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Western Transportation Institute
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EXECUTIVE SUMMARY

Concurrent to the applications of acetate-based deicing and anti-icing agents (deicers), some Nordic airports have seen accelerated degradation of asphalt concrete (AC) in the last two decades. The coincidence of the acetate applications and the premature AC deterioration, however, has’t received much attention in North America. A research study was recently conducted by the PI to investigate the potential AC deterioration by the acetate-based deicers and to explain its possible mechanism, of which the findings are presented in this study. Using a modified version of the ASTM Standard D3625-96, the field observation of acetate-induced AC deterioration was confirmed in the laboratory; and more severe mixture deterioration was consistently observed at higher acetate concentrations. Emulsification of asphalt was then studied in a series of aqueous solution tests that involved subjecting the asphalt binder to acetate solutions with different concentrations at different temperatures. The acetate-induced asphalt emulsification was further investigated using Fourier Transform Infrared (FTIR) spectroscopy, and a possible physiochemical mechanism was proposed based on which the process of acetate-induced AC deterioration was explained. This work tries to shed light on a somewhat neglected distress process occurring in AC pavements of U.S. airports, and can be expected to guide the best practices of deicer application, asphalt mix design, and the rehabilitation and maintenance of airfield AC pavements.
1. INTRODUCTION

Maintaining sufficient traction between pavement surface and gear tires of aircraft is essential for the safe and efficient operation of winter airfields. To this end, large amounts of deicing and anti-icing agents (a.k.a. deicers) are applied on airfield pavements for snow and ice control each year in the northern United States and Canada (1). Depending on rules of practice, pavement temperature, airfield weather conditions and other constraints, deicers have been used on the asphalt concrete (AC) pavements of airfields by state and federal aviation agencies, including mainly acetates (potassium acetate, sodium acetate, and calcium magnesium acetate (CMA)), formates (sodium formate and potassium formate), urea and bio-based products (2).

Currently, acetates and formates are used as the primary deicers on airfield pavements. The chloride-based deicers typically used on highway pavements are excluded from airfields to avoid potential metallic corrosion of aircrafts and adverse environmental impacts (3, 4, 5). The use of other deicers on airfields, such as glycols and urea that were popular before the 1990s, has gradually diminished mainly due to environmental concerns. While still used for aircraft deicing and anti-icing, propylene and ethylene glycol are no longer used as airfield pavement deicers due to their high biological oxygen demand (BOD) posing the risk of oxygen depletion in water. Urea has essentially been discontinued as it is known to deteriorate pavement materials and to cause over-fertilization of soil, which poses a serious problem for receiving waters adjacent to airports (6, 7). In contrast, acetates and formates are more environmentally friendly (8). Potassium acetate, sodium acetate, and sodium formate are more expensive, but also more effective than urea at lower temperatures (9).

Nonetheless, the application of acetates and formates on airfield cement concrete pavements has been found to significantly accelerate the alkali-silica reaction (ASR) in concrete. Laboratory investigation has shown that such deicers could lead to higher pH values in concrete pore solution and deteriorate concrete matrices that were otherwise resistant to ASR (10, 11). Not much attention has been paid to the potential negative impact of acetates and formates on AC pavements at U.S. airports, possibly due to the unproven premise that asphalt has sufficient resistance to chemical deicers. Such a premise, however, may have simply arisen from the fact that an asphalt pad is usually built as the storage bottom for various chloride-based highway deicers to prevent leakage (12). While asphalt is physicochemically stable to chlorides, it may not be the case for acetates and formates.

