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Bio-based Materials for Improving Winter Pavement Friction

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ABSTRACT

Over five million tons of salt (NaCl) is applied in Canada every winter to improve pavement friction in the winter season. While effective for improving pavement surface condition, salts at high concentrations are detrimental to the environment and corrosive to vehicles and infrastructure. New alternative salts (bio-based products), are increasingly available in the market as an alternative to regular salt; however, limited information on the performance of these alternatives is available for transportation agencies to make informed decisions for the usage. In this study, a set of bio-based products were selected and their performances were compared using pavement friction improvement as a measure. A multivariate linear regression analysis was conducted to identify the factors influencing pavement friction by utilizing these new materials. The analysis has indicated that using bio-based materials resulted in 10%-40% improvement in the friction level. However, these materials did not significantly outperform each other. The study also concluded that an application rate as low as 3L/1000sqft should be applied for parking lots or low volume roads, which is 25% less than the current application rates that are used in general for parking lot pavement maintenance.

Key words: Bio-based materials, pavement, friction, deicing, winter maintenance

INTRODUCTION

During the winter season pavement surfaces can be very unsafe for both pedestrian and vehicular traffic (Hossain 2014a). To alleviate the hazards of pedestrians slipping and vehicular accidents, a large amount of chemical materials is used on various transportation facilities (e.g., roadways, parking lots and sidewalks). For instance, an average of 5 million tons of salt (i.e., sodium chloride) is used each year (Environment Canada 2004) in Canada. Among chloride salts, sodium chloride is the most common material used in industry due to its abundance, low costs, and effectiveness in pavement surface condition in sub-zero temperatures (Paschka et al. 1999; Ramakrishna & Viraraghavan 2005; Fu et al. 2012).

The use of large amounts of chloride salts for maintain a safe pavement surface can pose significant negative impacts to the environment and infrastructure. According to Environment Canada, road salt causes immediate and long-term negative impacts on the environment and has been identified as “toxic” under section 64 of the Canadian Environmental Protection Act (Environment Canada 2000). In order to alleviate the negative impacts while maintaining a safe and functional transportation system, alternatives to chloride salts, including bio-based and semi-bio-based materials, have been sought by the industry.

Few field studies have been conducted to explore and evaluate the effectiveness of alternative bio-based products compared to conventional salts (Fu et al. 2012; Hossain 2014b; Hossain 2015a, Muthumani and Shi 2016). Because of this lack of research, as well as the higher material costs and the perceived risk associated with the use of new products have not been widely used to maintain transportation facilities. Based on a survey conducted in North America and Europe (Fay et al. 2008), it is reported that more than 80% of winter maintenance contractors use the popular chloride salts (i.e., road salts). While practitioners acknowledge that there are advantages to using bio-based deicers, the lack of dependable alternatives and statutory regulations, plus the increase in costs, have resulted in the industry continuing to use chloride salts.

The main goal of this research is to evaluate the effectiveness of three bio-based products in improving pavement surface condition by breaking snow and ice bond to the pavement surface. This is accomplished through a large scale field study conducted in the winter season of 2013-2014. This paper is organized as follows. First, an overview of current literature is presented. Second, the test site and the testing method is explained. This is followed by a detailed discussion and statistical analysis of the tests results to examine the performance of these alternatives. Lastly, the main findings and conclusions of the research are summarized.

LITERATURE REVIEW

Chloride salts, especially at high concentration, cause significant damage to soil, water, air, vegetation and, aquatic life (Ramakrishna & Viraraghavan 2005; Fay & Shi 2012; Fischel 2012) also causing damage to vehicles and infrastructures due to their corrosive nature (13). Due to these adverse effects of chloride salts, bio-based and semi-bio-based alternatives to chloride salts are sought by the transportation agencies.

