EARLY-AGE SPALLING ON USAF AIRFIELD PAVEMENTS

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Abstract

The U.S. Air Force (USAF) has had recurring problem with spalling occurring on new portland-cement concrete airfield pavements at early ages. These appear anywhere from before the pavement is turned over by the contractor to within one year of placement. Past studies of this problem have found early-age spalling is most generally associated with nondurable concrete that results from poor construction practices. The USAF implemented new requirements for mixture proportioning and an education program on the problem that has alleviated the problem to a degree. A recent runway and taxiway construction project is again suffering from early-age spalling, and the investigation to date again indicates nondurable concrete is the culprit.

Introduction

The existence of loose debris on the surface of a military airfield is a safety hazard. Such debris are considered a *foreign object damage* (FOD) hazard to aircraft engines, and flying personnel view such debris as a significant safety hazard. Air Force policy requires frequent sweeping to remove loose debris from the airfield surface, and pavement surface deterioration that produces potential FOD hazards gets priority for scarce maintenance funding. Furthermore, all vehicles entering the flight line must stop at the entry point, and vehicle occupants regardless of rank or position must inspect the tread of the vehicle tires and remove any rocks or similar particles that might be carried onto the flight line. Around the world, airman periodically gather for the infamous *FOD walk* during which they line up abreast and walk the runway length picking up all potential FOD hazards. In the US Air Force (USAF), FOD is a serious concern to the flying community, and one therefore that the civil engineering community must always be prepared to address.

Generally, spalling develops later in the life of the pavement and may arise for a number of reasons including durability problems (e.g., D-cracking or alkali-silica reaction), accumulation of incompressible material in the joints, corrosion of embedded steel, or deterioration around cracks and joints from loading (e.g., AFCESA 2007 and 2006, Markey et al 2005, Rollings and Rollings 1991, Hodges 1990, Belanie 1990, Mullen and Flegas 1972). However, the USAF has been plagued periodically by early-age spalling on airfield pavements wherein spalls form within

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the first year after construction; sometimes even appearing before construction has finished. Causes of this early-age spalling at joints is the focus of this paper. The most common and troublesome of these early-age spalls include sliver spalls (Figure 1) and failure of improper edge-slump repairs (Figure 2).

Figure 1. Examples of early-age sliver spalling on joints: (from left to right) a. Grissom AFB, IN freeze-thaw damage due to low entrained air content, b. McConnell AFB, KS freeze-thaw damage due to low entrained air content, and c. Randolph AFB, TX aircraft traffic abrasion and environmental effects damaging a thick covering of weak surface grout with low entrained air and high water-cement ratio.

Figure 2. Examples of spalling of edge-slump repairs: (from left to right) a. attempt to repair edge slump using mortar at Travis AFB, CA, b. resulting spalling of these weak edge-slump repairs at Travis AFB, CA, and c. edge-slump repair spalling at Kelly AFB, TX (note original down-slumped surface before repair visible at bottom of spall).

Background

During the inspections of USAF airfields as part of the Pavement Condition Index (PCI) development, the widespread sliver and small joint spalling presently causing issues in the USAF simply were not evident on airfields of the early 1970s (personal communication with Dr. Starr Kohn, now vice president, Soils and Material Engineers, then part of the CERL PCI team).
The PCI was originally developed by the U.S. Army Construction Engineer Research Laboratory

(CERL, today part of ERDC) for the Air Force Civil Engineering Center (today AFCESA) in the 1970s. Since then the PCI has been widely used and adapted by a variety of organizations and has become as the basis for American Society for Testing and Materials (ASTM) standards (ASTM 2004 and 2007). The PCI was originally developed to allow junior military personnel to consistently rate the condition of an airfield pavement the same as would an experienced senior USAF Major Command (MAJCOM) pavement engineer.