Premature deterioration of asphalt pavement due to the use of acetate/formate-based deicers was reported in as early as the 1990s, when asphalt pavement disintegration including asphalt binder softening, asphalt mixture stripping and loose aggregates were found on the runways at some Nordic airports (13). These problems were not observed prior to the airports changing from urea to potassium acetate and potassium formate deicers. The early 2000s saw more serious problems occurring to the asphalt pavements at these airports. Heavy binder bleeding and severe stripping problems were observed occurring together with loss of AC stability. Soft, sticky, and staining binder came to the pavement surface and a strong staining effect on electrical devices and airplanes showed up. The binder of the asphalt base layers was “washed” off, and significant loss of strength was observed for aggregates (14).
Deterioration of asphalt concrete similar to that observed in the Nordic counties could also occur at U.S. and Canadian airfield, considering the large quantities of acetate and formate-based deicers applied each year. Once such AC deterioration is confirmed, appropriate maintenance and rehabilitation measures ought to be taken for asphalt pavements to ensure safe and efficient operations at winter airfields. This study presents the findings of a recent study in the Corrosion, Electrochemistry and Analysis Laboratory at the Western Transportation Institute, aimed at investigating the potential for acetate- and formate-based deicers to deteriorate airfield asphalt concrete.
2. METHODOLOGY

This study aims at examining and explaining the mechanism of the temperature-dependant emulsification of asphalt binders when exposed to the acetate-based deicers of various concentrations. The asphalt, aggregate materials, analytical grade sodium acetate, as well as a commercial sodium acetate deicer (solid), were obtained from agencies and then used in three tests in a progressive approach. A modified boiling water test of asphalt mixture was developed and conducted first to examine the duplicability of the AC deterioration as observed at the Nordic airports. Then a series of aqueous solution tests were run on the asphalt binders to find out what functional ingredients induced the emulsification, if identified in the modified boiling water test. Factors including cation, anion, pH value and concentration of the simulated deicer solution, as well as asphalt type and temperature, were studied. Fourier Transform Infrared (FTIR) spectroscopy was used to examine the nature of the interaction between acetate and asphalt. An emulsification mechanism of asphalt binder when exposed to the acetate-based deicers was proposed based on the results of these three evaluation methods. According to the proposed mechanism, the process of acetate-induced AC deterioration was explained and recommendations regarding the practice of asphalt mixture design and pavement maintenance were made to minimize such deterioration.
3. LITERATURE REVIEW

3.1. Task A

**Modified Boiling Water Test**

The evaluation started with a series of modified boiling water tests that were developed based on the ASTM Standard D3625-96: Standard Practice for Effect of Water on Bituminous-Coated Aggregate Using Boiling Water (15). The Standard D3625-96 is commonly used to examine the moisture sensitivity of asphalt mixtures and entails an accelerated procedure for visually observing the loss of adhesion in uncompacted bituminous-coated aggregate mixtures subjected to the action of boiling water. In a modified boiling water test, a 250-gram uncompacted asphalt mixture sample was boiled for ten minutes in an aqueous solution of the commercial sodium acetate deicer. To look into the effect of deicer concentration, a series of aqueous solution tests were conducted, each at a different concentration of the deicer. All the other procedures remained the same as the ASTM Standard D3625-96. The post-testing weight percentage of unstripped aggregate with respect to the total weight of the asphalt mixture before the test was then reported to indicate the deteriorating effect of the deicer.

![Unstripped Aggregate versus Stripped Aggregate at Different Concentrations of the Sodium Acetate](image)

The modified boiling water tests were conducted in this study to imitate accelerated field action on the loss of bonding at the asphalt-aggregate interface when exposed to deicers and to double-check the deterioration of asphalt concrete as observed at the Nordic airports. Researchers also wanted to see if the deterioration was materials-specific and/or environment-specific. The asphalt mixture was prepared following the same procedure as used in sample preparation for measuring the theoretical maximum specific (Rice) gravity. A job mix formula of a mixture design released by the FAA was used, which included the PG 67-22 and a blend of crushed gravel and limestone. A total of five concentrations of the sodium acetate deicer were...
tested: 0% as the control sample, 5%, 10%, 20% and 40%. Figure 1 shows the unstripped aggregate with respect to the stripped asphalt mixture at different concentration of sodium acetate. Obviously, with the increase of the concentrations of sodium acetate, more loss of adhesion in the binder-coated aggregate mixtures was observed. Moreover, stripping happened to both crushed gravels and limestone particles in all the five tests, which might indicate that the physicochemical properties of the aggregate surface played a secondary role, if any, in the emulsification process.

