MAINTAINING AIRPORT PAVEMENT FRICTION USING SURFACE DENSIFICATION

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Abstract
Pavement structures are an airport's "greatest asset and greatest liability". As a result, preserving airport pavements is not only the most logical but also the most economical solution because preservation focuses on keeping good pavements in good condition rather than relying on reactive maintenance to merely repair problems after they occur. Therefore, the objective of this paper is to explore an underutilized pavement preservation tool - applying chemical surface treatments to new and existing pavements (runways, taxiways and aprons) to harden them against abrasion, minimize potential for foreign object debris (FOD), reduce permeability to retard degradation from deicing solutions, and to retain skid resistance lost to both snowplowing and rubber accumulation. Besides enhanced safety, one of the greatest benefits of preserving pavements is realized in the reduction of operational disturbance. Shutting down a runway at a major airport to perform unscheduled reactive maintenance can literally paralyze the throughput at that airport and disrupt traffic at connecting airports. Therefore, a treatment that has a marginally higher initial cost may become a bargain if it extends the service life of the pavement and more importantly, extends the time between maintenance disruptions. This paper explains the chemical treatment technologies in the context of airport pavements and explores cost effectiveness on a life cycle cost basis. The paper concludes that there is potential benefit to adopting lithium-based treatments as an airport pavement preservation tool.

INTRODUCTION

"Runway deterioration causes Corning Municipal Airport to close" *(1)* was the headline in the July 15, 2011 edition of the *Creston News Advertiser*, a local newspaper in Creston, Iowa. More recently, *The Chadron Record (2)* ran a story that started this way:

> "the Chadron Airport runway paving project that won the Nebraska Concrete Paving Association's Best Airport Project award for 2000 doesn't look as praiseworthy in 2012, and will have to be replaced at an estimated cost of $6.4 million…the [city's] public works director said 'We had hoped it would last for 40 or 50 years'… FAA representatives noticed a spiderweb effect on the surface of the runway during an annual inspection … and attributed it to Alkali-Silica Reaction (ASR) in the concrete that stems from the type of aggregate used in the mixture."

No airport pavement manager wants to wake up to this type of news. "Pavement structures are an airport's greatest asset and greatest liability, and along with their associated management systems, involve an intensive, expensive enterprise and consume massive amounts of nonrenewable resources at every airport" *(3).* As a result, preserving airport pavements is not only the most logical but also the most economical solution because preservation focuses on keeping good pavements in good condition rather than relying on reactive maintenance to merely repairs problems after they occur *(4).* Therefore, the objective of this paper is to explore a underutilized pavement preservation tool--applying chemical surface treatments to new and existing pavements to harden them against abrasion, reduce their permeability to retard degradation from deicing solutions, and to retain skid resistance lost to both snowplowing and rubber accumulation.

BACKGROUND

Preserving pavements, rather than allowing them to deteriorate and then replacing them, is the most cost effective and environmentally responsible approach to managing this vital asset. However, to be effective, the installed pavement preservation treatments must perform as intended *(5).* If the treatment fails prematurely, both benefits are lost as limited maintenance funding is wasted and nonrenewable materials and energy are consumed without return. US and Canadian pavement engineers have long used the motto of the North American pavement preservation movement by selecting "the right treatment, on the right road, at the right time" *(6).* While the highway pavement industry has been leading the way on implementing pavement preservation programs, those very same principles apply to airport pavements as well. In fact, the argument made in highways that a successful pavement preservation program minimizes disruption to the traveling public *(6)* applies in a much more intense manner for airports where disrupting operations on a runway at a major airport to perform unscheduled reactive maintenance can literally paralyze the throughput at that airport and disrupt traffic at connecting airports. Thus, while resource constraints are ever present regardless of airport size, airport pavement managers must evaluate pavement preservation tools in larger terms than just their initial cost. Including the cost of disrupted operations in the decision-making algorithm can make a treatment that is marginally more costly become a bargain if it extends the service life of the pavement and more importantly, extends the time between maintenance disruptions *(3).* Applying chemical surface treatments that harden the pavement's surface and increase its resistance to absorption of deleterious deicing solutions is one such tool that can be used to reduce costly operational disruptions. These surface treatments can be applied to both new and existing runways, taxiway, and aprons to harden those surfaces against deterioration due to ASR, abrasion from tires and snowplowing, edge cracking at joints, and the degradation of grooving due to rubber removal operations (7).