Limited studies have evaluated the performance of the alternative salts (Hossain 2015a, Hossain 2014b, Muthumani and Shi 2016; Fay & Shi 2011; Muthumani et al. 2016, Shi et al. 2009). A summary of these studies are brought as follows. Hossain et al. (2015a) found that, under deicing application, some bio-based solid salts outperformed regular salts. Earlier this group (Hossain et al. 2014b) studied a magnesium liquid salt, bio-based liquid salt, and brine; and found that they performed similarly. Fay and Shi conducted a series of lab tests to evaluate ice melting capacity, ice penetration depth and rate of ice undercutting (Fay and Shi 2011). The materials compared include solid and liquid chloride based, agricultural based, acetate and, formate based deicers. Results indicate that two $MgCl_2$ -based, one agro-based and, one KAc-based liquid deicer outperformed the others. In a similar study Shi et al. conclude that KAc-based deicers followed by $MgCl_2$ -based deicers outperformed the others in terms of effective temperature (Shi et al. 2009; Pan et al. 2008). The test results also indicated that agro-based deicers provided the least coefficient of friction while solid NaCl-based deicer provided the highest coefficient of friction. Nixon et al. also evaluated the melting capacity of seven deicing chemicals (NaCl, $CaCl_2$, KAc, CMA, MB, Caliber M1000 and Ice Ban Ultra) at four different temperatures (-18, -12, -6 and -1°C) (Nixon et al. 2005). Among these materials, Ice Ban Ultra, Caliber M1000 and CMA were not effective at -18°C. Ice Ban Ultra and CMA showed less effectiveness than the other materials by failing to work at even -12°C. After conducting a two-year field studies, Druschel (Druschel 2012) indicated that liquid salts was found less effective when temperature drops below -7 C. As temperature is very important factor that plays significant role in anti-icers' effectiveness and in the decision of maintenance manager on salt type or treatment form, Hosseini et al. (2016a) developed a model to predict this important factor over the snow event period after collecting two years of field data for parking lot and sidewalks, while in the road sector temperature is generally obtained from road weather stations.

Hossain and Fu at the University of Waterloo in Canada completed several research projects during the period of 2012-2015 to evaluate the performance of regular salt, solid bio-based salts; and developed optimal deicing and anti-icing models and application rates considering positive effect of pavement type, traffic volume, salt type and treatment type (Fu et al. 2013; Hossain et al. 2014b; Hossain et al. 2016a; Hossain et al. 2016b; Hossain et al. 2015b, Hosseini et al. 2016b). Studies found salt application amount can be adjusted or reduced for these factors. In low temperatures, despite of general belief, the bio-based liquid product did not show very high superiority compared to conventional salt, although a very few test was conducted during that time. However, in some cases, some of the bio-based solid salts

outperformed regular solid rock salt. These salts were reported very expensive when compared to regular salt though. More information on these salts and tests results can be found in Hossain et al. 2014b and Hossain et al. 2015a. This paper presents the results the performance of bio-based liquid salts to improve pavement friction under anti-icing application.

DESCRIPTION OF FIELD TEST

Test Site

All the field tests were conducted in large test area (Parking Lot C) at the University of Waterloo, Ontario, Canada. To be precise, the area of the parking lot is 25,540 m² (6.31 acres) and contains approximately 1000 parking stalls.

The tests were conducted in multiple test sections (e.g., 10'x20') with similar external conditions in terms of pavement type, initial snow type and depth, and traffic. Note that the pavement composition is asphalt concrete and it is in good condition with slight sloping. During the day, this parking lot is very busy due to its convenient location next to the University.

Data Collection Procedure

The field tests included both de-icing (post-application of salt after an event) and anti-icing (pre-application of salt before an event) tests, however, emphasis was given on anti-icing as using liquid materials is mainly used for anti-icing application. Test operations were started prior to a snow event with the goal of preventing the bond between the snow and pavement from occurring, resulting in a safer friction level for the pavement surface. Bio-based liquid materials were applied on the test sections using a liquid sprayer at various application rates based on the depth of the snow present, prevailing pavement surface temperature, and forecasted air temperature. To ensure uniformity in application, a significant amount of training was conducted during the initial stage of field tests. Each test section was approximately 10'x20', a relatively small area to achieve a high degree of uniformity. It should be noted that, in practice, the uniformity of spreading depends on the characteristics of the sprayer (e.g., manual rate setting vs. automatic rate control) and truck operational constraints (e.g., speed fluctuation).

In order to compare the performance of the treatments with different materials, data describing condition variables (e.g., precipitation amount, air temperature, pavement contaminant type) and treatment performance i.e., the coefficient of friction, CoF were collected at a fixed time interval for each test by a portable friction measurement device called, T2GO, manufactured by Swedish company ASFT.

Product Selection and Application Rates

After consulting with the Toronto Region Conservation Authority (TRCA), a regional environmental and conservation agency, a review was conducted to select the alternative materials for testing. The selection criteria used included the percentage of bio-based contents in the composition, the product's current usage, availability, price, and the performance of the product under low temperatures.

