomqvist 2001). Maintenance agencies are continually challenged to improve safety and mobility of winter roads in a cost-effective manner while minimizing corrosion and other adverse effects to the environment (Ružinskas *et al.* 2016; Kazlauskienė *et al.* 2013).

Transportation agencies are asked to use 'environmentally friendly' or less toxic alternatives wherever possible, but there is no commonly accepted guidance for determining which products meet these criteria.

Studies of the most common chemical alternatives – sodium chloride (salt, NaCl), magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), a mixture of sodium and calcium modified chlorides (NCMC), and a mixture of sodium acetate and sodium formate (SASF) – have focused on performance and cost under various weather conditions without evaluating their relative effects on the environment. Several new chemical preparations, including some that are proprietary formulations, have entered the market as snow and ice control chemicals for use by transportation agencies, but there is limited information about their efficiency under different conditions (environment, weather, surface temperature, traffic volume).

The aim of the research paper is to study the efficiency of five different SRMs under different conditions (environment, weather, surface temperature, traffic volume) and depending on the thickness of snow and ice layer.

Table 1. Friction coefficients and car accident rate – personal injuries per million vehicle kilometres (Wallman, Åström 2001)

Accident rate	Friction coefficient
0.80	<0.15
0.55	0.15–0.24
0.25	0.25–0.34
0.20	0.35–0.44
0.14–0.18	>45

2. Tests

2.1. Laboratory Tests on the Efficiency of SRMs and the Loss of Ice Mass

Laboratory tests were carried out by two different test methods in accordance with test methods developed by the State Road Testing Laboratory of JSC 'Problematika': tests on the ice mass loss and the efficiency of SRM. Tests were conducted with test samples (ice) under different constant temperatures –20, –15, –9, –6, –3 °C), and measurements were taken by applying SRM on the sample at different time intervals (2, 4, 6, 8, 10, 15, 20, 25, 30, 40, 50, 60, 90, 120 minutes).

Ice samples equal in thickness and width were prepared for the ice mass loss test. The required amount of water was poured into stainless steel trays to form a 3 mm ice layer. Trays with water were cooled in climatic chambers until ice formed. When ice formed, trays with ice were weighed, and the mass of ice was calculated. Samples were kept in a climatic chamber at a constant specified temperature. Trays with ice samples stayed in a climatic chamber until the temperature of ice surface reached the indicated temperature. When the required temperature was reached, an equal amount of about 10 g, fraction 0.5/1 mm of SRM was spread on the surface of an ice sample. Ice samples with SRM spread on top were kept in the climatic chamber for different, preset intervals of time. Then, trays were removed and weighed. The dissolved solution was poured off, and the remaining ice in the tray was weighed. The percentage change between the mass of melted ice and the mass of initial ice was calculated after obtaining the average value of three samples tested under equal conditions.

The study of SRM efficiency involved the measurement of SRM activity in the process of ice melting at different environmental temperatures. The SRM study using this method required formation of ice samples analogous to the ones used for ice mass loss test. The ice sample was kept at a constant specified temperature and was affected by ~10 g of SRM. The surface temperature of the sample was measured during the entire test period (120 minutes) (Bulevičius *et al.* 2014).

2.2. Measurements of Change in Road Slipperiness

There are several commercial options available to measure friction on roads: the traditional friction meters (calculate the friction on the basis of a vehicle wheel spinning speed and braking time); friction meters using acceleration sensor (calculate the friction on the basis of deceleration measured by acceleration sensor); optical friction meters (estimate the friction and road condition on the basis of the reflectivity of the road surface); mechanical friction meters (need additional measuring wheel or wheels, which have a constant or variable slip). The friction is calculated on the basis of slip or forces affecting the measuring wheel) and vehicle measurement instrument (measures the vehicle speed and braking distance on the basis of accurate GPS; the instrument doesn't display any friction values, but it can be easily calculated on the basis of speed and braking distance) (Malmivuo 2011).

An optical mobile sensor RCM 411 (road friction measuring device) was used during the experiment to measure the coefficient of road surface friction and the water layer thickness. Such devices are currently used in the Netherlands, Czech Republic, Finland, Germany and Switzerland (Chen *et al.* 2009; Flintsch *et al.* 2009; Lee *et al.* 2008; Munehiro *et al.* 2012; Nakatsuji *et al.* 2005, 2007).

This principle of operation is based on the determination of the road condition by using close infrared spectroscopy on the road surface. It determines the road surface condition, thickness of water or pure ice and friction value according to the measured content of snow or ice on the road surface. This is a very practical device that can be attached to the trailer hitch of any vehicle; it takes up little space, and it is quick and easy to use. The performance of RCM 411 was tested during the winter season of 2010–2011. The sensor distinguishes all important surface conditions fairly reliably. The model to estimate the coefficient of friction was tuned to correspond to an accelerometer based friction meter μTEC. This enabled verification of absolute friction whenever there was a need for accurate values. The standard deviation of the difference in the friction readings of the two sensors was typically on the order of 0.10 units in most winter surface conditions (Haavasoja *et al.* 2012; Malmivuo 2011).

