REPORT

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LIQUID ANTI-ICING CHEMICALS ON ASPHALT: FRICTION TRENDS

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EXECUTIVE SUMMARY

The purpose of this research was to determine whether there existed a chemical “slipperiness”, on an asphalt surface, as a result of a transition from liquid to a solid, and vice versa, of typical anti-icing chemicals presently in use.

The number of reported slickness issues as a result of chemical treatments is infinitesimally small, (presently estimated at less than 1/1000th of 1% of all liquid anti-icing treatments). Prior research has shown that the slickness issues are often related to driver perception, contaminants on the roadway, other than the chemicals themselves, and chemical dilution resulting in re-freeze. There have been some incidents reported where the chemicals themselves, prior to re-freezing, created a slipperiness for some unexplained reason. This research has shown that, indeed, when most chemicals transition from liquid to solid, and solid to liquid, a “slurry” phase is formed. This produces a relatively short-lived reduction in co-efficient of friction for most chemicals. This reduction is anywhere from non-existent (CMA and CMA-25) to a substantial 22%, (Liquidow).

The research has shown that all chemicals tend to be unstable in the “slurry” phase during the state transition, meaning that they pass through, this possibly slippery, phase quickly, and that it is unlikely that this phase can exist for long periods of time.

Relative humidity values above those required to cause the state transition, appear not to affect the friction dramatically. However, at humidity levels in the high 20's to low 30's, most chemicals will begin to dry out, (after application as a liquid) potentially resulting in somewhat lower friction values during the transition phase.

All chemicals, upon continued dehydration, reached a solid state. On the asphalt surface, the solid state co-efficient of friction, of most chemicals, is essentially equivalent to that of a clean and dry asphalt roadway. Some even increased the coefficient of friction above 1.0 (CMAK, Ice Ban, and MCP).

Due to an unexpected deterioration of the test tire during the research on asphalt, liquid and transition state friction results showed a steady decline as testing continued. These results should, therefore, not be used to compare chemicals. The results, however, are felt to represent conservatively low estimates of the friction which can be expected if one of the tested chemicals was applied to a contaminant free asphalt roadway. For continued testing a new tire will be used for each test.

It appears that prudent use of the chemicals, (particularly with regards to application rate, frequency, and other contaminants) bearing in mind expected humidity levels, can further reduce the likelihood of slickness developing, particularly in the fall season when most incidents are reported to have occurred. It is felt, that most anti-icing agent related incidents are most likely a result of the chemical being applied following a dry period, which likely causes a slippery emulsion to be formed by the chemical and the oil, grease, glycol, etc. contaminants which have build up on the roadway. Flushing the roadway with water, prior to chemical application, would prevent this.

ABSTRACT

This set of experiments flowed from prior work completed in May to August, 1999. The present research deals with tests which were performed on an asphalt surface, conducted in a similar fashion as the prior research, between October 1999 and May 2000. Whereas prior tests, which were performed on a sandblasted glass surface, were necessary to establish the reliance of anti-icing chemicals on temperature and humidity, this research was performed in an effort to better understand what effect these reliances would have on the road friction co-efficient (ie. on asphalt).

Prior research used a test matrix which involved a humidity range of 30 - 50% and a temperature range of -1 to +10° Celsius. The present tests were performed at a constant 5° Celsius (40° Fahrenheit) as prior work had indicated no direct relationship between chemical friction and temperature. A similar humidity range was employed.

The environmental chamber, which was used for the tests, was unchanged from prior work, with the exception that the sandblasted glass surface was changed to an asphaltic surface, which had been removed from approximately 15 years of service on a well-travelled arterial collector in Kamloops, British Columbia. Measurements of friction were recorded via a Mettler Toledo load cell with an accuracy of 0.001 pounds, as before. Seventeen chemicals were tested in this data set. These included:

- CMA
- CF7
- CMA25
- CMAK
- Corguard 2000
- CaCl 32%
- Freezgard 0
- Freezgard 0 with IceBan
- Freezgard 0 with Shield
- Freezgard 0 with TEA
- Ice Stop 2000
- Ice Ban with CaCl (50/50)
- Ice Ban with MgCl (50/50)
- Liquidow
- Liquidow Armor
- Cal Ban
- MCP

Note: Other chemicals were tested as a result of our involvement in litigation, and chemical manufacturer research and development. However, these results cannot be released at this time.

INTRODUCTION

It has been established that there is a dependancy on humidity for anti-icing chemicals, with regards to their friction capability.[1] However, no specific friction values on asphalt were presented in the prior work (the results tabulated and presented were based on a sandblasted glass surface). The purpose of an etched glass surface in the prior research was to eliminate any cross-contamination from an asphalt source.

Since asphalt is the preferred choice for most driving conditions (as opposed to a sandblasted glass surface) it was requested that similar experiments be performed on this surface, in order that users might have a better understanding of what friction they could expect to find. Presently, we are continuing to perform such tests for end-users, distributors and manufacturers. The involvement of an end-user generally coincides with a reported slickness and a concern by the user that the chemical he/she is in possession of, may not meet expectations. Manufacturer involvement usually indicates a desire, on the part of a progressive company, to design a product with better friction capability, as compared to a pure chemical or a chemical with a rust inhibitor mixed in solution.

The Dow Chemical company, for example, is experimenting with a variety of chemicals designed to increase the friction performance of their existing product.

The set of experiments included herein were the direct result of a meeting sponsored by the Snow & Ice Co-operative Pooled Fund Program (SICOP) of the American Association of State Highway and Transportation Officials (AASHTO) which was held in March of 1999, in Minneapolis.

At that time, it was theorized that some chemicals may contain a special “slippery” state, and that this special state was responsible for a small number of reported slickness incidents, which had occurred around the continent. Based on some preliminary computer modelling, Dr. Wilf Nixon, of the University of Iowa, concluded that the likelihood of a slickness incident occurring was less than 1/1000 of 1% of all liquid chemical applications.

There have been other reported reasons for slickness occurring, or conditions upon which slickness was thought to have occurred. These will be discussed later on.

The earlier research on a glass substrate indicated that when a liquid anti-icing chemical transitions into a solid, it may pass through what is referred to as a “slurry” phase. This has been shown to produce a relatively short-lived reduction in the co-efficient of friction for most chemicals. On a sandblasted glass surface, the reduction ranged from a low of 0.4% (Freezgard with IceBan) to 29% for Liquid Dow.

The purpose of this latest research was to determine whether such a friction reduction could be expected on asphalt.

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[1] *“Temperature & Humidity Effects on the Co-Efficient of Friction Value After Application of Liquid Anti-Icing Chemicals”, Leggett, September 30th, 1999*

PROCEDURE

All testing was performed in a climate controlled test chamber. The test surface was a 1.5 meter long, 0.3 meter wide, section of asphalt removed from an arterial road in Kamloops, BC, after approximately 15 years of service. The climate controlled test facility was used to set the test temperature at a constant 5°C and alter the humidity values, to permit the applied anti-icing chemicals to dehydrate, and subsequently re-hydrate on the asphalt surface. Such movement, between liquid and solid states, and back to liquid form, cannot be controlled in the real world, hence, the environmental chamber was necessary to fully modulate these transitions.

The friction was measured using a drag sled, equipped with a BF Goodrich tire, weighing precisely 10.9 lbs. The pull force was measured using a Mettler Toledo 100 lb load cell, with a sensitivity of 0.001 lbs. The drag sled was pulled across the test surface, using a constant velocity motor, at a rate of approximately 30cm per second. This allowed for data collection of approximately 30 dynamic force measurements, as the sled was pulled over an approximate one meter distance, at a sampling rate of about 10 measurements per second.

Each set of force measurements was averaged to determine the pull force for each test run. The available friction for each test run was calculated from this average pull force and the weight of the drag sled. Importantly, the data was collected at a drag sled velocity of about 1.0 kph (0.6 mph). Prior research has shown that friction is velocity dependent. The velocity dependance of friction will be discussed later in this report.