![Figure 1 Percent Stripped Aggregate at Different Concentrations of Sodium Acetate](image1)

Figure 1 Percent Stripped Aggregate at Different Concentrations of Sodium Acetate

The percentages of stripped aggregates versus the total uncompacted asphalt mixture at the different concentrations of sodium acetate were further calculated and are shown in Figure 2. For the aqueous solution with 0% sodium acetate, only 4% of uncompacted asphalt got stripped after the modified boiling test; however the stripped percentage increased to 42.4 when the concentration of sodium acetate increased to 40% in the aqueous solution. It also seemed that the percentage increase of the stripped versus the concentration of sodium acetate followed a bi-linear pattern. The dependency of stripping rate on deicer concentration appeared to be more significant below the 10% concentration of the sodium acetate.

![Figure 2 Percent Stripped Aggregates at Different Concentrations of Sodium Acetate after the Modified Boiling Water Test](image2)

Figure 2 Percent Stripped Aggregates at Different Concentrations of Sodium Acetate after the Modified Boiling Water Test

Although in an accelerated style, the modified boiling water test results conform to the observation of accelerated AC deterioration when exposed to the acetate-based deicers at the Nordic airports, which indicates that the deterioration may be a universal phenomenon that is not dependent on the specific types of binder, aggregate or environments. However, it should be noted that the apparent stripping phenomenon as observed in the modified boiling water tests may be attributed to the potential aggregate degradation at the binder-aggregate interface when subjected to the acetate. Accelerated ASR could occur to suspicious aggregates similar to what
was observed on cement concrete pavements (10, 11). Therefore, to what extent the stripping can be attributed to the acetate-induced asphalt deterioration needs to be further studied. The following sections of this study detail the development and results of an aqueous solution test of the asphalt binder as a further effort made by the investigators to address this issue.

3.2. Task B

Aqueous Solution Test

The objective of the aqueous solution tests was to isolate the deteriorating effect of the sodium acetate on asphalt binder from possible aggregate-related mechanisms. The possible environmental temperatures and deicer concentrations at the airfields were appropriately simulated to ensure a realistic evaluation of the acetate effects on asphalt concrete. The laboratory testing involved a series of aqueous solution tests conducted at different temperatures for a variety of concentrations as given in Table 1. The temperature levels in Table 1 were determined to simulate the actual conditions at the airfield. Thus, 0°C, 20°C, 40°C and 60°C were adopted to examine the extent of asphalt emulsification at low service temperature, at intermediate service temperature, at average summer temperature, and at high summer temperature, respectively; and 80°C as the lower boundary of the re-paving or overlay temperature.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Sodium Acetate Concentration (wt.%)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>0°C</td>
<td></td>
</tr>
<tr>
<td>20°C</td>
<td></td>
</tr>
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<td>40°C</td>
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<tr>
<td>60°C</td>
<td></td>
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<tr>
<td>80°C</td>
<td></td>
</tr>
</tbody>
</table>

The aqueous solution tests used analytical grade sodium acetate at various concentrations. The 0% concentration was used as the control sample and the 40% concentration was adopted to simulate the highest possible concentration when solid acetate was applied as a deicer. The 10%,
20% and 30% concentrations were adopted to simulate any concentration conditions between the two extreme cases. Deionized water (resistivity > 18.2 MΩ cm\(^{-1}\)) prepared by a Milli-Q 185 system was used for all experiments. The same asphalt binder, i.e., PG 67-22, and sodium acetate as used in the modified boiling water tests, were adopted in the aqueous solution test. Calcium magnesium acetate was also used for some aqueous solution tests. The following parts of this study first present the details of the aqueous solution test, followed by the results of the sodium acetate only, since there were no significantly different performances observed between these two acetates.