During the 1980s and 1990s early-age spalling was reported by the MAJCOMs with increasing frequency. These spalling problems were significant issues, e.g., at Travis AFB 69% of all joints spalled within one year on one project while on a project at Hector Field over 48% of the joints spalled within one year. During this period, one USAF MAJCOM grew so frustrated with the early-age spalling problem that it was on the verge of banning all slipform paving from its airfield construction projects under the mistaken belief that this, then new, construction technology was the cause of the spalling problems. Results of various early-age spalling studies at a dozen USAF bases were summarized in Rollings (1998). For 10 of the 12 bases studied, spalling generally developed because of nondurable concrete at the surface and along joints. The primary source of this nondurable material was usually poor construction practices (e.g., edge slump repairs with mortar, poor finishing techniques that left a weak surface paste, etc.). Spalling developed both at bases with severe winter weather and at bases with mild climates.

Most of the poor construction practices leading to the nondurable surface concrete were already forbidden in military construction specifications. Adding further specification verbiage offered little prospect of actually lessening the USAF's early-age spalling problem. Instead the USAF mandated that all concrete used on its airfields would use well-graded aggregates, and assessment of concrete workability based on aggregate characteristics got new emphasis (AFCESA 1997, Rollings et al 2007). The nexus between this graded-aggregate requirement and the early-age spalling issue was a desire to encourage use of concrete mixtures that could be more easily placed and consolidated without recourse to poor finishing techniques and to have mixtures that were not prone to edge slump and segregation (Rollings et al 2007). Certainly, there are other ways to obtain workable and optimized concrete mixtures rather than the graded-aggregate approach (e.g., Obla and Kim 2008). However, USAF experience finds many contractors working on USAF projects will tend to use the cheapest concrete mixture available, almost regardless of placing characteristics. This is often a necessary evil for the contractor because of the competitive bidding process used to procure USAF airfield pavements. A bid with a higher priced concrete with better construction and performance characteristics could lose the work to a bid with cheaper, poorer quality concrete. Use of graded-aggregate requirements provides more consistent concrete with less early-age spalling, and generally both government and contractor personnel have had favorable impressions of these mixtures. There is a cost associated with this, of course, but a lessening of the early-age spalling issue makes a good investment for the USAF situation.

This mandate for a new concrete mixture proportioning approach was also associated with a new emphasis on education. The Army Transportation Systems Center teaches a workshop for government and contractor personnel before major projects where the relation between poor construction practices and early-age spalling is stressed. The USAF Air Force Institute of Technology also covers this topic in their classes for USAF civil engineer personnel involved in airfield pavement construction and maintenance.

The early-age spalling issue led some in the military airfield community to argue that joints needed to be beveled to reduce corner stress concentrations and limit snow plow damage. The opposing view was that vertical joint faces had been used by the USAF for a half-century and more without spalling being an issue so, while beveling did no harm, it was not necessary. An early experiment in beveling at Grissom AFB, IN where the concrete had inadequate air entrainment for frost resistance found the beveled joint spalled after one winter as did the one with vertical faces (Figure 3). Nondurable concrete and not geometry was the issue. Beveling remains an unresolved issue with some organizations mandating it and some not.

The graded-aggregate mixture proportioning practices coupled with improved education efforts have lessened the problem with early-age spalling compared with its prevalence in the 1980s and 1990s, but the problem certainly is not solved. It continues to occur and remains unacceptable to the USAF.

Figure 3. Example of sliver spall on beveled joint.

Assessment of USAF Early-Age Spalling Problems

Table 1 provides a summary of early-age spalling and surface defect problems at USAF bases from 1981 - 2005. Of the 15 bases studied, snow clearing operations were the primary cause of damage in 13% of the cases, grinding operations in 7%, curing in 13%, inadequate air entrainment in 13%, and construction issues in 54% of the cases. As in most field failures, there are often multiple contributing causes for any one specific case, but clearly construction defects are the biggest single contributor to early-age spalling in USAF experience. In many cases, poor construction practices such as adding water to the surface during finishing, over finishing, edge-slump repairs with a slurry, etc. result in localized areas of weak concrete or surface paste with inadequate air entrainment.