Between tests, the drag sled was removed and triple washed and triple rinsed, as was the asphaltic surface. At the start of each test, prior to the introduction of the particular liquid anti-icing agent which was to be tested, a set of ‘dry runs’ was performed, and the dry friction value of the drag sled on the asphalt surface was verified to monitor the condition of the test apparatus. It was thought this would assure that the test set-up was identical for all tests. As in prior research, a baseline pure water test was performed at the beginning of the experiments, and at the end.

For each test, the anti-icing chemical was applied at a rate of 60 Liters per lane kilometer (25 gallons per lane mile), using a pump spray mister. This method of chemical application was implemented to model the chemical’s distribution on an actual roadway by traffic.

RESULTS

CMA & CMA 25

A CMA sample from Levelton Engineering, for prior research, was tested on November 5th, 1999. As can be seen from the enclosed graph, the chemical, when applied as a liquid, produces a friction of approximately 0.59. When the solution is allowed to dehydrate by evaporation, the friction value rises steadily and plateaus at a value of about 0.92. At this state, only a white precipitate was visible on the test surface. As humidity is reintroduced into the chamber (at the 100 minute mark), and the relative humidity rises from 25% to 65%, the solution does not re-enter the liquid phase. White precipitate is seen, but no liquid is observed. Importantly, for CMA, there is no drop in friction as it transitions from a liquid to a solid state.

On April 4th, 2000, CMA25 was tested. The initial liquid friction value was 0.42, and then climbed rapidly, as the product was dehydrated, to a solid state friction value of about 0.79, where it plateaued. Again, upon reintroduction of moisture into the chamber, the solution would not return to the liquid phase.

Regardless of the relative humidity level, both CMA samples will not return to liquid form after having dried out (note, it requires a relative humidity of approximately 33% to begin to dry out) until liquid water is added to dissolve the precipitate. This means, that unlike the majority of anti-icing chemicals, which will re-enter a liquid phase as a result of their hygroscopic nature, both CMA samples require snow or rain before this will take place.

CF7

On February 22nd, 2000, CF7 samples, received directly from Cryotech De-Icing Technology, were tested. Applied as a liquid, the friction value was initially 0.43. Under dehydration the friction initially dropped 11% to 0.38, before rising to 0.97, solid state, which was higher than the dry test bed with no chemical applied. When the relative humidity was increased, the dry precipitate began to absorb moisture and the friction reduced to 0.41, before reaching a liquid state friction of 0.42. The transition between liquid and solid states commenced at approximately 32% relative humidity.

CMAK

On April 11th, 2000, after receiving the product directly from Cryotech Industries, friction tests were performed. Upon initial application as a liquid (a transparent liquid) the friction was 0.36. As the solution dehydrated the friction rapidly dropped to a low of 0.33, a 10% drop from the initial state, before rising quickly to a very high level of almost 1.3, followed by a decline to approximately 0.9, solid state. It is not known why the solution went up so dramatically, followed by a decline. At the high point, the product was dry with a slightly oily appearance. When the relative humidity was raised from 27%, the friction climbed to over 1.0. However, at a relative humidity of approximately 55%, a liquid began to form and the friction dropped linearly to a value of about 0.47. Testing was continued for a total of 240 minutes, at the end of which the solution was still not liquified completely. A drop in friction during the solid to liquid state transition was not seen.

CORGUARD 2000

On January 3rd, 2000, Corguard 2000 received directly from General Chemical, was tested. This is a mixture of calcium chloride, water and corrosion inhibitor (a corrosion inhibitor percent of 7 - 8 % and calcium chloride 30 - 32%). As with all calcium chloride based products, Corguard 2000 went down as a liquid (brown liquid) with a friction of about 0.41. It then underwent a slight reduction in friction as the relative humidity was dropped, with the lowest "slurry" value being 0.36, or a reduction of approximately 13%. Under a relative humidity of about 27%, the material began to dry up and the friction increased to a value of 0.59. The friction level stayed at this value for approximately 1 ½ hours, until the relative humidity was increased. With a relative humidity of 35%, the solid began to become liquid again and the friction dropped. During the state transition a “slurry” was again observed, resulting in a friction drop of 9% compared to the final liquid friction of 0.40.

32% CALCIUM CHLORIDE

This chemical was received from General Chemical and tested on January 12th, 2000. It performed essentially identical to Corguard 2000, commencing with a liquid friction of 0.39, dropping to a value of 0.38, a reduction of 4%, during a “slurry” phase, before increasing to 0.63 at its solid state. When the relative humidity was increased in the chamber, the friction value dropped to 0.4, liquid state. During the solid to liquid state transition a “slurry” was observed, resulting in a friction reduction of 4% compare to the final liquid friction.

FREEZGARD 0 PLUS ADDITIVES

FREEZGARD 0

A test was performed on December 9th, 1999; on application as a liquid, the 28% Freezgard 0 produced a friction value of 0.47 (it was transparent). Upon dehydration, it went into a minor “slurry”, reducing friction to 0.46, a drop of 2%. Upon continued dehydration, the friction quickly rose to a level of approximately 0.84, and the solution was seen to be completely dry. The humidity was then increased and the material stayed as a solid until a relative humidity of about 32% was reached, wherein the solid quickly re-hydrated and resultantly, the friction level dropped to the previously seen liquid value of about 0.48. No substantial “slurry” during both state transitions of the experiment was observed. Freezgard 0 produced one of the lowest “slurry” friction reductions of just 2%.

FREEZGARD 0 Plus TEA

Freezgard 0 Plus 0.75% TEA was tested on November 25th, 1999. The overall behaviour of this chemical was nearly identical to Freezgard 0, with the exception that a slightly lower initial liquid friction of 0.42, and a higher dry friction of 0.95 was found. Similarly, the “slurry”, or friction reduction, between the liquid and solid states with Freezgard 0 Plus TEA was also minimal (a 3 to 4% reduction). Upon re-hydration, a relative humidity value of approximately 38 - 40% was associated with a rapid diminishment of friction as the chemical transitioned from a solid into a liquid state, with a friction of 0.41.

FREEZGARD 0 Plus ICE BAN

Two tests were performed with Freezgard 0 Plus IceBan on asphalt. The first was on November 26th, 1999, and the second was on December 8th, 1999. The purposes of the two successive tests were to determine whether repeatability of results existed. Both graphs were nearly identical. Both solutions were applied as a brown liquid, on November 26th producing a friction of 0.45, and on December 8th producing a friction of 0.47. Both solutions dehydrated rapidly at approximately 30% relative humidity and the friction rose to between 0.8 and 0.94. A 7% drop in friction was seen during the liquid to solid state transition. As well, both friction curves showed a drop during the transition from solid to liquid state, with a very slight “slurry” seen before reaching a liquid state with a friction of 0.43 to 0.46, a reduction of friction of approximately 5%.

FREEZGARD 0 with SHIELD LS 1.5%

The Freezgard 0 with Shield LS graph is also very similar to the other Freezgard 0 graphs. The friction values, however, were slightly higher for both liquid and solid states. The chemical was applied a brown liquid at a friction of 0.51. During the liquid to solid state transition a “slurry” phase occurred, causing a 9% friction reduction, before the friction climbed steadily, at a relative humidity of about 27%, to a value between 0.8 and 0.96, solid state. Upon re-hydration, the level of friction dropped steadily and a “slurry” was seen during the transition into a liquid state. The reduction of friction during the slurry was determined to be about 4%. The liquid friction value returned to about 0.49 after substantial humidity was introduced into the chamber.

ICE STOP 2000

Ice Stop 2000 (30% magnesium chloride) with 2.2% corrosion inhibitor was received directly from Reilly Industries and tested on November 18, 1999. As a transparent liquid, it produced an initial friction value of 0.50, and as dehydration occurred, it dried quickly, producing a low slurry friction value of 0.43, a 15% decrease. Below 35% relative humidity, it began to dry quickly, and the friction value rose almost immediately to 0.83. Again, with increasing relative humidity (at about 35%), liquid began to appear and the friction reduced to a value just below that of initial application (0.48). Prior to becoming fully liquid, it passed through a slurry phase, where it produced a low friction value of 0.45, a reduction of 6% from the final liquid friction value.

