EXPERIENCES ON THE EFFECTS OF DE-ICING CHEMICALS ON BITUMINOUS AIRFIELD RUNWAYS IN FINLAND

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ABSTRACT

This research was initiated by the damage observed in Rovaniemi and Oulu airfield pavements after the use of new deicing chemicals, acetates and formates. Runway pavements were overlaid in 2000 and in the following year they suffered some severe surface damage in the form of softening of bitumen in the mixture. Both airfields are located at the northern part of Finland. Similar damage has been experienced by other Nordic countries, Sweden and Norway. The scope of the research project, launched at 2003, was to investigate possible factors affecting pavement damage when using these new deicing chemicals and the major objective was to study pavement damaging mechanisms in the laboratory. For verification of laboratory test results, a full scale testing area was constructed in the Kuusamo airfield also located in the northern part of Finland. In addition, in 2001 the Finnish Civil Aviation Administration constructed test sections in the Rovaniemi airfield. Over 30 different laboratory tests were conducted in the project by Helsinki University of Technology and some other laboratories. The major finding was that the durability of asphalt pavements is decreased by the exposure to acetates and formates. To avoid damages, the best way is to use other chemicals instead of acetates or formats. For example, in Rovaniemi test area, 11 test sections from 13 sections experienced some degree of damaged after four years of construction. These study findings might be very important not only in terms of selecting certain maintenance practices but also in terms of preserving sustainable development globally; therefore, studies of pavement damage mechanism exposed to deicing chemicals should be continued . In addition, economical benefits of using current de-icing chemicals should be assessed.

INTRODUCTION

After the introduction of new deicing chemicals, acetates and formates, pavement damage has been observed in several airfields in Finland. In Rovaniemi and Kuusamo airfields, runway pavements were overlaid in 2000 and in the following year they suffered some severe surface damage in the form of softening of bitumen in the mixture. Both airfields are located in the northern part of Finland. Damaged asphalts bitumen was B160/220, which has been generally used in northern part of Finland - in southern part of Finland B70/100 is normally used. Damages has been experienced by other Nordic countries, Norway and Sweden. At Gardemoen and Bergen airports in Norway and Arlanda and Sundsvall airports in Sweden. Problems related to the corrosion caused by de-icing agents have been detected in aircrafts and airfield equipment.

In many cases, soon after overlaying, blisters have been observed in the asphalt pavement. Bitumen has also become staining due to exposure to deicing chemicals and has blemished the runway markings and runway devices. Some loose aggregate material from which bitumen has been washed away has been observed in the old asphalted layer located under the new pavement layer. Some loose aggregate has also been detected on the surface of asphalt pavement. All these problems are causing aviation-safety risks at airfields.

Since 2003, the Laboratory of Highway Engineering at Helsinki University of Technology has studied the destructive effects of de-icers on asphalt pavements and in 2005 they finished the large project on this issue. The major goal of the research was to investigate the possible factors affecting pavement decoration by trying to isolate the damaging mechanism that takes place in the asphalt pavements.

In addition, the effects of de-icing chemicals on material properties were studied. Possible effects were thought to be physical, physico-chemical and chemical. During the project it became evident, that the damaging mechanism was difficult to troubleshoot. Therefore, a new goal of developing a new test method to investigate the compatibility of asphalt pavement and de-icing chemical was established. This would allow better understanding of pavement damage mechanism, which would prevent premature damages and save maintenance and rehabilitation costs.

The research approach was to study mixture components first to find some clues of the damage mechanism. Studies in Norway and Sweden have showed that the pH level of de-icing solutions has an affect on how aggressively these chemicals attack the pavement. The research was divided into laboratory tests and large scale field testing. Laboratory tests included testing bitumen behavior, mineral aggregates, interaction between aggregate and bitumen, and the effects of overlaying. Field test sites were in Kuusamo airfield, where 10 different test sections with different asphalt mixtures were constructed in 2004, and in Rovaniemi, which was constructed in 2001. Test sections consist of 12 different asphalt mixtures.

This paper covers the major findings of the project and discusses some new ideas emerged form the project. Since the damage of the runway asphalt pavements is quite random and localized and the damage mechanism seems to be very complex, the overall damage theory is yet to be developed.

