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THE EFFECT OF MAGNESIUM CHLORIDE AS AN ANTI-ICING AGENT ON TIRE/ROAD FRICTION CO-EFFICIENT

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EXECUTIVE SUMMARY

The purpose of this research was to determine the overall effect of $MgCL_2$ application on the measured co-efficient of friction between a standard automobile tire and a well-travelled asphalt surface.

While some users have found that $MgCL_2$ application, as an anti- or de-icer, causes a "greasy" road surface; generally speaking, this was not found. When $MgCL_2$ solution at 30% concentration with 4% ice-ban used as a rust-inhibitor, is put down at typical application rates, the road surface friction will drop by about 18-21%, as compared to a dry road condition. However, when used in anticipation of incoming inclement weather, this relatively-minor drop is still far better than the expected road surface condition under snow or ice conditions. This minor drop in friction, as compared to a dry road condition, can be directly compared to that which occurs when the roadway becomes sufficiently wet from a rainstorm. In other words, the application of $MgCL_2$ as an anti-icer on a dry road, will cause friction to decrease to the same level as a wet road, but this indeed is far superior than what would expectantly occur under typical winter conditions (snow, ice and/or black ice).

In the moments following $MgCL_2$ application, the friction will gradually improve for some time (presently it is considered to be 15-20 minutes) before levelling off. If humidity conditions are appropriate (if ambient conditions provide low humidity), the $MgCL_2$ will become more concentrated as the water molecules are evaporated, and once dry, the road friction will return to pre-application condition. If moisture is introduced to the system (as a result of rain, snow or fog), the solution concentration will drop, and a re-freeze may occur at values approaching 0°C (depending on the concentration). Generally speaking, this re-freeze would occur with or without the application of $MgCL_2$, which means the introduction of the magnesium chloride does not in itself, under these conditions, cause the co-efficient of friction value to become lower than what would otherwise be expected.

Initial studies with regard to application rates show no definitive link between lowering of the roadway friction with increased application rates of the solution.

ABSTRACT

A series of skid tests were performed on January 14, 1999 and February 16-17, 1999 in Kamloops, British Columbia, in order to assess the overall effect of $MgCL_2$ application on the co-efficient of friction value. The tests occurred with an ambient temperature ranging from -2°C to +8°C. Surface temperatures ranged from -2.1°C to +5.6°C. The test vehicle was an ABS-equipped, 1996 Chevrolet Caprice, with Good Year P235 70R15 Eagle Mud and Snow radials in good condition. Air pressure was recorded as 34 psi.

Two sites were chosen; the Kamloops weigh scale facility was considered to be "newer" asphalt, with low service life, and the Kamloops prison road, which was constructed of well-travelled asphalt with extensive surface life.

Fifty-seven skid tests revealed trends relating to application rate, temperature, moisture levels, and time.

The results suggest users can expect a co-efficient of friction after $MgCL_2$ application equivalent to that typical for a wet road condition. This would involve a drop of about 18-21% from dry road conditions, but an improvement of 163% as compared to a snow-covered roadway, and 191% improvement as compared to compact snow with ice-covered surface and a near 600% improvement over glare ice.

INTRODUCTION

The purpose of these tests was to determine the overall effect of a $MgCL_2$ application, and to determine a time line for the return of the expected lowering of friction values to near normal values. As with any friction study of winter road conditions, numerous factors must be taken into account. These include:

- ROAD SURFACE
  - Gradient
  - Bare, wet, dry
  - Temperature
  - Ice, snow
  - Snow depth and density
- VEHICLE
  - Braking ability
  - Tire tread depth and pattern
- ANTI-ICING AGENT
  - Application rate
  - Scrub-off from passing vehicles
  - Additives
  - Ambient conditions (humidity, temperature, and wind)

Unfortunately, because of the mild fall and winter experienced (1998-1999), an exhaustive study on $MgCL_2$ effectiveness under cool temperatures (below freezing) could not be performed. From the phase diagram of the solution, it can be seen that the product is very temperature-dependent. Accordingly, the reader is urged to use caution when drawing conclusions from this study for varying (i.e. cold) conditions. Future work will deal exclusively with varying ambient temperature and humidity changes, as well as various other de-icing solutions. Future work will also address compound issues such as the effect of CMA, CF-7, M-50, and $CaCl_2$.

