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Effect of anti-icing chemicals on stripping of asphalt concrete mixtures for airport runway wearing courses / Santagata, Ezio; Baglieri, Orazio; Riviera, PIER PAOLO. - STAMPA. - (2013), pp. 1229-1239. (2013 Airfield & Highway Pavement Conference Los Angeles, CA, USA June, 9-12 2013) [10.1061/9780784413005.104].

Availability:

This version is available at: 11583/2505180 since:

Publisher:

ASCE - American Society of Civil Engineers

Published

DOI:10.1061/9780784413005.104

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Effect of anti-icing chemicals on stripping of asphalt concrete mixtures for airport runway wearing courses

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ABSTRACT

As part of a wider research project for the study and development of a system for the prediction, monitoring and management of meteorological winter emergencies in airports (Airport Weather Information System, AWIS), the experimental investigation reported in this paper focused on damage phenomena caused by anti-icing chemicals on asphalt concrete mixtures for airport runway surface courses, with an emphasis placed upon stripping. Asphalt mixtures derived from the combination of aggregates of two different mineralogical types (basaltic and siliceous) and two bituminous binders (one neat bitumen and one SBS polymer modified binder). The testing program included determination of aggregate-binder affinity, indirect tensile strength and fracture properties. A potassium formate solution was employed as anti-icer. Obtained results indicated that anti-icing treatments may promote stripping phenomena to an extent which depends on aggregate and binder type.

INTRODUCTION

Winter maintenance operations play a crucial role in ensuring safety and efficiency of any airport located in cold-climate regions. For this purpose, significant amounts of anti-icing chemicals are spread every year on airfield paved surfaces in order to prevent ice and snow formation.

In recent years, traditional products such as urea and glycol-based chemicals have become less diffused due to their hazardous environmental impacts. In fact, it has been demonstrated that urea causes eutrophication and oxygen depletion in water

environments while glycol-based products increase biochemical oxygen demand (BOD) and carcinogenic effects to stream fauna (D'Itri 1992, Kalevi et al. 2011, Fay et al. 2012, Shi 2008, Corsi et al. 2009 and 2012, Sulej et al. 2012).

The abovementioned drawbacks have promoted the use of acetate and formate based salts as alternative chemicals which, even if more expensive than traditional ones, seem to be less toxic and more effective at lower temperatures (Shi 2008, USEPA 2000, Christensen et al. 2007 and 2010, Comfort 2000, Hellstén et al. 2005). However, the occurrence of premature deterioration of runway asphalt pavements has been observed in many airports after moving from traditional to alternative anti-icing products, commonly in the form of binder softening associated to stripping and raveling (Pan et al. 2006, Edwards et al. 1999, Nilsson 2003, Alatypö et al. 2007).

Several laboratory and field studies have been carried out by researchers to evaluate the impact of acetate/formate-based chemicals on asphalt concrete mixture properties (Christensen et al. 2010, Nilsson 2003, Hassan et al. 2002, Nilsson 2006, Santagata et al. 2009). From the findings of these studies it can be concluded that anti-icing chemicals have detrimental effects on aggregates, binders and aggregate-binder adhesion. Chemical reactions, distillation and emulsification have been identified as main phenomena which contribute to pavement damage (Alatypö 2005, Pan et al. 2008).

With respect to aggregate-binder adhesion, Christensen et al. (2010) found that, depending on chemical type and concentration, the new generation of anti-icers tends to increase moisture damage and susceptibility to stripping of asphalt concrete mixtures. Other factors that may influence material deterioration include aggregate type, binder chemistry and/or modification, mixture permeability and volumetrics.

The main objective of the experimental investigation reported in this paper was to investigate the effects caused by a potassium formate anti-icing solution on asphalt concrete mixtures for airport runway surface courses, with an emphasis placed upon susceptibility to stripping.

The study was carried out as part of a wider research project for the development of a system for the prediction, monitoring and management of meteorological winter emergencies in airports (Airport Weather Information System, AWIS).

Asphalt mixtures derived from the combination of different component materials (two aggregate types and two bituminous binders). Testing included determination of aggregate-binder affinity, indirect tensile strength and fracture properties.