LABORATORY TESTS ON THE MIXTURE COMPONENTS

First, the bitumen behavior was investigated using four different experiments. The Laboratory of Organic Chemistry in the Helsinki University of Technology conducted experiment where bitumen was boiled with different deicing chemicals and concentrations and then tested using gas chromatograph. Study was unable to find differences between the original bitumen and boiled bitumen. Sample weight clearly decreased in the boiling process; however, reason for this is unknown. The chemical analysis report can be downloaded from the website by Laboratory of Highway Engineering.

In the Laboratory of Organic Chemistry tests were conducted where changes in pH levels of bitumen and de-icing solution were tested in an experiment that lasted one month. Study did not find remarkable changes.

The physico-chemical properties and their effects on bitumen were studied by Nynas ltd. Studies showed that chemicals were penetrating into the bitumen due to a significant density difference. Also, interfacial tension between bitumen and chemicals was examined; results are shown in Table 1. The conclusion of the experiment was that chemicals decrease surface tension which facilitates substantial penetration of water and chemicals to the bitumen and mineral aggregate. Forming of emulsion was tested in the Laboratory of Organic Chemistry and Nynas ltd. Studies found that the bitumen was emulsifying less when solution was more concentrated.

Experiments showed that formate-water solution was dispersing into bitumen as small droplets, while it was hard to mix pure water into bitumen, see Figure 2. The bond between aggregate and bitumen-formate blend seemed to be much weaker than the bond between bitumen-water blend. The bitumen-formate blend was also much tarnishing.

Table 1.
Interfacial Tension Between Chemical and Bitumen B160/220 in 90°C.

Tested fluid	Interfacial tension, mN/m
Water	22
Meltium (Potassium formate), 5 w-%	6
Meltium, 50 w-%	5,5
Safeway KA (Potassium acetate), 5 w-%	6,5
Safeway KA (Potassium acetate), 50 w-%	10

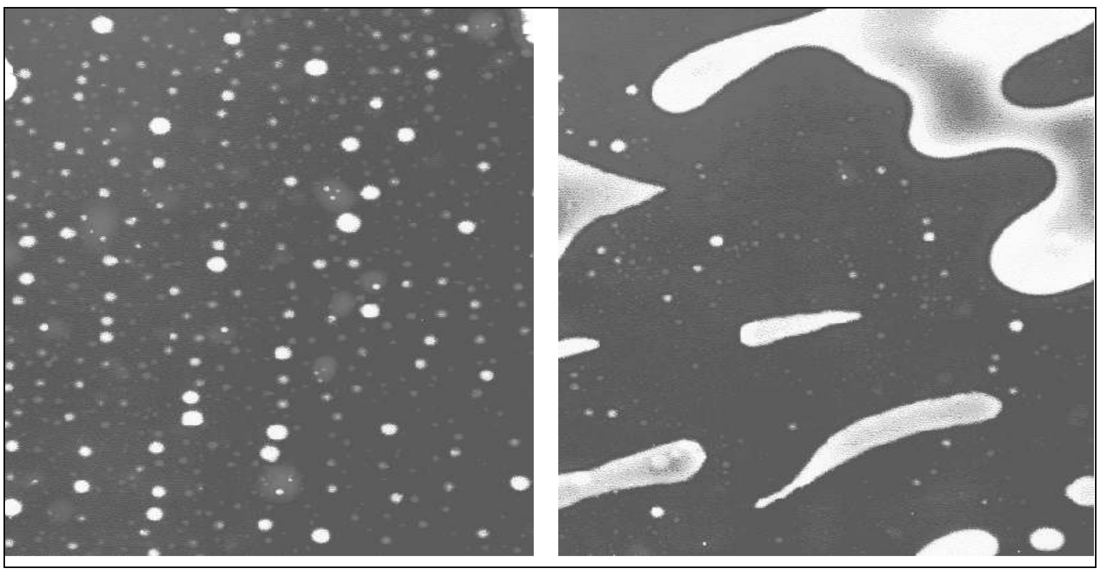

Figure 1. Formate-Water Solution Blended into Small Drops in Bitumen, When it was Hard to Mix Pure Water into Bitumen.

The Laboratory of Highway Engineering examined aggregates decomposition sensitivity with absorption test. The result shows that the type of the aggregate and chemical have an effect to absorption and the decomposition sensitivity. However results did not exceed limit value and aggregates were not intense to decomposition. One discovery was that some neutralization is taking place between chemicals and felsic aggregate. Neutralization increases the sensitivity of the decomposition.