ICE BAN FORMULATIONS

ICE BAN M-50

Tests were performed on an M-50 blend (50% magnesium chloride, 50% Ice Ban) on May 1, 2000. The initial liquid friction value was 0.36, with an orange/brownish solution. It dried very quickly upon dehydration, reaching a very high friction of approximately 1.2, on average. However, on continued dehydration, the solid state friction dropped to 0.82. Then, as humidity was introduced, the friction increased back to 1.2, before decreasing to 0.35, liquid state. A slurry was observed during this second transition, where both liquid and solid was present, with a friction of 0.31, a reduction of about 12%. The “double-dip” in the middle portion of the graph was unseen before in other tests. It is unknown why the essentially solid state’s friction capabilities were altered during the course of the drying an re-hydration procedures.

ICE BAN C-50

The C-50 (a blend of 50% Ice Ban and 50% calcium chloride) was also tested on May 1, 2000. The results of this test were nearly identical to the magnesium chloride blend tests. Upon application, the friction of the liquid was about 0.36, it solidified to a friction of 1.2. As the M-50, a “double-dip” was seen in the friction curve during the latter portion of dehydration, and start of re-hydration. During the solid to liquid state transition a low friction of about 0.33, a 5% drop, was recorded.

Notably, of all the chemicals tested, the M-50 and C-50 blends, with substantial Ice Ban components, produced the highest solid state friction values.

LIQUIDOW

Liquidow was tested on November 23rd, 1999. As expected, it was behaved similarly to the other calcium chloride based chemicals tested. The friction started at 0.5 in it’s liquid state, and reduced to a low of 0.39 during the liquid to solid transition, a 22% drop. It dried slowly and produced a friction value of approximately 0.7 under solid conditions. Upon re-humidification, it reduced to a slurry phase friction of approximately 0.39, followed by a return to liquid friction of about 0.46, a 16% drop. The relative humidity associated with the lowest portion of the friction curve (i.e. transition) was approximately 30 - 32%.

LIQUIDOW ARMOR

Liquidow Armor was received directly from Dow Chemical and tested on November 9, 1999. The nature of the friction curve was nearly identical to all other calcium-based products tested. The initial liquid friction value was high, at 0.5. The solid state friction, however, was 0.66, and the solid to liquid state transition slurry friction was 0.39, a reduction of nearly 25% from final liquid state friction. A 13% reduction in friction was seen during the liquid to solid state transition.

CAL BAN

On February 12, 2000, this product, shipped directly from America-West Environmental Supplies, was tested. It is a blend of calcium and Ice Ban (note the precise percentages are proprietary information). The material was a brown liquid, which upon application, produced a coefficient of friction of approximately 0.46. As with all other calcium blends, upon de-humidification, the friction rose quickly, peaking out at a value of about 0.69, solid state. During the liquid to solid state transition the friction dropped to a low of only 0.43. The relative humidity required to cause dehydration was below approximately 30 - 32%. On reintroduction of moisture into the environmental chamber, the friction dropped rapidly as liquid began to form. The liquid friction returned to a value of approximately 0.47, however, beforehand, passing through a slurry, or transition phase, friction of about 0.45, a drop of about 9%.

MCP

On November 22, 1999, a test was performed on the MCP deicer product. The material, when applied as a transparent liquid, produced a liquid coefficient of friction of 0.49. As de-humidification took place, the coefficient of friction dropped 8%, to 0.45 during the transition, before rising to a very high 1 to 1.1. Upon re-humidification, the friction value dropped to approximately 0.46, liquid state, after passing through a very slight slurry with a friction of 0.44, a drop of 4%.

ANALYSIS AND DISCUSSION OF RESULTS

Overview

Prior research has shown that there is a chemical-induced slipperiness that occurs in the transition phase between most anti-icing chemical's liquid and solid states. The present research was necessary to provide an indication as to whether this transition phase slipperiness was something that also occurred on asphalt and, if it was shown that it did occur on asphalt, what degree of friction reduction would be expected for each anti-icing chemical.

This set of test has shown that, even on asphalt, most anti-icing chemicals tested go through a liquid-solid transition phase, during which a reduction in friction, compared to each chemicals liquid friction value, can be seen. In fact, we have determined that the average reduction in friction, during this transition, is about 8.1% for the majority of chemicals tested. Not all chemicals tested went through a slurry state during the solid to liquid state transition.

Effect Of Tire & Test Speed Differences

The wet asphalt, (water only), friction measured using our drag sled diminished over the course of this testing from 0.65 to 0.48. No change was noted in the dry asphalt friction measurements taken before, during, and after this set of test, using this drag sled tire.

This is consistent with findings of others[2] who have suggested that tire degradation plays a role in wet friction but not in dry friction. In this set of experiments, conducted with a full size vehicle on both wet and dry days, it was found that the friction values derived remained relatively constant over three distinct dry test days, however, the friction values declined over three wet test days, for all tire types tested. The authors concluded that environmental variables were not likely an explanation for the difference. However, tire wear would explain the detriment.

Accordingly, as the overall performance of the drag sled obviously declined over the tests performed, it would be imprudent to use these set of experiments to compare anti-icing chemical friction performance. Obviously, those chemicals which were tested later in the sequence, would show a slightly lower liquid, and likely transition, friction value than those tested in the earlier stages of the experiments.

Accordingly, for accident reconstruction purposes, it is again imprudent to use the results of the present study, to predict a friction value. If a precise, or actual, value of friction is required, the subject tire in question must be used in a chamber or, alternatively, a tire of similar construction and wear must be in place.

As the tests performed for the purposes of this paper use the older drag sled tire, which clearly has not the liquid friction characteristics of newer tires, naturally, the friction values contained in this report are likely conservatively low. In other words, for liquid, and perhaps transition, friction values a scale factor of at least 1.25, and more likely 1.35, should be used to correct the results of this paper to more accurately reflect the level of friction which would be typical for motorists on well travelled asphalt. The solid friction levels that have been measured are at a value consistent with what one would expect for a typical passenger vehicle on well travelled asphalt.

As indicated previously, wet friction diminished over the course of testing on asphalt from 0.65 to 0.48. Most liquid anti-icing chemicals produced friction values in the range of 0.35 to 0.57, or about 12% to 27% less, indicating that the friction on wet (water only) well travelled asphalt, is larger than the friction provided by any of the tested anti-icing agents, when first applied. In the real world, as a result of traffic scrub off, and surface contaminants, this difference will likely be less.

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[2] *"Tire Friction During Locked Wheel Braking", SAE 2000-01-1314, Goudie et al*

Humidity Levels

Prior research has shown[3] that with a relative humidity between 28 and 32%, most anti-icing chemicals pass through a transition phase, which is characterized by a somewhat reduced friction value. Accordingly, for the tests performed on asphalt, the environmental chamber was specifically modulated to allow all chemicals to pass through this area of humidity. During the testing the relative humidity was continuously decreased during dehydration, and continuously increased for re-hydration of the chemical. As the humidity is increasing or decreasing in the chamber, the chemical is attempting to reach an equilibrium vapour pressure with the air in the test chamber. To achieve equilibrium takes some time, which was not provided during the latest set of tests. Therefore, at this time we can only conclude that, at the test temperature of 5°C, a relative humidity level between 28 to 32% is required to cause most chemicals to transition from a liquid state to a dry state. Further tests could be performed to precisely locate the relative humidity at which a specific chemical undergoes a state transition, and at which it experiences, if at all, a slippery state.