Experimental results obtained from mixtures conditioned in water and in the potassium formate solution were compared to each other and the magnitude of damage caused by the anti-icing chemical was assessed in relative terms.

MATERIALS

The anti-icing chemical used in the experimental investigation described in this paper consisted of a commercially available potassium formate (KF) solution (50% concentration) which has been routinely employed for winter maintenance operations in several airports located in north-western Italy. The product contains no glycol, urea or triazoles; it is formulated with corrosion inhibitors and conforms to AMS 1435A compatibility requirements as specified by the supplier.

Two aggregate types differing in mineralogical characteristics and two bituminous binders were employed as component materials for the preparation of wearing course asphalt concrete mixtures.

Mineral aggregates included silica (Si), supplied in three size fractions (0/4, 3/8, and 8/15 mm), and basalt (Ba), supplied in a single size fraction (4/10 mm).

The bituminous binders were a standard 70/100 penetration grade bitumen (NB) and a SBS polymer modified binder (PMB). Both binders were subjected to preliminary rheological characterization in order to determine Performance Grade in accordance to AASHTO M320. Obtained results are reported in Table 1.

Table 1. Bituminous binders used in the investigation

Binder code	Description	Penetration Grade	PG
NB	Neat	70/100	58-22
PMB	Modified with SBS	50/70	76-22

Two different wearing course asphalt concrete mixtures (Mix A-NB and Mix B-PMB) were made from the component materials. Both mixtures were specifically designed for runway maintenance works of a major Italian airport and were produced by a specialized contractor in a standard hot mix asphalt plant.

The job-mix formula of Mix A-NB was constituted by a blend of the three silica size fractions (gradation A) combined with the standard binder NB at a dosage of 5.7% (on the dry weight of aggregates).

In the case of Mix B-PMB, the aggregate blend (gradation B) resulted from the combination of two silica size fractions (0/4 and 8/15 mm) and the single basalt size fraction (4/10 mm) with PMB at 5.4% dosage.

Compositions and aggregate gradations of the two asphalt concrete mixtures are summarized in Table 2 and Figure 1.

Table 2. Aggregate fractions, binder types and binder contents used for the preparation of the wearing course asphalt concrete mixtures

Wearing course asphalt concrete mixture	Aggregate fractions	Binder type	Binder dosage
Mix A-NB	Si 0/4 mm Si 3/8 mm Si 8/15 mm	NB	5.7 %
Mix B-PMB	Si 0/4 mm Ba 4/10 mm Si 8/15 mm	PMB	5.4 %

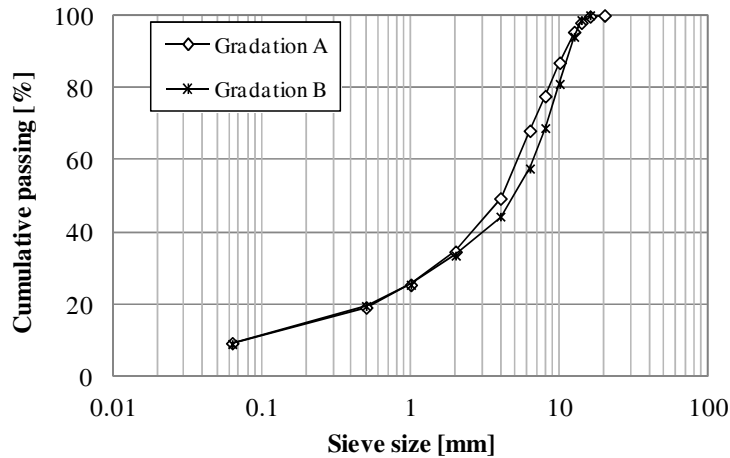


Figure 1. Aggregate gradations of the wearing course asphalt concrete mixtures

METHODS

Damage caused on asphalt concrete mixtures by the anti-icing chemical was evaluated by means of laboratory tests carried out both on loose blends and compacted specimens. In particular, the testing program included the determination of affinity between aggregate and binder for loose blends, and the determination of mechanical characteristics such as indirect tensile strength and fracture properties for compacted specimens.