The major findings are that acetic aggregates decomposition level is higher than the one of caustic aggregates when exposed to de-icing chemicals. Since second item was meant to be concise, detailed mineral effect could not estimate exactly.

The third item of research was to examine interaction between bitumen and mineral aggregate exposed to de-icing chemicals. The very first experiment was to evaluate effect of de-icers density to bituminized aggregate. When testing pure bitumen the same phenomenon perceived was also iron out in this test: The higher density of chemical the more effect to emulsify bitumen. When exposed to de-icers some lightweight carbon hydrides are being loosen from bitumen.

Nynas ltd. examined the stability of asphalt mixture in water with Vändskak-test. Test is conducted by first exposing fine compacted asphalt mixture to water under vacuum, storing mixture at 40 °C with 48 hours and then rolling the mixture 3600 times in a flask filled with water or deicing solution. The measured quantity is the weight loss of the sample. The weight loss was greatest for samples exposed to solution of 14 pH. The weight loss of samples exposed to 5 % diluted deicing chemicals solutions was similar compared to reference samples exposed to water, see Figure 2. The Rolling bottle test results, discussed later, agreed with the Vändskak-test results. The deicer exposed asphalt samples were notably softer and staining than the ones exposed to water.

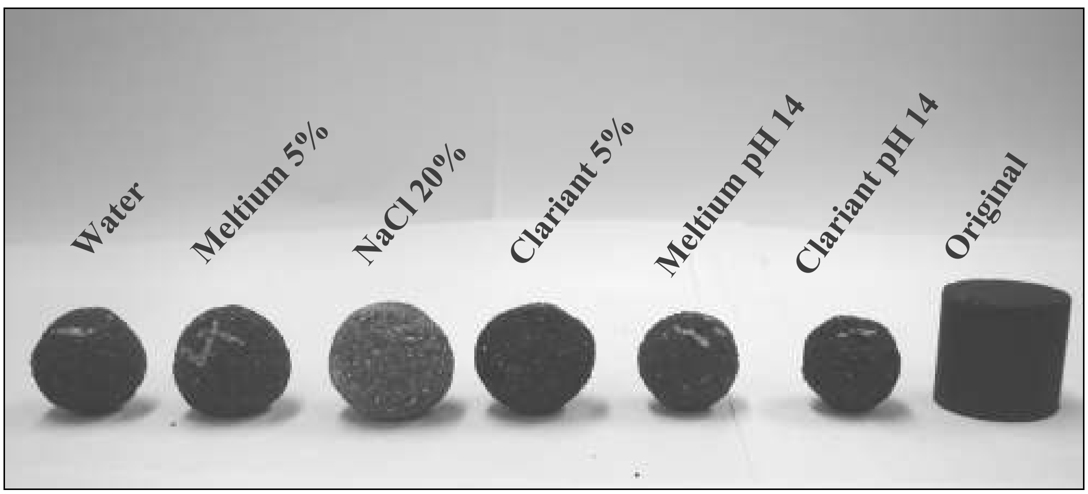

Figure 2. Test Specimens After the Vändskak Test. Meltium is Potassium Formate and Clariant is Potassium Acetate.

The Laboratory of Highway Engineering tested changes that occurred in bituminized aggregates when boiled in a solution of deicing chemicals at 100°C. This test tried to simulate the heat peak caused by overlaying and it was expected to be closest to the real damage mechanism of pavements. Two versions of the boiling test were used. In the first version, bituminized aggregates were boiled one minute in the solution. After boiling aggregates were pored to the filter paper, see Figure 3. Binder content and stripping of aggregates was then evaluated and changes in the bitumen content compared to the original content are shown in Figure 4. In addition, bituminized aggregates were also analyzed with gas chromatograph by Laplands Water Research Ltd. With this gas chromatograph analysis method only the lightweight hydro carbon compounds (up to C_{40}) could be detected.

The boiling test showed that even 1 to 5 % diluted deicer solutions caused stripping of binder and also affected the distribution of hydrocarbons, which is in agreement with literature. Farha [2] has noticed that diluted solutions (1 to 2 %) are more aggressive than solutions of 50 %. From the boiling test it is suggested that the formate is more aggressive than the acetate: binder content changes more when boiled in the formate than in the acetate.