μTec is an application for the mobile phone that uses the accelerometer for calculations of road surface friction. The main advantage of this application is adaptability i.e. the phone position in the car can be easily changed, while the other applications do not provide this possibility. Accuracy and reliability of μTec, when the higher class mobile phone is used, are the same as 'Gripman' meter, which is officially approved and used in Finland (Haavasoja *et al.* 2012; Malmivuo 2011).

The State Road Testing Laboratory of JSC 'Problematika' has performed tests with new mobile friction measurement devices. During the tests, road surface friction measurements were carried out under different road conditions (the surface was covered with snow or a water membrane), and the results were compared with the data from Road Weather Information System (RWIS) stations. Classification of friction values and recommendations, based on the test results, were proposed. It was concluded that the package of friction measurement tools is suitable not only for the estimation of road maintenance quality during the winter period but also for planning road maintenance operations (Malmivuo 2011).

Road surface friction is the main indicator describing the quality of winter road maintenance on the roads of the national significance of Finland, Sweden and Norway. The coefficient of friction is an absolute value that indicates the adhesion between the road surface and vehicle tyres (Haavasoja *et al.* 2012). A Swedish-based literature review also examined friction and its correlation to traffic safety (Wallman, Åström 2001; Wang *et al.* 2004; Andersson *et al.* 2007; Malmivuo 2011).

Though the manufacturers ('Teconer Oy') of remote mobile system RCM 411 have proposed the classification of adhesion coefficient values (Haavasoja *et al.* 2012), the adhesion coefficient classification, dividing the conditions of adhesion into three gradations, was used in this research (Table 2).

Table 2. Friction coefficient

Road surface (driving conditions)	Friction coefficient
Dry road	>0.80
Slippery road	0.80–0.40
Solid ice	<0.4

A tested road section was constructed on the road No 107 Trakai–Vievis (14.32–15.4 km, Annual Average Daily Traffic (AADT) – 1802 veh/day) to study the impact of different SRMs on the change in road slipperiness in winter. The tested road was divided into three sections. Two (traditionally used and tested in Lithuania) SRMs were spread on those sections under different temperatures, precipitation conditions and considering the thickness of road surface (ice, snow, wet snow, etc.). The change in slipperiness was measured and then analysed under the same environmental conditions. Measurements were made and the following data was recorded:

- tested road section;
- date of measurement, start time and finish time;
- environment, weather conditions;
- air temperature [°C];
- road surface temperature (on each tested road section, at different time intervals) [°C];
- test materials (amount, concentration, etc.).

3. Test Results

3.1. Test Results on SRM Efficiency and the Loss of Ice Mass

All SRMs were tested under equal conditions, as defined in test methods. Measurements of ice mass loss were expressed in percentage. The initial mass of ice was taken to be 100%. The change in ice mass loss is given in Figs 1–5, which show the impact of different SRMs on ice under the same environmental conditions. In addition, the graph displays the change in temperature of the ice sample surface under the effect of SRMs, which showed extreme ice melting values.

To analyse the impact of SRM on ice, four ice mass loss intervals were selected and divided into four categories of SRM efficiency. The categories of SRM efficiency are listed in Table 3.

The intensity [%/min] of melting (the change of ice mass) was calculated upon receipt of the results of different SRM application on the ice sample. Four values [%] of change in ice mass were taken for the analysis of ice melting intensity. These values were divided into four categories of ice melting intensity. The categories of ice melting intensity are listed in Table 4.

The results of ice melting intensity are presented in Table 5.

After performing the SRMs efficiency tests, it was observed that independently of the environmental temperature and SRMs used, ice melting intensity was considerably reduced (<0.5 %/min) in the time interval from 10 to 20 minutes (Bianchini *et al.* 2011; Matsuzawa *et al.* 2009; Samodurova *et al.* 2010; Rezaei, Masad 2013).

To figure out the cause of such a sharp decrease in intensity, additional measurements of ice surface temperature were made after applying SRM to its surface. The temperature of ice surface was measured for SRM, when melting intensity at different environmental temperatures and time intervals reached the extremes (min, max).

Table 3. Categories of SRM efficiency (Bulevičius *et al.* 2014)

The category of SRM efficiency	Ice mass losses [%]
High efficiency	>40
Average efficiency	20–40
Low efficiency	5–20
Inefficient	<5

Table 4. Categories of ice melting intensity (Bulevičius *et al.* 2014)

The category of ice melting intensity	Ice melting intensity [%/min]
High intensity	>2
Average intensity	1–2
Low intensity	0.5–1
Very low intensity	<0.5

Table 5. Results of the ice melting intensity (Bulevičius *et al.* 2014)

