Influence of Wind, Temperature, and Deicing Chemicals on Snow Accretion

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Tests run for natural snow deposition on asphalt pavement treated with highway and airport runway deicing chemicals demonstrate that, for conditions of strong wind and cold temperatures, these chemicals can have a deleterious effect. Friction is assumed to be the primary criterion for judging chemical efficacy. Statistical correlations with meteorologic data support observations that some conditions that produced scouring on nonchemically treated pavement caused snow to accumulate on areas that had been treated with deicing chemicals.

The use of chemicals is a vital aspect of snow and ice control in many nations of the world. In addition to the direct cost, however, the adverse environmental effects of these chemicals on the transportation infrastructure is a serious concern. Since 1975, an estimated 10 million tons of road salt has been used annually in the United States alone, causing corrosion of cars, roads, and bridges; adverse influences on vegetation; and contamination of water supplies. Noncorrosive, environmentally safe alternative deicers have higher initial prices, although this may be offset by the long-term full cost of salt. In any case, efficient, effective application of chemicals is essential from the standpoint of monetary and environmental concerns.

The use of measured friction values as an objective parameter for judging the efficacy of chemicals in deicing and anti-icing field tests in Michigan produced some seemingly anomalous results in an objective statistical ranking of the effectiveness of the independent test sections. However, further analysis using meteorologic data exhibited a correlation between wind speed, temperature, and the effectiveness of deicing chemicals. This result supports observations made in this study and mentioned in the literature (*1*) that the use of chemicals in conjunction with wind-transported snow can induce snow accumulation on pavement that would otherwise have been scoured bare.

OBJECTIVES

The objective of the field study was to compare the efficacy of deicing and anti-icing chemicals in a realistic, but controlled, well-monitored environment. Chemicals were applied to large asphalt test sections under naturally occurring snow conditions. This work considered proprietary research materials, as well as commercially available deicing products. In one aspect of the study, reported here, an interaction of wind and temperature on the deicing chemicals is apparent. Because the subject phenomenon was observed among all the test deicers, it is not necessary for the purposes of this discussion to identify specific chemicals. This conclusion differs somewhat from the observations of Fromm (*2*) who conducted studies on wetting of NaCl with $CaCl_2$ solutions. He observed that the wetted salt caused blowing snow to stick, but that the untreated salt allowed the road to dry.

Because surface friction is critically important to vehicle traction, handling, and safety, it was used as the primary measure of chemical efficacy. This paper addresses only the influence of wind speed and temperature with the use of deicing chemicals.

TEST PROCEDURE AND EQUIPMENT

Two testing areas designed to simulate highway and airport operations were established on an unused portion of asphalt runway at the Houghton County Airport, Houghton, Michigan. Each test area contained two separate parallel lanes to allow for different maintenance operation tests to be made during a single test. All test sections were 30.5 × 7.3 m (100 × 24 ft). In order to mitigate cross contamination, these sections were separated from each other along the path of vehicle motion by a 61.0-m (200-ft) buffer zone. A map view of these sections reveals a checkered pattern with four test sections used for vehicle motion in one direction and three sections staggered and offset along the 61.0-m (200-ft) buffer zones for returning traffic. This checkered pattern is apparent in the background shown in Figure 1.

On the highway course, the two separate lanes were divided into a lane on which traffic was simulated using a roller built for this purpose, while the other lane and the airport lanes were left undisturbed except for the occasional passage of the Saab Friction Tester. The friction tester measured values by means of a rotating fifth wheel with a constant 12 percent slip relative to the vehicle speed. The measuring wheel was connected by a chain drive to the freely rotating rear axle of a Saab automobile. A computer recorded a friction measurement taken every 1 m (3 ft) and presented an average of these values taken over each 30.5-m (100-ft) test section. An attempt was made to run the Saab on approximately a 15-min interval. From these friction measurements, the effectiveness of each test section could be viewed in comparison with the others.