The materials selected for testing are as follows: brine, Snowmelt (fully bio-based), Fusion (mixture of bio-based ingredients and chloride salt) and, Caliber M1000 (bio-based and chloride content). In addition, Snowmelt was tested at two concentration levels: 100% concentrated Snowmelt, and Snowmelt diluted with brine at a ratio of 30:70 (snowmelt to brine). This ratio was used for majority of the tests as recommended by the supplier. The brine used in the tests was regular brine (23% sodium chloride by mass) and was supplied from the City of Kitchener's winter road maintenance facility. It should be noted that the City of Kitchener filled the brine containers with an injecting pipe system, which was also used for providing other types of anti-icing materials (e.g., Fusion, Beet juice – bio-based products). While there was a potential for cross contamination of the brine, the degree of this effect was considered to be relatively small. Information regarding the materials used for testing is summarized in Table 1.

Our test plan included conducting a fractional factorial experiment (i.e., investigating the response of some major influencing factors at their different levels) that enabled us to investigate the sensitivity of the major influencing factors, e.g., the application rates of the materials to the response factors (i.e., the performance measure - CoF). As a part of this design process and recommendations that were provided by the suppliers, three application rates for each of the product were tested for each day, i.e., 3, 6 and 9L/1000sft. Note that the application rates in the road industry vary from 3 to 10 L/1000sqft (Blackburn, Bauer, Amsler, Boselly, & McElory, 2004), while 4L/1000sqft is the most common application rate being used and recommended for parking lots.

DISCUSSION ON TEST RESULTS

For each snow event, different materials were applied to a set of test sections following test protocols and time series performance and condition data were collected as described in the previous section. The winter season had widely varied weather conditions, including a number of days with an average pavement surface temperature of below -10°C . The winter season had more than 20 regular snow events (less than 2 cm), 10 medium to heavy events (2 to 5 cm) and 5 extremely heavy events (more than 5 cm) while the pavement surface temperatures ranged from -15°C to 1°C and the average air temperature varied between -22°C and -2°C . The following section examines all the data collected and compares the performances of the materials, and their influencing factors.

Performance of the Tested Materials

As discussed previously, the main object of these materials is to prevent the bonding of snow and ice to a pavement surface by lowering the freezing point of water. To evaluate the effectiveness, friction levels at the treated sections are compared to those of the control sections (i.e., no treatment was performed). For both cases, the accumulated snow was first removed by the plow truck or using a shovel before observations and friction were taken by T2GO friction tester. Also, note that anti-icing treatment can only be conducted when the pavement is initially bare. As a result, anti-icing cannot be performed each day during a continuous event. This limited testing to a total 13 anti-icing events, while de-icing treatments were conducted in 32 events.

Figure 1 shows the CoF gained over the control sections for the three materials (brine, snowmelt and fusion) at an application rate of 3L/1000sqft. Caliber M1000 was introduced towards the end of this season, and is not included in this comparison. More results for the Caliber M1000 product can be found in a previous publication reported in another study (Hossain et al. 2014b).

It can be seen from the test results that, using these materials helped improve friction level; meaning that these materials are capable of preventing the bonding of snow and ice to pavement surface. However, as expected, in some cases anti-icing treatments with these materials were not effective as liquid salts become less effective under a temperature below -7°C . Figure 2 shows the relationship between CoF and pavement surface temperature under an application rate of 3L/1000sft, observed in the field tests. While there is some small variation in the CoF within the temperature range for different products, it can be seen that anti-icing were almost not effective below -10°C as CoF is dropped significantly under this temperature.

To identify whether the friction improvements over the control sections are statistically significant, friction measurements on control sections and treated sections were paired and the differences in CoF were then computed for t-test. The mean difference of CoF was found statistically significant at 95% confidence level for all materials. The result from the t-test analysis is summarized in Table 2.

To determine whether the anti-icing performance of these alternatives had differed significantly, an ANOVA analysis is conducted on paired test results, grouped based on the testing day and the application rate used. The summary statistics of the data and ANOVA results are shown in Table 3 and 4. This statistical analysis concludes that the differences in performance between the alternative materials are not statistically significant. This finding suggests that the bio-based alternatives are at least as effective as the regular brine for anti-icing operations.

Modeling the Performance of the Materials

To model the performance of CoF of the materials and the factors (e.g., temperature, application rate) that influence this performance with statistical reliability, a multiple linear regression analysis has been conducted. The descriptive statistics of the data used in the regression analysis are first summarized in Table 5 followed by Table 6 showing model results.