SRM	Time [min]	Ice melting intensity [%/min]				
		Temperature [°C]				
		−3	−6	−9	−15	−20
NaCl	4	1.0	0.5	0.3	0.1	0.0
	10	1.7	1.0	0.5	0.2	0.0
	20	0.3	0.2	0.0	0.0	0.0
	30	1.7	0.5	0.4	0.2	0.0
	60	0.2	0.2	0.0	0.0	0.0
	120	0.0	0.0	0.0	0.0	0.0
$CaCl_2$	4	2.3	2.0	2.0	1.2	0.9
	10	0.9	0.5	0.3	0.1	0.1
	20	0.1	0.0	−0.1	0.0	0.0
	30	0.6	0.2	0.3	0.0	0.0
	60	0.1	0.0	0.0	0.0	0.0
	120	0.1	0.0	0.0	0.0	0.0
NANF	4	1.4	0.7	0.3	0.1	0.0
	10	1.2	0.8	0.5	0.0	0.0
	20	0.2	−0.1	0.3	0.0	0.0
	30	1.1	0.5	0.1	0.1	0.0
	60	0.3	0.2	0.0	0.0	0.0
	120	0.1	0.0	0.0	0.0	0.0
$MgCl_2$	4	3.1	2.5	2.2	1.7	1.3
	10	0.6	0.4	0.4	−0.1	−0.2
	20	0.1	0.0	−0.1	0.0	0.0
	30	0.4	0.0	0.1	0.0	0.1
	60	0.1	0.1	0.0	0.0	0.0
	120	0.0	0.0	0.0	0.0	0.0
NCMC	4	1.1	0.8	1.0	0.4	0.3
	10	1.1	0.8	0.4	0.2	0.1
	20	0.4	0.4	0.0	0.0	0.0
	30	1.8	0.7	0.3	0.1	0.0
	60	0.3	0.2	0.1	0.0	0.0
	120	0.1	0.0	0.0	0.0	0.0

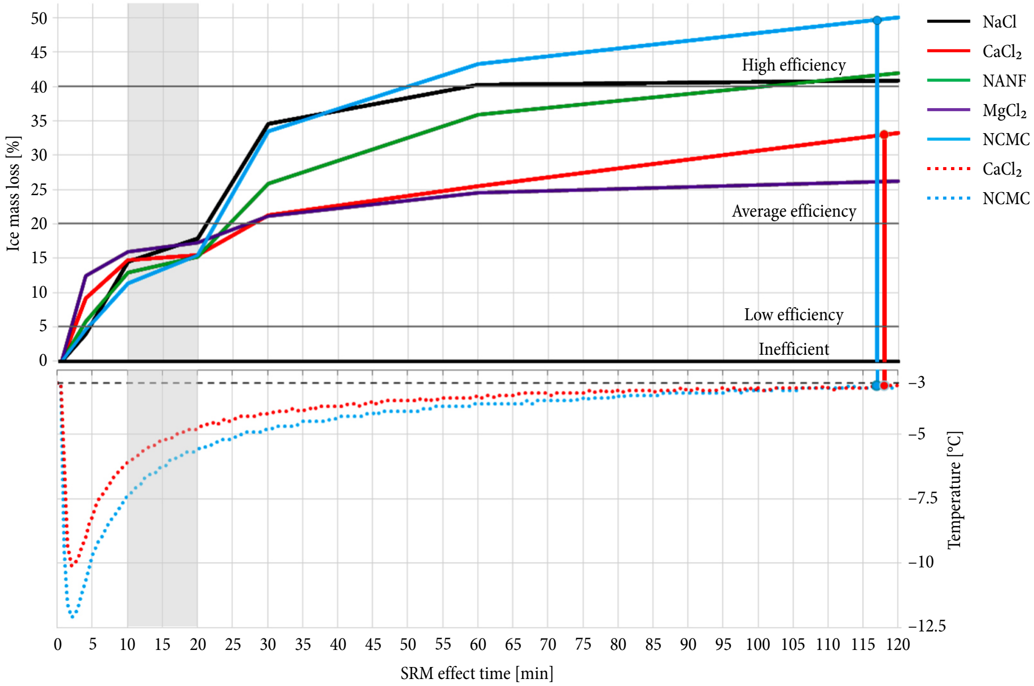

Fig. 1. Loss of ice mass and the change in surface temperature (t = –3 °C) (Bulevičius *et al.* 2014)

The change in temperature of ice sample surface was measured by taking the maximum and minimum melting intensity of SRM in the time interval from 10 to 20 minutes. The results obtained from measurements showed that when different SRMs had been applied to an ice sample, ice surface temperature decreased within the first minutes of testing and then stabilized at the test environmental temperature at different time intervals. It was also noted that the time interval, during which the ice sample surface temperature stabilized, depended on the environmental temperature. To find out the impact of the change in ice surface temperature on melting process, the time, during which the temperature of sample surface reached the test environmental temperature ±0.1 C, was measured. The points of temperature stabilization were marked on the graph that shows the change in temperature (Figs 1–5).

3.1.1. Study of SRM Efficiency Depending on the Environmental Temperature (t = –3 °C)

The loss of the ice mass and the change in surface temperature with respect to time at an environmental temperature of –3 °C are shown in the graph (Fig. 1).