The application rates for highway chemicals were chosen to compare with highway maintenance standards. Road salt per application is frequently applied at a rate of 23 g/m² (300

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FIGURE 1 Foreground, Test Section 8 was nontreated section. Background, chemically treated sections are offset rectangular patches. Snow accumulation is apparent on chemically treated test sections, whereas untreated pavement has been scoured.

lb per linear mile) in actual highway maintenance operations, so rates similar to this were used for the test. The airport test area was used to simulate chemicals applied in airport maintenance activities. The major difference between this procedure and the highway scenario was that traffic was not simulated and sweepers were sometimes used for snow removal. Rates were chosen for these chemicals that were more typical of airport operations. Application rates were up to three times that used on the highway.

Chemicals were applied simultaneously by using individual walk-behind spreaders. This application was carried out either in anticipation of a storm, in an attempt to evaluate anti-icing properties, or immediately after plowing any accumulated snow. The sections were prepared for each test by plowing any accumulated snow. This plowing was performed to determine the effect of chemicals applied before an anticipated precipitation event, or to observe residual chemicals present from previous tests. Immediately after plowing, measurements were made using the Saab friction tester. The chemicals were usually applied on the test sections after the initial plowing, although this was sometimes delayed or not done, to observe the residual chemical effect after the overburden was removed. Throughout testing, plowing was performed as needed. When reapplication of chemicals was deemed prudent, it was always carried out immediately after plowing. In any event, the Saab was used to bracket any maintenance operation.

Meteorological data collected during testing were ambient air temperature, snow surface temperature, bare pavement temperature (when exposed), wind speed, wind direction, relative humidity, incoming infrared (long wavelength, 4- to 50-μm) and both incoming and reflected solar (short wavelength, 0.28- to 2.8-μm) radiation. Ambient air temperature and relative humidity were measured at approximately 3 m, and wind data at 4 m above the ground, on the roof of the mobile laboratory. Ambient temperature was obtained using a shielded thermocouple; the snow and pavement temperatures were measured using a shielded thermocouple probe. Data from the airport station, collected 24 hr a day, were used to complement these data.

DISCUSSION OF RESULTS

Friedman statistical tests (*3*) were conducted to analytically check for differences in the distributions of the friction measurements. These statistical tests were conducted on the results of 22 days for which data were gathered during January through March of 1990. The Friedman test is a nonparametric two-way analysis of variance (ANOVA) test. It treats each test time within a given day as a block in which it ranks the friction coefficient values. The ranks of a treatment over that day are then summed and compared to those of the other treatments. The analysis is based on the hypothesis that there is no difference in the distributions and that it determines the probability that the hypothesis is correct. This test was repeated for each test day.

Using this method, there were a number of days for which the section on which no chemical was applied resulted in superior performance. The fact that the nonchemically treated section worked, as well as or better than all of the treated sections (in some instances) was at first somewhat disconcerting, because it did not coincide with the intuitively expected results. Meteorologic conditions, however, afford an explanation and should in fact lead to methods that help optimizing the application of deicing chemicals.

Figure 1 shows a dramatic example of an instance in which higher relative friction values were recorded on the nonchemically treated sections. Keeping in mind the pattern in which chemicals were applied and that the clear test section shown in the foreground was a nonchemically treated area, note that the checkered pattern of snow accumulation is on the chemically treated surfaces. During the field testing, this situation was often associated with windy conditions in which the nonchemically treated sections and in fact the runway in general were wind-scoured and bare, whereas areas that were chemically treated tended to exhibit snow accumulation, a fact that had been noted by others as well (*1*).

Physical Motivation

Although wind is a dominant mechanism, it alone does not determine when an untreated pavement would necessarily result in higher frictional values than those of the chemically treated sections. Other interacting conditions are required as well and the situation is more involved than that discussed here. An obvious requirement is that there be snow or ice particles available to accumulate. This mass supply may be in the form of precipitating, drifting, and saltating (i.e., ice grains bouncing along the surface) snow or often a combination of these. In the case of redeposited snow, there is a threshold wind velocity necessary to produce a shear stress on the snow surface sufficiently large to cause particles to be transported. This threshold velocity is highly dependent on the texture of the snow surface, which in turn is dependent on antecedent meteorologic conditions.

