Airport Cooperative Research Program (ACRP)

Synthesis 6 – Impact of Pavement Deicing Products on Aircraft and Airfield Infrastructure

Presented to: **SWIFT Conference, 2009**

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Date: September 14, 2009
Toronto, Canada

Overview

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- **PDP 101**
  - Types
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- **PDP Effects on Aircraft**
- **PDP Effects on Airfield Infrastructure**
  - Concrete Pavement
  - Asphalt Pavement
  - Other (GSE, Lighting, Signage, etc.)

ACRP Synthesis Background Program Purpose

- **ACRP Synthesis Program**
  - Premise - The solution to a particular problem for a given subject area already exists.
  - Information is scattered, fragmented, or unevaluated, and may be in documented form or as undocumented experience and practice.
  - By assembling, evaluating, and distributing data, problems can be solved.

ACRP Synthesis Background Project Panel

- TRB Manager
  - Gail Staba
- Panel Members:
  - Michael Arriaga (Boeing Company)
  - Daniel C. Bergman (Dallas/Fort Worth Intl Airport)
  - Todd Cavender (Indianapolis Intl Airport)
  - Ed Duncan (Continental Airlines)
  - Kevin A. Gurchak (Allegheny County, PA Airport)
  - Dr. Dean Mericas (CH2M Hill, Inc.)
  - Dr. Prasad Rangaraju (Clemson Univ.)
  - John Wheeler (Des Moines Intl Airport)
- Liaisons
  - George Legarreta (FAA)
  - Paul L. Friedman (FAA)
  - Tim A. Pohle (ATAA)
  - Jessica Steinhilber (ACI-North America)
  - Frank N. Lisle (TRB)
- Interested Observers
  - Susan Royer Baum (Cryotech Deicing Technology)
  - Alun Williams (Airbus SAS)
- Principal Investigator
  - Dr. Xianming Shi (Montana State University)

ACRP Synthesis Background
Project Scope

- **Why Project is Needed**
  - Situation of competing objectives in airport operations
    - Aircraft/Flight safety is of the highest priority
    - Environmental regulatory compliance
    - Material compatibility b/w deicing products and aircraft/airfield infrastructure
    - FAA operational implementation viability

ACRP Synthesis Background
Project Scope

- **Project Objectives**
  - To report how airports chemically treat their airfield pavements to mitigate snow and ice and chemicals used;
  - To review damage reported to aircraft components and airfield infrastructure in association with the use of traditional or modern pavement deicing products (PDPs); and
  - To identify critical knowledge gaps on these subjects.

ACRP Synthesis Background
Project Methodology

- **Information Sources**
  - Literature Review
  - EPA Questionnaire (~100 airports)
  - PI Survey (43 stakeholder responses)
  - PI Laboratory Data

Pavement Deicing Product (PDP) Primer

Pavement Deicing / Anti-Icing Fluids:

Solids

- Urea
- NaF
- NaAc

Liquids

- Ethylene glycol
- Propylene glycol
- KF
- KAc

(Where: Na = Sodium, K = Potassium, F = Formate, Ac = Acetate)

Environmental Protection Agency (EPA) Survey

- **2006 EPA Survey -** 152 airports surveyed, 139 responses, 130 conducted deicing activities – results from 102 of those obtained for project.

TYPE OF PDP USED AT U.S. AIRPORTS DURING 2004/2005 WINTER SEASON

	Size Classification				
Chemical/Material	Large Hub (17)	Medium Hub (21)	Small Hub (19)	Non-Hub (44)	Total
Airside Urea	4	6	6	14	30
Sodium Formate	1	6	3	3	13
Sodium Acetate	7	8	6	6	27
Potassium Acetate	14	18	16	20	68
Propylene Glycol-Based Fluids	3	0	2	4	9
Ethylene Glycol-Based Fluids	1	0	1	1	3
Sand	12	15	10	25	62