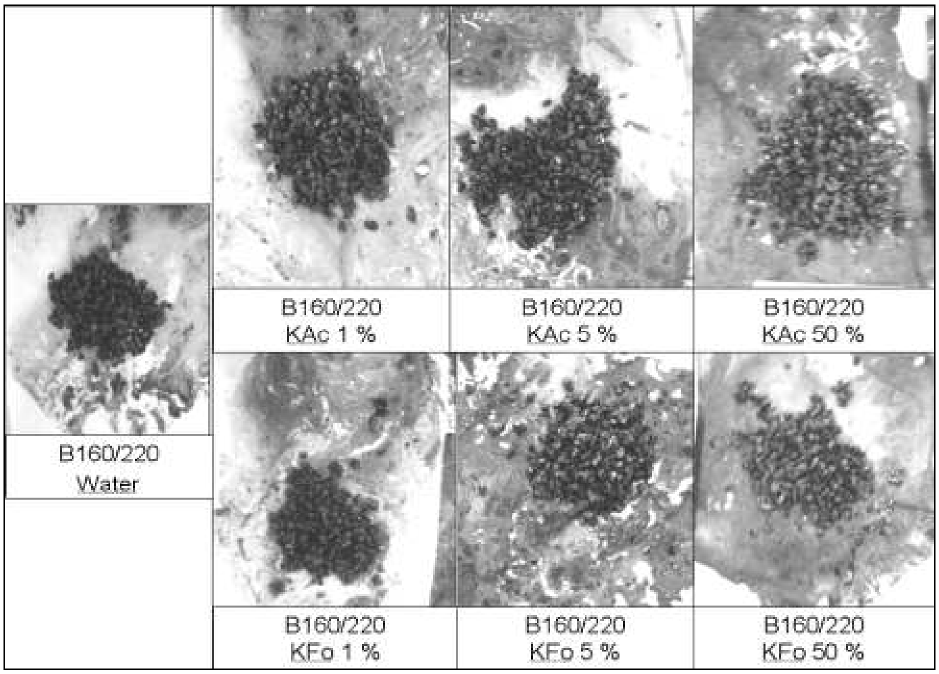

Figure 3: Open Beaker Boiling Test with Bitumen B200. (Even a 1 w-% solution of de-icer has an effect on the bitumen content.)

