REHABILITATION OF CONCRETE AIRFIELD SURFACES

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ABSTRACT

Numerous techniques have been tried for concrete surface rehabilitation, and the results have ranged from excellent to poor. This paper will review the successes and causes of failure for various rehabilitation techniques for portland cement concrete airfield surfaces. Techniques to be reviewed will include sealing, surface treatments, overlay methods and philosophies, and patching.

INTRODUCTION

A concrete airfield surface may be unsuitable for a variety of surface problems including cracking, faulting, roughness, spalling, scaling, popouts, etc. These defects may develop over time or may be a product of poor initial construction. Alternately, they may develop from structural loading, environmental effects, or may reflect material deficiencies. Any rehabilitation technique must be selected in conjunction with an understanding of the cause of the problem. Failure to address the cause of the deficiency usually results in unsatisfactory performance of the repair.

Any defect that produces loose debris on the airfield surface is of particular concern as this debris poses a potential foreign object damage (FOD) hazard to jet aircraft engines. This is of particular concern on military airfields where high performance systems may be particularly vulnerable and formation take-offs accentuate the problem.

This paper will provide an overview of surface rehabilitation techniques and their success or lack there of on airfields. It is initially largely drawn from U.S. military airfield experience. The PIARC airfield committee hopes to use this beginning effort as a catalyst for further world-wide discussion of the issue.

JOINTS AND CRACKS

Joints are a construction necessity of concrete pavements, and cracks from construction deficiency, poor dimensioning, material problems, or structural loading seem to be an ineradicable problem for the airfield engineer. Conventional wisdom is to seal cracks and joints and maintain these with resealing efforts as needed over the life of the pavement. This is to limit water ingress into the pavement structure and to prevent incompressible debris from accumulating in the joint during the natural opening and closing of pavement joints in response to temperature and moisture changes.

There is an alternate view promulgated in the UK, Australia, and by a limited number of highway engineers in U.S. state departments of transportation that holds joints should be left narrow (e.g., single 3-mm wide saw cut contraction joints) and left unsealed. Sealing should only take place if the opening widens to 6 mm. The implications for savings in initial cost and future maintenance is quite significant.

Airfield joint sealants used by the U.S. military in the 1960s and 1970s (asphalt-, coal tar-, polyurethane-, and polysulfide-based sealants) averaged only 3- to 5-year effective lives in the field. No maintenance budget could replace sealants on that frequency so U.S. military airfield sealants were not really “water-tight” through significant portions of their life although the sealants continued to limit debris intrusion into the joint. Philosophically, the U.S. military has always designed for wet conditions under their pavements and since 1991 has mandated subsurface drainage layers for major pavement facilities. However, U.S. Air Force (USAF) experience found poorly maintained joint sealants did lead to increases in spalling and FOD hazards. For example, a taxiway at an airfield on the Gulf of Mexico had joints with badly oxidized10-year-old sealants. The failed sealant allowed the joint to fill with fine debris and sand, and spalling developed on every transverse joint during a single week during a hot summer (Rollings and Rollings 1991). The U.S. Air Force has generally found a good joint resealing and crack sealing program helps maintain a higher pavement condition index (PCI, condition rating system used by the USAF) and promulgates this as their general policy.

However, in the UK the USAF bases follow the UK practice of narrow, unsealed joints, and these have performed well. There are also some unusually favorable conditions in these pavements: only carbonate aggregates are used (favorable coefficient of thermal expansion for concrete), lean concrete bases with polyethylene separator between base and pavement are standard (limit adverse moisture effects), and mild climate (small joint opening and closing). Such favorable conditions do not exist at other USAF bases, so the practice has not been extended elsewhere. The unsealed joint practice appears viable under some conditions, but more work is needed to determine its practical applications and limitations.

During the 1970s, tests by the U.S. military found that manufacturer certified joint sealants generally failed to actually meet the specifications - for one class of sealants failure rates exceeded 80%. Since then, the U.S. military requires every individual lot of joint sealant to be used on a military airfield to be individually and independently tested for specification compliance. Manufacturer certification of compliance simply cannot be relied upon.