In addition to wind velocity and previous environmental conditions, another parameter that greatly influences the snow scouring-deposition relation is temperature. In the presence of a cold, dry environment, saltating ice particles will act in a manner similar to the drifting of dry sand. This behavior is shown in Figures 2 and 3, in which these conditions prevailed.

FIGURE 2 A "river" of wind-transported snow, flowing along the asphalt road surface and obscuring the pavement.

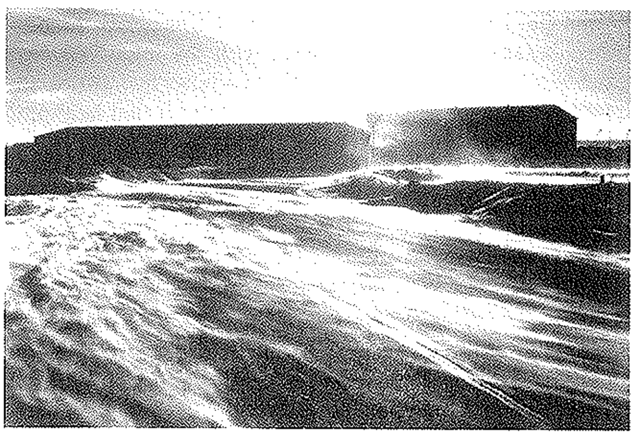

FIGURE 3 When drift intensity has momentarily decreased below that shown in Figure 2, snow is not accumulating on pavement.

Regions of scouring and deposition in this situation are governed predominantly by wind velocity and the terrain geometry. At warmer temperatures, however, at which the ice is relatively close to its temperature of phase change, grains that impact the untreated pavement are more likely to adhere to and accumulate on the surface. Extreme cases of this would be freezing rain and sleet.

In contrast, when the situation was examined in which scouring was occurring on the untreated pavement surface, an obvious residual effect of the chemicals was apparent on the treated sections, as evidenced by the snow accumulation pattern in Figure 1. It is important to note that this condition occurred even when the treated sections had not been recently treated and were bare at the start of the precipitation event. These chemicals are freezing point depressants, and therefore, act to effectively lower the temperature of phase transition for the ice. This effect results in some melting and adhesion to the pavement surface. If the rate of melting is insufficient to keep pace with the quantity of snow being transported, a net accumulation results.

This effect was essentially the same for all of the chemicals tested. A graphic demonstration of this wind-driven snow accumulation on chemically treated pavements is shown by the photographs in Figures 4 and 5. When this scouring and accumulating situation occurred, friction on the nonchemically treated sections, naturally, was better than on the chemically treated pavements.

As stated previously, tests include instances for which chemicals were placed on the pavement during the particular storm event and for those in which no new chemicals were added. Results indicate that residual chemicals dissolved on the pavement surface during previous events were sufficient to cause snow accumulation.

The surface appearance of the accumulating snow displayed an orientation in which sharp features developed and grew into the prevailing wind. The snow was rather slush-like and all but a thin film of ice grains could be easily removed with a standard snow plow cutting edge. This thin film often presented the impression of a relatively bare pavement. However, measurements using the friction tester revealed a surface of low friction. When the causal conditions persisted, accumulation again resulted. A polyurethane cutting edge was tested in an attempt to remove this poorly bonded film, but to no advantage. The use of a sweeper was more effective but did not halt reaccumulation.

FIGURE 4 An example of considerable snow transport occurring on test course.

FIGURE 5 Accumulation is taking place preferentially on chemically treated rectangular sections, as can be seen when visibility improved briefly from that of Figure 4.

This snow scouring and accumulating condition should not be misconstrued to imply that the studies indicated that the use of chemicals in general has an adverse effect. As the photograph of Figure 6 demonstrates, the chemicals often worked more in the way desired when the type of conditions discussed here were not dominant. The chemically treated sections produced clear, wet pavement, with no melting taking place on the untreated test section or in the general vicinity.