Affinity between aggregate and binder provides a direct assessment of susceptibility to stripping of the mixtures. Tests were carried out following the static method specified by European standard EN 12697-11:2012. Aggregate samples constituted by a given number of stone particles (at least 150) passing the 10 mm and retained on the 6 mm sieve were mixed with a predefined amount of binder, equal to 4% by dry weight of aggregates. Four different blends were obtained from the factorial combination of aggregates types and bituminous binders (Si-NB, Si-PMB, Ba-NB, Ba-PMB). The abovementioned standard requires materials to be conditioned in distilled water; in this study the same procedure was adopted in the case of the anti-icing solution. As a consequence, two samples of each blend were submerged in distilled water and potassium formate solution, respectively, and stored for 48h at 19°C. Affinity was expressed in terms of degree of binder coverage by visually registering the number of particles with an incomplete coating after storage.

Indirect tensile strength and fracture properties were used as surrogates to evaluate water and anti-icer sensitivity of the two asphalt concrete mixtures considered in this study.

Indirect tensile strength was determined according to EN 12697-23:2003. Cylindrical specimens (150 mm diameter, 60 mm height) were prepared by using a gyratory shear compactor (GSC) at a target void content fixed at 4.4%, which corresponds to the design void content required in the field by airport authority specifications. Measurements were performed at a displacement rate of 50.8 mm/min and at a temperature of 20°C both on specimens subjected to no treatment (dry) and on those

which were conditioned for 7 days at 20°C either in distilled water (W-7D) or in the potassium formate solution (KF-7D). Three replicates were carried out for each type of treatment.

An indirect tensile strength ratio (ITSR) was then calculated as follows:

$$\text{ITSR (\%)} = \frac{\text{ITS}_{\text{W-7D (or KF-7D)}}}{\text{ITS}_{\text{dry}}} \cdot 100$$

where $\text{ITS}_{\text{W-7D}}$ and $\text{ITS}_{\text{KF-7D}}$ are the average indirect tensile strength values obtained after conditioning and ITS_{dry} is the average tensile strength obtained with no preliminary treatment.

Fracture properties of the mixtures were evaluated in terms of resistance to crack propagation by means of the Semi-Circular Bending (SCB) test method, according to EN 12697-44:2010. Semi-circular specimens (25 mm thickness) with a centre notch (0.35 mm width, 10 mm depth) were made by cutting GSC cylindrical samples compacted at the same target void content of indirect tensile strength test specimens. Four semi-circular notched specimens were obtained from each cylindrical sample. SCB tests were performed at a displacement rate of 5 mm/min and at a temperature of 20°C on untreated specimens (dry) and on specimens previously subjected to three different types of treatment: storage in distilled water for 24h at 20°C (W-24h), storage in potassium formate solution for 24h at 20°C (KF-24h), storage in potassium formate solution for 24h at 20°C plus 24h at 50°C (KF-48h). In this last type of treatment the introduction of an additional conditioning phase at an increased temperature aimed to reproduce thermal conditions in which damaging effects induced by anti-icing chemicals can be significantly promoted (Edwards et al. 1999, Alatyppö et al. 2007, Hassan et al. 2000). Three replicates were carried out both for untreated and treated specimens. A fracture toughness ratio ($K_{\text{IC}}\text{R}$) was calculated from average fracture toughness (K_{IC}) values obtained both for conditioned and untreated specimens as follows:

$$K_{\text{IC}}\text{R (\%)} = \frac{(K_{\text{IC}})_{\text{W-24h (or KF-24h or KF-48h)}}}{(K_{\text{IC}})_{\text{dry}}} \cdot 100$$

EXPERIMENTAL RESULTS

Binder-aggregate affinity

Results obtained from aggregate-binder affinity tests are summarized in Table 3, which reports the number of particles with an incomplete coating after storage and the degree of binder coverage for the four blends considered in the study. It can be observed that no stripping phenomena occurred after storage in distilled water, thus indicating a good affinity of each aggregate-binder combination. However, aggregate-binder adhesion in all cases appears to be greatly affected by the interaction with salt.