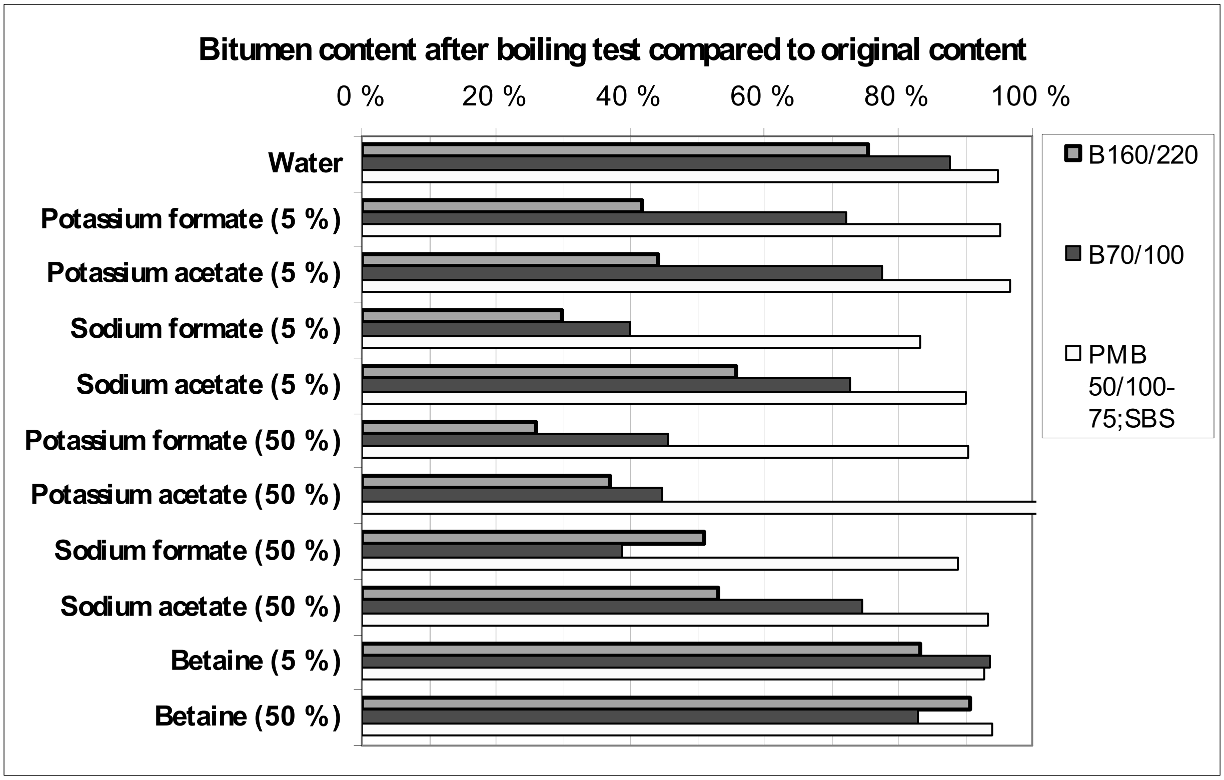

Figure 4. Bitumen Content After the Boiling Test.

From the boiling test it is suggested that the formate is more aggressive than the acetate: binder content changes more when boiled in the formate than in the acetate. Tests also suggest that the higher the concentration of solution the more changes occurred in the bitumen. Tested bitumen was B160/220, B70/100 and rubber modified bitumen PMB 85. More changes occurred with softer bitumen and rubber bitumen remained practically unchanged.

Gas chromatograph tests of bitumen obtained from the aggregate surface showed that small amounts of PAH compounds were forming. This unexpected result was repeated by investigating several core samples obtained from airfield pavements. It is possible that some hydrogen bonds in the largest bitumen molecules (where for example is over 30000 carbon atoms) are breaking. Verification of this hypothesis needs complex chemical analyze of bitumen. Without gas chromatogram analysis, changes in PAH compounds may not have been detected.

Since the residue of the first version of the boiling test was only coated aggregates, another test was performed using closed bottles to collect the binder stripped off the aggregates. In this test bituminized aggregates were heated in the oven at three different temperatures of 40, 70 and 100°C to investigate at which temperature the distribution of hydrocarbons in the bitumen start to change. Bottles were heated to the target temperature, kept in the oven for one minute, and then bottles were allowed to cool to back to room temperature. Testing consisted of using 5 % potassium formate solution and three types of bitumen. These samples are shown in two columns on the right hand side of Figure 5 while samples in the first column are in pure water. At target test temperature of 100 °C results were similar to the first version of the boiling test. Some small changes in the chemistry of bitumen were also detected between 70 and 40 °C temperatures. Similar to the first version of the boiling test, PAH compounds were detected also in the bottle test. The increase in the amount of PAH compounds agree with test results obtained from the runway samples.

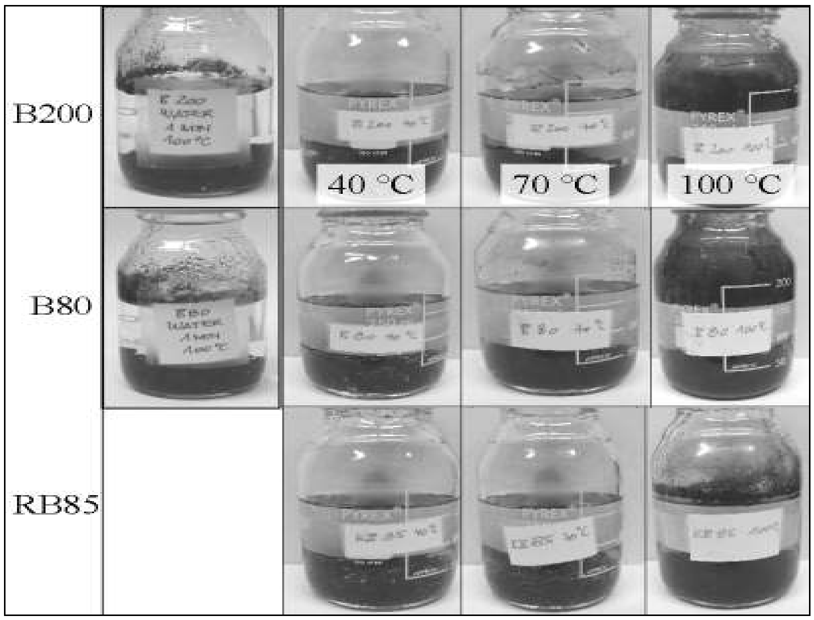

Figure 5. Samples in the Bottle Test. (Matrix 3x3 on the right are 5 w-% formate solutions and two bottles on the left are pure water solutions.)