Concrete Densification

From a technical standpoint, “densify” is defined as a chemical process where a reaction between a surface treatment’s hardening agent and the concrete creates a denser surface texture, which is harder than plain concrete in the near-surface region. Lithium silicate is a common, reliable agent to harden the surface of Portland cement concrete *(8)*. It has been used successfully to extend the service life of concrete floors in industrial settings. It works by reacting with the calcium hydroxide produced by cement hydration. The reaction produces calcium silicate hydrate. This is the same product that is produced by adding water to Portland cement, which develops the strength and hardness in Portland cement concrete. During hydration, the calcium hydroxide is dissolved in the water; migrates to the surface where the lithium silicate reaction occurs; and the newly formed calcium silicate hydrate deposits itself in the pores and voids on the concrete’s surface. The lithium’s function of the silicate is to “stabilize and solubilize the silicate so it can remain in solution until it penetrates the concrete and then can react with the abundant calcium hydroxide found in the concrete” *(8)*.

Lithium silicate has two main advantages over other, less expensive hardening agents. First, it forms a dust rather than a crust when it dries. Second, when the lithium silicate penetrates the pores in the concrete, an insoluble reaction with calcium hydroxide occurs that creates both chemical hardening and densifying, increasing the concrete's surface strength and resistance to wear to traffic abrasion. A recent highway study of a Portland cement concrete pavement (PCCP) found that the treatment made the pavement more rut resistant and resistant to wear from snow plow abrasion *(9)*. The reaction is greatest on a porous concrete surface because the porosity promotes penetration of the hardening agent, which in turn results in a deeper hardened surface *(8)*.

A major concern on airport pavements is skid resistance as a result of Federal Aviation Administration (FAA) friction standards *(10)*. Thus, any concrete surface treatment must not negatively impact skid resistance. A typical example are bridge deck curing compounds and sealants, which often specify restoration of surface texture using shotblasting after the curing is complete.*(11)*. Therefore, while the preservation of airport PCCPs by hardening their surface to make them less permeable and more wear resistant certainly makes sense, this quality cannot be achieved while sacrificing safety.

Airport Pavement Distresses

Like all pavements, airport runways, taxiways, and aprons are susceptible to environmental stresses that cause the concrete’s surface to degrade and the pavement cross-section to be compromised. Airports however must be much more concerned about the side effects of pavement surface degradation due to the potential for developing foreign object debris (FOD), which can create both financial and safety issues for the airplanes using the pavement. One report credits FOD with causing $1.1 billion worth of damage at the 300 busiest airports in the US *(12)*. Therefore, while the structural integrity of the pavement is important, surface defects that produce FOD are the primary short-term concern for most airports. The same FOD report also found that air traffic delay costs average $40 per minute per aircraft *(12)*, which creates a powerful argument for selecting pavement preservation treatments that specifically address surface distress issues to reduce FOD and disruption of operations.

Common causes of surface degradation of PCCPs include scaling and spalling due to ASR and deicing chemicals, edge cracking at joints, and surface degradation from the chemical and mechanical systems used to remove tire rubber accumulations *(13).* A study was conducted on the use of surface applied lithium nitrate to retard deterioration of PCCP from ASR *(14).* It conducted field testing on existing PCCPs at airports in Cheyenne, Wyoming, Phoenix, Arizona, and Atlanta, Georgia. Its findings validated the need for airport pavement preservation programs. The Cheyenne airport's pavement was initially in "fair to good" condition while the other two were rated in "very good to excellent" condition. Of the three, Cheyenne was the only case where application of the pavement preservation treatment appeared to have no effect. In the words of the researchers it was "too far gone" at the start of the experiment to benefit from a topical treatment. As a result, the report recommended that lithium only be used on good pavements. It also found that after lithium application "significant change of major deterioration indicators such as crack expansion, joint raveling and further cracking were not observed during the study period" *(14).* Another study reached the same conclusion and stated: "despite small depths of penetration associated with topical applications, such treatments appear to have been effective in extending the life of pavement structures suffering from ASR, where the most severe deterioration occurs at the surface" *(15).* Furthermore ASR may be induced or aggravated by de-icing chemicals such as potassium acetate or sodium hypochlorite used in removing rubber due to additional alkalis being introduced to the concrete surface. Even though preventive measures (i.e. fly ash or lithium admixtures) may have been engineered in the original mix design, the use of lithium nitrate as a pretreatment to help mitigate surface ASR caused by a higher concentration of alkalis, followed by a post lithium Densification will help lock in the free lithium ions as well as reduce permeability and increase wear abrasion of the pavement's surface.