Test results showed that at a given environmental temperature of –3 °C and under the effect of SRMs, the lowest measured ice mass loss interval of 2.7% (NaCl, SASF) was reached in 20 minutes, and the highest measured ice mass loss interval of 23.9% ($MgCl_2$, NCMC) was reached in 120 minutes. On the basis of the obtained test results it can be concluded that at a given temperature and under the effect of different SRMs, ice melting properties can be identified after 30 minutes.

According to the categories of SRM efficiency indicated in Table 3, at a given environmental temperature of –3 °C, NaCl, NCMC and SASF can be attributed to the category of very efficient SRMs. NCMC reaches the highest efficiency level after 50 minutes, while NaCl and SASF do it only after 110 minutes. The calculations showed that $CaCl_2$ and $MgCl_2$ were of average efficiency. The average efficiency of all SRMs was reached after 20–30 minutes, therefore it can be concluded that at a given environmental temperature of –3 °C, NCMC melts the ice most efficiently, and the effectiveness of NaCl and SASF is lower by 10%.

When ice samples were affected by SRM in accordance with the categories of ice melting intensity indicated in Table 4, the highest ice melting intensity was observed at the beginning of the test in the 10 min time interval. When an ice sample was affected by $CaCl_2$ and $MgCl_2$, ice melted most efficiently at 2.3–3.1 %/min within the first 4 minutes, and in the time interval from 4 to 120 minutes, the intensity of ice melting decreased to low and very low levels. The ice melting intensity of other samples affected by SRM up to 30 minutes, except for the time period from 10 to 20 minutes, remained average. After 30 minutes, the ice melting intensity of all SRMs decreased to a low level, and after 60 minutes it decreased to a very low level. Having analysed the obtained results, it can be stated that at a given environmental temperature of –3 °C, high ice melting intensity was observed only at the beginning of its operation, in the time interval up to 10 minutes.

The most efficient melting in the time interval from 10 to 20 minutes was observed when NCMC was applied, and the lowest melting efficiency was observed when $CaCl_2$ was applied. The change in temperatures is shown in Fig. 1.

When NCMC was applied to an ice sample, the ice surface temperature decreases by 9.1 °C within the first 2 minutes, while the application of $CaCl_2$ caused a decrease of 7.1 °C. Both temperatures stabilized at the set temperature of –3)°C at the end of the test. Having analysed the results of ice surface temperature measurements, it can be stated that at a given temperature of –3 °C, better efficiency is achieved when using an SRM, which shows best temperature reduction results. This is achieved with the application of NCMC. The stabilization of ice surface temperature after the same time interval under the effect of SRM shows that the effective interval of both SRMs is the same.

3.1.2. Study of SRM Efficiency at the Environmental Temperature (*t* = –9 °C)

The loss in ice mass and the change in surface temperature with respect to time at an environmental temperature of –9 °C are shown in Fig. 2.

Test results showed that at a given environmental temperature of –9 °C and under the effect of SRMs, the highest measured ice mass loss interval of 7.6% (SASF, $MgCl_2$) was reached in 4 minutes, and the lowest measured ice mass loss interval of 3.8% (NCMC, SASF) was reached in 120 minutes. On the basis of the obtained test results, it can be concluded that at a given temperature and under the effect of different SRMs, ice melting properties can be identified at the beginning of the test, during the time interval of 4 minutes, and in the course of time, ice melting properties become similar.

According to the categories of SRMs efficiency indicated in Table 3, at a given environmental temperature of –9 °C, all SRMs only reached the low-efficiency category. NCMC reached the highest efficiency value of 13.3% in 60 minutes. The effect of all SRMs on ice melting approached zero in 60 minutes; therefore, it can be concluded that at a given environmental temperature of –9 °C, NCMC melts the ice most efficiently. The efficiency of NCMC after 120 minutes was at least 2% higher than that of other SRMs.

When ice samples were affected by SRM in accordance with the categories of ice melting intensity indicated in Table 4, the highest ice melting intensity was observed at the beginning of the test in the time interval of 10 minutes. When an ice sample was affected by $CaCl_2$ and $MgCl_2$, the ice melted very efficiently at 2.0–2.2 %/min within the first 4 minutes, and in the time interval from 4 to 120 minutes, the ice melting intensity decreased to a very low level. Ice melting intensity under the effect of NaCl, NCMC and SASF was very low during the entire test period, except for the period from 4 to 10 minutes, when the melting intensity was average. Having analysed the obtained results, it can be stated that at a given environmental temperature of –9 °C, high ice melting intensity of $CaCl_2$ and $MgCl_2$ was observed only at the beginning of the operation, in the time interval up to 10 minutes. The melting intensity of NCMC was average in the time interval up to 10 minutes, however, it continuously increased up to 60 minutes.

During the time interval from 10 to 20 minutes, the most efficient melting was observed when SASF was applied, and the lowest melting efficiency was observed when $CaCl_2$ and $MgCl_2$ were applied. The change in temperatures is shown in Fig. 2.