LABORATORY TESTS ON ASPHALT MIXTURE

The fourth part of the research project focused on testing asphalt mixture samples fabricated in the laboratory or taken from the field test sections. Testing included indirect tensile strength (IDT) tests performed in the HUT and Nynas ltd. laboratories. Tests were conducted for asphalt samples exposed to deicers and conditioned with freeze-thaw cycles. Nynas ltd. made splitting tensile strength experiments only for samples exposed to deicers. Tests were done in water and 50% concentration of potassium formate solution and maximum curing period was three months. Asphalt mixture was an open graded asphalt concrete, maximum grain size 11 mm, bitumen Pen 70/100, binder content was 5.3 % and air void content was 18 %. Main result was that water or 50 % potassium formate had no effect on strength of the mixture after thee months of curing time. The conducted test was static, which may not describe the real pavement conditions with dynamic stresses and changes of temperature. Because of this Highway Engineering Laboratory added the freezing-thawing cycle for conditioning samples. Differences between water and deicers were not detected in the static tests. Nynas Co. also performed dynamic creep test but results from different test series were contradictory. However, one logical result was obtained: samples exposed to acetate were softer than the ones exposed to water and formate exposed samples were the softest.

Field observations suggest increased pavement damage when old pavements exposed to deicers have been overlaid. To study this in the laboratory, HUT prepared asphalt samples in metal moulds and then exposed them to deicing chemicals. After exposure a new layer of mixture was laid over the previous layer and compacted in the mold. Cooled samples were then sawn into two pieces. Visual inspection of dried samples showed that unexposed saw cut surface was light colored and clean but the surface exposed to chemicals was dark colored and dirty looking, see Figure 6. Similar phenomenon had been observed in the field.

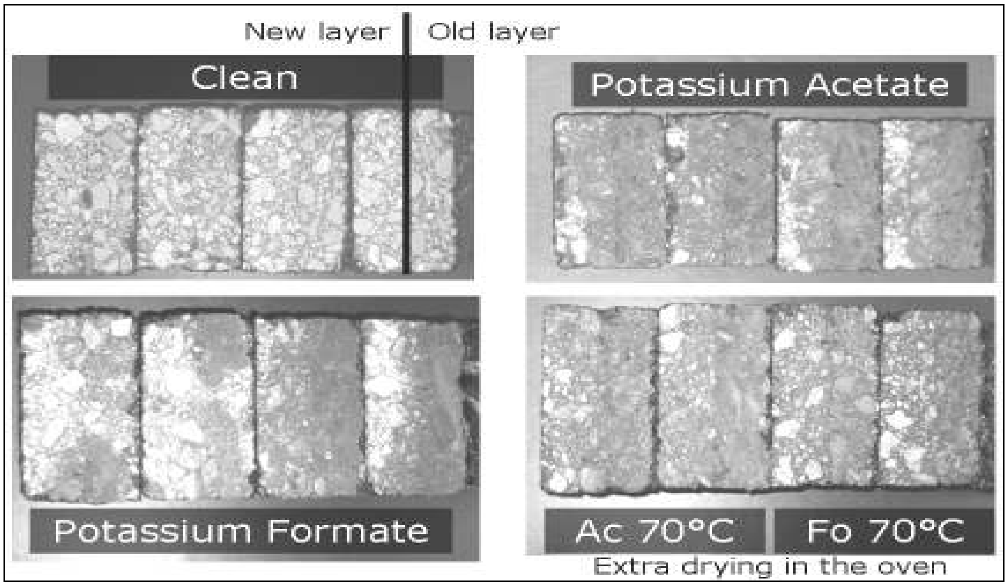

Figure 6. Sawed Asphalt Core Samples, Where Effect of the De-icers Could be Perceived Easily.

Asphalt samples drilled from the runaway of Helsinki-Vantaa airport showed significant damage and softening of mixture especially at deeper in the pavement layer. Base layers were so soft that pieces from mixture could be broken off by hand. Samples also had strong odor. Samples were analyzed for contents of acetate, formate and urea, pH and electrical conductivity, hydrocarbon and PAH compounds. Samples contained small amounts (class ppm) of de-icing chemicals and pH of samples were quite high (8.9-11.6). The PAH compound content was remarkably high in one sample.