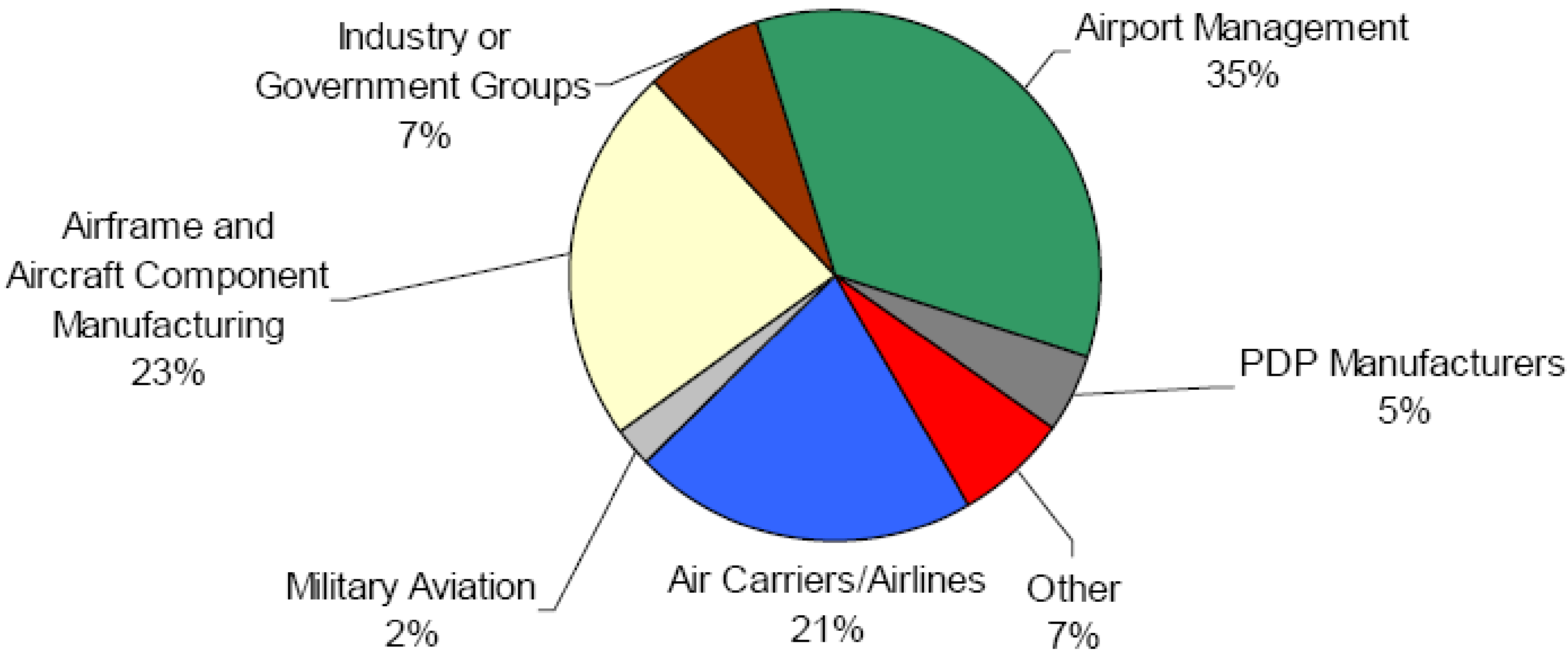
Environmental Protection Agency (EPA) Survey

2006 EPA Survey – Amounts of PDP applied

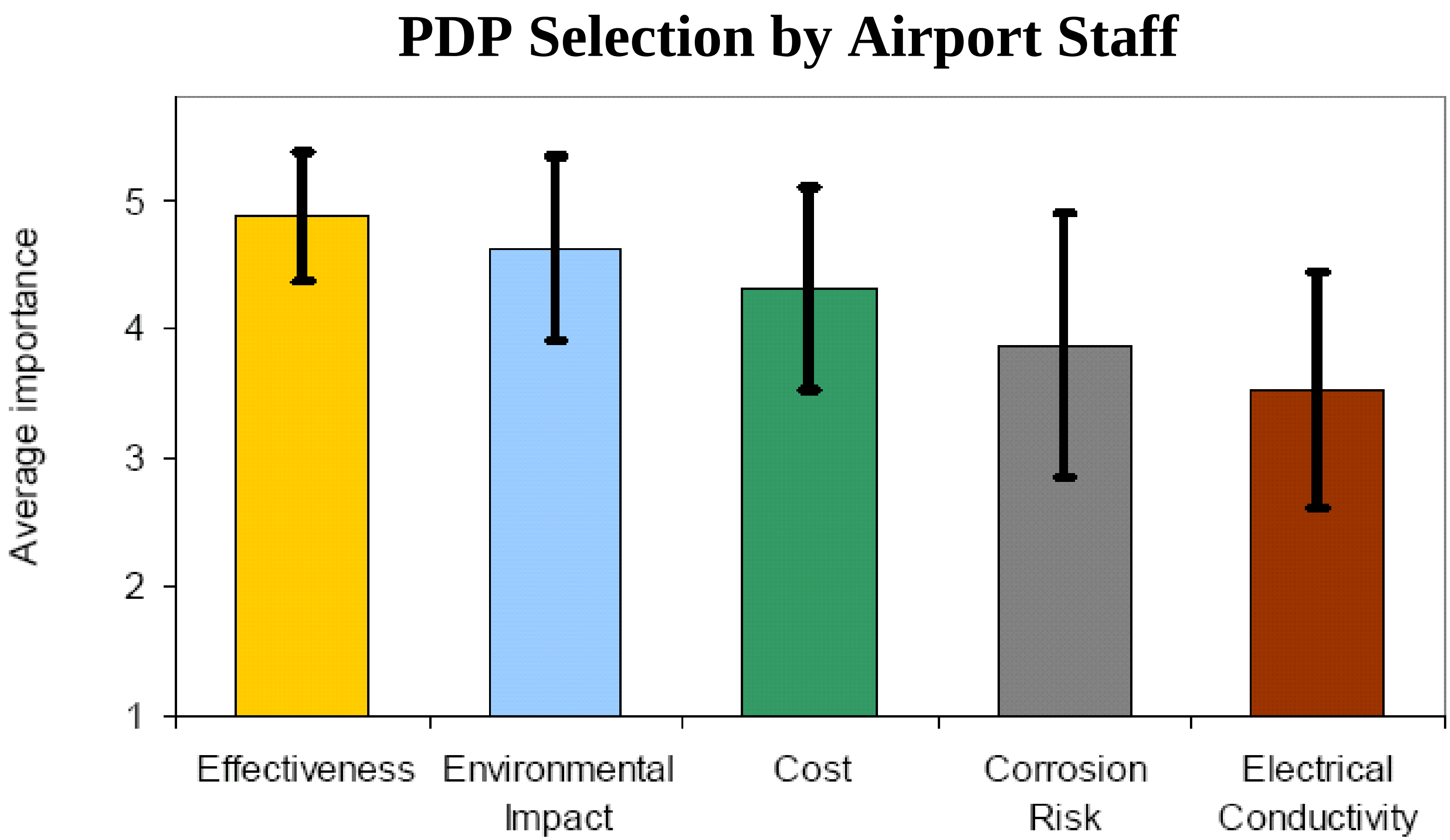
	2002/03		2003/04		2004/05	
Chemical/Material	No. Airports	Amount	No. Airports	Amount	No. Airports	Amount
Airside Urea (pounds)	14	2,056,988	16	4,330,356	17	2,451,914
Potassium Acetate (gallons)	35	4,146,441	36	4,598,292	36	2,792,393
Sodium Acetate (pounds)	13	5,068,222	12	5,764,147	16	4,365,449
Sand (pounds)	25	29,413,920	26	27,949,397	32	34,372,627
Sodium Formate (pounds)	5	248,283	6	486,813	7	365,073
Ethylene Glycol-Based Fluids (gallons)	1	373,185	1	151,118	1	261,887
Propylene Glycol-Based Fluids (gallons)	4	225,800	4	226,200	4	256,537