When SASF was applied to an ice sample within the first 2 minutes, the ice surface temperature decreased by 0.9 °C, $CaCl_2$ reduced the temperature by 4.8 °C, while $MgCl_2$ caused a reduction of 2.6 °C. The temperature of ice affected by SASF stabilized at the set temperature of –9 °C in 15 minutes, $CaCl_2$ and $MgCl_2$ reached it in 20 minutes. Having analysed the results of ice surface

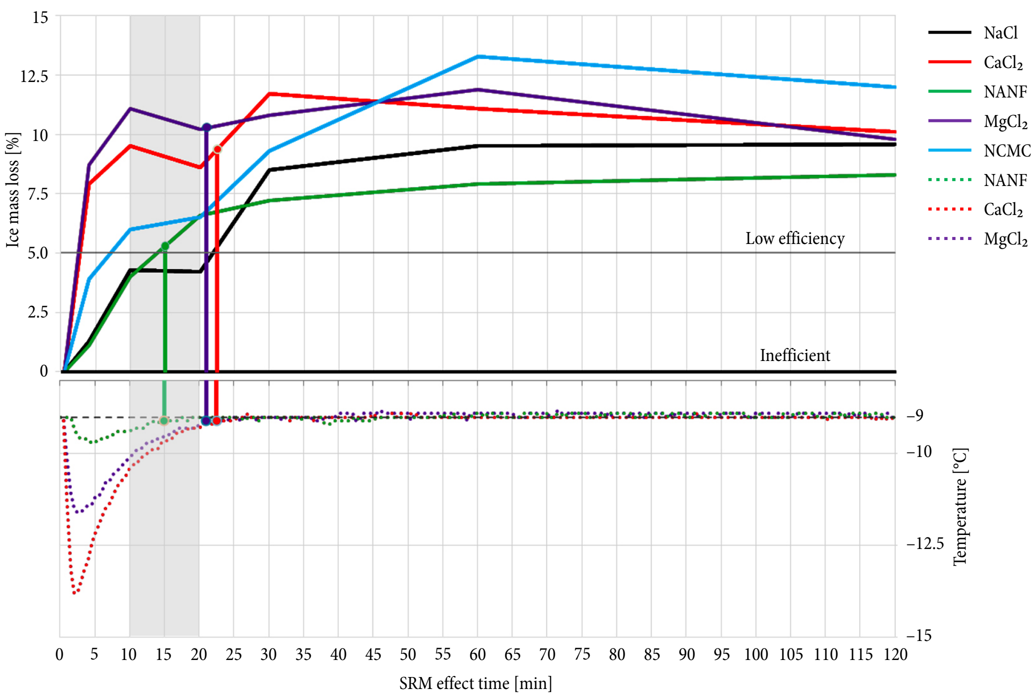

Fig. 2. Loss of ice mass and the change in surface temperature (*t* = –9 °C) (Bulevičius *et al.* 2014)

temperature measurements, it can be stated that at a given temperature of −9 °C, better efficiency was achieved when using an SRM, which exemplifies the best results in the reduction of ice surface temperature. $CaCl_2$ was the most effective agent at reducing ice surface temperature at −9 °C.

3.1.3. Study of SRM Efficiency at the Environmental Temperature (t = −20 °C)

The loss of ice mass and the change in surface temperature with respect to time at an environmental temperature of −20 °C are shown in Fig. 3.

Test results showed that at a given environmental temperature of −20 °C and under, the effect of SRMs, the highest measured ice mass loss interval of 5.1% (NaCl, $MgCl_2$) was reached in 4 minutes, and the lowest measured ice mass loss interval of 4.1% (SASF, $MgCl_2$) was reached in 20 minutes. On the basis of the obtained test results it can be concluded that at a given temperature of −20 °C and under the effect of different SRMs, ice melting properties remain the same during the entire test period.

According to the categories of SRM efficiency indicated in Table 3, at a given environmental temperature of −20 °C, $CaCl_2$ and $MgCl_2$ can be attributed to the low-efficiency SRMs. This category of efficiency is reached at the very end of the test, in 120 minutes. Other SRMs melt ice under these environmental conditions inefficiently.

When ice samples were affected by an SRM in accordance with the categories of ice melting intensity indicated in Table 4, the highest ice melting intensity was observed at the beginning of the test in the time interval of 4 minutes. When an ice sample was affected by $CaCl_2$ and $MgCl_2$, the ice melted most efficiently at 0.9–1.3 %/min within the first 4 minutes, while during the time interval from 4 to 120 minutes, the ice melting intensity decreased to a very low level. There was no need to study the efficiency of other SRMs, as the ice mass losses did not exceed 5%.

The most efficient melting in the time interval from 10 to 20 minutes was observed when $CaCl_2$ was applied, while the lowest melting efficiency was observed when $MgCl_2$ was applied. The change in temperatures is shown in Fig. 5.