With regards to temperature, prior research has shown that the friction dependence on this parameter was low, if not at all existent. No tests were performed on asphalt under varying temperature conditions. It has previously been found, that a chemical's state follows it's vapour pressure curve, and therefore, temperature will affect the humidity at which precipitates begin to form (i.e. the solution passes through the slurry). However, in the general temperature range at which wintertime anti-icing operations are conducted, a change in temperature will not dramatically affect the humidity at which precipitates begin to form. For example, at 15°C, precipitates of liquid calcium chloride will begin to form at less than 36% humidity. At 0°C, the humidity must be less than 43%.[4]

Chemical Slipperiness

Most chemicals follow a friction curve which reaches a minimum as the chemical transitions from liquid to solid, or solid to liquid. An exception to this is CMA and CMA25 which show no friction reduction during the transition. The average friction drop, compared to the liquid state friction, during this transition, was approximately 8.1%. About b of all chemicals had a drop of a single-digit percentage or less. Liquidow and Liquidow Armor had the greatest percentage reductions in friction during the transition.

At present, the physical mechanism for the chemical-induced slipperiness during the transition from solid to liquid, and liquid to solid, is not well explained. One possible mechanism may be a change in the chemicals viscosity during the state transition. An increase in viscosity, due to the precipitates in the solution, could essentially create a lubricant between the tire and the asphalt, resulting in the friction drop observed. Testing could be performed to test this theory.

The research confirms earlier suspicions that the effect of an additive (such as a corrosion inhibitor) dramatically affects the coefficient of friction performance of all solutions. Therefore, it would be imprudent to assume that similar compounds exhibit similar friction properties, without actually testing the solution used.

Application Rate

Generally speaking, application rate was not investigated at length in this research. This will be reported on at a later date. Tests were performed, however, with Liquidow Armor on November 8 and 9, 1999, at two different application

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[3] *Leggett,T.S.., "Temperature and Humidity Effects on the Co-Efficient of Friction Value After Application of Liquid Anti-Icing Chemicals", September 30, 1999.*

[4] *"Calcium Chloride Handbook" Dow Chemicals (A Guide to Properties, Form, Storage, and Handling)*

rates. With an application rate of 60 L/lane Km, the lowest friction value (at the slurry phase) was 0.38. With an application rate of 150 L/lane Km (approximately 64 gallons/lane mile), the lowest slurry friction value was 0.34, about 11% less. This relatively minor drop is less than that seen in prior research (Kamplade and Siebert). For this Swedish research, with 22.5 g of salt/m^2, the coefficient of friction was 0.36, whereas at 3.8 g/m^2 (about six times less), the coefficient of friction value was 0.60.

Tests performed by Tom Byle, P. E. of Kent County, Grand Rapids, Michigan[5] also found that increasing the application rate of Liquidow Armor typically reduced the coefficient of friction. After application at 60 gallons/lane mile, an average coefficient of friction of about 0.43 was seen. For 30 gallons/lane mile, an average coefficient of friction of 0.52 was observed, for a difference of about 17%. Interestingly, for wet pavement, a coefficient of friction of 0.62 was seen (therefore for 30 gallons/lane mile), a drop of about 16% was seen as compared to wet, or a drop of about 31% for 60 gallons/lane mile, as compared to wet pavement value. The dry pavement friction value varied between 0.69 and 0.74, depending on the pavement temperature.

Also in this data set, where comparisons between Liquidow and Liquidow Armor, both at a rate of 15 gallons/lane mile. On initial application, both produced relatively low friction values, but rose steadily until approximately 25 minutes post-application. At that time Liquidow Armor produced an average friction of 0.62, whereas Liquidow produced a value of 0.63. The friction curves were very similar with the exception that Liquidow Armor produced higher friction values more quickly after initial application compared to Liquidow.

From this research, we can conclude that, consistent with the tests performed in our climate-controlled facility, Liquidow Armor performs marginally better than Liquidow. Also, as has been reported previously, for Liquidow Armor, increasing the application rate will reduce the coefficient of friction. The lowest friction found was synonymous with the highest application rate and the highest friction found was synonymous with the lowest application rate. From Byle's research, using full-scale skid tests (with a 1998 Ford Taurus sedan equipped with General all-season radials with approximately 20,000 miles), it can be seen that for Liquidow Armor, application rates in excess of 30 gallons/lane mile should be avoided, as this will generally provide a coefficient of friction less than 0.5, which is considered a friction value associated with a still safe roadway.

Whether these trends are also determinable for other solutions is yet to be determined. It is encouraging that the full-scale test results, obtained with a skidding vehicle appear to emulate the drag sled test results obtained in the climate-controlled test facility.

Time of Reduced Friction

As with the tests performed on glass, the friction values associated with the transition phase between a liquid and solid state, were reduced for only a very short period of time, typically less than several minutes. It would appear that the transition state is not very stable for a long period of time. Accordingly, from a safety standpoint, if the chemical does pass through this slippery phase of the state transition relatively quickly, (i.e. a few minutes), it is unlikely a large number of vehicle operators will experience this reduction in friction.

Putting It All Together - What Does It All Mean?

Unfortunately, there are limitations to the friction tests that can be performed in the climate-controlled facility. Firstly, and most importantly, the values derived are, as indicated previously, recorded at a relatively slow drag sled velocity. This means that we are actually measuring the near peak friction, as opposed to the dynamic or sliding coefficient of friction, which is measured at higher speed tests (i.e. with skidding vehicles). The literature suggests that the dynamic,

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[5] *Private correspondence dated February 23, 2000*

or sliding coefficient of friction, can be as much as 15% lower, than the peak, or static coefficient of friction.
Of further importance, for the purposes of assessing friction between tires and roadways, is the fact that there are substantial differences between tires and their performance on wet and dry road conditions. Most notably, it was found that tire wear can significantly decrease the friction between a worn tire, and a wet, or liquid anti-icing chemical covered, asphalt roadway. Other research has shown, for example, that economy tires typically perform to a lower standard (in terms of friction capability) than performance tires, again, a finding that would be intuitive to most of us. Therefore, one must be aware of the tire which is to be modelled and compare it to the tire used for these asphalt tests. Of course, all road surfaces are not equal; the roadway material, construction, and contamination, can all have large effects on the available friction at any given time.

This requires a strong word of caution, therefore, for anyone who might consider using the results presented herein and extrapolating this data into real world events (i.e. for the use in accident reconstruction). For the determination of a suitable coefficient of friction for a real world event, we consider it essential that a similar, if not the actual vehicle tire be used for friction testing.

Recent real-world testing by Tom Byle, in Kent County, Michigan, has shown that for Liquidow and Liquidow Armor, the liquid friction is about 16% less than compared to a wet road, for an application rate of 30 gallons/lane mile. Our testing also indicated, that most anti-icing chemicals, when initially applied as a liquid to the asphalt test surface, had friction values slightly lower than for only water on the surface.

As the drag sleds test tire degraded during testing, THESE RESULTS CAN **NOT** BE USED TO COMPARE THE PERFORMANCE OF ONE CHEMICAL AGAINST ANOTHER CHEMICAL! The data, however, can be used to compare the performance of an individual chemical as it transitions between liquid and solid. For example, the data shows that, for CMA, there is very little, if any reduction in friction as the chemical transitions from liquid into solid. However, for Liquidow Armor, this reduction is rather substantial (up to 25%).

When one scrutinizes the solid friction values, they are random with no definite decline as testing progressed. Again, this relates to the previously discussed feature of tire degradation, which is that dry friction values are not, or at least not significantly, affected by tire degradation, but wet friction values are.

It is also possible to use the data to determine the approximate humidity at which the liquid to solid transition, and the slurry phase during this transition, will occur, bearing in mind that, as these values were recorded without allowing the time required for the system to reach equilibrium, the relative humidity value seen at the lowest friction value is not necessarily the precise relative humidity at which this phenomena occurs.

Does It Make The Roads Slick?

The question which logically arises is this: is the relatively minor reduction in friction seen when an anti-icing chemical transitions from liquid to solid, or solid to liquid, associated with slickness reported traffic incidents? The answer is that it could be, but more likely than not, other factors are at play.