Note: Data based on a subset of the data from the 2006 EPA questionnaire.

ACRP Survey Respondents



ACRP Survey - Factors



(Where: 1 – Unimportant, 5 – Very Important)

PDP Effects on Aircraft

- **3 Areas of Focus**
  - Catalytic oxidation of carbon matrix reinforced carbon fiber (C/C) composite brakes
  - Corrosion of a/c alloys (focus on cadmium plating)
  - Interaction with a/c deicing and anti-icing products

PDP Effects on Aircraft

- C/C compsite brakes introduced mid-1980s
- KAc introduced in 1995
- KFm introduced in 1998
- A/C operations in N. Europe displayed high K contamination
- A/C operations in S. Europe and Med. Were lowest.

PDP Effects on Aircraft

PDP Effects on Aircraft Test Protocols

- **Solid deicers:**
  - **SAE AMS 1431C - Compound. Solid Deicing/Anti-Icing Runways and Taxiways**

- **Liquid deicers:**
  - **(SAE AMS 1435B - Fluid. Generic. Deicing/Anti-Iicing-Runways and Taxiways) deicers,**

PDP Effects on Aircraft

Summary of Results – C/C Brakes

PDP Impact	Information Sources	What Is Known	What Is Unknown
Catalytic oxidation of carbon–carbon composite brakes	1. Academic-peer-reviewed literature 2. Industry-peer-reviewed publications and reports 3. Survey of stakeholder groups	1. A growing body of field evidence from airline operators suggests that the use of KAc and KF on airfield pavements leads to catalytic oxidation of C/C composite brake components. 2. Existing research in the laboratory has demonstrated the catalytic effects of potassium, sodium, and calcium on carbon oxidation.	1. There is still a need to establish a comprehensive PDP catalytic oxidation test protocol. 2. More research is needed to better understand relationships between brake design, AO treatment, and PDP contamination as factors in catalytic oxidation.

