R&T UPDATE
Concrete Pavement Research & Technology

CONCRETE MIXES AND PAVEMENT CONSTRUCTION FOR AIRCRAFT DEICING FACILITIES

NOTE: This R&T Update summarizes an Innovative Pavement Research Foundation (IPRF) research project funded by the Federal Aviation Administration (FAA). The text in this R&T Update was extracted from report # IPRF-01-G-002-03-3 by Van Dam, et. al.

Premature distress, in the form of scaling, joint spalling, crazing, and map cracking of the slab surface, has been observed on some concrete airfield pavement dedicated deicing facilities (DDFs) in North America, occurring as soon as 2 to 3 years after construction. Because the DDFs are specialized facilities that are used strictly for deicing aircraft, there was a concern that the heavy applications of glycol-based deicing fluids might somehow be contributing to the development of the premature distress through interactions with the concrete constituent materials, the construction techniques, and the environment.

A project was sponsored by the Innovative Pavement Research Foundation (IPRF) to determine if there was a relationship between the application of the aircraft deicing fluids and the observed distress. Based on an extensive petrographic analysis, no common cause of distress was identified in the evaluated concrete, and no evidence was uncovered to suggest that the use of glycol-based aircraft deicers is directly implicated in the degradation of the concrete. Indeed, the most common problems noted in the samples can be broadly categorized as poor placement and consolidation, and poor finishing and curing.

In general, current construction practices appear adequate to prevent the construction-related problems observed. Although the extremely stiff mixtures associated with slip form paving of airport pavements can pose difficulties during placement, it is clear from the example set by a good performing site that such mixtures can be placed and consolidated with little entrapped air and sufficient entrained air. Better mixture design and proportioning, improved consolidation, and the timely and thorough application of an effective membrane-forming curing compound would prevent much of the distress observed.

Background

The chemicals used for aircraft deicing are distinctly different from those commonly used for pavement deicing. For roadways, the chloride salts of calcium, magnesium, and sodium (along with other chemicals containing calcium and magnesium) are primarily used. For airside pavements at airports, only non-chloride deicing agents are used, including urea, potassium acetate, sodium acetate, sodium formate, calcium magnesium acetate, and propylene and ethylene glycols [1]. The latter two deicers are also commonly used for aircraft deicing, making up 30 to 70 percent of the as-applied solution, with propylene glycol increasingly being used because of toxicity concerns with ethylene glycol [2].

Being organic in nature, (propylene glycol: $C_3H_8O_2$, ethylene glycol: $C_2H_6O_2$) these deicers are free of chlorides and thus some of the physical and chemical mechanisms responsible for the adverse effects of deicers on highway transportation structures (e.g. corrosion of embedded steel and salt crystallization pressures) are not relevant. These deicing agents also have little potential to accelerate alkali-silica reactivity, as would alkaline halide, salt-based pavement deicers, or those containing potassium, such as potassium acetate. Yet, based on the available literature, the use of glycol-based aircraft deicers could, in theory, contribute to concrete deterioration through enhanced paste freeze-thaw damage and/or chemical/bacteriological deterioration.

Test Program

Members of the IPRF research team conducted a detailed visual assessment of the concrete pavement deicing facility at nine airports to determine the nature and extent of deterioration. In general, the survey guidelines developed under a recent Federal Highway Administration (FHWA) project were followed [3]. These guidelines provide a standardized approach for the field evaluation of concrete pavements exhibiting materials-related distress (MRD), such as the fine cracking, scaling, and perhaps spalling that might be exhibited by concrete pavements exposed to aircraft deicing agents. However, these guidelines were modified slightly for use on airfield pavements and to incorporate the Pavement Condition Index (PCI) survey method as documented in ASTM D 5340 [4]. Based on these results, follow-up investigations were recommended at the four DDFs that exhibited the most damage.

During the second visits, a more detailed visual assessment of the concrete pavement was conducted, and cores were obtained from various locations within each DDF for later laboratory analysis and petrographic evaluation. The four airports, year the DDFs were built, slab design, and observed distresses at each are presented in Table 1. Available materials, pavement design, and construction information was also collected during each site visit.

Table 1: Airports in Detailed Field Investigation

Airport	Built	Slab Design	Observed Distresses
A	1998	15-in JPCP 20 x 20 ft	Low-severity spalling, low-severity patching, hairline cracking, gray exudates.
E	1999	15-in JPCP 20 x 20 ft	Low-severity joint spalling, hairline cracking
F	1999	17-in JPCP 18.75 x 20 ft	Low-severity scaling, popouts, hairline cracking, some gray staining.
G	1990	15-in JPCP 25 x 25 ft	Low-severity cracking, low-severity shattered slab, hairline cracking, and map cracking.

Forensic Evaluation

A forensic evaluation was conducted on the airports listed in Table 1. This investigation included collection of field core samples for strength testing and petrographic analysis. In addition to the cores at the four airports chosen for further investigation, core samples were obtained from Airport D to evaluate factors contributing to its exceptional performance.