FIELD EXPERIMENTS

The Kuusamo airfield test area is located at northern Finland where the ultraviolet radiation and temperature variations are extreme throughout the year. Ten different test sections were constructed in 2004. Research variables included filler, bitumen, mineral aggregate and voids content. These variables were selected to investigate mixture properties which could produce better resistance to damage caused by deicers. Old pavement surface was covered by Potassium formate (Meltium) which was spread before paving using 400 g/m2. In the following winter 700 g/m2 of potassium formate (Clearway KF HOT) was used as anti-skid treatment.

Test area was visually inspected by HUT after one year of construction. Four relatively small areas potential for damaged by deicers were detected. Additional damage caused by heating oil was also detected. These areas were deliberately treated with heating oil during construction, and the ”finger print” of the heating oil used was detected by the gas chromatograph analysis conducted one year after construction. Since the amount of damage caused by deicers was relatively low, conclusions about damage resistant mixture properties could not be made. However, based on the formation of early damaging, it is expected that damaging will continue in the future.

In 2001 Finnish Civil Aviation Administration (FCAA) constructed 12 hot mix asphalt test sections to Rovaniemi airfield, where the first damages of runway pavements had been detected earlier. Research variables included simulated traffic loading, mix type (dense graded and SMA), aggregate type (felsic and mafick), bitumen grade and additives (B160/220, B70/100, B70/100+gilsonite and rubber bitumen), filler type (calcium carbonate and baghouse fines) and bonding between the new asphalt layer and old surface. Each test section was divided into four areas of deicing chemical exposure: formate (solid and liquid), acetate (solid and liquid), liquid formate, and liquid acetate. In the study, the total amount of chemicals used was equivalent of deicing treatment of 15 winters. The amount used was 6500 to 7800g/m2 of 50 % liquid solution.

Indirect tensile strength and stiffness of the control and exposed mixtures were studied after one year and two years of exposure of deicers. The strength of mixture with quartz rich mineral aggregate was lower than that of mixture made of alkaline aggregate. However, the strength and stiffness of mixtures exposed to different deicers were quite similar and based on FCAA no significant differences were detected. Based on FAA’s inspections at 2004, the most important finding of the experiment was that all test sections withstood the heavy exposure to chemicals without any damages. It should be noted though, that the use of chemicals was different than the exposure in the normal anti-skid treatment would be: pavement was new and exposure took place in accelerated manner as worth of 15 years of deicing chemicals were used in two years.

In 2005, a visual inspection of test site at Rovaniemi was conducted by HUT; based on the report, almost every test section showed some degree of surface damage, see figure 7, and the only test section without damage was composed of alkaline mineral aggregate with B70/100+gilsonite binder. Core samples were taken from four damaged spots of the pavement surface, see Figure 8-a. Two of the mixtures had acetic aggregate and two were alkaline aggregate. Bitumen like substance bleeding from the specimens was very soft, see Figure 8-b, and it has stayed soft till today.