Snow-Clearing Operations. The two bases where snow-clearing operations were the primary cause of spalling (Myrtle Beach and Cannon AFBs) seldom have snow and ice. In both

Table 1. Causes of early-age spalling on USAF projects built in 1981- 2005		
Airbase	Primary Contributor	Secondary Contributors
Cannon AFB, NM	Snow clearing	Grade changes
Ellsworth AFB, SD	Construction practices	Inadequate air entrainment
Elmendorf AFB, AK	Curing	Early loading
Grissom AFB, IN	Inadequate air entrainment	
Hector Field, ND	Construction practices	Inadequate air entrainment
Kelly AFB, TX	Construction practice	Concrete mixture
Laughlin AFB, TX	Grinding operations	
Malmstrom AFB, MT	Construction practice	Aggregates
McConnell AFB, KS	Inadequate air entrainment	Concrete mixture
Myrtle Beach AFB, SC	Snow clearing	
Randolph AFB, TX	Construction practices	Inadequate air entrainment
Tonopah Test Range, NV	Construction practices	
Travis AFB, CA	Construction practices	Unsound aggregates, Concrete mix
Whiteman AFB, MO	Construction practices	Concrete mixture, Inadequate air
Wright-Patterson AFB, OH	Curing	
Table based on Rollings and Wong 1992, Rollings et al 1998, Rollings 1998, Rollings et al 2002, Rollings and Rollings 2005, Rollings 2005, Rollings 2006 and unpublished data.		

cases, motor graders with inexperienced operators were pressed into service for snow and ice removal after unusually severe weather. Spalling occurred primarily at the centerline and consisted of essentially triangular fragments 25-mm deep and 25-mm wide (Myrtle Beach AFB) or deep gouges and chipping (Cannon AFB). The situation at Cannon was further compounded by unusual transverse grades that changed near the centerline and grooves that passed through the centerline that together provided geometric catchments for the grader blade.

Certainly, snow clearing operations can cause damage to pavements. However, under normal conditions these should be little more than scrapes and occasional pitting. Unsound concrete or surface irregularities may be revealed as spalls and gouges by snow clearing operations, however. A past study (Rollings et al 1998) that included the assessment of horizontal loading on the face of a pavement joint such as one would expect from snow-clearing operations found the spalling would tend to be shallow and extend away from the joint rather than be the deep, narrow sliver spalls seen in Figures 1. Snow clearing operations are a routine USAF operation with standardized procedures, equipment, and training. Appearance of early-age spalling issues for the USAF, especially in mild climates like California and Texas, simply does not correlate with snow clearing operations nor do they seem to be the right mechanism to cause early-age sliver spalls.

Sawing and Grinding. Improper sawing or grinding operations have the potential to cause spalling and raveling along the joints. However, Laughlin AFB is the only situation where the problem was significantly severe to cause a USAF investigation. In this case, poor construction left a runway surface that had to be ground back to smoothness tolerances. The grinding was deep, often as much as 12.5 mm or more, and the fins of concrete between the grinding saw blades failed to break off as they normally do. A motor grader was used to scrape and break these off. Popouts of elongated aggregates left by the grinding and spalling of the surface was widespread. This could be ascribed to the deep grinding, resulting unusual surface aggregate shape, and damage to the concrete matrix and aggregate-paste bond caused by the scrapping of the surface with the grader to remove the fins left by grinding (Rollings 2006). Randolph AFB had spalling and raveling begin to appear as soon as joint sawing and grooving began. However, the investigation found widespread weak surface paste throughout the project. This weak surface grout was the actual cause of problems, and the sawing was simply the catalyst to reveal the weak material that continued to deteriorate with time from environment and traffic.

Curing. At Elmendorf AFB, failure to properly restore curing conditions for joints after saw-cutting combined with early loading caused shallow spalls along one side of almost all the joints in the traffic area on one end of a runway (Rollings et al 1999). In 2002 a new C-5 ramp at Wright-Patterson AFB developed widespread surface scaling of thin oval sections of surface mortar. This developed because of too early application of the curing membrane that trapped excess bleed water below the finished surface and led to delamination.

Construction. Construction defects leading to early-age spalling can generally be associated with either edge-slump repairs of slipformed pavements, poor finishing practices, or a combination of these. These often result in localized areas of nondurable concrete and other areas that are durable.