Table 3. Binder-aggregate affinity test results

Blend	Conditioning (48h @ 19°C)	Particles with an incomplete coating after conditioning (-)	Degree of binder coverage (%)
Si-NB	Distilled Water	0	100
	KF solution	25	83
Si-PMB	Distilled Water	1	100
	KF solution	33	78
Ba-NB	Distilled Water	0	100
	KF solution	21	86
Ba-PMB	Distilled Water	0	100
	KF solution	37	75

Such an evidence can be related with the well-known capability of chemicals of penetrating through the binder matrix with subsequent emulsification and simultaneous neutralization of carboxylic acids (which contribute to the development of bond to aggregate surfaces) (Christensen et al. 2010, Alatyppö 2005).

By comparing the blends to each other, it can also be observed that the effects produced by the anti-icing solution on adhesion properties mainly depend on binder type rather than on the aggregates mineralogy. The most severe damage was recorded for Si-PMB and Ba-PMB blends, indicating the SBS modified binder to be more sensitive to the presence of salt than the unmodified one. This is in contradiction with expectations, since binders with high viscosity as polymer-modified binders are believed to improve the resistance to anti-icers (Pan et al. 2008).

Indirect tensile strength

The values of ITS and ITSR obtained from indirect tensile strength tests carried out on the asphalt concrete mixtures are reported in Figure 2 and Table 4, respectively.

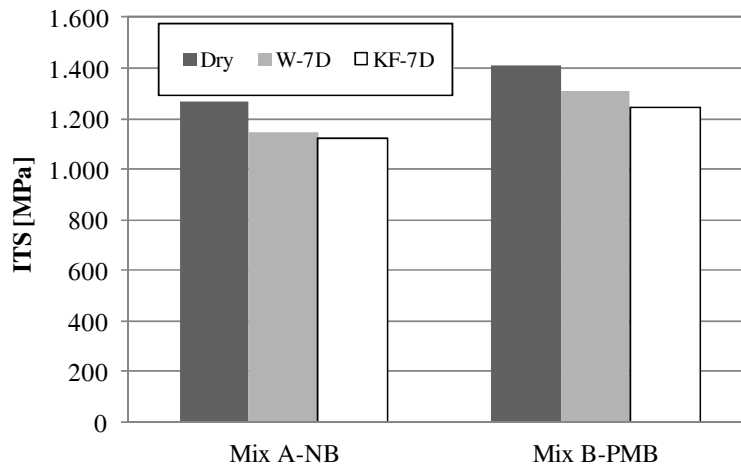
**Figure 2. Average indirect tensile strength obtained for asphalt mixtures**

Table 4. Indirect tensile strength ratios

Wearing course asphalt concrete mixture	ITSR (%)	
	W-7D	KF-7D
Mix A-NB	90.4	88.3
Mix B-PMB	92.8	88.6

Even though no stripping phenomena after water conditioning were registered in aggregate-binder affinity tests, average ITS measured on W-7D specimens decreased with respect to dry specimens. This can be due to the longer duration of storage in water (7 days versus 48 hours) which allows moisture damage to occur within the mixtures. A decrease of ITS values was also observed on KF-7D specimens. In addition, Mix B-PMB showed higher ITS values than Mix A-NB regardless of the type of conditioning.

The magnitude of strength reduction, as indicated by ITSR values, was higher in the case of potassium formate conditioning with respect to water conditioning (11.7% against 9.6% for Mix A-NB, 11.4% against 7.2% for Mix B-PMB). However, very small differences in ITSR values were observed between Mix A-NB and Mix B-PMB when comparing results obtained after the same type of treatment, thus revealing a negligible influence of binder type on mixture susceptibility both to water and anti-icing chemical.

This seems to be partially in conflict with the results of the abovementioned affinity tests. A higher loss in strength properties was expected in the case of KF-7D specimens of Mix B-PMB with respect to those of Mix A-NB, due to the weaker bond with aggregates exhibited by the SBS polymer modified binder after being stored in potassium formate solution (see Table 3).

A coherent interpretation of the entire set of experimental data requires two factors to be taken into account. The first factor relates to the use in Mix B-PMB of basaltic stone particles in partial substitution of siliceous ones, with the consequent formation of a tougher aggregate skeleton. The second factor relates to the use of the polymer modified binder, whose higher stiffness and strength counterbalance the detrimental effects of the potassium formate solution. In conclusion, the combined effects of a stronger aggregate structure and a stiffer binder overcome the lack in binder-aggregate adhesion properties of Mix B-PMB in the presence of salt, resulting in an overall improvement of material strength and resistance to the anti-icing chemical.