(a), (b) The 24-hour Reservation of the 60°C Aqueous Solution Test with the 20% Acetate Concentration

(c), (d) The 24-hour Reservation of the 60°C Aqueous Solution Test with 40% Acetate Concentration

Figure 3 Suspension Solution of the 60°C Aqueous Solution Test
For each aqueous solution test, 80 ml of deionized water was poured into a glass container that had a fluoroplastic sealed spout at the bottom. Sodium acetate was added to the container to prepare solutions at the specified concentrations. The container was heated through a thermostated water bath. When the targeted temperature was reached, four grams of asphalt binder was added to the container. A low-speed magnetic stirring was used in the container to ensure a uniform distribution of the emulsified suspension. After two hours, the glass container was taken out and the suspension solution was separated from the top layer of floating asphalt. The suspension solution was then diluted using deionized water and its suspended substances were separated using a centrifuge separator. The separated suspended substances were finally collected after a 10-hour vacuum-drying separator.

The suspensions were found to be highly steady in the 24-hour reservation at room temperature. Figure 3(a) shows a photo taken of the 24-hour suspension solution of the 60°C aqueous solution test with a 20% acetate concentration. An optical microscope was used to exhibit the morphology of the suspended substances as shown in Figure 3(b) for the same aqueous solution. Figure 3(c) shows a photo taken of the 24-hour suspension solution of the 60°C aqueous solution test with a 40% acetate concentration, and the morphology of the same aqueous solution is shown in Figure 3(d).

The morphology and size of the suspended substances in solution were observed using an OLYMPUS BX41 optical microscopy (OM) equipped with a Nikon COOLPIX4500 high-resolution digital CCD camera, and the average droplet/flocule diameters were measured from at least 100 droplet/flocules on the OM photos. It was observed that the suspended substances were mainly dark colored asphalt droplets surrounded by light brownish flocules. With the increase of sodium acetate concentration, more asphalt droplets can be seen and the color of the suspended substances changed from beige to dark.

For the control aqueous solution test that included 0% sodium acetate, no suspended substances can be identified after a two-hour bath. To look into the individual roles played by the sodium cation (Na⁺) and the acetate anion (CH₃COO⁻) in the emulsification process, an aqueous solution test was performed with the substitution of sodium chloride (NaCl) for sodium acetate at a 23% concentration. The solution was pellucid from beginning to the end, and no suspended substances could be observed under the optical microscope. The results of the sodium chloride test suggested that the acetate anion should be the reason for the asphalt emulsification considering that asphalt has good resistance to Cl⁻. Another test was conducted using CMA with the same molar concentration as the sodium acetate test, which showed a similar level of suspension in the sodium acetate solution, further confirming the role of the acetate anion in the asphalt emulsification.

At the 40% acetate concentration, the pH of the solution was measured to be approximately 9. A sodium hydroxide (NaOH) solution of the same pH was tested to examine the potential influence of pH on the asphalt emulsification. Still no suspended substances were found under the same optical microscope at the same magnification as was used in examining the acetate tests. The pH value of the NaOH solution was monitored throughout the process of the aqueous solution test. The pH did not show measureable changes (still around 9), which indicated that the OH⁻ concentration did not change much, or equally speaking, the OH⁻ anions were not consumed or reproduced to a significant level during the aqueous solution test. Therefore, the possibility that high alkalinity be responsible for the asphalt emulsification was excluded. Suspension of a certain substance in an aqueous solution can be greatly facilitated.
when the suspended substance has a density close to the aqueous solution. The aqueous tests using sodium chloride and sodium hydroxide, both having a density close to that of the acetate at the same concentration, actually indicate that the effect of the density of the aqueous solution, if any, is not overwhelming. To sum up, results of all these tests lead to the conclusion that it is the acetate anions (CH₃COO⁻) that function to emulsify the asphalt binder, and certain bonding could be established between the CH₃COO⁻ and certain ingredients of asphalt binder during the emulsification process.