A review of other instances of slipperiness, where anti-icing chemicals have been blamed for accidents, has confirmed that, firstly, they are not geographic specific. We have investigated incidents in British Columbia, as far south as Arizona, and as far east as Pennsylvania. The common denominator for these reported incidents is that they occur at temperatures of 4 to 12°C (and most often at 8°C, or 46°F) with a relative humidity of approximately 45 - 50%. More often than not, they occur in the fall, and generally involve an application of anti-icing chemical that has been applied in anticipation of the first precipitation, or freezing, event. As well, a review of the meteorological data confirms that little if any rain or snow had been seen in the weeks or months previous to these incidents.

In one particular incident, which occurred in Washington State, it was found that two passes were treated at the identical time. One pass became slippery, while the other did not. Under investigation, it was found that the pass, which had not become slippery, had received precipitation just before the application was made and the other pass did not. In this circumstance, the anti-icing applications made in the absence of any recent rain or snowfall, it is clear that the anti-icing agent mixed with contamination on the roadway (glycol, oils, greases, etc.) and formed a very slick solution. Again, it is intuitive that the mixture of water (essentially the major component in any anti-icing chemical) with oil-based residue on the roadway, from automobiles, will result in a dramatically reduced friction surface. In this way, the anti-icing chemical itself does not produce a reduced friction road surface, but it is the catalyst that causes the reduced friction surface to develop. The same result would apply if, instead of anti-icing, mother nature would provide a light precipitation event. Any time there is an extended period with no rainfall (particularly in high traffic areas), automotive residues will build up. Then, when moisture is produced, a greasy, slippery, solution can develop. To eliminate the possibility that such a condition will occur, users must be very cautious when applying an anti-icer in anticipation of an incoming event, if no snow or rain has fallen in the prior time period.

We are attempting to design a set of experiments which will provide more definitive answers with regards to this aspect, but it would appear that, if two weeks has transpired with no moisture, and average daily traffic counts are moderate to high, extreme care should be exercised in deciding to anti-ice in anticipation of an incoming event. If the decision is made to anti-ice, the research shows that it would be best to choose a very low application rate (i.e. 15 - 20 gallons/lane mile at most) or preferably, if the event is appropriate, and if manpower is available, it may be best to de-ice (i.e. as in a reactive method) instead of anti-ice (as in a pro-active measure).

As many of the reported incidents have occurred on concrete bridge decks, which by nature provide less friction than asphalt roadways, it may also be advisable to “flush” the bridges themselves with water, or other means, to eliminate any automotive residues before anti-icing efforts commence.

The above-noted conditions, it is believed, constitute the vast majority of slickness reported incidents.

A third reported situation involving liquid anti-icing chemical attempts is one which involves poor quality chemicals. In several incidents that have been investigated by the author, it was determined, through laboratory analysis, that the chemical used was not what it was supposed to have been. Furthermore, whereas major chemical companies such as Dow Chemical are cognizant of what is in their product and go to great pains to enhance that product by research and developing additives, there appears to be a trend where distributors, and sub-distributors, are adding their own inhibitors or additives, in many cases, without knowledge of what it is they are concocting. At least in one incident, it has been discovered, that one such middle man apparently used vegetable oil as a rust control polymer, obviously with unintended results. Therefore, it is deemed very important for users to be able to be assured what chemical it is they have (as to being told what it is they have) and also to be able to determine the resultant coefficient of friction which they can expect after application. Naturally, a laboratory test will not provide any indication of whether or not the solution is slippery, nor will a friction test provide any indication as to what the solution is comprised of.

As stated previously, a “safe” roadway is one which has a coefficient of friction of about 0.5, or better. For acceleration, a friction of about 0.3 is needed. For a swerve, a friction of 0.2 to 0.3 is required (the overwhelming majority of drivers do not swerve their vehicle at greater than this level), and for most brake applications, a friction of 0.4 - 0.5 is all that is required.

CONCLUSIONS/RECOMMENDATIONS

There are a wide variety of reasons why road conditions can become less than ideal. The purpose of this research is to determine what effect liquid anti-icing chemical efforts have on available roadway friction. Awareness of these issues, along with seasoned good judgement, by maintenance managers, will further eliminate the likelihood that traffic incidents associated with anti-icing use, will take place in the future. This research has shown the following:

1. Tire degradation over a series of skid tests precludes the ability to compare specific chemicals that have been tested in this batch of asphalt tests. While solid or dry friction values remain unchanged, liquid, or wet, friction values show a declining trend between the onset of testing, and the conclusion.

2. Some chemicals produce lower friction values than others. This is particularly related to the addition of rust-control polymers, which are often added after the anti-icing chemical has left the manufacturer. The addition of such inhibitors at the local level, by well-meaning individuals, who have limited knowledge of rudimentary analytical chemistry and no means of determining what effect their concoction will have, should be strongly discouraged. Our research has shown that even trace elements can provide substantially different friction results.

3. This research has upheld the previous theory that chemicals which are transitioning from liquid to solid, and solid to liquid, produce lower friction values. The average reduction of all chemicals, compared to their liquid friction values, was approximately 8%, with the lowest being 0% and the highest being 25%.

4. This transition phase occurs, however, at relatively low humidity levels (below 28 - 32%) which, apart from in desert areas, are relatively unseen in wintertime operations. Therefore, for most areas, this is not seen as being problematic.

5. The research is beginning to confirm that the application of liquid anti-icing chemicals in reasonable amounts will provide a level of friction equal to, or up to about 20% less than, that seen when the road is wetted by mother nature. Over application of some chemicals can lead to lower overall friction values.

6. The greatest concern appears to lie in the application of liquid anti-icing agents, when no appreciable precipitation has occurred in the time period prior to application. This, along with high average daily traffic counts (providing substantial oil-based residuals from the vehicles) will produce a “slick” surface identical to that which is seen by a light rain shower preceded by a long dry spell. Therefore, the anti-icing chemical may not be directly the cause of the reduced friction, but it certainly is the catalyst which promotes a reduced friction surface. Accordingly, users should be cautious of applying anti-icing liquids in anticipation of an incoming event, particularly if no rain or snow has fallen for some time beforehand. Users may further reduce the risk of slickness developing under these conditions, by utilizing low application rates (15 - 20 gallons/lane mile) or by flushing critical areas (concrete bridge decks, sharp corners, etc.) with pure water, or other means, prior to chemical application.

7. None of the common anti-icing chemicals in use today, applied at the correct application rate, reduced the road friction to a level which is below that which is required for safe motor vehicle operation. Some chemicals which have been mixed with rust control polymers can produce lower friction surfaces than others. Accordingly, prior to initial application, users should ascertain that the chemicals they are in possession of have not been unduly “enhanced” with an inhibitor, or other solutions, which will tend to make the mixture slippery upon application.

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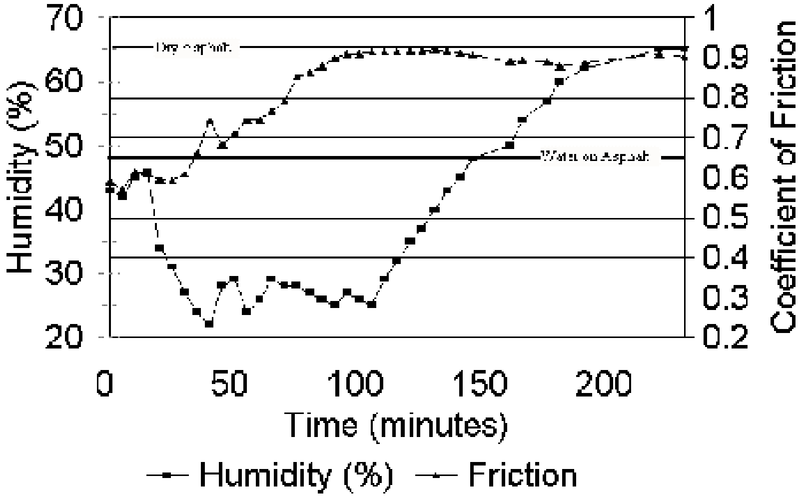
Lastly, the author is indebted to Mr. Tom Byle, P.E. from Kent County, Grand Rapids, Michigan for forwarding his real-world skid data, which was included in this report.