PDP Effects on Aircraft

Alloy Corrosion

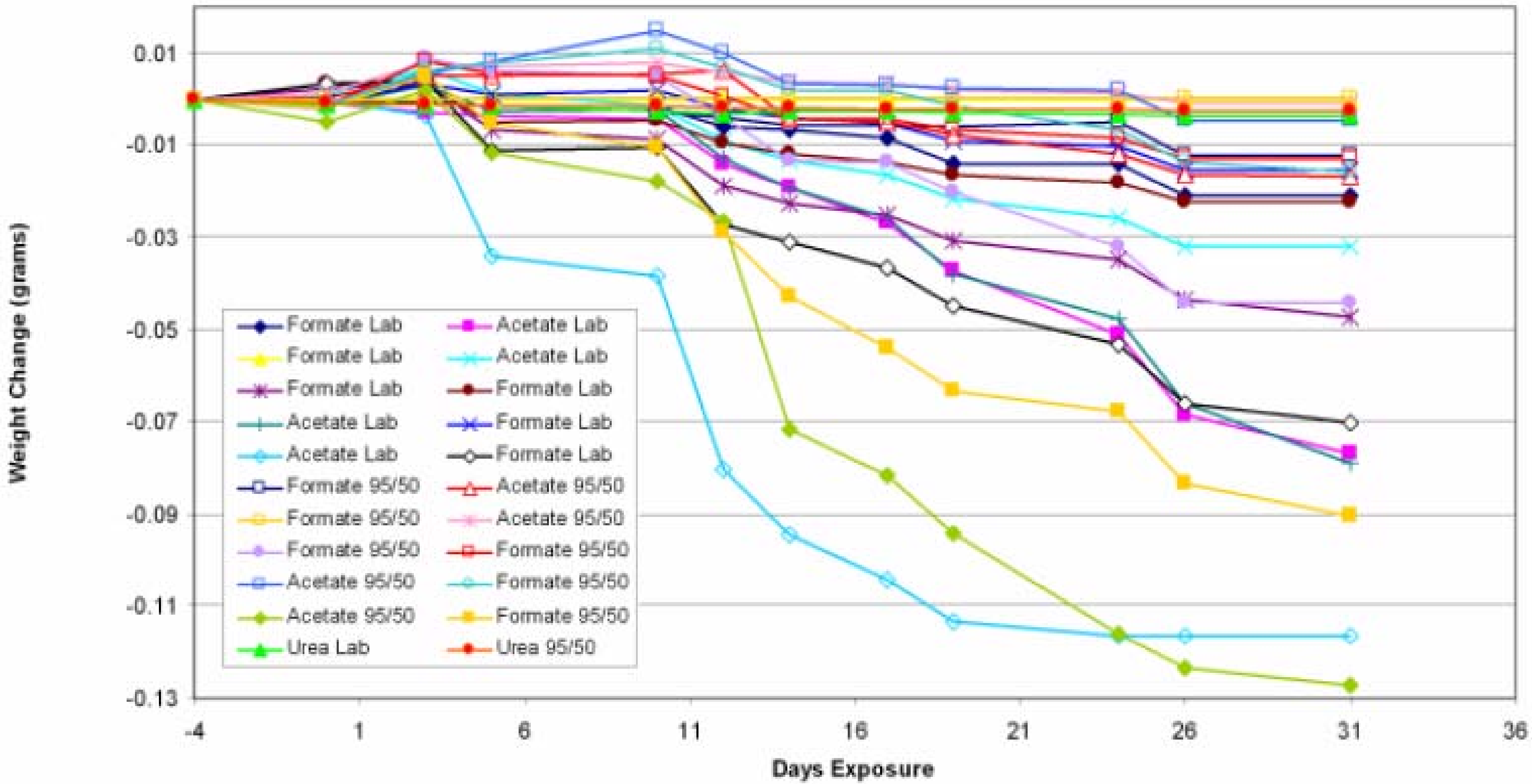
PDP Effects on Aircraft Cd Corrosion

- **TC Aerodrome Safety Circular, April 2002**
  - **Refrain from using KFm**
- **Boeing Service Bulletin**
  - **B737 prone to KFm corrosion in MWW**
- **FAA Airworthiness Directive**
  - **B737-600/900, determine KFm exposure or regular inspections**

Cd Corrosion Field Reports

- Continental & Scandinavian Airlines:
  - MWW electrical connectors, components, a/c bay packs
- PDPs potential cause of:
  - premature failure of landing gear joints,
  - accelerating the degradation of electrical wire harness insulation, and
  - promoting the corrosion of aluminum (Al) hydraulic lines and belly skin

Cd Corrosion
Corrosion Test Data Variability



Cd Corrosion Test Protocols

- **Under development:**
  - **Boeing initiated comprehensive testing (ASTM F1111-02)**
  - **SAE G12 Deicing Committee Cd Corrosion W.G. since 2003**
  - **Currently being refined for inclusion to SAE AMS 1431B & AMS 1435A**

PDP Effects on Aircraft

Summary of Results – Alloy Corrosion

PDP Impact	Information Sources	What Is Known	What Is Unknown
Corrosion of aircraft alloys (with a focus on cadmium plating)	1. Industry-peer-reviewed publications and reports 2. Survey of stakeholder groups	1. Until recently, the principal evidence connecting alkali-metal-salt-based PDPs with Cd-plating corrosion has been a trend of increased reports of the latter occurring simultaneously with the introduction of the former. 2. Very little research has been conducted to investigate the mechanism of Cd corrosion or Cd-steel corrosion in the presence of alkali-metal-salts (e.g., KF andKAc), partly owing to the high toxicity associated with Cd and its compounds.	1. There is still a need to establish a comprehensive metallic corrosion test protocol for PDPs. 2. More research is needed to better understand the interactions among the aircraft component design, the CICs used, and the contamination of PDPs in the processes of metallic corrosion. 3. There is still a lack of academic research data from controlled field investigation regarding the aircraft metallic corrosion by PDPs.

Aircraft Deicing and Anti-Icing Fluids (ADAFs)

- **4 Types A/C Fluids - Society of Automotive Engineers (SAE):**
  - Type I - Low viscosity, "unthickened". Provide only short term protection. Typically sprayed on hot (130° - 180° F) at high pressure to remove snow, ice, and frost.
  - Type II - "Pseudoplastic" - contain a polymeric thickening agent, breaks down at ~ 100 kts.
  - Type III - Compromise b/w Types I and II. Intended for slower a/c.
  - Type IV – "Anti-icing." A/c must be deiced prior to application. Same viscosity specs as type II, but provide a longer holdover time.

Aircraft Deicing and Anti-Icing Fluids (ADAFs)

Aircraft Deicing and Anti-Icing Fluids (ADAFs)