Asphalt-based joint sealants are relatively inexpensive, but they are neither fuel nor jet-blast resistant and have had recurrent bubbling problems. Despite their relatively low cost, their use on U.S. military airfields has declined greatly. Coal-tar based sealants are fuel resistant but not jet blast resistant. There is an increasing trend to limit coal-tar based materials in construction due to health concerns. Polyurethane- and polysulfide-based sealants can be both fuel and jet-blast resistant and find wide application in U.S. military airfields. Silicone sealants have been increasingly used on military airfields in the last decade. Their performance has generally been very good, but they tend to be expensive and fail the fuel exposure test. Preformed polychloroprene or neoprene sealants have become the USAF preferred joint sealant for new construction. When properly installed, their satisfactory field life has been in excess of 10 years. Because they require vertical joint walls they are best suited for new construction and not resealing of existing joints. Over the last 15 years or so, the USAF has been plagued by recurrent early-age joint spalling on new concrete airfield pavement construction which has generally been due to poor field construction practices (Rollings 1998). Not only does this early-age spalling pose a FOD hazard, but it also impairs the performance of the preformed sealants.

While good materials are crucial to proper performing joint and crack seals, poor joint preparation remains the overwhelming major cause of premature joint and crack sealant field failures on US military airfields. U.S. military concrete airfield joint and crack repair recommendations have been summarized in a field manual (Lynch et al, no date) and an updated version is being posted as a U.S. military Unified Facility Criteria document on the world-wide web.

Periodically, late sawing of contraction joints by the contractor or some similar problem leads to uncontrolled cracking at a very early age. Often the contractor proposes epoxy injection of the cracks as a solution. USAF experience with this has been uniformly disappointing. Epoxy or other polymer injection of cracks is highly effective as long as the joints are not "working" or moving. Cracks that form because of ineffective contraction joints are invariably the true working joints, and the saw-cut fails to crack. Hoping the polymer injection will glue the crack together sufficiently quickly and strongly that the saw-cut cracks properly proves futile. The concrete's natural volume change in response to every temperature and moisture change leads to rapidly reestablishing the original crack despite the polymer injection. In such cases, one has little to choose from other than: (1) removal of the cracked slabs with problems tying the repair back into the pavement properly or (2) sealing the saw-cut kerf with grout, routing the crack, and then sealing and maintaining the routed crack as the actual contraction joint for the adjacent slabs.

SURFACE TREATMENTS, COATINGS, AND MEMBRANES

To start this discussion, one should first recognize that properly proportioned, placed, finished, and cured concrete can stand up to every load and environmental condition required for airfields. US military experience generally supports this statement for environmental exposures from the Arctic to the deserts of the Tropics and for aircraft wheel loads over 30,000 kg and tire pressures up to 2.8 MPa. The only exceptions are the impact and abrasion damage from barrier cables for fighter aircraft, thermal and blast damage from vertical take-off aircraft, and the downward exhaust of the auxiliary power unit on F-18 and B-1 aircraft which can lead to scaling damage from chemical reactions between the cement matrix, elevated concrete temperature, and spilled ester-rich fluids such as hydraulic fluids. The first is best handled by installing replaceable panels of ultrahigh molecular weight polyethylene. The last two have yet to find a totally satisfactory solution, although the U.S. Navy favors installing steel plates in such exposure areas.

In general, when one considers surface sealants and membranes, one is already dealing with deficient concrete. Such treatments should never be considered as routine treatments for new concrete that has been properly placed. The application of a surface treatment or membrane will not make bad concrete into good concrete; one simply hopes it will make it less bad.

A number of concrete surface sealers are marketed that are essentially linseed oil, silane, or siloxane. These penetrate shallowly into the concrete surface, reduce permeability, and thereby are claimed to enhance freeze-thaw durability. U.S. military experience finds these treatments of negligible value for airfield pavements in the field. Proper proportioning and air entrainment are the only reliable way to obtain freeze-thaw durability. In a pavement, water enters the concrete as vapor or capillary water from the bottom as well as from surface infiltration. Consequently, freeze-thaw damage to the underside and along the face of joints of improperly protected slabs often is worse than on the surface. Surface sealers offers no help in these problem areas.