It can be seen that, the distribution of some variables varied for some of the products. For instance the highest and lowest testing temperatures are similar for most of the products; however, there is a significant difference in both kurtosis and skewness coefficients for some of the products. This suggests that the distribution of the test temperatures were not uniform for all the products.

The significance of each contributing variable was tested using a p-value at 5% level of significance. The coefficient values determine how strongly the CoF improvement is impacted and whether the impact is positive or negative. A binary variable was also used to represent snow moisture content (dry snow=1, wet snow=0) to quantify its effects on the performance. The following section summarizes the main results of the regression and the corresponding interpretations.

Intercept

The intercept of the regression model, which can be interpreted as the expected mean in percentage of friction improved for sections treated with ant-icing over untreated sections within the context of experiment being conducted. As previously mentioned, the testing season was extremely cold; however, the regression results showed that the intercept coefficients for all products are positive which indicates that CoF has improved with the usage of these products. This overall improvement of CoF found in this analysis reconfirms the t-test results obtained in the previous section for all the products.

Application Rate

Intuitively, application rate should have a positive effect on improving the effectiveness of these materials. However, the statistical tests could not confirm this expected effect; in fact, the application rate was not found to be statistically significant at a probability of 5%. Despite this result, it can be seen that the coefficient for all of the products is positive suggesting positive effects in general. It should however be cautioned that this finding should not be extrapolated beyond the range of the application rate being covered (i.e., 3, 6 and, 9 l/sqft). While the rates being tested were selected on the basis of practicality, it is theoretically possible that the performance of these materials could change dramatically when the rate increase or decrease beyond this range. However, it can be mentioned, since there was only small improvement in

CoF for a large increase in material usage, the lowest application rate should be used for preventing bonding to occur. Recall that, in the current industry for parking lot maintenance, the recommended application rate is 4L/1000sqft. Therefore, the lower application rate of 3L/1000sqft would represent a 25% reduction in material usage.

Pavement Surface Temperature

Pavement Surface temperature is another factor that is considered to have a significant effect on the performance of a chemical used to improve winter pavement friction. As such, lower pavement temperatures may result in the ineffectiveness of liquid materials, as the water in the liquid mixture may simply freeze. A decrease in pavement temperature means that a higher concentration of salt needs to be used to create a liquid salt-snow mixture and break the snow-pavement bonding. Thus, an increase in pavement temperature should result in a comparative increase in performance of the liquid salt over the control.

As expected, the regression analysis shows that pavement temperature is positively associated with performance of brine, concentrated Snowmelt and Caliber M1000, which was found statistically significant at 95% confidence level. The positive coefficients associated with brine and Caliber suggest that they performed significantly better under warmer event than colder events. The negative coefficient for Snowmelt suggests that, in general this material performed comparatively better than other in colder temperatures, as it can be seen from the Figure 2. The performance of diluted Snow melt and Fusion was not significantly affected by the temperature. Caution should be taken that all of these findings are only valid within the temperature ranges observed.

Amount of Snow

The amount of snow that had accumulated on the test sections by the end of the event (before being plowed for friction measurement) is another fact being examined. The larger amount of snow a pavement surface is covered, the quicker the liquids may be diluted, and thus the less effective they would be. This was confirmed, as all of snow amount coefficients obtained were negative. However, only in the sections with brine as material, the effect of snow amount was found to be statistically significant at a level of significance of 0.05. The dilution effect for the other materials was found to be insignificant, suggesting that the performance of the other liquid salts did not change significantly with snow amount.

Snow Type

Before plowing, snow on each test section was checked and classified as either dry or wet. To examine the effect of snow type on the performance of the materials, snow type was

included in the regression analysis. For brine and Caliber M1000, anti-icing operations were found to be more effective for dry snow than wet snow and the relationship is statistically significant at a significance level of 5%.

CONCLUSIONS

A suitable and dependable alternative to regular chloride salts for winter snow and ice control is an undeniable need now. The industry is coming up with a number of alternatives in the marketplace with a few with proven results from independent research. This study has concluded with some significant findings on the comparative performances of some of the relatively new products.