![Graph](image)

Figure 4 Level of Asphalt Emulsification in Sodium Acetate Solution as a Function of: (a) Sodium Acetate Concentration at 80°C and (b) System Temperature at 40% Sodium Acetate

To better understand the emulsifiability of asphalt in sodium acetate solution, the aqueous solution tests were conducted with different concentrations of sodium acetate solution and different system temperatures. The percentage of the emulsified asphalt for the 80°C aqueous solution test is shown in Figure 4(a). With the increase of sodium acetate concentration from 0% to 40%, the emulsifiability of asphalt slowly increased in the beginning and then increased rapidly. Asphalt emulsification at the 40% acetate concentration is shown in Figure 4(b). It is noteworthy that below 40 °C, the emulsification was not obvious (below 0.05% by weight of total asphalt before test); however, when the system temperature increased to 80°C, the emulsified asphalt in the sodium acetate solution increased up to 0.5% by weight of total asphalt.

The same aqueous solution test was also conducted on two other asphalt binders, i.e., the PG 58-22 and PG 64-22. The asphalt binder PG 58-22 showed slightly higher emulsifiability than the binder PG 67-22 under the same testing condition, indicated by a higher amount of suspended substance than the binder PG 67-22 at the same temperature and the same acetate concentration. However, no significant difference was identified between the amounts of the suspended substance of asphalt binders PG 64-22 and PG 67-22.
3.3. Task C

FTIR Characterization

The aqueous solution tests indicate that the acetate anion (CH$_3$COO$^-$) may probably bond to certain ingredients of asphalt binder and lead to emulsification. To elucidate the emulsification mechanism, Fourier Transform Infrared (FTIR) spectroscopy was performed using a Bruker Vector-22 FTIR spectrometer with the Potassium Bromide (KBr) pellet. FTIR is a commonly used measurement technique in analytical chemistry that measures the temporal coherence of a radiative source in the spectra form. The FTIR technique was used in this study to determine and compare the ingredients of the asphalt before the aqueous solution test and the ingredients of the suspended substance in the aqueous solution after the test. The FTIR spectrum of the sodium acetate was also obtained to examine the nature of the bond between the CH$_3$COO$^-$ and asphalt ingredients.

![FTIR Spectra](image)

Figure 5 FTIR Spectra of Asphalt before the Aqueous Solution Test (A), the Suspended Substances after the Test (B), and Sodium Acetate (C)
The FTIR spectra of asphalt before the aqueous solution test, the suspended substances after the test, and sodium acetate are shown in Figure 5. The spectrum of asphalt (Curve A) demonstrates well-defined characteristic bands (2921 cm⁻¹, 2851 cm⁻¹, 1464 cm⁻¹ and 1377 cm⁻¹) of the alkane units (mainly CH₃- and CH₂--). In the spectrum of the suspended substances (Curve B), the appearance of characteristic peaks at 2921 cm⁻¹, 2851 cm⁻¹, 1464 cm⁻¹ and 1377 cm⁻¹ indicates the alkane component of the original asphalt was emulsified and became components of the suspended substances. The characteristic peaks at 1600 cm⁻¹, 1451 cm⁻¹ and 927 cm⁻¹ are attributed to CH₃COO⁻ groups as compared with the spectrum of sodium acetate (Curve C), indicating the incorporation of CH₃COO⁻ in the suspended substances also.

Since no significant amount of new chemicals (indicated by new peaks) can be identified on Curve B as compared to Curve A and Curve C, it can be inferred that intermolecular binding between the CH₃COO⁻ groups and the alkane component of the asphalt, if not the only mechanism, must have contributed to the asphalt emulsification in the acetate solution. It should be noted that other components such as the aromatic groups might also contribute to asphalt emulsification. They were not detected by the FTIR technique mainly due to their low fraction in the specific asphalt binder. However, the alkane component must contribute to the emulsification since a significant amount alkane component showed up in the emulsified asphalt (Curve B).