The USAF has used high molecular weight methacrylate as a surface penetrator and crack infiltration agent to reduce FOD hazards from deteriorating concrete pavement. It changes the appearance of the concrete, effectiveness is moderate, and cost is high. It is a recourse of last resort. Treatment with methyl methacrylate (similar but somewhat less effective compound compared to high molecular weight methacrylate)of a badly cracked surface from alkali-silica reaction at Seymour-Johnson AFB, NC was ineffective for that application.

Plastic shrinkage cracking that appears at early age commonly manifests itself as a series of shallow map cracks. This common defect is entirely due to inadequate construction curing procedures that allow excessive moisture evaporation from the surface - albeit achieving adequate curing in hot, windy conditions can be a challenge. Such cracking generally causes great distress to the pavement owner. However, such damage is largely cosmetic. In severe climates, this cracking has sometimes been observed to the source of raveling late in the life of the pavement (15 or more years later). Any "fix" for this type of cracking should balance the cost of fixing versus the fact that the damage is generally cosmetic only. There have been several projects where a polymer material was used to fill the cracks using gravity penetration or vacuum methods. Conceptually, this should decrease the potential for future late-age raveling, but no such project has been monitored for a sufficient length of time to ascertain whether the benefit is real or illusory. The cosmetics appearance of the project is not improved, and the cost of the treatment is quite high.

The technology for applying a thin (0.25 - 6 mm)coating or membrane of polymer (e.g., epoxy, urethanes, or acrylics) with or without reinforcement and fillers to concrete is well advanced. The cost of high-quality polymer membranes is excessive for most paving applications, and the selection, design, and application of such is best undertaken by specialists in the area. The USAF has used such membranes on ramps where aircraft are stripped and repainted.

Thin applications of polymers and sand have been used a number of times to deal with shallow surface problems such as scaling. Results have been mixed, and FOD hazards from failed sections have been very severe. Their use is feasible, but caution and trial are advisable before wholesale applications are tried.

PARTIAL-DEPTH REPAIRS

Localized damaged areas can be removed, cleaned and patched to restore their utility. This is a common method of dealing with spalls and similar localized deterioration. The results of this type of work are mixed. Some patches last for a decade or longer; others fail within days of being placed. The keys to successful patching are (1) proper repair area preparation, (2) selection of proper repair material, and (3) proper placement and curing.

The deteriorated concrete must be identified and removed so that the repair bonds to sound concrete. To be successful, the repair area requires a vertical saw cut outlining the repair area. Attempts to carry out the repair by feathering the repair material onto the concrete surface without vertical saw cut patch edges has given uniformly poor results for the U.S. military. The concrete surface to which the repair material bonds must be clean. A small film of dust is all that is needed to cause bond and patch failure. Lack of a clean bonding surface is probably the single greatest cause of patch failure. Patching materials often have exceptional bonding capability, so the joint must be maintained with inserts, barriers, etc. to prevent the repair material from bonding across the joint to the adjacent slab as well as to the slab being repaired. If this is not done, the patch is often pulled loose by the differential movement between slabs. The USAF had a number of patch failures of this sort before emphasizing this detail in repair manuals and training.

A wide variety of repair materials are marketed for patching concrete pavements. For repairs of 100-mm depth or thicker, conventional portland-cement concrete is adequate. To the extent possible, the patching concrete should match the original concrete mixture proportions to minimize differences in thermal and shrinkage characteristics. For thin patches or patches that must be reopened to traffic rapidly or for other considerations, there are a large number of proprietary patching compounds that have good bond to concrete, gain strength rapidly, and are durable. Most of these proprietary materials are based on magnesium phosphate cements, polymeric materials, gypsum, or special purpose portland-cements. The portland-cement based systems obtain their rapid set and early strength by adjusting the chemical composition of the cement, finer grinding, addition of admixtures such as accelerators and superplasticizers, or some combination thereof. Some of these proprietary patching materials have excessive shrinkage and should be avoided. Others have poor durability under some conditions, and some have such rapid set that it limits the size of the repair area that can be accomplished. Because these are proprietary compounds, it is also prudent to independently test the potential patching material to confirm its properties are suitable for the desired patching application. There is considerable variation, and caution mixed with skepticism is warranted when evaluating manufacturers' claims.