When $CaCl_2$ was applied to an ice sample, the ice surface temperature decreased by 1.2 °C within the first 2 minutes, while the use of $CaCl_2$ caused a 1.3 °C reduction. Both temperatures stabilized at the set temperature of −20 °C on the 12th and 14th minute of the test. Having analysed the results of ice surface temperature measurements, it can be stated that at a given temperature of −20 °C, better efficiency was achieved when applying an SRM, which shows the results of reduction in ice surface temperature, and NCMC was again the most effective agent in this category. The fact that temperatures stabilized at −20 °C on the 12th and 14th minute indicates that two tested materials have the shortest period of operation.

3.2. Measurement of Change in Road Slipperiness Test Results

Measurement of road slipperiness was performed by using a mobile phone and the μTec friction meter. The μTec friction meter provides a possibility not only to see the measurement results on the phone screen, to save the measurement results (and GPS data at the same time) on a phone's internal memory or on additional memory, but also send the results in real-time to an indicated server.

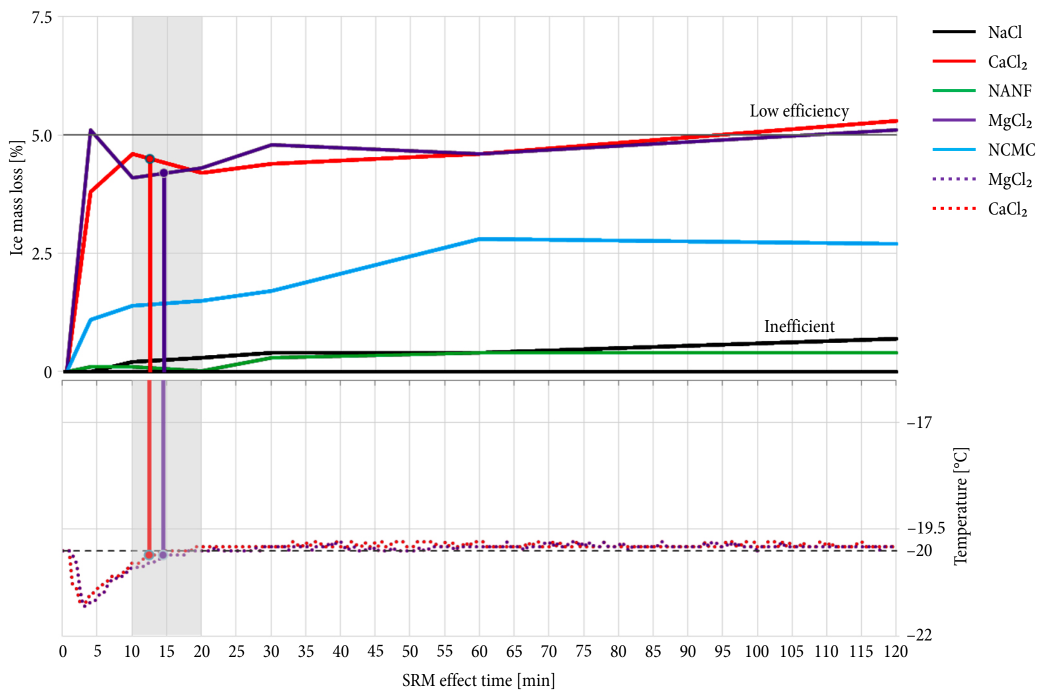

Fig. 3. Loss of ice mass and the change in surface temperature (t = −20 °C) (Bulevičius *et al.* 2014)

Road slipperiness can also be measured indirectly. It can be done using the road surface condition sensor RCM 411. It is an optical measuring device, which determines:

- road surface condition: dry, wet, moist, ice, snow, wet snow;
- road surface layer thickness;
- friction coefficient.

The device (RCM 411) was installed on a tow-ball of the vehicle (Fig. 4).

The colour of the line indicates the surface condition: red stands for ice, blue stands for water, violet stands for wet snow and white stands for snow. A thin line is water layer thickness in millimetres. The data is communicated to a user interface running on a mobile phone (Fig. 5) and can be sent to a server to be displayed on a color-coded map. The data can also be stored on internal device memory, and it can be transferred further in *Excel*-file formats.

Typical variants of friction coefficients (informative):

- dry road 0.80 ± 0.10 (depends on the tyres and the condition of road surface);
- solid ice 0.20 or less (for all tyres where there is a thin layer of solid ice).