Both the aqueous solution test and the FTIR analysis indicate that acetate anion (CH₃COO⁻) enhances emulsification of the asphalt binder. As such, a possible mechanism is proposed to explain the emulsification of asphalt in exposure to acetate-based deicers. The following paragraphs summarize the proposed mechanism.

An acetate anion has a lipophilic organic chain (CH₃-) and a hydrophilic polar end (COO⁻) that qualify it as an emulsifier (surfactant) in aqueous solution. At the high service or re-paving temperature, asphalt tends to swell and suck in acetate anions together with the aqueous solution. The swelling and intake actions both significantly increase the contact area of the asphalt with the acetate anions. The extent of the swelling and intake of acetate anions depends on the environmental temperature and the sodium acetate concentration of the aqueous solution. When acetate anions contact the asphalt surface, their organic chain CH₃- will “anchor” the molecular chain of asphalt (CH₂-CH₂-) by van der Waals forces, and simultaneously the polar end (COO⁻) will disperse the acetate anions into the water phase by forming hydrogen bonds with water molecules. Such dispersion acts as a type of “dragging” force upon the surface of the swollen asphalt. As a result, when the dragging force exceeds the intermolecular forces (also mainly van der Waals forces) within the asphalt, asphalt starts to be emulsified in the form of floccules that can be steadily dispersed in the water phase maintained by the Brownian Motion and the repulsive forces among the floccules that carry a negative charge on their surface (due to the COO⁻ from the acetate anions).

At a relatively low concentration of acetate, the acetate anions can be consumed and only asphalt floccules can form up. The proposed mechanism for the low emulsification is illustrated in Figure 6(a). With the increase in concentration of the sodium acetate solution, more acetate anions provide the stronger anchoring and dragging action with the asphalt binder, leading to the appearance of asphalt droplets in the solution. Bigger asphalt droplets can also steadily suspend in an acetate solution of a higher concentration that has a higher density. The proposed mechanism for the high emulsification is illustrated in Figure 6(b).
(a) Low-Level Emulsification

(b) High-Level Emulsification

Figure 6 Schematic Representation of the Asphalt Emulsification
The deterioration process of asphalt concrete can be explained based on the emulsification mechanism proposed above. Considering the hydrophile-lipophile balance value of the acetate anion, its hydrophilicity is stronger than its lipophilicity due to the shorter organic chain (only one methyl group). Acetate anions, when available, tend to emulsify asphalt components of weak polarity, which usually have low molecular weight. At higher acetate concentrations, asphalt components of higher molecular weight can also be emulsified as indicated by Figures 3(c) and 3(d). Since the asphalt is bound to the aggregate surface mainly through the polar constituents at the asphalt-aggregate interface, the loss of these polar constituents in asphalt will lead to the decrease of bonding force between asphalt and aggregates, which can eventually aggravate adhesion failure in asphalt concrete pavements. Another possible reason for the aggravated adhesion failure at the asphalt-aggregate interface is that aggregates prefer to bind with acetate anions that have higher polarity than the asphalt molecules. Such preference could also reduce the binding establishment between aggregate and asphalt. The adhesion failure at the asphalt-aggregate interface can take forms of raveling and stripping, like what is usually observed in moisture damaged asphalt concrete. If no preventive measures are taken, such distresses could also lead to or exacerbate certain structural problems such as excessive rutting, premature fatigue and thermal cracking.
4. CONCLUSIONS

This study presents a laboratory investigation of the emulsifying effect of acetates on asphalt. A commonly used deicer, sodium acetate, demonstrated emulsifiability on asphalt. The modified boiling water test of asphalt mixture confirmed the AC deterioration as observed at the Nordic airports. The aqueous solution tests showed that up to 0.5 wt.% asphalt could be emulsified in a 40% sodium acetate solution at 80°C. The laboratory tests also showed that asphalt binders soaked in deicer solution started to emulsify at temperatures as low as 20°C. The emulsifiability was also found to increase with deicer concentration and system temperature. Both the aqueous solution test and FTIR analysis showed that asphalt emulsification could be attributed to the acetate anion. An emulsification mechanism was proposed based on the results of the aqueous solution test and FTIR analysis.