- A large number of tests were conducted on the field performance of three bio-based products on improving winter pavement friction in the winter season of 2013-14 at a parking lot of University of Waterloo in Ontario, Canada. Statistical technique is employed to examine the performance of these bio-based materials over regular salt.
- The benefits of using the materials tested were clearly confirmed in the field tests, regardless the materials being used. The average friction gain on the treated tests sections over the control sections (without treatments) varied from 10 to 40% depending event conditions.
- The comparative performance of the bio-based materials differed by events; however, the test results did not indicate statistically significant difference in performance between the bio-based products and chloride based salts. This finding has confirmed that the bio-based products are at least as effective as the regular products for improving pavement friction, while the former has the added advantage of being environmentally friendly.
- The field test results also indicated that the pavement friction gain was generally not sensitive to the application rate. While this finding is constrained to the range of the rate being tested (3, 6 and 9L/1000sqft), it did suggest that an application rate as low as 3L/1000sqft could be recommended for a safer pavement friction level in parking lots or low volume roads, regardless the types of materials being used. It should be pointed out that this rate is about 25% less than the current application rates that are used in general for parking lot maintenance. Being able to use a low application rate also makes the higher priced bio-based alternatives more attractive and acceptable in practice.
- The test results also showed the variation in the event conditions that affected the benefit of using bio-based materials for improving pavement friction. Among those the three most important factors were pavement temperature, snow amount and snow type. The

nature of the effects was found to be intuitive. For example, anti-icing treatments were less effective for wet snow and heavy precipitation under low temperatures. Also, it is observed that the effectiveness of anti-icing decreases under pavement temperature below -10°C .

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Table 1: Key information of the materials tested

Trade Name	Composition (Provided by suppliers or obtained from literature)	Effective Temp.	Cost (\$/L)*	Physical Look
Brine	23% NaCl 77% Water	-7°C	0.15	
Fusion 2350	12% NaCl 50% Degraded Beet Juice 38% Proprietary Ingredients	-27°C	0.30	
Snow Melt	15-20% Glycerine 10-20% Polyether Polymer 3-8% Lactic Acid 2-4% Sorbitol 1-3% Formic Acid 1-3% Acetic Acid 1-2% 1,2-Butanediol Balanced with Water	-20 to - 40°C	0.29	
Caliber M1000	27% MgCl ₂ 6% Carbohydrate 67% Water, Proprietary and Unknown Ingredients	-29.40°C	0.40	

Table 2: 't-tests' results for improvement of friction at anti-icing sections vs. control sections

Statistics	Brine	Diluted Snowmelt	Fusion	Concentrated Snowmelt	Caliber
Observed Difference in Mean CoF (Treated site over Control Site)	0.0575	0.0615	0.0571	0.0675	0.0574
S.E	0.0124	0.0087	.0091	0.0083	0.0208
Sample Variance	0.0071	0.0033	0.0036	0.0012	0.0091
# Sample	44	44	38	16	21
Degrees of Freedom	43	43	37	15	20
Hypothesized Difference in Mean CoF (Treated site over Control Site)	0	0	0	0	0
t-calculated (t-critical)	4.63 (1.68)	7.06 (1.68)	6.27 (1.68)	8.13 (2.02)	2.78 (1.72)
P-value (at the probability of 5%)	2.49E-5	5.1E-9	5.6E-7	6.6E-7	0.0061
Statistical Conclusion	No evidence to accept the null hypothesis that the mean CoF in both treated and control sections are equal.				

Table 3: Summary of treatment performance data for ANOVA (N=162)

Statistics	Treatment by Brine: Avg. CoF	Treatment by Diluted Snowmelt: Avg. CoF	Treatment by Fusion: Avg. CoF	Treatment by Snowmelt: Avg. CoF	Treatment by Caliber M1000: Avg. CoF
Sum	18.79	18.79	16.54	6.79	10.47
Avg. CoF	0.43	0.43	0.43	0.42	0.50
Variance	0.016	0.012	0.013	0.10	0.015

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Table 4: Results of ANOVA

Source of Variation	Sum of Squares	Degree of Freedom	Mean Squares	F-Observed (5% significant level)	F-Critical (5% significant level)	P-Value	Conclusion from ANOVA
Between Treatments (Brine, Diluted Snowmelt, Fusion, Concentrated Snowmelt and, Caliber M1000)	0.0882	4	0.0221	1.6236	2.4288	0.1709	No evidence to reject that the mean performances (Avg. CoF) for all treatments are equal
Within Treatments (Brine, Diluted Snowmelt, Fusion, Concentrated Snowmelt and, Caliber M1000)	2.1471	158	0.0135				
Total	2.2354	162					