As the title implies, this is a study of friction. It has been well known that friction acts as a resisting force to motion between two mating surfaces. Higher friction values equate to faster stopping and steering characteristics in automobiles, which often proves very helpful in accident avoidance strategies. In simple terms, friction, μ, is defined as the horizontal pull force, F, divided by the weight, W of the object, i.e. $\mu = F/W$. Friction is affected by speed, temperature, road surface quality, and tire construction, among others.

For this study, we will attempt to hold constant most variables, varying the rate of $MgCL_2$ and/or H_2O to determine what effect on friction is observed.

Literature Research

A less-than-exhaustive search of friction studies turned up about 500 titles, many of which were reviewed. Most papers deal with the expected friction rate for use in accident reconstruction studies. Some studies deal exclusively with winter conditions.[1 2 3] One of the earliest studies completed in 1928[4] found that icy roads produce co-efficients of friction as low as .17. This is about one-half the friction design range used in highway construction, and of course, causes drivers and designers great concern.

Unfortunately, no papers dealing with the effect of $MgCL_2$ could be uncovered with regard to friction. A paper by Schultz[5] studied the effect of Urea and CMA as a de-icer, but again, did not include $MgCL_2$. Friction values of about .58 for Urea and about .56 for CMA were found, whereas water produced a value of about .59 (the Urea and CMA produced slightly lower friction values).

The Pennsylvania Transportation Institute also researched this phenomenon[6]. Again, the tested salts did not include $MgCL_2$ (they were Urea, CMA, $CaCl_2$, and NaCl). The authors concluded that CMA did not lower the friction number, but the Urea did lower the skid number substantially.

To assess the expected overall benefit of $MgCL_2$ as a de-icing salt, the literature was reviewed for common winter driving conditions for which the solution is designed. These range from ice to partial frost. Please see Table 1, a synopsis of the friction effects tabulated by Martin and Schaefer. Values for sheet ice ranged from .054-.19, and for snow from .24-.37. Frost showed values at .48-.58. As can be seen, if no action is taken, and these surfaces are encountered, a very dangerous condition will exist for most motorists, even those who choose to travel at a lower velocity.

Test Equipment and Procedure

The chosen vehicle for all skid tests was a 1996 Chevrolet Caprice. This is a present-use RCMP vehicle. It is equipped with Good Year Eagle Mud and Snow radials. The vehicle has ABS braking, and this was not disabled. The vehicle tires were maintained at approximately 34 psi.

The vehicle was instrumented with a no-longer-available Valentine Research G-Analyst. This unit, mounted on the floor of the passenger side footwell near the vehicle's center of gravity, measures longitudinal and lateral acceleration in 0.01 g increments at a sampling rate of 10 times/sec. The pitch was set at 0°/g, for suitable comparison.

The vehicle was also equipped with a brake-activated bumper gun, which pin-pointed the location of brake application for each test run. The vehicle is equipped with a digital speedometer, and the driver was instructed to maintain a value of approximately 50-53 kph for each test. Before brake application, the driver noted pre-brake speed. The braking distance was then measured, using a measuring tape, by the author.

The test procedure involved over fifty skids under various conditions as they arose. For example, $MgCL_2$ was applied on a dry road and later, moisture fell. $MgCL_2$ was also applied after the existence of snow and ice (i.e. as a de-icer as opposed to an anti-icer), and finally, tests were performed after substantial time intervals to determine overall time effect on friction.

Experimental Results

The first experimentations occurred on January 14, 1999 at the Kamloops westbound weigh scales. The ambient temperature was 10.0°C, the pavement temperature was 4.2°C, and the relative humidity was 53%. The asphalt was dry, but as a result of melting snow, patches of well-wetted surface were present, and these caused all tires to be completely lubricated with water. The average co-efficient of friction value derived was .695. This would represent a slightly better than expected value for a wetted asphalt roadway (typically, a value of about .55 is associated with most asphalt surfaces that have sufficient moisture to be considered wet). In a similar area, which had not yet melted, friction tests performed indicated that a mixture of slush and ice on this surface produced a value of .41.