The deteriorating process of asphalt concrete when exposed to the acetate-based deicers can be explained with the proposed emulsification mechanism. Deicers migrate into the asphalt after application onto pavements and saturate asphalt mixes during the winter. The deicer solution intrudes into asphalt due to gravity and temperature rise (a result of a hot asphalt overlay or summer weather), or for other unknown reasons. Due to the low surface tension between deicers and bitumen, the deicers are absorbed in the binder that in turn starts to emulsify. It is possible that the chemical composition of the binder also changes during emulsification. Due to emulsification the binder comes loose and the aggregate particles get cleaned, followed by bleeding and stripping. In short, the deterioration of AC appears to be predominantly an emulsification process that works through asphalt binder in the mastic and at the asphalt-aggregate interface. Asphalt bleeding and mixture raveling and stripping can lead to additional stress inside the AC to cause more seriously premature structural distresses.

This research shows that acetate-based deicers, water or humidity, and heat are necessary for the deterioration to occur on airfields. Asphalt concrete distresses will occur mainly during the repaving process, or in the long run, in combination with hot summer days. Dynamic wheel loading and unloading could accelerate transport of the deicer solution and reduce the time it takes for damage to occur. It was also found that after the boiling test, acetate crystalline grains tended to form on the loose mixture of well-coated aggregate, bare aggregate particles and mastic strip-offs when the acetate solution was removed. To determine the net weight proportions of the stripped aggregate material vs. unstripped aggregate and mastic leftovers, these boiled materials were soaked in D.I. water at room temperature and the acetate crystals were cleansed effectively. Such finding may suggest that preventive measures be taken by using mixtures of low air voids, or by washing the acetate-contaminated mixtures.
5. RECOMMENDATIONS

Based on the findings from the study, recommendations are made to improve the resistance of asphalt pavements to deicers through mixture design and airfield deicer application. The resistance of asphalt pavements to acetate-based deicers can be improved partially by mix design in the following aspects:

- According to the results of the aqueous solution test, stiffer binders may reduce asphalt emulsification. Therefore polymer-modified binders or binders with high viscosity are recommended when acetate-based deicers are to be used;
- High-quality (sound) aggregates can possibly improve the durability of asphalt pavements in presence of such deicers;
- Asphalt mixes with low void content are also preferred to limit deicer intake in pores.

Important recommendations regarding the airfield application practice of the acetates-based deicers to prevent asphalt damages are summarized below:

- The most secure way is to find substitutes for acetate-based deicers that do not effect the emulsification of asphalt.
- When acetate-based deicers are used, compatibility between the asphalt mixture and the deicers should be tested beforehand;
- When repaving, the wearing course containing residual deicers must be milled away and the recycled asphalt pavement (RAP) should be washed.

Admittedly, this study focuses on acetate-induced asphalt emulsification and subsequent AC deterioration, however it does not elaborate on the degradation of aggregate materials in exposure to acetates, which can also cause adhesion failure at the asphalt-aggregate interface. Suspicious aggregate materials should be eliminated in the mixture design stage. Also, new chemicals such as some Polycyclic Aromatic Hydrocarbons (PAHs) may be produced in the emulsification process, however, chemical changes or new chemicals were not found in the FTIR spectrum of the emulsified asphalt. Actually only slight red shifts could be identified for certain peaks, which however cannot be used to make reasonable judgments. Other analytical methods such as the Mass Spectroscopy (MS) and Nuclear Magnetic Resonance (NMR) spectroscopy may be used to detect the new materials possibly generated in the emulsification process.

More importantly, results from the laboratory study ought to be combined with those of the field investigation to better understand and mitigate the AC deterioration. Some important factors may not be effectively studied using laboratory tests only, such as the scouring effects due to wheel motion and the freeze-thaw cycling effect.
6. REFERENCES