Beyond cracking caused by ASR, airport pavements are also damaged by stress cracking at edges and joints as a result of normal freeze-thaw, and wet-dry cycles *(14).* One way to reduce the amount of damage from the environment is to make the PCCP less permeable and prevent the water intrusion through absorption as well as via hairline cracks. Sutter et al. *(15)* investigated the efficacy of various sealers and concrete pore blockers. One important finding of the study was: "when concrete reaches a critical degree of saturation, its freeze-thaw behavior is compromised." The study also called for new maintenance practices that are focused on sealing the PCCP's surface against water and deicing chemicals because "what worked in the past is not working now… deicing practices have changed the game." It also recommended that low permeability concrete and "thoughtful deicing practices" were necessary to prevent surface distress as well as structural damage from occurring in concrete pavements. Therefore, the potential for lithium products' potential promise to furnish a means to reduce the permeability of new concrete and through densifying the surface layer, may be realized by inhibiting water and chemical intrusion into existing concrete *(8).*

A study by Zollinger *(16)* found that using a lithium-based curing compound on new concrete improved the curing process and reduced uncontrolled top-down cracking in continuously reinforced concrete pavements. The study also found that less chipping in the tines was observed on the lithium cured test sections. Many airports have grooved concrete runways to promote drainage (13). These grooves are deeper than standard surface tining and as such would also potentially benefit from the use of lithium curing compounds. Additionally, the requirement to regularly remove rubber from grooved runways also creates a need to increase the durability of the substrate to resist damage from waterblasting or the brooming that occurs if chemical rubber-removal products are used. Densifying the surfaces of the tines and grooves will make them more abrasion resistant and hence extend the period between needing to recut the grooving or to diamond grind the tining. Additionally, past research has shown that applying a lithium densifier to newly ground or shotblasted pavements further extends the pavement's life (9).

Given the above discussion, one can conclude that using a densifier to harden PCCPs holds promise as a cost-effective pavement preservation treatment for airport pavements. Therefore, the remainder of the paper will explore the potential benefit of adopting lithium-based densifier as a pavement preservation tool on a life cycle cost basis.

CASE STUDY LIFE CYCLE COST ANALYSIS

To evaluate the potential of lithium-based densfiers from a financial standpoint, the Denver International Airport (DIA), a case study from ACRP Synthesis 11*(13)* is selected since its PCCP runway maintenance and repair program was collected for that study, making all the necessary input data available for the life cycle cost analysis (LCCA). DIA is the nation's 5th busiest commercial airport *(18)* with over 600,000 operations (take-offs and landings) annually. It has five 12,000 foot and one 16,000 foot grooved concrete runways. For the analysis, a LCCA will be conducted for one of the 12,000 foot runways. The analysis will calculate the equivalent uniform annual life cycle cost for the four alternatives listed below. Each alternative's life cycle starts with a hypothetical 10 inch (25.4 cm) unbonded PCC overlay which provides a newly constructed surface and the option to either use a standard or lithium-based cure.

1. Standard cure and resurfacing/regrooving uses no lithium-based products. *(18).*
2. Standard cure and lithium densifier applied over shotblasting (DOS) at every resurfacing/regrooving.
3. Standard cure and lithium densifier applied over light diamond grinding (DODG) at every resurfacing/regrooving.
4. Lithium cure and lithium densifier applied over shotblasting (DOS) at every resurfacing/regrooving to harden the runway surface and preserve the grooving.

Since the salient difference between alternatives is the lithium products and when each is applied, the additional expense must be justified by a commensurate runway service life extension that is long enough to reduce the life cycle cost. Therefore, the following analysis will be made using a very conservative set of assumptions for the performance enhancement of the lithium. First, a 2011 study *(19)* on a PCCP field test site on I-80 the Donner Pass in California found that DOS reduced the amount of rutting caused by abrasion from snow chains and plows by about 50% from that measured on the same new pavement without treatment. While that was a highway environment, the form of abrasion was arguably very aggressive and thus, it can be used as a measure of the increase in PCCP durability that would be experienced at the Denver airport. The literature shows that a typical grooved concrete runway at the JFK International Airport is scheduled for resurfacing (shoulder/erosion/fillets seal coat/PCC repairs/regrooving) once every 8 years *(20).* Hence, a 50% reduction in surface loss would equate in the need to resurface once every 12 years. To be conservative, the assumption that only 2 years of extended service life is realized is made in the LCCA calculations to follow. In the same report, the Tulsa International Airport used a 6 year maintenance cycle to rout and seal the joints on its PCCP runway, and the same 2 year extension will also be applied to that task in the LCCA.