Fracture properties

The values of K_{IC} and K_{ICR} obtained from semi-circular bending tests are reported in Figure 3 and Table 5, respectively. The 24h storage in distilled water produced no substantial effects on the fracture properties of both mixtures (in the case of Mix B-PMB, the increase of average K_{IC} value of W-24h specimens with respect to dry specimens can be attributed to variability in sample preparation and testing). Thus, based on the analysis of ITS and SCB data, it can be stated that a sufficiently long period of storage is needed to induce a certain level of moisture damage in the materials.

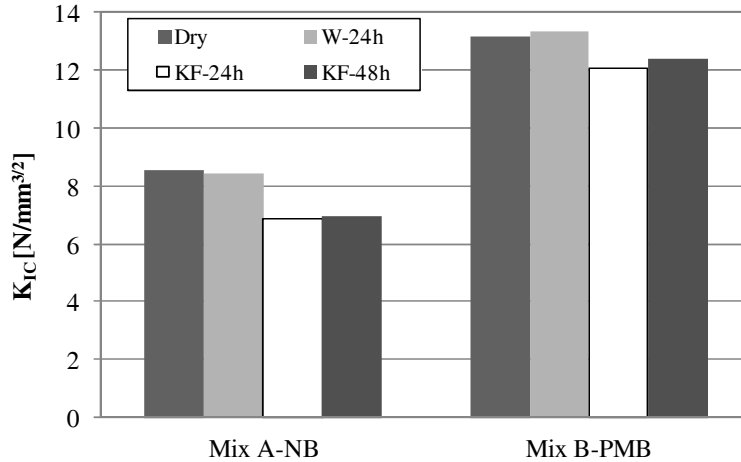


Figure 3. Average fracture toughness obtained for asphalt mixtures

Table 5. Fracture toughness ratios

Wearing course asphalt concrete mixture	K _{IC} R (%)		
	W-24h	KF-24h	KF-48h
Mix A-NB	99.0	80.7	81.7
Mix B-PMB	101.4	92.0	94.3

On the contrary, detrimental effects caused by the anti-icing chemical occur more quickly. As indicated by K_{IC}R values, after 24 hours a reduction of fracture toughness of the order of 20 and 8% was recorded for Mix A-NB and Mix B-PMB, respectively. K_{IC}R values also reveal that the increase of conditioning temperature (from 20 to 50°C) and storage duration (from 24 to 48 h) produced small variations in fracture properties.

In accordance with ITS data, Mix B-PMB exhibited a superior performance than Mix A-NB regardless of the type of conditioning.

CONCLUSIONS

The experimental study described in this paper focused on the effects caused by a potassium formate based anti-icing chemical on asphalt concrete mixtures for runway wearing courses, with an emphasis placed upon stripping. On the basis of the results obtained from testing the following conclusions can be drawn:

- The anti-icing solution produced a significant loss in aggregate-binder adhesion for each aggregate-binder combination considered in the investigation. In contrast with expectations, the magnitude of stripping was higher for blends containing the SBS polymer modified binder with respect to those containing the neat binder.

- Mechanical properties of asphalt concrete mixtures, expressed in terms of indirect tensile strength and fracture toughness, were reduced after storage in the formate solution. A higher degree of damage was induced by the anti-icer with respect to water.
- Damaging effects produced by the anti-icing solution occurred more quickly than those caused by water and were not affected by increasing conditioning temperature.
- Susceptibility to the anti-icing chemical, as measured by indirect tensile strength ratio and fracture toughness ratio, was lower for the mixture containing the SBS polymer modified binder. For this mixture it was supposed that the stronger aggregate skeleton and stiffer binder could overcome the poor adhesion properties in the presence of salt.

This limited study needs to be completed by extending the investigation to a wider range of asphalt concrete mixtures and anti-icing chemicals. Evaluation of the effects of anti-stripping additives is also recommended.

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