Patch construction should follow conventional good practice (proper storage of materials, placement conditions, mixing, repair area preparation, use of bonding grout if required, placement, consolidation, finishing, and curing). However, because most of these are proprietary materials, it is crucial that the manufacturers' recommendations be explicitly followed. For example, dry versions of magnesium phosphate cements are very sensitive to excess water, and inexperienced crews may easily add too much water trying to achieve good workability - thereby ruining the material. Epoxies are very sensitive to proper proportioning and mixing, and failing to do these steps properly may result in the material not setting properly. For these types of reasons, use of proprietary patching materials requires proper understanding and execution of the manufacturers' recommendations. It is always prudent to have a manufacturer's representative to assist on-site when using a product for the first time.

OVERLAYS

Overlaying the existing pavement with asphaltic or portland-cement concrete is a very common technique for dealing with a concrete pavement with some unsatisfactory defect. Each overlay material has certain advantages and limitations, and there are several different techniques for undertaking the overlay. Rigid (portland-cement concrete) and flexible (asphaltic concrete) overlays will each be discussed separately in the following sections as they each have very different design and performance concepts.

Rigid Overlays. These are typically classified as fully-bonded, partially-bonded, or unbonded rigid overlays. The bonding terminology refers to construction method and not to bond levels per se. All of these have some degree of bond in the field, and with the occasional rare exception of fully bonded overlays, degree of bond is neither specified directly nor tested in the field. The requirements for each class of overlay can be summarized as

Fully-Bonded Explicit steps are taken to achieve bond between the old and new concrete and to achieve monolithic behavior. These steps commonly include vigorous surface roughening or texturing, possible application of a grout, and placement of the new concrete.

Partially-Bonded — No specific effort to achieve or prevent bond is taken. The base concrete is simply swept and cleaned.

Unbonded — A separating layer is placed between the old and new concrete. This layer most commonly is 25 to 50 mm of high-quality asphaltic concrete. Cores through such unbonded overlays commonly recover all three layers in a single intact core. Hence, there is adhesion and bond between the layers. Rather than being truly unbonded, it may be best to consider this a separating layer of dissimilar material. Other separating layers beside asphaltic concrete have been used and are summarized and evaluated by Hutchinson (1982).

During the 1940s and 1950s the U.S. Army Corps of Engineers conducted a series of full-scale trafficking tests and developed the following basic equation to design rigid overlays:

$$h_o^n = h_{eq}^n - C_r h_e^n$$

Where

h_0 = thickness of overlay

h_{eq} = thickness of an equivalent concrete slab designed as though base concrete slab to be overlaid was not present

C_r = condition factor for existing concrete, = 1.0 if in good shape, reduced below 1.0 for cracking, etc.

h_e = thickness of existing concrete to be overlaid

n = power reflecting nominal bond condition
= 1.0 for fully bonded
= 1.4 for partially bonded
= 2.0 for unbonded

Because of funding limitations, these tests were not adequately documented. The available data has been summarized and analyzed in Hutchinson and Wathen (1962) and Rollings (1988). The earliest known use of an equation of this form was to analyze a pavement composed of bricks bonded to a concrete base pavement (Older 1924), but it came into widespread use for overlays for lack of a better approach (American Concrete Institute 1967). One may derive equations somewhat similar in form to this based on equivalent beam theory (Rollings 1988), but the design remains essentially an empirical approach based on matching an equation of questionable theoretical rigor to results of limited and poorly documented full-scale traffic tests. This equation has been used by the U.S. military and others for overlay design for over a half century and has been widely adopted by others. Performance of overlays designed by this approach has generally been good.

The U.S. Federal Aviation Administration (FAA) funded development of a new overlay design procedure with a more rigorous theoretical basis using layered elastic theory (Rollings 1988) and has incorporated this in their new LEDFAA layered elastic design computer program. This approach allows superior modeling of the interaction between layers and cumulative damage of traffic but is still calibrated using the same accelerated traffic data that was the basis of the empirical Corps of Engineers equation. Future FAA accelerated traffic testing on overlays is planned for their pavement test facility at Atlantic City, NJ.