When a slipform paver moves forward, the edge of the concrete extruded from the rear of the machine may slump downwards (edge slump). This is unacceptable as it will fail to meet military airfield smoothness requirements and will result in water collecting along the longitudinal joints. The defect cannot be repaired during construction by adding slurry or mortar to the restore the surface (Figure 2 a) as such repairs later spall and separate from the originally placed pavement (Figure 2b and c). Adjustments to the concrete mixture proportions or the equipment are needed to correct this defect. Ellsworth, Kelly, Tonopah, and Travis AFBs in Table 1 had spalling predominately from edge-slump repairs as their primary cause of early-age spalling. Malmstrom AFB had significant edge slump repair spalling but also had some potential problems with poor bond between aggregates and paste in some areas that compounded the spalling problems.

Finishing problems that typically lead to spalling include practices such as (1) adding water to the surface and then working that into the surface to produce a high water-cement ratio nondurable surface paste, (2) excessive hand work that floats a thick paste to the surface which then often has a high water-cement ratio and low entrained air content, (3) working a slurry, paste, or mortar into to the surface to close cracks, fill low spots, etc., (4) excessive passes with a mechanical finisher such as a tube float that works a paste to the surface, sometimes so extreme that slurry pours over the side of the pavement, or (5) some combination of these activities. Often these poor practices seem necessary to the field crews because the concrete mixture is hard to work or finish or is tearing and if the pavement is slipformed, excessive edge slump may well be occurring also. Hector Field, Randolph AFB, and Whiteman AFB in Table 1 were predominately poor finishing practices that left widespread surface areas with nondurable paste at the surface and along joints.

Poor construction practices leading to early-age spalling usually are a combination of factors, and the attempt to identify the predominant contributor above is only approximate. The variable nature of these construction practices often results in localized areas of nondurable and durable concrete.

Inadequate Air Entrainment. Five runway, taxiway, and apron projects at McConnell AFB were built with a high sand content concrete mixture between 1985 and 1988 (Rollings 1998, Rollings and Wong 1992). This high sand mixture was used along with reduced aggregate size to combat D-cracking problems with the local aggregate. The D-cracking problem was solved, but one project reported multiple blisters behind the paving machine, one reported minor blistering problems, and all suffered from early-age spalling problems. Figure 1b shows the narrow slivering spall that was characteristic of the spalling seen here. Three separate petrographic examinations were conducted of the blistering and spalling problems at different times by the Waterways Experiment Station (WES, now part of ERDC) and the Corps of Engineers Missouri Diver Rivision (MRD) Laboratory. The results are summarized in Table 2. These sticky high-sand concrete mixtures usually had high total air but also had unusually high entrapped air and low entrained air. The resulting spacing factors are almost universally high suggesting high vulnerability to freezing and thawing damage. When such pavements are exposed to freezing weather, the observed damage is sliver spalls on the joints.

Table 2. Air-void analysis of spalled pavements at McConnell AFB					
Project & Year Built	Lab Work Performed by	Average Air Content, %			Spacing Factor, L-bar, mm
		Entrained,%	Entrapped, %	Total, %	
No. 1, 1986[5]	WES[1]	-	-	11.7	0.254
No.1, 1986[6]	WES[2]	2.5	3.3	5.8	0.305
No. 1, 1986[5]	MRD[3]	4.3	7	11.3	-
No. 2, 1987[6]	WES[4]	1.9	6.0	7.9	0.444
No. 3, 1985[6]	WES[4]	5.4	5.6	11.0	0.190
No. 4, 1986[6]	WES[4]	3.1	3.9	7.0	0.305
No. 5, 1988[6]	WES[4]	1.6	2.5	4.1	0.470
	Average	3.1	4.7	8.4	0.328

Notes: Entrained air defined to be air bubbles 1-mm or smaller in diameter.L-bar of 0.20 mm or less usually considered durable to freezing and thawing. Project No. 1 had extensive blistering and project No. 2 had limited blistering.
1. air content average of 7 specimens, L-bar average of two (0.229 mm and 0.280 mm)
2. air content average of 7 specimens, L-bar average of two (0.178 mm and 0.432 mm)
3. average of 3 specimens
4. Single specimen
5. Conducted as part of an investigation of blistering on the pavement.
6. Conducted later as part of a USAF study of early-age spalling problems

At Grissom AFB, slivering-type spalls developed on one runway and 3 apron projects built in 1985 and 1986. Spalling occurred on both transverse and longitudinal joints. A petrographic examination of cores from an apron built in 1985 and one built in 1986 was conducted by the WES and found that the concrete was generally well consolidated with little evidence of segregation or excess surface mortar. However, entrained air contents tended to be low, and the spacing factor, L-bar, ranged from0.140 to 0.643 and averaged 0.364 mm. This high spacing factor clearly indicates the bulk of this concrete was clearly vulnerable to freezing and thawing. When inspected in 1988, spalled fragments were typically 6 mm thick and 25 to 38 mm long and existed as a series of back-to-back slivers extending 12 to 25 mm deep away from the joint face. Figure 1a shows the appearance of this progressive slivering spall failure. Location of slivering spalls were random and they existed on both longitudinal and transverse joints.