Statistical Analysis

To date, and thus far in this presentation, the phenomena under discussion have been based on observational information. At this point, using the data collected and the Friedman analysis, it is possible to give some statistical basis to the snow scouring and accumulating effects of the wind-temperature interaction. The results of the Friedman tests were further analyzed to see if there is a relationship between the rankings of the untreated sections and the wind speed.

Because the snow scouring and accumulating effects were apparent for chemicals applied before a specific test, it was considered likely that, in some cases, the effect of the scouring was the result of antecedent wind conditions. It was also felt that a sustained wind, rather than a maximum peak value, was more relevant. For these reasons, three different averaged wind speeds were used for the analysis. Wind speed was considered to be the maximum of the 3-hr average for the following periods: (a) 24 hr before testing—$W1$, (b) 12 hr before testing—$W2$, and (c) during the test—$W3$. These average values ranged from 0 to 10 m/sec (0 to 22 mph). The influence of temperature was examined by considering all tests and then excluding days when the average air temperature was warmer than approximately −4°C. This condition includes some instances of freezing rain.

A correlation analysis was done on the rank of the nonchemical treatment with the wind speeds during and before the test periods, as described earlier. Sample correlation coefficients are used to do this. These sample coefficients are presented in Table 1 for the four test lanes and the three different wind speed time periods. They were computed using

FIGURE 6 Example of test in which chemicals were effective in achieving desired results.

data for 11 days of testing on the highway section and 11 days of testing on the airport section. These results are shown under the column headed Full. As an example, consider the airport inner lane, using the maximum 3-hr average of the 24 hr before the test (i.e., W1)—the sample correlation coefficient is 0.334.

The p-value (*4*) is the probability of observing a particular sample correlation value when there is actually zero or no correlation between the two variables. For example, on the airport inner lane, the p-value of 0.164 in the table is the probability that there is no correlation between friction rankings and wind speed $W1$. Next, the correlations were recomputed after removing days with relatively warm temperatures (≥ −4°C), 3 days from the highway and 2 days from the airport. These values are under the column headed Reduced with their p-values in the last column; p-values close to their maximum of 1 are indicated by two asterisks in the table. Except for the highway outer section when using all the test days, there are significant correlations between the rank of the nontreated section and the wind speed during at least one of the three periods. These correlations are positive values, which indicates that the nontreated section ranked higher as the wind speed increased, but it does not yield information on the actual magnitude of the velocity.

If observations are removed from the data at random, the sample p-value of the correlation coefficient would in general tend to increase, indicating that the relation between wind speed and ranking would be nonsignificant. In order to check for a temperature effect, data for days with relatively high temperatures were removed from the correlation. The resulting sample correlation coefficients are generally higher with smaller p-values. This effect is consistent with the claim that lower temperature and higher wind speed can result in better friction on untreated pavement.

Another correlation analysis (Pearson) was made using the friction values versus the weather parameters. Correlations were computed for the 7 days on which additional chemicals were applied on the highway and 8 days on which additional chemicals were applied on the airport section. Days on which only residual effects were examined were excluded. This procedure permitted the correlations to be matched by the times from the application of chemicals and by days. The statistically significant correlations for the three maximum wind speed averages for each of the treatments are presented in Table 2. Only those correlation values that had p-values <0.05 are presented in the table, except as noted by the asterisk; p-values >0.05 are generally not considered statistically significant. This table combines the airport results, but the highway is broken down into traffic and nontraffic sections.

In Table 2, the nonchemically treated section for the highway test is denoted by $T1$ and for the airport by $T8$. The other T values denote the various chemical deicers. The correlations for the chemically treated sections with $W3$ are all statistically significant and all negative; the only positive correlations occur in the nontreated sections. This result means that friction tended to decrease for each of the chemically treated sections as the wind speed increased during the period of the testing. On the other hand, although some negative correlation did occur for the nonchemically treated sections, it was only the nonchemically treated sections that had a significant positive correlation with wind speed. These cases occurred either dur-