Fig. 4. Sensor for measurement of friction (RCM 411) installed on a tow-ball of a vehicle (Bulevičius *et al.* 2014)

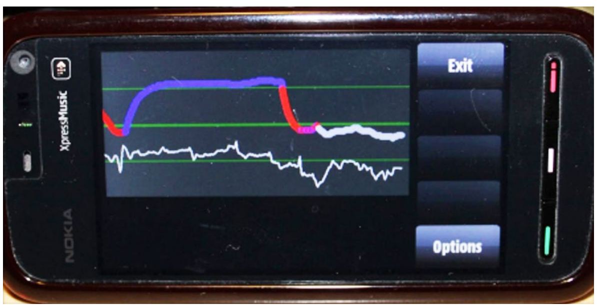

Fig. 5. Friction measurements on the screen of a mobile phone (Bulevičius *et al.* 2014)

Measurements were carried out on the road No 107 Trakai–Vievis (14.32–15.4 km, AADT – 1802 veh/day) under different temperatures, precipitation conditions and considering different thicknesses of road surface layers (ice, snow, wet snow, etc.). The measurements were conducted on a 600 m long experimental road section and a 200 m long tested road section. The obtained test measurement results showed that materials spread on short road sections of the road, mixed together under the wheels of passing cars. Therefore, it was rather difficult to study the impact of test materials on the road surface. To study the efficiency of ice melting materials, the tested road sections were lengthened up to 400 m (the total length of tested road section was 1200 m). The lengths of experimental road sections were constant during the entire experiment. A typical scheme of the tested road sections is shown in Table 6. Traditional winter maintenance and test ice melting materials were spread on the road to perform measurements in accordance with the currently valid requirements in Lithuania (amount, method, concentration, etc.). Materials were spread on the road at the same time. Road surface friction measurements were taken prior to spreading the two materials. Friction coefficient measurements were carried out immediately after spreading the ice melting materials and measurements were continued in equal time intervals until materials were fully activated (friction coefficient ≥0.80) or until the coefficient became constant.

The first measurements were performed on the road in February 2012, at about 0° of air and –3° C of coating temperature, and 1–2 cm layer of snow on road coat. After carrying out the measurements on the road, the results were presented to make it possible to compare the efficiency of researched materials under the variation of friction coefficient in respect of time (Fig. 6).

Table 6. Typical road measurement scheme (Bulevičius *et al.* 2014)

Tested road section length [m]	1200		
Tested road section [m]	400	400	400
Spreading material	traditional spreading material (NaCl)	test spreading material	traditional spreading material (NaCl)

While measuring, the increase in the road surface friction was observed immediately after spreading SRM.

After analysis of measurement results on the road, it could be said that the impact of calcium chloride to the coefficient of friction and ice melting showed up faster than another researched materials. However, seeking to determine the efficiency of ice melting materials, it has been decided to carry out additional measurements on the road, at a wider range of weather conditions next year.

Measurement results showed a large difference, which depends not only on a test SRM but also on the