$MgCL_2$ was applied at a rate of 45 litre per lane kilometer, and with tests performed at 52-54 kph, 8°C with a relative humidity of 57%, the average co-efficient of friction was determined to be .692.

Later, a re-application on the existing site of 150 litres per lane kilometer was requested. However, due to a malfunction of the truck (a discoupling of the PVC piping attachment at the spray nozzle), approximately 50 litres of solution was dispersed over a distance of about 30 m (the test site). On the surface, the material formed as a thick, gooey liquid, which did not disperse. With a road temperature of 3.4°C, the friction value determined was .697.

On the same day, additional tests were performed in front of the Kamloops prison. The dry asphalt well-travelled surface produced an average co-efficient of friction of .790. The surface was then applied with 45 litres per lane kilometer of $MgCL_2$ with a surface temperature of 3.2°C, a relative humidity of 57%, and an ambient temperature of 8°C. The co-efficient of friction was determined to be .63 at two minutes, fourteen seconds after application, elevating to .66, five minutes after application, to .67, seven minutes after application. However, the co-efficient of friction reduced to .64 approximately twenty minutes after application.

On February 16, 1999, an additional set of experiments was completed exclusively at the Kamloops prison road. The humidity was 62%, the pavement was -1.2°C, and the ambient temperature was 2°C. At 06:00 hours, the westbound lane was applied with $MgCL_2$ at a rate of 45 litres per lane kilometer. The eastbound lane was untreated. The previous evening, snow had fallen and had formed compact snow with ice. At 08:30, the eastbound lane was still fully compact snow, with some ice and it was beginning to melt. The average co-efficient of friction for wet compact snow was .562. Other areas were completely snow-covered (comprised of 50-150 mm of primarily compact snow), with some sand and gravel remaining. This produced a co-efficient of friction of .432. At the same time, the westbound lane was fully wet, after having received the $MgCL_2$ in a post-incident treatment. With the roadway completely wet, the friction value recorded was .706. Approximately three hours later, the eastbound lane, which had been untreated melted, as a result of the ambient air temperature, and when later tested, this wet surface (again, with no $MgCL_2$ present) produced a friction co-efficient of .664.

At 13:00 on February 16, 1999, as a result of a slight breeze, the moisture of both eastbound and westbound lanes had evaporated. No visible traces of $MgCL_2$ remained. At 13:30, with a pavement temperature of 5.6°C, an ambient temperature of 8° and a relative humidity of 35%, the lane which had an application of $MgCL_2$ that morning produced a dry co-efficient of friction of .805. The eastbound lane, which was also dry but had not received $MgCL_2$ treatment in the morning, produced a co-efficient of friction value of .811. At 14:25, an additional application of $MgCL_2$ at a rate of 60 litres per lane kilometer was put down. The truck in question had its nozzles removed, and hence, there were four lines of $MgCL_2$ visible for each wheel track. The relative humidity had increased to 50%, the ambient temperature was 8°C, and the pavement temperature, as a result of some sun, had also increased to 7.8°C. The initial friction co-efficient was determined to be .616 upon fresh application. Three minutes later, this had increased to .637 and four minutes later, it also increased to .656. Five minutes later, however, the friction level had dropped to .628 and then fifteen minutes after that, it again rose to .656 before returning to .622. The average friction for this series of tests with fresh application of 60 litres per lane kilometer of $MgCL_2$ was calculated to be .636, or a loss of about 21% as compared to the dry road friction.

At 19:15, the roadway was re-attended with an average friction value of .612 determined (this produced a 4% drop from the values obtained in the afternoon, immediately after fresh application).

During the evening of February 16, 1999, according to Kamloops City Weather Station at Pacific Way, approximately two kilometers away from the test site, it rained from 8:34 p.m. to 9:05 p.m. and then snowed from 9:05 p.m. until 12:02 a.m. on the morning of February 17, 1999. Finally, from 01:31 to 01:41, again on the morning of February 17, 1999, it also rained (in a future publication, the precise amount of moisture will be utilized to determine the precise level of $MgCL_2$ concentration). At 08:00 hours on the morning of February 17, 1999, it was determined that the roadway was snow and ice covered. There was no difference between the eastbound lane which had not been treated the previous day with $MgCL_2$, and the westbound lane which had in fact received two treatments; one at 06:00 and one at 14:25 hours. The average co-efficient of friction for these tests performed over a 15 minute time frame was .341. The ambient temperature was -2°C and the road temperature was approximately -2°C.