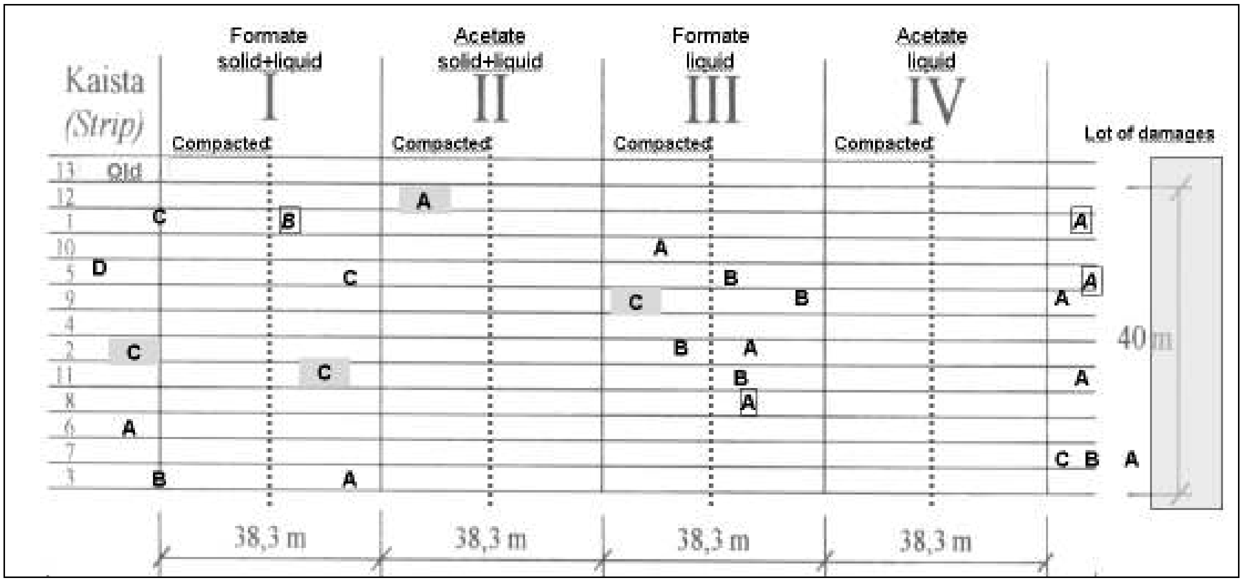

Figure 7. Location of damage in the Field Test Area in Rovaniemi.

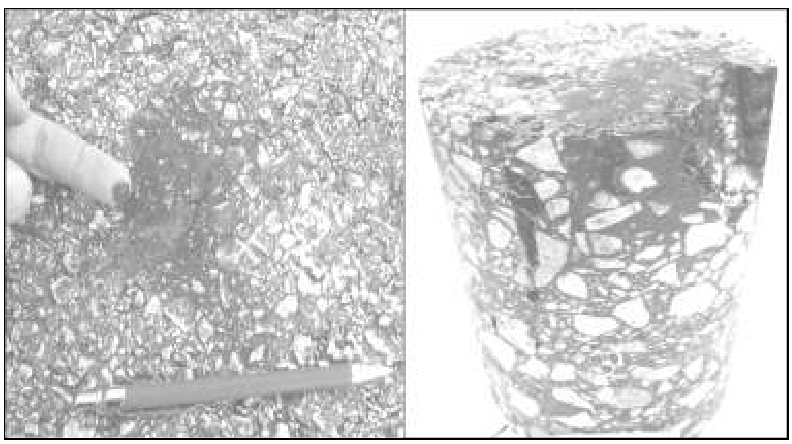

Figure 8. Damage “A” at Strip 5. (At room temperature, bituminous fluid trickled from the side of the asphalt core sample. Bitumen was so soft that it stuck to the finger.)

THE DEVELOPMENT OF DE-ICING CHEMICAL RESISTANT ASPHALT PAVEMENTS

The most reliable way of avoiding pavement damages is to avoid using acetates and formates as anti-skid treatment. If they are to be used, one way of mitigating pavement damage seems to be using polymer modified bitumen or harder i.e., more viscous bitumen (B70/100 or harder). The type of mineral aggregate is also essential when designing chemical resistant pavements. Type of mineral aggregate is also essential when considering chemical resistant pavements. Mineral aggregate should not be prone to chemical or mechanical weathering and it should be mafic. The extent of damage in the existing pavement layers exposed to the deicing chemicals should be examined before overlaying and damaged areas should be removed by milling.

Recycling of deicer contaminated asphalt mix should not be allowed without first confirming that the mixture is not hazardous.

CONCLUSIONS

One of the aims of the study was to study the damage mechanisms of pavements exposed to deicing chemicals. Based on the studies, the high density and low surface tension of deicing chemical facilitates the penetration of these chemicals to the bitumen and aggregate interface. In addition, deicers are highly hydroscopic causing the exposed pavement stay wet which in turn makes pavements prone to moisture damage. The analysis of hydro carbon compounds suggests that some chemical changes take place in the bitumen exposed to chemicals. Increased PAH compound contents were detected in many different experiments. The increase in PAH compounds was associated to heat peak of exposed pavement. The PAH-compounds are carcinogenic and very poisonous but they will not dissolve to water.

Studies also suggest that a sufficient heat peak is required in addition of chemical exposure to cause damage. Field experiments in Rovaniemi and Kuusamo test sites showed some different rates of damaging for acetate and formate. In Rovaniemi test area damages started to be visible after four years of construction. However, if acetates and formates are used together, it is possible the PAH-compounds are dissolving to acetic acid which may allow PAH-compounds to migrate environment and ground water. What is not known is if the PAH-compounds are dissolving to the formic acid. Laboratory tests of contaminated pavements suggested that the deicing chemicals were migrating from contaminated layer to the new pavement layer above. Pavement damages are not the only issue associated to the use of acetates and formates. Problems related to the corrosion have been detected especially in aircrafts and airfield equipment.

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