There has always been some debate whether the partially bonded overlay represents a truly separate condition from the unbonded condition. This division was defined based on performance of the full-scale traffic tests results. The military design manual that was current at the time (Department of the Army 1958) explained the situation as:

> *The results of the traffic testing at Lockborne No. 1 and No. 2 and Sharonville No. 2 indicated that the above relation* (unbonded, where n = 2) *was approximately correct when a leveling course, cushion course or bond-breaking course was placed between the two slabs, and that the relationship was too conservative when the overlay was placed directly on the base slab without purposely destroying the bond between the slabs.*

The Corps of Engineers plot of the data showing the best-fit relation for partially-bonded overlay was not publically published until 1988 (Rollings) as part of the poor documentation associated with the overlay work. Comparison of the empirical Corps equations with layered elastic results found that the unbonded equation (n = 2) was always conservative and the partially bonded equation (n = 1.4) was an approximate best fit when compared to the layered elastic analysis (Rollings 1988, 1989). This is consistent with the original Corps findings from the 1950s.

In addition to the design equation differences, reflection of joints and cracks are major factors for the overlays. Joints and cracks will reflect through fully-bonded and partially-bonded overlays but not unbonded overlays. The U.S. military found the fully-bonded overlay to be unsuitable for structural upgrades because when dowels were placed in the bonded overlay at the Sharonville Heavy Load Tests, spalling occurred over the dowels shortly after traffic began (Hutchinson and Wathen 1962, Rollings 1988, 1989). Since the military airfield pavement design concept relies on positive load transfer between slabs (Rollings 1981, 1988), and there has yet to be a method to achieve this load transfer in a bonded overlay, the fully-bonded overlays are only used to correct surface deficiencies. The unbonded overlay will always be the thickest followed in order by partially-bonded and fully-bonded (if the load transfer issue could be resolved) overlays. Surface preparation for the different overlays is most expensive for the fully-bonded followed in order by unbonded and partially-bonded overlays. U.S. military experience and philosophy suggest the following as the best application for each overlay system

Overlay	Application	Comments
Fully-Bonded	Correct surface problems	50 to 100 mm thick, not to be used for structural upgrade because of load transfer issues. Match joints.
Partially-Bonded	Upgrade structural capacity for pavement in good condition. Typical application would be to upgrade existing pavement in good shape to take new, heavier aircraft.	Minimum thickness 150mm. Match joints. Cracks will reflect so must repair base slabs as needed.

Unbonded	Restore condition and load capacity of deteriorated pavement.	Minimum thickness 150 mm. Do not have to match joints and underlying cracks will not reflect through.

Proper bonding of fully-bonded overlays is crucial to their good performance. Boyer et al (1981) examined the performance of fourteen fully-bonded overlays placed between 1959 and 1967 at four Air Force bases in Texas, Michigan, Ohio, and Indiana. These had been placed to correct problems with excessive popouts, roughness, spalling, and surface irregularities. These pavements with an average age of 18 years generally maintained bond and a condition rating of good. In isolated areas where bond was lost, cracking was a problem. In contrast to these bases, a recent job at Spokane AFB suffered massive debonding because the bonding grout was allowed to dry excessively before overlay placement. This resulted in widespread corner breaks and cracking and required replacement of the job. Petersson and Fredback (2003) describe satisfactory performance of five bonded overlays at Swedish airfields. The USAF experiences mirror those reported by others (e.g., Darter and Barenberg 1980, Gillette 1965, Petersson and Fredback 2003).

There are several suggestions as to what degree of bond is needed for a fully bonded overlay. Felt (1956) is the oldest, and he reports that 1.38 MPa is the minimum required for satisfactory performance. Wells et al (1999) suggest 0.9 MPa based on Canadian standards, and Petersson and Fredback (2003) suggest 1.0 MPa based on Swedish floor requirements. Table 1 summarizes the results of bond strength tests for different preparation techniques. In general, most investigators found surface preparation is necessary to get bond, both cold milling and shotblasting have proven consistently successful in the field, shotblasting offers some operational advantages and tends to be preferred today, epoxy bonding agents offer no significant advantage over cheaper cement grouts, and as the quality of texture improves the need for a bonding agent declines.