ANALYSIS AND DISCUSSION OF RESULTS

The primary purpose of this work was to determine if there was an overall decrease in the road surface co-efficient of friction after application of $MgCL_2$ as an anti-icing measure, and if so, to what extent the overall decrease in friction performance would expectantly last. From previous work, it was recognized that $MgCL_2$, by definition, is hygroscopic[7] in nature (i.e. suitable conditions exist). Accordingly, the relative humidity levels in the atmosphere during testing was deemed important for the purposes of establishing the above-noted time line. Unfortunately, as nature would have it, the relative humidity levels primarily stabilized between 50-60%. While some tests were performed outside this range, there was insufficient data to arrive at any conclusions with regard to humidity effects, vis-a-vis road surface friction.

To the touch, 30% concentration of $MgCL_2$ with a 4% ice-ban mixture as a rust inhibitor, is a rather slippery, greasy substance when run between the fingers. It was, therefore, quite surprising that values of .636-.70 were found for $MgCL_2$ application on a dry road. Other researchers have found that the introduction of a contaminant on a road surface dramatically reduces the expected co-efficient of friction. Limpert,[8] for example, notes that diesel fuel on a wet asphalt produces a friction value of .25-.30. Immediately upon $MgCL_2$ application, such a dramatic reduction of the available friction value is not seen. To the touch and as well to some degree the eye, $MgCL_2$, on application, appears to "look" and "feel" slippery, but the results of our experimentation indicate that any reduction in available road friction co-efficient is relatively minor. On straight comparison between dry road and a road which has had an application of $MgCL_2$, the reduction in available co-efficient of friction appears to be 18-21%. From the author's work in accident reconstruction, it is known that moderate braking effort would encompass a deceleration rate of .3-.5 g (i.e. using a road co-efficient of friction of about .30-.50). This means that the effect of $MgCL_2$ would only be felt if a driver were to require threshold braking (i.e. require a sudden, skidding stop).

To envision the effect of $MgCL_2$ on a dry road, or to compare it with a known hazard, wet skid tests were also performed. The test site, under wet conditions with no $MgCL_2$, produced a co-efficient of friction of .664. Therefore, a friction value with $MgCL_2$ of .636-.650, or .697, can be directly compared to a wet road condition. In short, the application of $MgCL_2$ onto a dry road in anticipation of a storm will reduce the available road friction value to what would be expected if the roadway became wet through rain application.

With regard to application rate during the first series of experiments, the authors had $MgCL_2$ applied at a rate of 45 litres per lane kilometer. Again, with eight nozzles removed, eight distinct $MgCL_2$ lines on the pavement were observed, and these did not disburse until passenger vehicles were intentionally driven over the surface many times. Once continuous, the average co-efficient of friction for this particular test of 45 litres per lane kilometer of $MgCL_2$ was .692. Shortly thereafter, with all other ambient conditions essentially the same, the surface was re-applied at a rate of 150 litres per lane kilometer; however, during the application, a hose blew off the truck, causing a massive over-application, the quantity of which can only be estimated. Surprisingly, the average co-efficient of friction value determined was .697. This means that the effect of $MgCL_2$ on the co-efficient of friction value is essentially not dependent on application rate. Others have determined that similar solutions (Urea and CMA) also had little effect on co-efficient of friction when saturation level was increased. It was only when Urea, at 6.82 lbs/gallon was introduced that a 15% drop in friction was noted.[9] Therefore, with regard to choice of application rate, consideration should be given to which rate will provide the best overall treatment, based on the usual input variables, rather than on what negligible effect the application will have on road friction co-efficient.