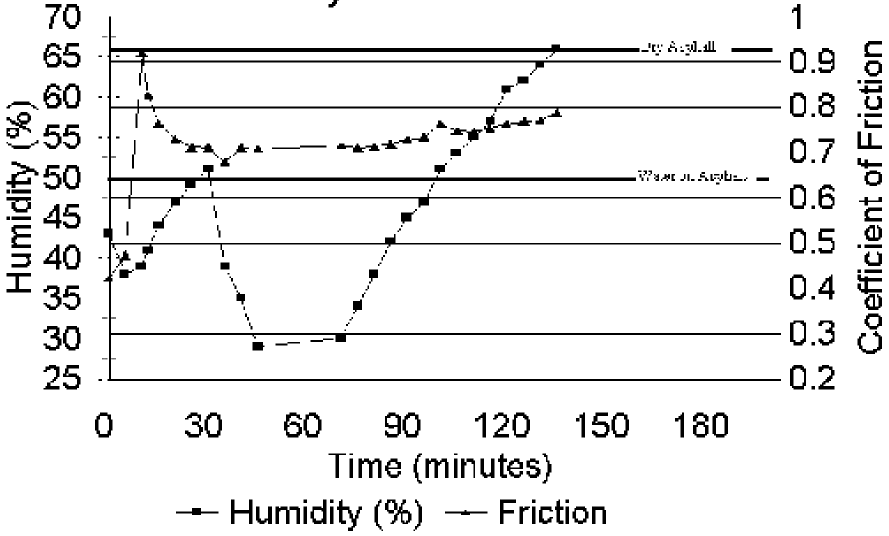
CMA - Asphalt

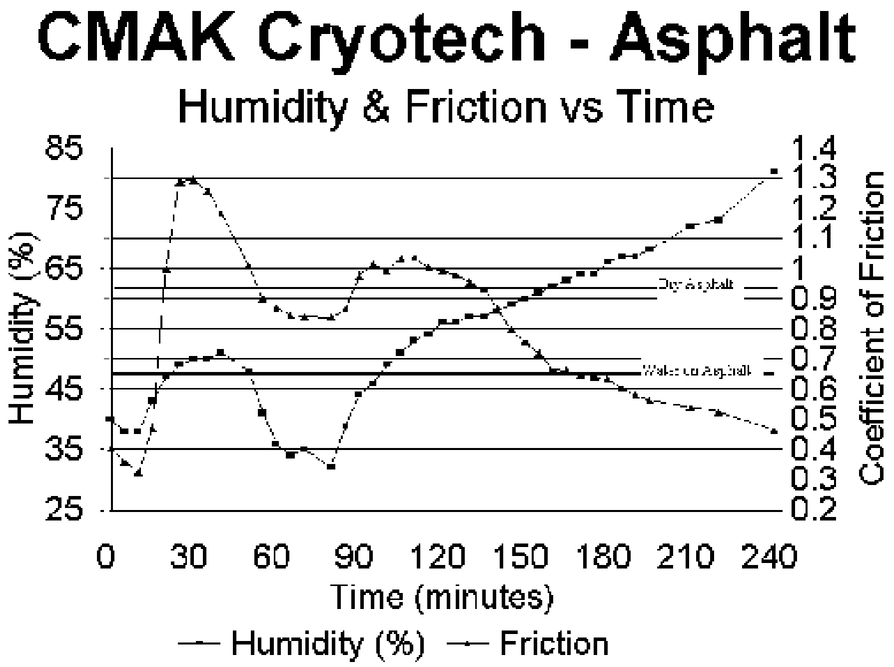
Humidity & Friction vs Time

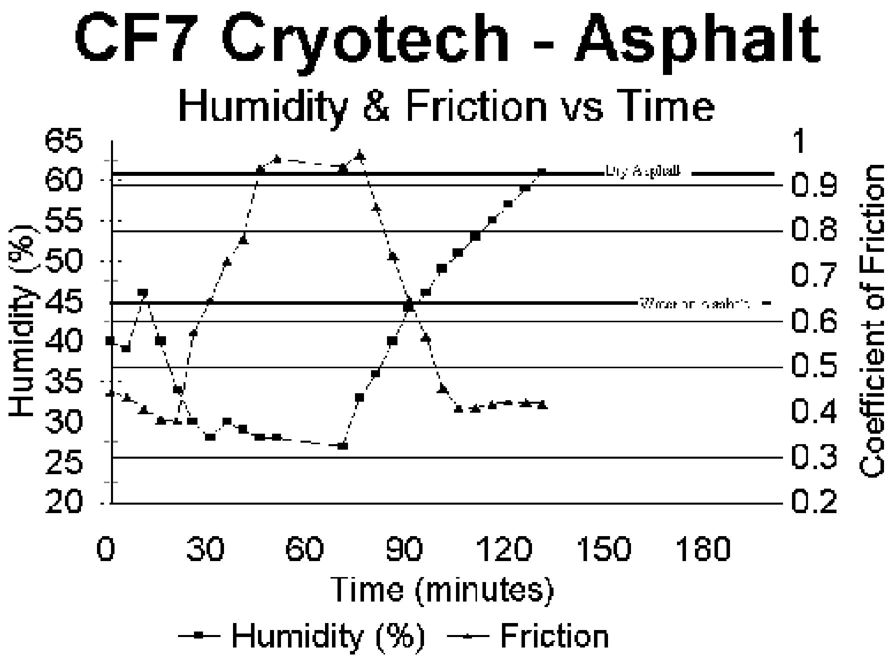


CMA 25 Cryotech - Asphalt

Humidity & Friction vs Time

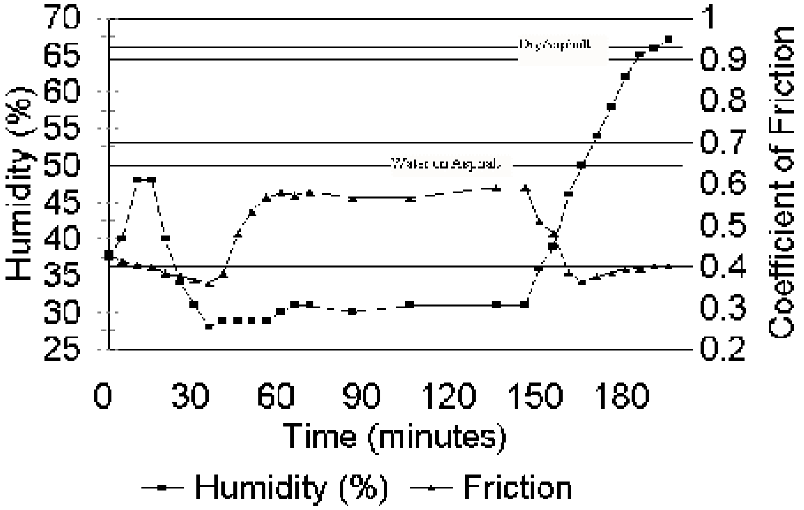



CMAK Cryotech - Asphalt
Humidity & Friction vs Time
Humidity (%)
85
75
65
55
45
35
25
Coefficient of Friction
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Dry Asphalt
Water on Asphalt
0
30
60
90
120
150
180
210
240
Time (minutes)
Humidity (%)
Friction


CF7 Cryotech - Asphalt
Humidity & Friction vs Time
Humidity (%)
65
60
55
50
45
40
35
30
25
20
Coefficient of Friction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Dry Asphalt
Water on Asphalt
0
30
60
90
120
150
180
Time (minutes)
Humidity (%)
Friction