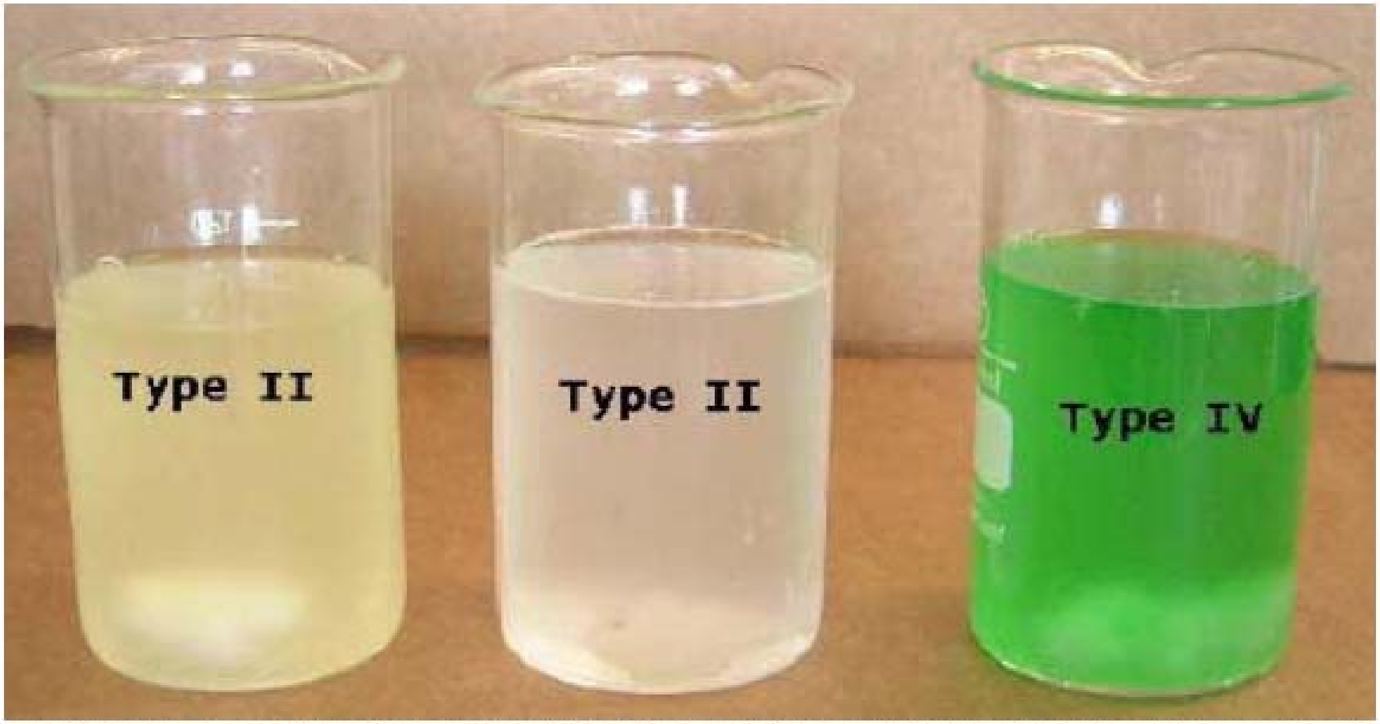


FIGURE 15 Photos of thickened fluids after addition of 5% KF: immediate reductions in viscosity, followed quickly by precipitation of thickener additives [adapted from Ross, 2006]

ADAF Interactions
Test Protocols

- **SAE AMS 1428F for Type II/III/IV aircraft deicers, but does not address this interaction.**

- **The SAE G-12 Fluid Residues W.G. is leading research efforts in this field.**

PDP Effects on Aircraft

Summary of Results – ADAF Interactions

PDP Impact	Information Sources	What Is Known	What Is Unknown
Interaction with aircraft deicing and anti-icing products	1. Industry-peer-reviewed publications and reports 2. Survey of stakeholder groups	1. Recent laboratory data appear to corroborate anecdotal reports of increased rates of thickener residues in environments where alkali-metal-salt- based PDPs have been used.	1. The contamination effects of ADAFs by runway deicing fluids have been well-observed, but not yet thoroughly quantified. 2. Further research is needed to better understand the interactions between ADAFs and PDPs, as new ADAFs and PDPs are continually introduced to the market.

PDP Effects on Airfield Infrastructure

- **3 Focus Areas: The Impact of PDPs on**
  - Concrete Pavement
  - Asphalt Pavement
  - Other Infrastructure (GSE, Lighting, Signage, etc.)
- **5 Aspects are Explored**
  - Potential Role of PDP in Impact
  - Mechanism / Reason for Impact
  - Standards and Test Protocols
  - Prevention and Mitigation
  - Knowledge Gaps

PDP Effects on Airfield Infrastructure

- **The Field Environment – Difficult Research Factors**
  - Variable / uncontrolled conditions
  - Lack of documentation
  - Many PDPs used at same airport
  - Aggregates (reactive vs. nonreactive)
  - Mix design
  - Construction quality
  - Climatic conditions
  - Traffic loading

PDP Effects on Airfield Infrastructure

- **Field Data**
  - Comfort Survey (2000) – 12 Canadian Airports
    - Operators found no damage due to PDPs
    - Crack and joint sealants possibly affected
    - PDP may aid in rubber removal
  - ACRP Survey (2007) – Airfield Impact Portion
    - Distributed to operators at 50 busiest airports
    - 17 respondents / only 4 provided detailed usage info
    - Results indicated little to no observed damage
    - Changes in mix design and construction consistent w/ FAA specifications

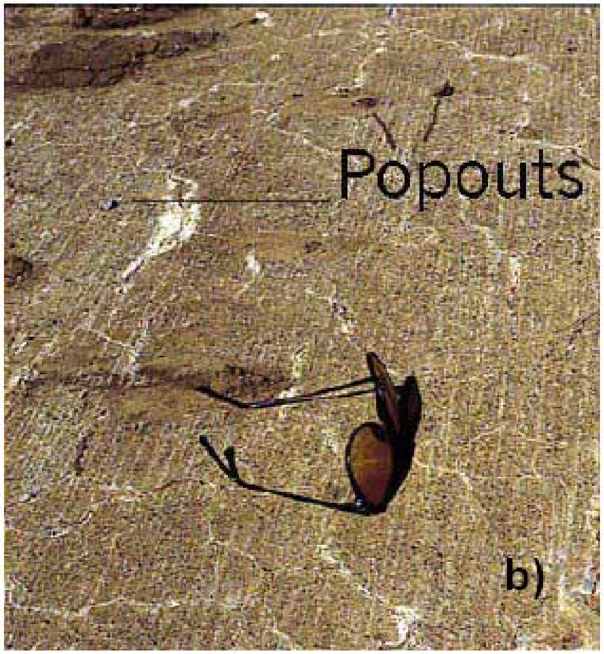
PDP Effects on Concrete Pavements Potential Role