During initial discussions leading to this experimentation, users expected that after application of $MgCL_2$, the road friction would return to standard within minutes. This, generally speaking, was not observed in the tests. In the first set of experiments, the value did increase from .63 to .66 to .67 over a time frame of about seven minutes. This would infer a relative increase of .006 per minute. In the second set of experiments, the friction increased from .616 to .637 to .656. This involved an increase of .003 per minute. However, a continuing trend of increasing friction values did not appear past the 15 minute level. In fact, on both occasions, the recorded friction value suddenly dropped approximately 15 minutes post-application. This relatively surprising result may be explained by several factors. First, it is possible that as the tests proceeded, the $MgCL_2$ solution was disbursed away from the test location. In the future, greater care will be taken so that additional tests are not replicated in the precise location of prior tests, to ensure a continuous $MgCL_2$ surface. Secondly, because the tests were performed in rapid succession, there may have been a slight rise in tire temperature. However, other work[10] has indicated that generally, an increase in temperature will result in lower friction values. Therefore, this would not explain this occurrence. Additional work will also take into account whether this phenomenon, a gentle increase in friction followed by a drop-off after 15 minutes, is $MgCL_2$-related, or simply the result of other issues not related to this type of application. It may well be that there is an increase in the road friction co-efficient after application of $MgCL_2$ for some time. Some may suggest the values obtained may well be within the test sensitivity, given the test protocol. From other work and from analysis of non-$MgCL_2$ applied surfaces, it is felt that the sensitivity of the tests, on a repeatability assessment, would be in the order of .03. Again, the friction values increased approximately .04-.05, which would be greater than the expected error range. In short, something other than a deviation in the test method was at play. Future work will verify whether this observed trend will continue to be seen.

In the long term (i.e. after several hours post-application), the road surface friction co-efficient does not appear to change. In fact, approximately 12 hours past an application of 60 litres per lane kilometer, the co-efficient of friction actually reduced from an average of .636, in the minutes following the test, to approximately .612, which was produced approximately six hours after initial application. Whereas the humidity levels stayed somewhat constant (initially 50%, increasing to 58%), the only significant difference was a drop in temperature from 8°C to 4°C. Of course, the roadway was also well-travelled by rush hour motorists, and again, this may have caused a slight reduction of about 4% over six hours.

The most troubling finding of this study was the return to the test site in the early morning hours on the following day. The night after initial testing, substantial rain and snow was experienced (at this juncture, the precise quantity has not been determined). This, in conjunction with a drop in temperature overnight, caused a sudden re-freeze at some point in the early morning hours. On testing at 08:00 hours, there was snow and ice found in both the previously-treated $MgCL_2$ lane, and the lane which had not been treated. Both lanes provided similar results, producing an average friction of .341. The westbound lane, which had previous $MgCL_2$ application, produced a friction value of .334, whereas the lane which had not been applied, produced a friction of .349. The relatively minor difference between the lane which was applied and the lane which was not applied with $MgCL_2$ cannot be taken to mean that during re-freeze, it is best not to have a slight residual amount of $MgCL_2$ present. In this particular circumstance, it is clear that the $MgCL_2$ went into a very dilute solution, and as a result of a low solution concentration, the road surface simply froze. According to the phase diagram of $MgCL_2$, at a 5% solution concentration by weight, the freezing temperature is about 26°F, or -3.3°C. Since this was the approximate value of overnight temperatures, we are assured that the $MgCL_2$ solution must have been less than 5% concentration. In this particular circumstance, a re-application to bring the solution concentration above 10% would be required to prevent the surprise re-freeze from occurring. Furthermore, by not re-attending the site to perform a re-application, the friction is not made any worse than what would be expected if $MgCL_2$ had not been applied in the first place. In other words, the diluted and frozen solution of $MgCL_2$ was considered no worse than areas simply frozen from precipitation.