All cores were nominally 4 inches in diameter. The exact coring locations were established in the field based on the nature and extent of distress. The coring pattern and the disposition of each core are presented in Table 2, where the core location refers to whether the core was obtained from an area receiving heavy or light deicer application and whether the core was located at a joint or interior (center) portion of the slab. Each core was immediately labeled, photographed, logged, and enclosed in plastic bubble wrap in preparation for shipping. In most cases, one 8-inch long compressive strength specimen and one or two 2-inch thick split tensile strength specimens were obtained from each core.

Table 2: Coring Pattern and Core Disposition for the Six Cores at Each Airport

Core ID	Deicer App.	Loc.	Condition	Type of Testing	
				Petro.	Strength
A	Heavy	Joint	Distressed	X	
B	Heavy	Joint	No Distress	X	
C	Heavy	Center	Distressed	X	
D	Heavy	Center	No Distress		X
E	Light	Center	No Distress	X	X
F	Light	Center	No Distress		X

A systematic approach [3] was taken to examine the core specimens in an attempt to determine the cause of concrete pavement deterioration. The key to accurately identifying the deterioration mechanism(s) is to determine “what it is not” rather than “what it is.” By using all available information without preconceived notions as to the cause of the problem, the analyst works through a process of elimination to determine the most likely cause(s) of deterioration. It is recognized that concrete is an inherently complex material and, particularly in the case of DDFs, can be subjected to very complex environmental conditions. Only through such a thorough, unbiased, and systematic evaluation can mechanisms of distress be identified and preventive strategies devised.

Although the strength testing provides a general measure of quality, it offers little direct information on the nature of the deterioration. For this purpose, petrographic analysis was conducted on polished slabs and thin sections. The petrographic analysis used various instruments to examine the concrete microstructure, including visual assessment, staining techniques, stereo microscopy, petrographic microscopy, and scanning electron microscopy. Optical stereo microscopy (stereo OM) was used to assess the overall condition of the microstructure and to determine relevant air-void system characteristics, including the spacing factor and specific surface. The analysis also drew on information collected using environmental scanning electron microscopy (ESEM), petrographic microscopy (petrographic OM), and a flatbed digital scanner.

Completion of all aforementioned forensic evaluation tasks conforms to the process used for diagnosing the MRD of a concrete, shown in Figure 1. Addressing individual tasks in this manner ensures unbiased, independent determination of MRD, allowing this investigation to determine if deicing salts have caused or aggravated any observable MRDs.

Investigation Results

The water/cement ratio for each Airport was estimated at 0.41, 0.35, 0.34, 0.33, and 0.30 for A, D, E, F, and G, respectively, versus 28-day moist cured mortar cylinders of known w/c ratio. The primary MRDs, as determined by forensic analysis for each airport are summarized in Table 3.

Two cores from Airport A exhibited large interconnected pores close to the surface (Figure 3 on next page), indicative of poor construction practice (i.e. poor consolidation and excessive bleeding), and an assured catalyst for the ingress of deicer and subsequent freeze-thaw damage. Airport A was also the only site where a supplementary cementitious material was not used. In the absence of supplementary cementitious materials, higher quantities of calcium hydroxide would be expected in the hydrated cement paste. An abundance of secondary calcium hydroxide deposits suggests leaching of calcium hydroxide in the cement paste and re-deposition in the entrained air voids, a phenomenon made possible by the increased permeability associated with the highest w/c ratio of any site.

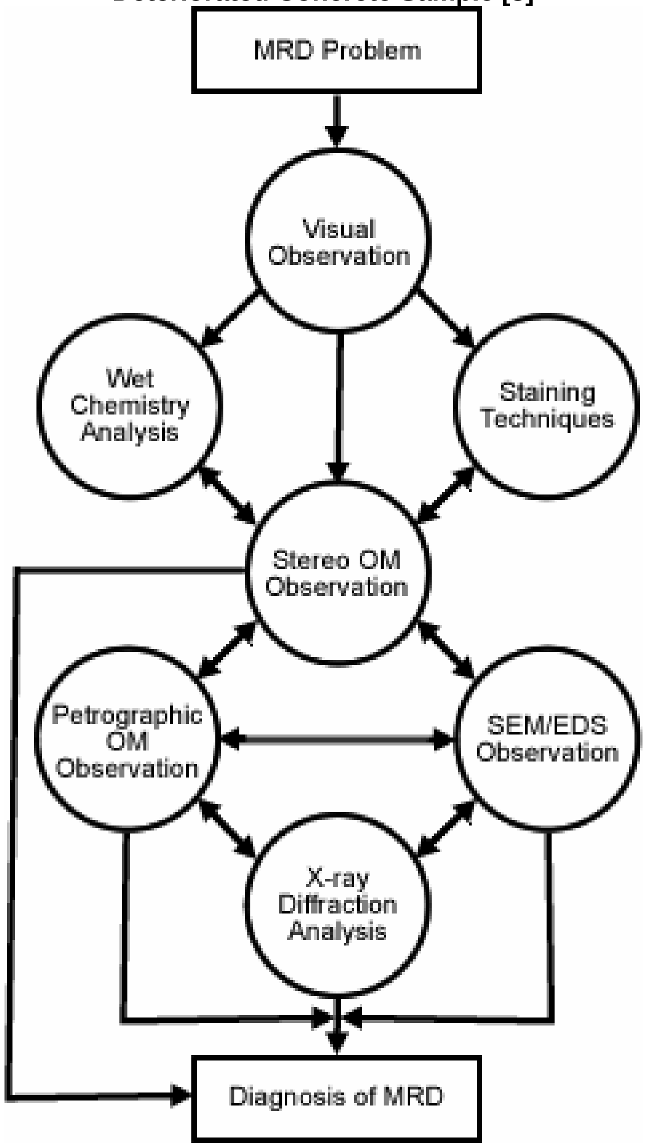
Since Airport D was chosen as a superb example, no MRDs were observed in any forensic analysis test.