Table 5: Descriptive statistics of the data

Products Name	Variable	Salting Rates (lbs/1000sqft)	Pavement Surface Temperature (°C)	Amount of Snow in kg/m ² (Snow Depth in cm x Density in kg/m ³)	% Improved in CoF
Brine	(Minimum, Maximum)	(3, 9)	(-14.8, -1.7)	(0.08, 4.74)	(-12.73, 87.5)
	Mean	5.93	-8.32	1.12	15.79
	Std. Dev.	2.46	3.97	1.30	21.69
	Variance	6.07	15.74	1.70	470.46
	Kurtosis	-1.51	-0.84	2.14	3.85
	Skewness	0.04	-0.43	1.71	1.75
Diluted Snowmelt	(Minimum, Maximum)	(3, 9)	(-14.8, -1.7)	(0.08, 4.74)	(-9.09, 50)
	Mean	5.93	-8.32	1.12	17.70
	Std. Dev.	2.46	3.97	1.30	17.16
	Variance	6.07	15.74	1.70	294.61
	Kurtosis	-1.51	-0.84	2.14	-0.64
	Skewness	0.04	-0.43	1.71	0.46
Fusion	(Minimum, Maximum)	(3, 9)	(-14.8, -1.7)	(0.08, 4.74)	(-12.73, 53.33)
	Mean	5.93	-8.52	1.15	16.04
	Std. Dev.	2.46	4.23	1.40	16.11
	Variance	6.07	17.90	1.96	259.68
	Kurtosis	-1.52	-1.15	1.41	0.07
	Skewness	0.05	-0.27	1.56	0.70
Snowmelt	(Minimum, Maximum)	(3, 9)	(-14.8, -1.7)	(0.2, 4.74)	(3.7, 50)
	Mean	5.63	-7.04	2.16	19.84
	Std. Dev.	2.42	4.74	1.66	11.63
	Variance	5.85	22.45	2.75	135.31
	Kurtosis	-1.37	-0.78	-1.19	1.70
	Skewness	0.25	-0.79	0.34	1.15
Caliber	(Minimum, Maximum)	(3, 9)	(-9, -4.4)	(0.08, 2.51)	(-16.67, 87.5)
	Mean	6.00	-6.66	0.60	13.05
	Std. Dev.	2.51	1.86	0.82	23.98
	Variance	6.30	3.44	0.67	574.90
	Kurtosis	-1.58	-1.84	2.48	3.49

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	Skewness	0.00	-0.12	1.96	1.38

Table 6: Model to predict the performance of the materials

Product	Sample Size, R Square	Variable Name	Coefficient	P Value
Brine-Control	44, 0.31	Intercept	29.812	0.011*
		Application Rate (l/sqft)	1.375	0.247
		Pavement Temp (°C)	3.107	0.001*
		Snow Amount (kg/m ²)	-6.653	0.006*
		Snow Type	13.992	0.099
Diluted Snow Melt-Control	44, 0.09	Intercept	15.895	0.124
		Application Rate (l/sqft)	0.024	0.982
		Pavement Temp (°C)	0.167	0.837
		Snow Amount (kg/m ²)	-3.109	0.148
		Snow Type	8.225	0.282
Fusion-Control	38, 0.12	Intercept	27.883	0.011*
		Application Rate (l/sqft)	0.433	0.688
		Pavement Temp (°C)	0.887	0.262
		Snow Amount (kg/m ²)	-3.034	0.136
		Snow Type	-4.005	0.642
Snow Melt- Control	16, 0.71	Intercept	6.354	0.415
		Application Rate (l/sqft)	0.640	0.444
		Pavement Temp (°C)	-2.064	0.002*
		Snow Amount (kg/m ²)	-1.231	0.330
		Snow Type	-2.456	0.672
Caliber M1000- Control	20, 0.57	Intercept	31.666	0.102
		Application Rate (l/sqft)	-1.581	0.324
		Pavement Temp (°C)	8.025	0.005*
		Snow Amount (kg/m ²)	-4.370	0.420
		Snow Type	54.744	0.000*

Figure 1: Improvement of friction for anti-icing by different liquid salts. Fusion was not tested on 17th and 18th. Caliber and Concentrated snowmelt results were not included in this Figure since they were only tested approximately 5 days.

Figure 2: Effect of temperatures on the CoF. Caliber was not tested under -10 C as it was introduced towards the end of the testing season.

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