TABLE 1 FRIEDMAN TESTS RESULTS—WIND EFFECTS (*W1* = MAXIMUM 3-hr AVERAGE FOR PREVIOUS 24 hr; *W2* = MAXIMUM 3-hr AVERAGE FOR PREVIOUS 12 hr; *W3* = MAXIMUM 3-hr AVERAGE DURING TESTING)

Airport Inner Lane				
Wind	Full	P-Value	Reduced	P-Value
W1	0.334	(0.164)	0.315	(0.211)
W2	0.450	(0.085)	0.686	(0.020)
W3	0.534	(0.046)	0.539	(0.069)
Airport Outer Lane				
Wind	Full	P-Value	Reduced	P-Value
W1	0.016	(**)	0.233	(0.281)
W2	0.640	(0.017)	0.722	(0.013)
W3	0.764	(0.002)	0.865	(0.000)
Highway Non-traffic Lane				
Wind	Full	P-Value	Reduced	P-Value
W1	0.328	(0.166)	0.584	(0.068)
W2	-0.075	(**)	0.080	(**)
W3	0.391	(0.122)	0.616	(0.055)
Highway Traffic Lane				
Wind	Full	P-Value	Reduced	P-Value
W1	0.518	(0.051)	0.773	(0.011)
W2	0.133	(**)	0.393	(0.179)
W3	0.146	(0.340)	0.355	(0.203)
** = p-value near maximum value = 1				

TABLE 2 CORRELATION OF FRICTION WITH WIND

Highway Treatment - Traffic							
Wind	T1	T2	T3	T4	T5	T6	T7
W1	0.45	-	-	-	-	-	-
W2	-	-	-	-	-	-	-
W3	-0.43	-0.40	-0.60	-0.55	-0.49	-0.50	-0.66
Highway Treatment - No Traffic							
Wind	T1	T2	T3	T4	T5	T6	T7
W1	0.77	-	-	-	-	-	-
W2	-0.60	-	-	-	-	-	-0.39
W3		-0.31	-0.47	-0.40	-0.31*	0.39	-0.79
Airport Treatment							
Wind	T8	T9	T10	T11	T13	T14	
W1	-	-0.31	-0.35	-	-0.23	-0.37	
W2	0.33	-0.40	-	-0.30	-	-0.36	
W3	0.23	-0.33	-0.35	-0.42	-0.45	-0.36	
*=confidence interval of 7%							

ing the 24-hr period before testing for the highway or during the 12 hr before testing for the airport section. The trend in this table further substantiates observations of the snow scouring and accumulation effect.

The implication of these results are that the effect of scouring on the nonchemically treated sections was generally dominated by wind speed which occurred during a period before testing, because it takes some time for the effect of the wind to clear the surface. On the other hand, the accumulation of snow onto the chemically treated areas was most closely related to wind speed during the removal operation. If the wind transport condition had lessened by the time of the actual testing, the snow that had accumulated because of the chemicals during the earlier high-wind period could more likely be removed.

SUMMARY

Saab friction values were used as the primary standard for evaluating the efficacy of deicing chemicals during the winter field program. These values were examined using the Friedman test, a statistical method of ranking the relative performance of the different chemicals.

There were a number of occurrences in which the non-chemically treated test section had an overall higher performance rating. This effect was demonstrated to be statistically correlated to wind speed and temperature—which supports previous observations. The events at higher wind speeds caused decreases in measured friction values for the chemically treated sections, but scouring of snow tended to increase the friction values for the nontreated surfaces.

As a practical consideration, these data indicate that for sections of highway prone to high wind and low temperatures, chemical control methods may in fact yield a negative effect. In this situation, the consideration of snow fences might well prove to be a practical alternative as a complementary means of maintenance. It also indicates that, for specific sections of highway, chemicals should be used judiciously.

Additional work of this sort, based on quantitative measurements, may lead to specific recommendations for highway and airport maintenance operations. This work would include correlating the magnitude of the wind speed to chemical effectiveness in combination with site location, temperature, and other pertinent meteorological parameters. The final outcome of such work would be included in manuals that recommend conditions that best suit the use of chemicals before, during, and after a storm event.

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