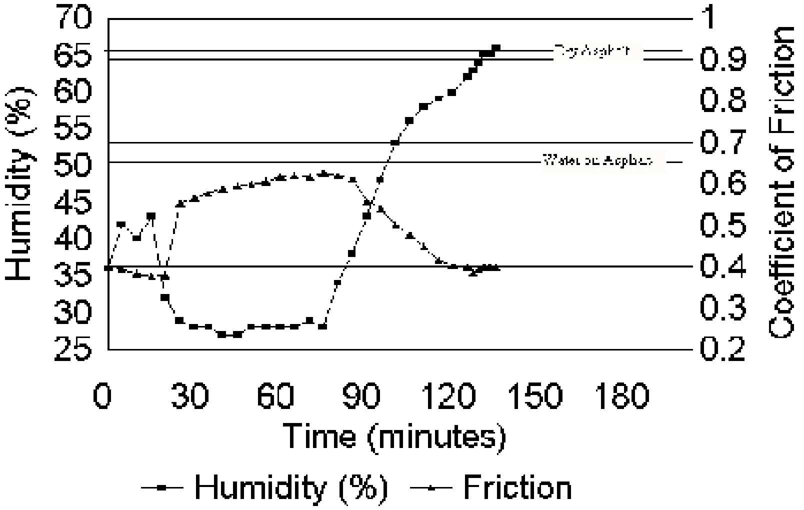
Corguard 2000 - Asphalt

Humidity & Friction vs Time



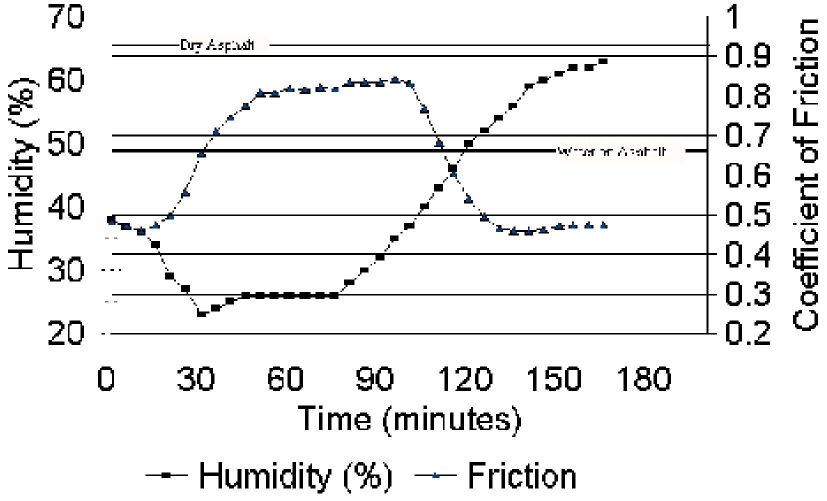
General Chemical CaCl - Asphalt

Humidity & Friction vs Time



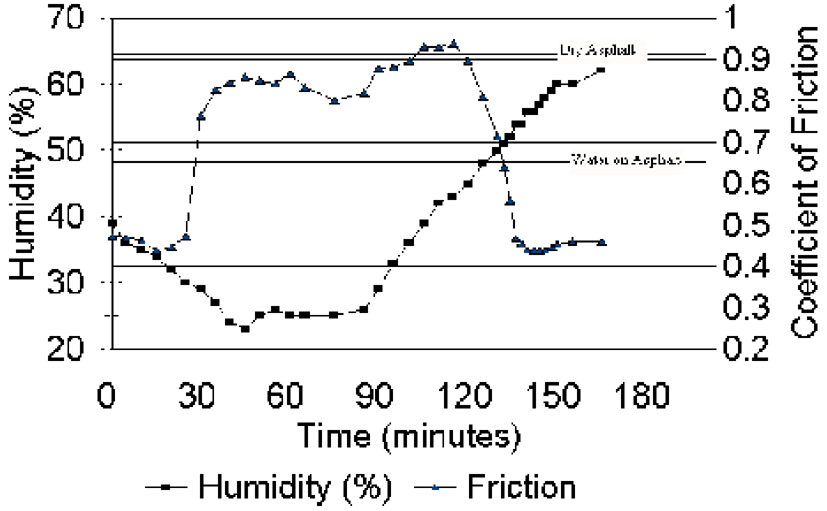
Freezgard Zero - Asphalt

Humidity & Friction vs Time



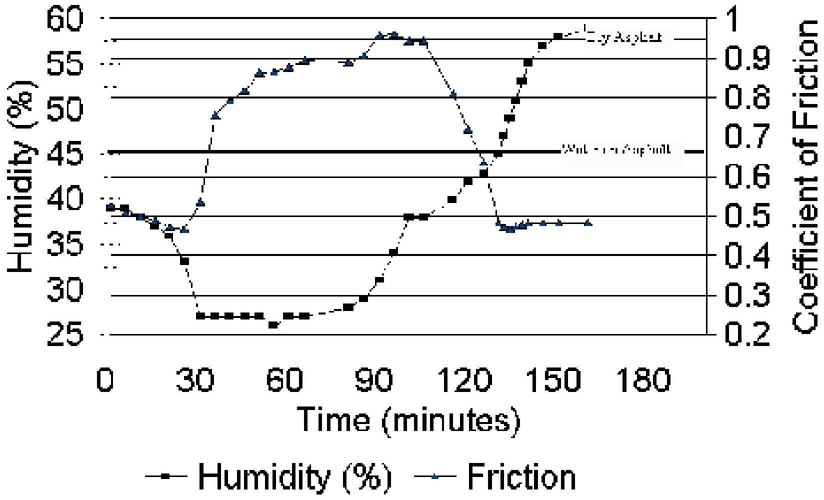
Freezgard 0 & IceBan - Asphalt

Humidity & Friction vs Time



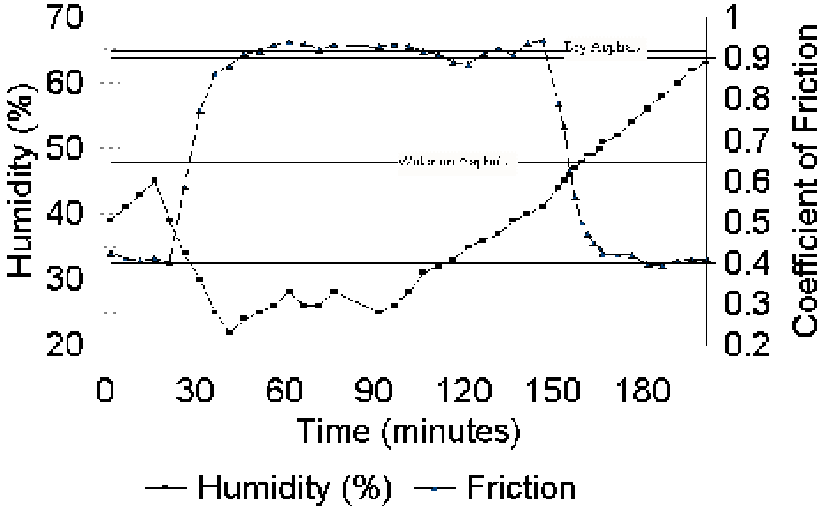
Freezgard 0 & Shield LS - Asphalt

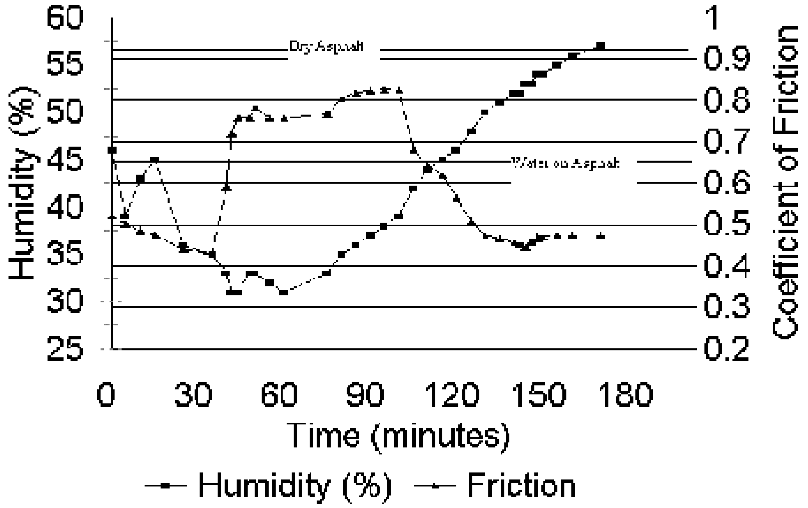
Humidity & Friction vs Time



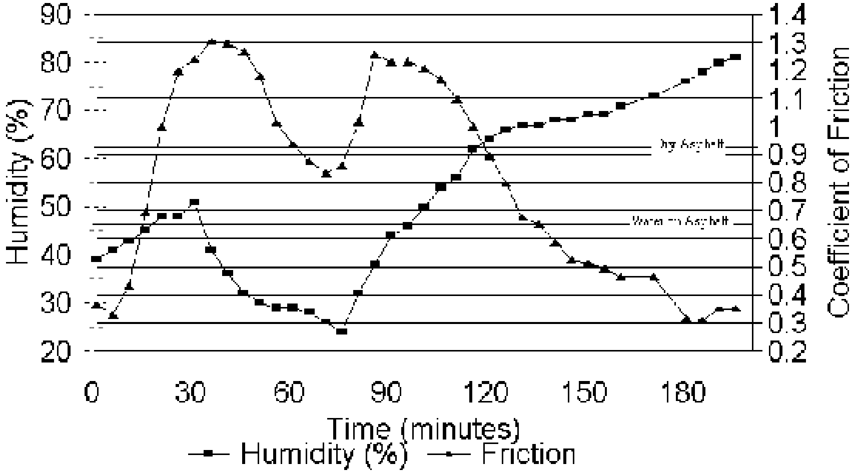