The following are the remaining input values and assumptions used in the LCCA.

- DIA's air traffic volume translates to an average of 36 operations per hour, which at $40 per minute per plane delay cost *(12)* translates to $86,400 per hour total. As most scheduled maintenance work is conducted at night to minimize operational impact, 25% ($21,600/hour) of that delay cost will be used on each of the alternatives.
- ACRP Synthesis 11 *(13)* found that the average period of full runway shut-down on the case study airports for rubber removal was 7 hours per night, and this figure is to determine the length of time for all the maintenance treatments based on production rates found in the same source (DOS = 3,200 SY/hr; other treatments = 2,000 SY/hr).
- One DIA runway that is 12,000 feet long and 150 feet wide will be operated and maintained over the period of analysis. Each alternative will be evaluated over three complete maintenance cycles.
- Equivalent uniform annual life cycle cost will be used because the alternatives have different service lives (20).

Table 1 shows the cost input data using a range of possible values based on information gleaned from the literature.

Table 1 Construction Cost Input Data

Alternative	Input Cost Data		
	Low	Likely	High
10" PCC Overlay	$11,700,000	$11,700,000	$11,700,000
Standard	$642,400	$1,079,900	$1,642,400
DOS at resurfacing	$590,400	$851,400	$1,166,400
DODG at resurfacing	$858,400	$1,354,400	$1,984,400
Lithium cure +DOS at resurfacing	$660,400	$926,900	$1,292,000

Table 2 contains the output of both the deterministic and the stochastic LCCA. One can see that even though all the assumptions were conservative, that the use of the lithium products had a marked effect on the service life of the DIA runway. The alternative with the longest life also translated to the one with the lowest annual life cycle cost. In fact, the stochastic analysis found that the 90% confidence value for the last alternative was less than the 10% confidence value for the standard alternative. This indicates that the probability that the additional cost for the lithium products will prove to be cost effective is very high.

Table 2 Life cycle Cost Analysis Output.

Alternative	Service Life	Deterministic Annual Life Cycle Cost			Stochastic Annual Life Cycle Cost		
		Low	Likely	High	10%	50%	90%
Standard	18	$801,113	$856,041	$926,663	$842,174	$860,918	$880,843
DOS at resurfacing	24	$731,825	$758,696	$791,127	$762,562	$772,098	$781,800
DODG at resurfacing	24	$742,444	$770,250	$803,809	$809,826	$828,375	$847,564
Lithium cure + DOS at	26	$770,996	$823,837	$890,954	$751,350	$760,524	$769,801

resurfacing							

CONCLUSIONS

This study has shown that the use of lithium cure and DOS to extend the life of concrete runways by making them more wear resistant is both technically and financially viable. Specific conclusions are as follows:

- The use of a lithium curing product on the PCC overlay and topically applied lithium densifiers over shotblasting provides the lowest life cycle cost.
- Airports with existing concrete pavements can also gain a benefit by applying densifier over either shotblasting or light grinding as shown by the lower life cycle costs.

The above conclusions provide a proof of the economic viability of the lithium products as a pavement preservation tool. Not only is it cost effective, but it also enhances operational sustainability by reducing the number of times in a runway pavement's service life where it must be fully closed and disrupt airport operations.

The above analysis, while realistic and pragmatic, is hypothetical meant only to demonstrate the promise that these products embody for airport pavement preservation. The authors would like to recommend that rigorous full-scale field testing be conducted as future research to replace the assumptions that had to be made to complete the analysis. As the world's air traffic continues to grow, airport pavement managers will come under more pressure to maintain the required level of service with increasingly fewer mandatory maintenance and repair disruptions to the flow of airplanes and passengers. Lithium densification and curing compound must be rigorously tested to permit the industry to adopt it as a new tool in the pavement preservation toolbox.

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