Flexible Overlays. Asphaltic concrete overlays suffer from one major problem. Joints and cracks in the underlying portland-cement concrete reflect through the asphalt layer. The formation of these cracks is an environmental effect, and load may contribute to the cracks but is not necessary for their formation. In a cold climate these cracks may appear over the course of a single winter. Once formed, these cracks deteriorate and become a FOD hazard. Despite many experiments with geotextiles, stress absorbing membranes, large aggregate mixes, and various kinds of geosynthetic, fiberglass, and steel reinforcing, no system has yet demonstrated that any of them can reliably prevent reflective cracking. In warm climates, these systems seem to slow the formation of the reflective crack and slow its deterioration. In cold climates, the systems are usually ineffective.

Since there is no recognized way to prevent reflective cracking, the USAF's preferred policy for asphaltic overlays on concrete pavements is to saw a joint in the asphalt directly above the portland-cement concrete joint. This joint is then sealed and is easier to maintain than an uncontrolled reflective crack.

Another technique is to break the existing portland-cement concrete into pieces 0.5 m or less in size, seat the broken pieces by rolling with a pneumatic roller, and then overlaying with asphaltic concrete. The process is termed crack and seat or rubblizing depending on the degree of breakup. Equipment has been developed to carry out the breakup of the concrete efficiently. The process essentially converts the broken up and overlaid rigid pavement into a flexible pavement. There have been a number of successful applications of the concept, and it is accepted by the USAF as a viable overlay alternative.

Design methods for flexible overlays over intact portland cement concrete implicitly accept reflective cracking occurs and do not address this issue directly. The Corps developed an empirical flexible overlay equation at the same time it developed the rigid equations discussed earlier (Mellinger and Sale 1956). This equation is based on complete subgrade shear failure and shattering of the base pavement at the end of design traffic, and results of the empirical equation can be erratic and hard to interpret (Rollings 1988, 1989). A layered elastic flexible overlay design system based on protecting the base slab from additional damage was developed for the FAA (Rollings 1988) and is included in their new LEDFAA computer design program.

CONCLUSIONS

This paper provides a brief synopsis of techniques available for restoration of portland-cement concrete airfield pavements. The topic is complex and rich, and no single paper can be comprehensive. In conclusion, we should recognize that properly designed and constructed airfield pavements using proper materials minimize the need for these restoration efforts. The basic underlying cause of the pavement defect must be identified so that an appropriate restoration technique can be selected. And finally, we must welcome and try innovations in the field but should maintain a healthy skepticism as claims that are not fairly and independently evaluated often are unduly optimistic.

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Table 1. Bond Strength for Different Surface Preparations			
Surface Preparation	Reference	Strength, MPa	Comments
Sweeping/Brooming	Kohn and Rollings 1988	0.6 to 2.3	6 field projects, average 1.2 MPa, Coef. of variation (COV) = 57%
Sandblast/Waterblast	“	3.8 to 4.1	4 field projects, average 3.9 MPa, COV = 4%, may have included mechanical abrasion, may not be repeatable
Sandblast	Silfwerbrand 1990	1.1 to 1.8	
Water Jetting	“	1.4 to 1.8	
Jackhammer	“	0.7	
Abrade/Air-Water Clean	Kohn and Rollings 1988	1.8 to 3.9	6 field projects, average 2.7 MPa, COV = 29%
Abrade/Acid or Water Clean	“	2.3 to 3.4	6 field projects, average 2.7 Mpa, COV = 25%
Cold Mill/Sand or Water Blast	“	2.5 to 7.4	9 field projects, average 4.3 Mpa, COV = 36%
Cold Mill/Water Blast	Petersson and Fredback 2003	1.6 to 2.4	4 field projects, average 2.0 Mpa, COV = 21%
Shotblast	Wells et al 1999	2.1 to 2.8	