Freezgard 0 & TEA - Asphalt

Humidity & Friction vs Time




ICE STOP CI 2000 - Asphalt

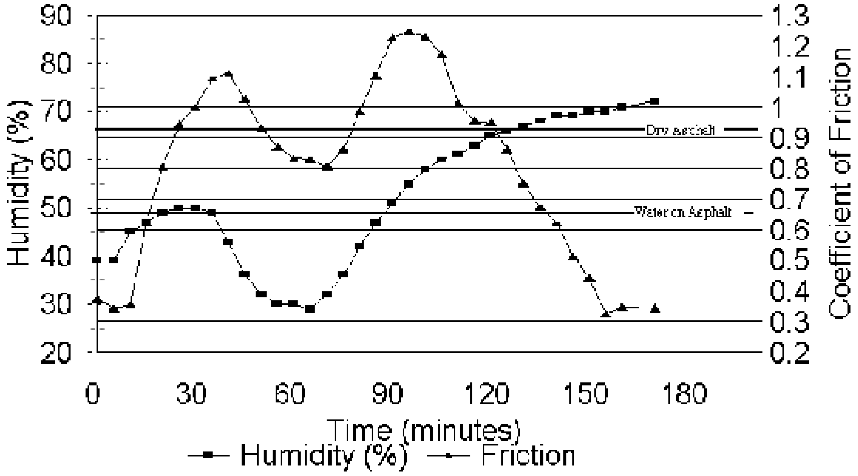
Humidity & Friction vs Time


Ice Ban w/ 50% MgCl2 - Asphalt

Humidity & Friction vs Time

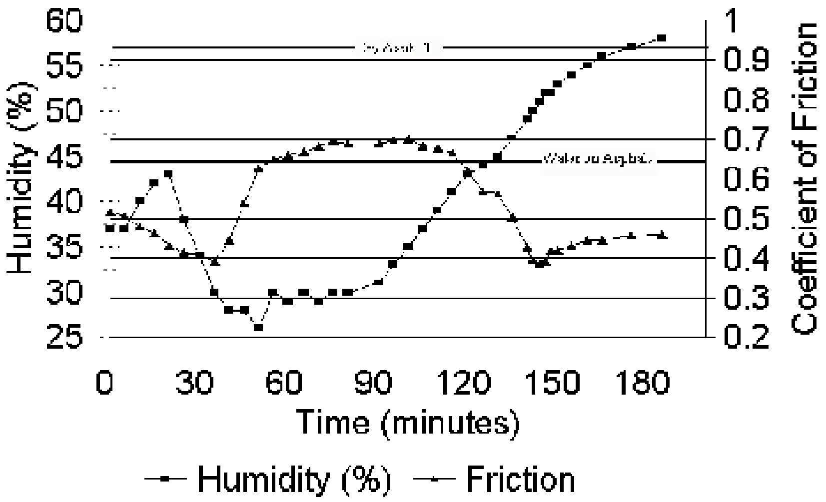
Ice Ban w/ 50% CACl2 - Asphalt

Humidity & Friction vs Time



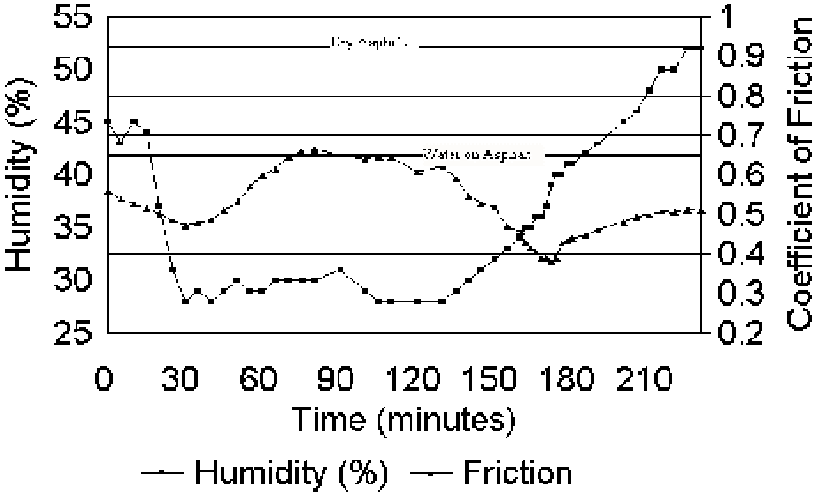
Liquidow - Asphalt

Humidity & Friction vs Time



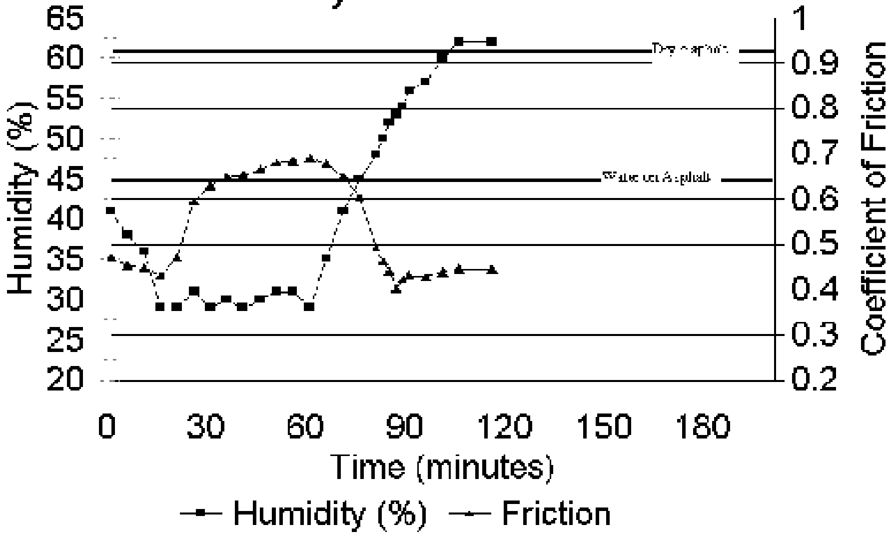
Liquidow Armor - Asphalt

Humidity & Friction vs Time



Cal Ban - Asphalt

Humidity & Friction vs Time



MCP - Asphalt

Humidity & Friction vs Time