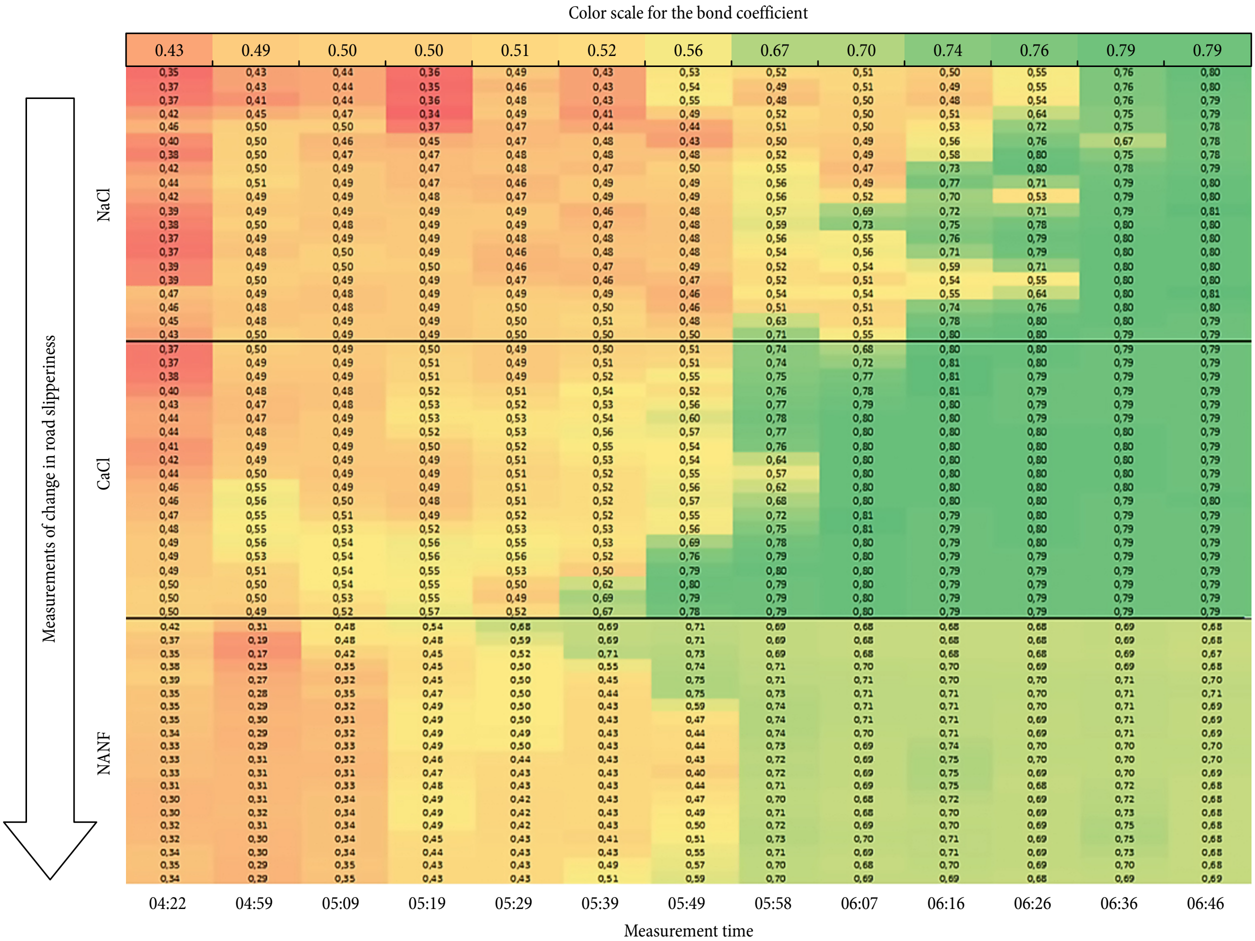

Fig. 6. Results and analysis of field research

relief of the road, the surrounding environment, vegetation, structures and other factors. Therefore, according to the results obtained, no accurate conclusions could be drawn regarding the efficiency of SRM tested in the laboratory and on road surface friction in the natural environment.

Conclusions

1. In February 2012, first tests regarding the *Study on the Efficiency of Winter Road Maintenance on the Roads of National Significance of the Republic of Lithuania* were performed to develop a research program and methods. Test methods included the selection and analysis of test methods of ice melting materials (methods used in foreign countries), road surface condition measuring devices and techniques. The research program was designed, test methods were developed, and the following tests were carried out:
   - 1.1. laboratory tests on the efficiency of SRMs;
   - 1.2. friction measurements on the roads.
2. While conducting a laboratory experiment on the efficiency of SRMs, it was observed that independently of environmental temperature and SRMs used, ice melting intensity reduced considerably in the time interval from 10 to 20 minutes. While performing road measurements, the increase of road surface friction was observed immediately after spreading SRM. The testing methodology of ice melting efficiency was developed to find the cause of this phenomenon. The obtained results showed that a sudden decrease in temperature of the ice surface, when it is affected by SRM, depends on the environmental temperature and chemical properties of SRM. The developed method allows studying the efficiency of SRMs at different environmental temperatures.
3. In compliance with the results obtained from the experiments, the efficiency and intensity of SRMs can be grouped according to resulting values, which allows dividing SRMs into categories according to their different properties.
4. In accordance with the ice melting efficiency, SRMs were divided into the following categories:
   - 4.3. at a given environmental temperature of –3 °C, NaCl, SASF and NCMC were of high efficiency, while $CaCl_2$ and $MgCl_2$ were of average efficiency;
   - 4.4. at a given environmental temperature of –6 °C, NaCl and NCMC were of average efficiency, while SASF, $CaCl_2$ and $MgCl_2$ were of low efficiency;

4.5. at a given environmental temperature of –9 °C, all tested SRMs were of low efficiency;
4.6. at a given environmental temperature of –15 °C, $CaCl_2$ and $MgCl_2$ were of low efficiency, while NaCl, SASF and NCMC were ineffective.
4.7. at a given environmental temperature of –20 °C, $CaCl_2$ and $MgCl_2$ were of low efficiency; however used together with NaCl, SASF and NCMC, they can be considered ineffective.

5. Tested SRMs can be divided according to the time intervals where SRMs were effective:
5.1. at a given environmental temperature of –3 °C, SRMs were effective up to 120 minutes;
5.2. at a given environmental temperature of –6 °C, SRMs were effective in the time interval from 50 to 70 minutes;
51.3. at a given environmental temperature of –9 °C, SRMs were effective in the time interval from 15 to 22 minutes;
5.4. at a given environmental temperature of –15 °C, SRMs were effective in the time interval from 30 to 32 minutes;
5.5. at a given environmental temperature of –20 °C, SRMs were effective in the time interval from 12 to 14 minutes.

6. Sections of the trial stretch of the road were covered with different ice melting materials (sodium chloride, calcium chloride). The change in the coat friction coefficient and the thickness of water layer were measured immediately after pouring of researched materials in equal time intervals using a mobile measurement sensor of optical friction RCM.
7. To study and compare the impact of different SRMs on the road surface friction, experimental road section should be rather long (not less than 400 m) and similar in terms of the environment, relief, etc.
8. After the analysis of measurement results on the road, it is possible to confirm that the impact of calcium chloride on the friction coefficient and ice melting occurs faster than in the case of sodium chloride.
9. To find out the efficiency of an SRM and the required amount and concentration of the material to achieve safe driving conditions in winter, it is necessary to conduct additional measurements that would allow developing a thermal map of a particular road section.

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