The "dissipation" of $MgCL_2$ is, however, far different if moisture is introduced as opposed to when the solution is applied to a dry road condition. In other words, the research suggests that, so long as no moisture (in the form of rain or snow) is experienced, the co-efficient of friction of the $MgCL_2$ treated roadway will probably stay at about the level achieved immediately after application for an extended period of time, unless humidity levels are low, in which case the water molecules will evaporate, leaving a concentrated solution of $MgCl_2$ behind. Expectantly, heavy traffic would "scrub-off" the solution over time, thus returning the surface to near pre-test levels. However, from the testing, it was determined that if the $MgCL_2$ is applied as a de-icer, and therefore goes into a weakened solution concentration (as a result of dilution), it will evaporate at a similar rate as pure water. In this condition, the $MgCL_2$ is completely removed from the road surface, and when drying occurs the road friction will be essentially the same as it was before treatment began. Please note that the dry roadway without $MgCL_2$ produced a co-efficient of friction of .811, whereas the dry roadway with $MgCL_2$ (in its dissipated stage) produced a co-efficient of friction of .805. This involves a reduction of less than 1% as compared to the lane which had not been applied with $MgCL_2$, and the values obtained are within the repeatability level of the skid tests, which means that for all intents-and-purposes, there is no long-term, negative effect of $MgCL_2$ application on a road surface after dissipation has taken place.

Needless to say, because the solution is hygroscopic in nature, it will maintain itself on the road surface for quite some time. It is anticipated that heavy traffic volume may speed-up the rate of dissipation, resulting primarily from scrub-off. It does, however, seem that only once the solution becomes relatively dilute (by virtue of the addition of moisture) does it evaporate. Naturally, if ambient humidity levels are low, the water molecules will evaporate, leaving a very concentrated solid on the roadway. This condition has yet to be tested. The 3-4 hour time of evaporation experienced during testing was no doubt assisted with a stiff westerly breeze of approximately 20 kph, and a lower, 35% relative humidity level.

CONCLUSIONS AND RECOMMENDATIONS

As with all tests involving winter road friction determinations, the numerous input parameters require a very diligent and thorough review of the test procedure, before applying the results of this data to a specific concern. For example, as yet, because of the warm winter experienced in 1998-1999, little testing has been performed below freezing level. Because it is anticipated this is the primary temperature range for product use, care should be used in extrapolating the results presented herein to below freezing conditions. Furthermore, what effect relative humidity levels have on, for example, the effect of dissipation has also not been addressed. Further, as other studies have determined[11] there is a difference between de-icing salts. It would be inappropriate to generalize the results found for $MgCL_2$ with, for example, other saturated solutions such as Urea, CMA, $CaCl_2$, or NaCl. These issues will be addressed in future work.

That having been said, as a result of our preliminary work, we are able to arrive at the following conclusions:

1. After application of $MgCL_2$ on a dry road surface, in anticipation of an impending storm, the overall friction co-efficient will be reduced 18-21%. Accordingly, $MgCL_2$ should not be applied indiscriminately. (Obviously, there are also cost benefits available to those who apply $MgLC_2$ prudently.)

2. This reduction in available friction, however, can be directly compared to that which occurs during a common rain storm. In other words, from a traction standpoint, a $MgCL_2$ roadway will perform very nearly the same as a wet road.

3. If $MgCL_2$ is not applied to a road surface, and hazardous climatic conditions arise, excessively low friction values can be seen. These include ice values as low as .054-.19, black ice from .12-.26, snow and ice from .18-.45 and frost from .48-.58. In all cases, the $MgCL_2$ applied surface, even wetted, is far superior.

4. So long as moisture is not introduced, the reduced co-efficient of friction as a result of $MgCL_2$ application will generally prevail for an extended period of time, unless humidity levels are low. If moisture is introduced in the form of rain or snow, then later on, if climatic conditions are agreeable, the weakened solution will evaporate at about the same rate as other wetted surfaces which have not been treated with $MgCL_2$.

5. In the short term, (15-20 minutes post-application), there appears to be a very slight increase in the expected co-efficient of friction levels. This is at a rate of about .003-.004 per minute.

After 15-20 minutes however, the friction appears to reduce for some, at present, unexplained reason. The lack of adequate data on this phenomenon precludes an accurate opinion as to which, if any, anomalies are at play. Future work will deal with traffic volume versus scrub-off rate (i.e. it is anticipated higher volumes of vehicles passing over the surface will decrease the time for the return to normal surface friction).

6. When moisture is introduced, and the weakened $MgCL_2$ solution evaporates, thus producing a dry road, the expected co-efficient of friction for this type of road will be nearly identical to a road which has not been previously treated in the long term.

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