- **Definition of Alkali-Silica Reaction (ASR)**
  - A chemical reaction between alkalis present in the cement paste and siliceous minerals in the reactive aggregates of Portland Cement Concrete (PCC), which produces a hydrophilic gel that expands when sufficient moisture is available.
  - Effects include:
    - Cracks – Allow water to enter concrete
    - Popouts – Create Foreign Object Debris (FOD)
    - Expansion – Can damage adjacent pavement/structures

PDP Effects on Concrete Pavements Potential Role

ASR Effects

Cracks



Popouts

Expansion

PDP Effects on Concrete Pavements Potential Role

- **Physical Distresses - Common forms of concrete deterioration include:**
  - Scaling and/or Spalling – damage from hydraulic pressures of freeze-thaw cycles of concrete pore solution

Scaling

Spalling

PDP Effects on Concrete Pavements Potential Role

- Chloride-based salts and alkali-metal-salt-based PDPs may exacerbate distress when used in concentrations high enough to induce osmotic pressure upon moisture
- PDP application increases rate of cooling of pavement, and increases number of freeze-thaw cycles over ambient conditions.
- Entrained air in concrete provides room for internal expansion
- Existing research shows that high quality concrete with 5%-7% entrained air is more resistant to freeze-thaw cycles.

PDP Effects on Concrete Pavements Mechanisms

- Alkali content of modern cement is much higher than cement manufactured pre-1970s
- Explanation
  - Research sponsored by the IPRF implicates acetate/ formate-based deicers in increased occurrence of ASR, likely by increasing the pH of concrete pore solution.
  - Nature of reactions remain unclear

PDP Effects on Concrete Pavements Standards and Protocols

- U.S. Air Force requires:
  - ASTM 1260 “Standard Test Method for Potential Alkali Reactivity of Aggregates” (Mortar-Bar Method)
  - ASTM 1293 “Standard Test Method for Determination of Length Change in Concrete Due to ASR” (this test takes over 1-year to complete)
- If reactive aggregates must be used, then mitigation methods required:
  - ASTM C1567 “Standard Test Method for Determining the Potential for ASR of Combinations of Cementitious Materials and Aggregate” (Accelerated Mortar-Bar Method) or equivalent
- Further FAA refinement as part of the IPRF 05-7 project. Proposed inclusion in SAE AMS 1435 & 1431, and ASTM C672 “Scaling Resistance of Concrete Exposed to Deicers”

PDP Effects on Concrete Pavements Prevention and Mitigation

- Follow best possible practices in concrete mix design and construction
  - Consideration of supplementary cementitious material to alleviate excess bleed water
  - Aggregate blends that do not lack mid-sized aggregate
  - Suitable air-void systems
- Use good curing practices
- Use polymer sealants – minimize contact b/w PDP and pavement, and reduces ingress of water into concrete

PDP Effects on Airfield Infrastructure Summary

Summary of Results – Concrete Pavements

PDP Impact	Information Sources	What's Known	What's Unknown
Impact of PDPs on concrete pavement	1. Academic-peer-reviewed literature; 2. Industry-peer-reviewed publications and reports; 3. Survey of stakeholder groups	1. The last decade has seen an increase in the premature deterioration of airfield PCC pavements with the use of alkali-metal-salt based PDPs. 2. Limited existing laboratory studies indicated that alkali-metal-salt based deicers could cause or accelerate ASR distress in the surface of PCC pavement, by increasing the pH of concrete pore solution.	1. There is a need for research data from controlled field investigation regarding the effects of alkali-metal-salt based PDPs on concrete pavement. 2. There is a need to unravel the specific mechanism by which alkali metal salts cause or promote ASR.

PDP Effects on Asphalt Pavements Potential Role

- **Field Observations**
  - Concurrent to the use of acetate/formate-based deicers in the 1990s, asphalt pavement in Europe (esp. Nordic countries) saw the increase in durability problems such as:

Binder Emulsification

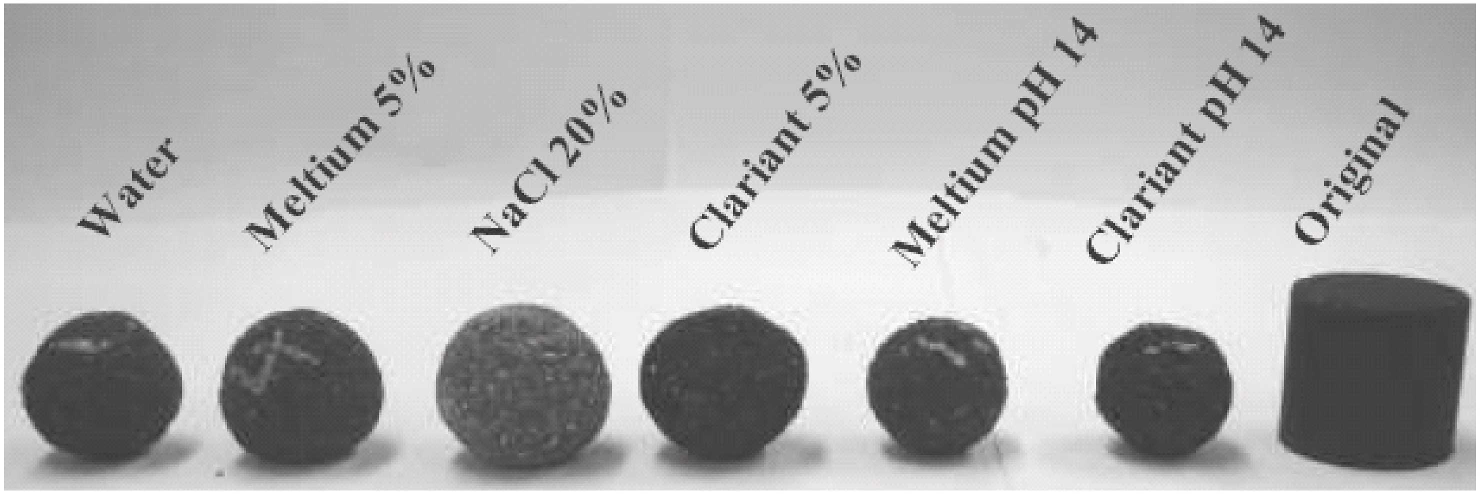
Disintegration

Stripping

  - No field evidence of damage reported in U.S. or Canadian airports

PDP Effects on Asphalt Pavements Potential Role

- **Laboratory Observations**
  - Significantly accelerated deterioration of asphalt when exposed to acetate/formate-based deicers
  - 1990 study in Canada reported loss of indirect tensile strength in asphalt core immersed in a 2.5% urea solution, as compared to core immersed in distilled water. <u>Overall findings were inconclusive.</u>



PDP Effects on Asphalt Pavements Potential Role

- **JAPA Finnish De-Icing Project**
  - Formed to investigate problems at Nordic airports
  - 3 goals of project:
    - How damages are generated,
    - How to determine compatibility b/w asphalt and PDPs, and
    - How to prevent damages by mix design

PDP Effects on Asphalt Pavements Potential Role

- **JAPA Finnish De-Icing Project**
  - Asphalt binders soaked in PDP solution showed:
    - Lower softening points
    - Dissolve at lower temps (down to 20 deg C)
  - Asphalt mixes soaked in PDP solution showed:
    - Lower surface tensile strength
    - Lower adhesion properties
  - Experiments showed that deicer (formate or acetate), water or moisture, and heat necessary for damage to occur
    - In the field, these conditions occurred during repaving or on hot summer days with residual PDP on airfield.

PDP Effects on Asphalt Pavements Mechanisms

- Canadian research did not propose and mechanism or scientific explanation for laboratory observations
- Advanced Asphalt Technologies proposed that:
  - Damaging mechanism is a disruption of the asphalt-aggregate bond as a result of ASR
- However, Pan et al. (2008) research shows asphalt emulsification:
  - Occurring to mixes w/ both reactive and non-reactive aggregates, and
  - Not occurring in NaOH solutions of the same pH values as the NaAc solution
- Thus, research indicates emulsification may be a more critical mechanism of asphalt mix deterioration than ASR unless very reactive aggregates are used in the asphalt mix.

PDP Effects on Asphalt Pavements Mechanisms

- Efforts from the JAPA Finnish De-Icing Project Appear to best explain the cause:
  - Damaging mechanism appears to be due to:
    - Chemical changes in binder (emulsification)
    - Distillation
    - Generation of additional stress in asphalt mix

PDP Effects on Asphalt Pavements Standards and Test Protocols

- Two existing Swedish test methods related to asphalt and PDPs:
  - LFV Method 1-98 “Bituminous Binders, Storage in De-Icing Fluid”
  - LFV Method 2-98 “Effect of De-Icing Fluid on the Surface Tensile Strength of Asphalt Concrete for Airfields – Adhesion Test
- The Aqueous Solution Test developed by Pan et al. (2008) shows high efficiency in examining the emulsifiability of asphalt
- The Modified Boiling Water Test, also proposed by Pan et al. (2008) can be used as a routing laboratory test for evaluating suspicious asphalt mixes when exposed to alkali-metal-salt-based PDPs.

PDP Effects on Asphalt Pavements Prevention and Mitigation

- Follow best possible practices in asphalt mix design and paving
  - Reduce asphalt pavement air void
  - Use of a polymer-modified binder
  - FAA recommended use of PG76-32 asphalt binder
- Use of high viscosity or polymer-modified binders when formate/acetate-based PDPs are to be used
- Use of high quality, high pH aggregates (alkaline, avoiding limestone filler)
- Use of harder bitumen (penetration max 70/100) or modified

PDP Effects on Airfield Infrastructure Summary

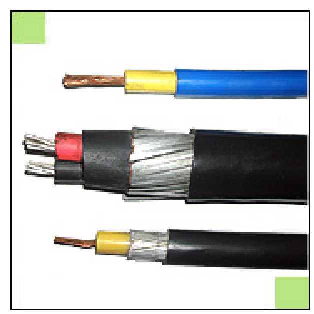
Summary of Results – Asphalt Pavements

PDP Impact	Information Sources	What's Known	What's Unknown
Impact of PDPs on asphalt pavement	1. Academic-peer-reviewed literature; 2. Industry-peer-reviewed publications and reports; 3. Survey of stakeholder groups	1. Although it was observed in some Nordic airfields that exacerbated asphalt deterioration occurred with applications of alkali-metal-salt based PDPs, there is thus far little observation reported in U.S. or Canadian airports. 2. Significantly accelerated deterioration of asphalt pavements was found in laboratories when exposed to acetate/formate-based deicers.	1. There is a need for research data from controlled field investigation regarding the effects of alkali-metal-salt based PDPs on asphalt pavement. 2. There is a need to unravel the specific mechanisms by which alkali metal salts and other PDPs (e.g., bio-based deicers) deteriorate asphalt pavement.