Airport E exhibited surface cracking that forensic analysis attributed to early age plastic shrinkage and poor consolidation at the surface of the pavement, similar to Airport A. The poor consolidation again led to freeze-thaw damage. A low amount of alkali-silica reaction (ASR) was also observed.

Airport F again displayed a network of large interconnected pores in two cores, which was directly related to observed surface cracking. The high compressive but low tensile strength of the concrete indicates that there might be an undetected microstructural weakness (i.e. paste-aggregate interface) and this low tensile strength aids in freeze-thaw damage. A very low level of ASR was also observed.

Despite being well consolidated, early-age plastic shrinkage cracking attributed to poor finishing/curing was observed in Airport G cores and in one core this further propagated via drying and environmental loading. An adequate freeze-thaw resistant air void system was present at construction but secondary ettringite filled in many of the air voids, making the freeze-thaw resistance marginal and causing damage.

Figure 1: Fundamental Process for Analyzing a Deteriorated Concrete Sample [3]

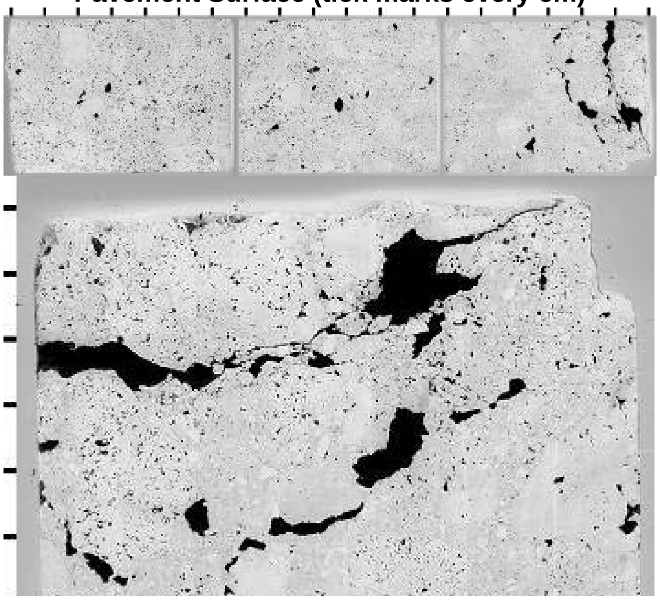


Low levels of ASR and sulfate attack were also observed in the DDF at Airport G but were not considered part of the distress.

Table 3: Summary of Distress Levels

Air-port	Likely Cause of Distress Based on Evaluation of Cores				
	Construction	Paste F-T	ASR	Deicer	Sulfate
A	High	Low	None	Low	None
D	None	None	None	None	None
E	High	Low	Low	None	None
F	High	Moderate	Low	None	None
G	Moderate	Moderate	Low	None	Low

Figure 3: Polished Slab from Core C at Airport A (tick marks every 2 cm) and a Close Up at the Pavement Surface (tick marks every cm)



Conclusions

The following conclusions are drawn from this study:

- No evidence exists for either a chemical or biological distress mechanism associated directly with the use of glycol-based aircraft deicers.
- The most common problems associated with the evaluated concrete can be broadly categorized as poor placement and consolidation and/or finishing and curing.
- The air-void systems were marginal in some cases, a bad scenario as the environmental conditions present on a DDF are fairly severe due to the presence of moisture under freezing conditions and induced freeze-thaw cycles.
- Alkali-silica reactive aggregate particles were observed in three of the sites, but in no case was the occurrence of reactive aggregates linked to the observed distress.
- Ensuring that a proper air-void system is entrained in the concrete is a more difficult problem, as common test methods only measure the total air content of the concrete and not the adequacy of the air-void system (e.g., spacing factor, specific surface).

It is also recommended that construction specifications for DDFs be modified to incorporate a test method to measure the degree of consolidation of the concrete and adopt an acceptance criterion to prevent poor consolidation on future projects.

For more information, see Reference 5.

References

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