PDP Effects on Other Infrastructure

- **Other Airfield Items include:**
  - Ground Support Equipment (GSE)
  - Signage
  - Lighting
  - Airfield electrical systems

- Empirical evidence exists indicating PDP responsible damage, but no academic peer-reviewed scientific information available



PDP Effects on Other Infrastructure

- In 2004, the United Kingdom Civil Aviation Authority issued a Notice to Aerodrome License Holders about corrosion effects on ground lighting
- Rubber removal cleaner partially attributed to premature failure of an centerline lighting fixture
  - Cleaner destroyed the passivated corrosion protection layer – and it was thought that PDPs could do the same
- Recommended action to:
  - Inspect fittings,
  - Repassivate if needed, and
  - Prevent fittings from contacting fluids with pH outside of the range of 4 to 8.5

PDP Effects on Other Infrastructure

- In 2005, one European airport switched from urea and ethylene glycol to formate-based PDPs
    - Corrosion of zinc-coated steel occurred on light fixtures, and maintenance/ground operations vehicles
    - Airport found that washing airport vehicles decreased corrosion effects
    - Airport now uses stainless steel light fixtures

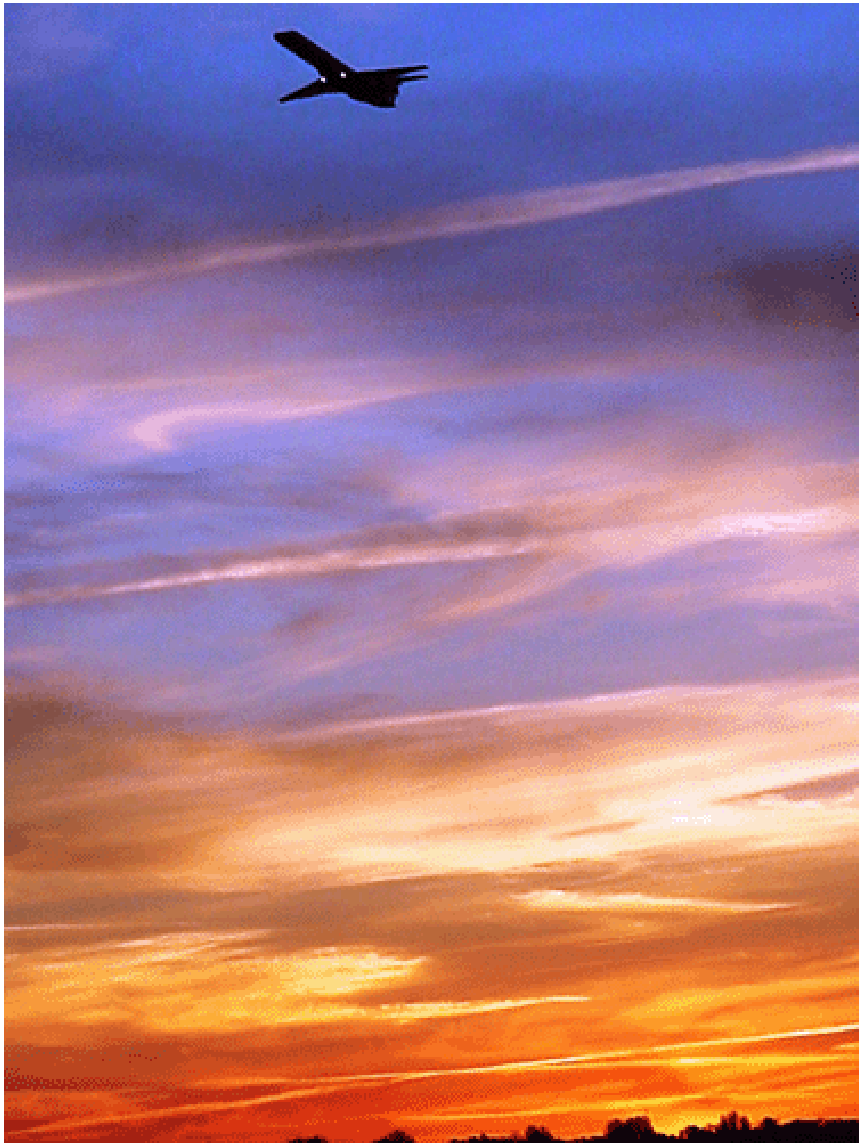
PDP Effects on Other Infrastructure

- ACRP survey results indicated lighting cable deterioration during or shortly following deicing events at 2 U.S. airports.
  - Old cable insulation suspected as playing a role in damage
  - One airport upgraded to more resistant lighting cable and remote system monitoring capabilities
- FAA test method for containers used in the presence of KAc:
  - AC 150/5345-42F "Specification for Airport Light Bases, Transformer Housings, Junction Boxes, and Accessories"

PDP Effects on Airfield Infrastructure Summary

Summary of Results – Other Infrastructure

PDP Impact	Information Sources	What's Known	What's Unknown
Impact of PDPs on other airfield infrastructure	1. Industry-peer-reviewed publications and reports; 2. Survey of stakeholder groups	1. Empirical evidence exists indicating that PDPs are responsible for damaging other airfield infrastructure (GSE, signage, lighting and other electrical systems).	1. No academic-peer-reviewed scientific information could be found to corroborate these empirical observations.



Thank You

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For more information

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