A NEW OCCURRENCE OF EARLY-AGE SPALLING

Between June and November of 2006, portions of a concrete runway and two taxiways at an airbase in the Midwest (hereafter identified as Airbase A) were replaced with new 21-in. thick concrete. In March 2007, USAF began observing spalling on this new pavement (Figure 4) which was producing an unacceptable amount of debris that posed a significant FOD hazard (Figure 5).

Figure 4. Examples of runway spalling at Airbase A along (from left to right) a. a centerline joint, b. a longitudinal construction joint, and c. a transverse joint.

Figure 5. Example of spall fragments collected from new runway and taxiway pavements at Airbase A.

The construction agency for the spalling pavement inspected the damage and concluded that the damage was from snowplow operations by the base personnel. The base personnel and Major Command (MAJCOM) for the base took exception to this finding and noted that there was significant spalling damage that visibly was identical to that previously associated with poor concrete durability (e.g., compare Figure 4 with Figure 1).

An on-site review of snow-clearing procedures at Airbase A by specialists from the MAJCOM and AFCESA found that equipment, procedures, and training were in compliance with USAF standards. As in all military bureaucracies, the USAF has highly standardized procedures and operating procedures for snow clearing along with specific planning and training requirements for personnel involved that are enforced with periodic inspections from headquarters and inspection organizations. From the USAF perspective, approximately half of their 84 major active-duty facilities conduct snow clearing operations, and if their standard snow-clearing procedures and equipment were causing spalling problems, there should be a wave of FOD hazard problems sweeping through the USAF. Such is not happening.

To resolve this impasse, the construction agency performed a petrographic examination of cores from the project. This examination found the concrete appeared sound, and the only deficiency noted was that the air was lower than specified. The project specifications required 6% air with a tolerance of 4.5 to 7.5% allowed, and the in-place air content of the cores ranged from 1.5 to 2.7 % with an average of 2.5%. Contractor quality-control (QC) tests at the time of construction reportedly were all within the project specifications. QC tests of air content during construction are made at the time of concrete delivery, and some change between the concrete as-delivered and after placement procedures is not surprising, although this magnitude of change is larger than usually observed on USAF pavements.

The specified air content, allowable ranges, and QC testing procedures have been used for decades to provide military airfield pavements that are generally very durable when exposed to freezing and thawing. During this construction project, the target air content was reportedly reduced from 6% over concerns about strength, but all air and strength results reportedly remained in specified ranges. Some gross defect such as a faulty pressuremeter, inadequately trained testing personnel, failure to adjust air entrainment dosage for temperature change, variable carbon content in the fly ash, etc. could cause low air content, but the construction agency was unable to identify any such deficiency during construction. This particular office of the construction agency and the contractor are both experienced with airfield construction and have a sustained reputation for producing good airfield pavement work.

Measurement of concrete total air content using pressuremeters or similar devices during construction is a convenient and generally effective way of producing durable concrete. However, it is actually the small, well-dispersed entrained air bubbles that provide the freeze-thaw durability of the concrete paste and not the total air, which is the sum of the entrained air and larger entrapped air bubbles. A better assessment of freeze-thaw durability is provided by measuring the spacing factor, L-bar, between bubbles. Generally, the concrete is considered durable when exposed to freezing and thawing if this value is 0.20 mm or less (e.g., Kohn et al 2003, Neville 2002, American Concrete Institute 2001, Portland Cement Association 1988). However, limiting values for freeze-thaw durability ranging from 0.152 to 0.25 mm have also been proposed (Jenknavorian 2006). The spacing factor, L-bar, is widely recognized as an improved tool to provide a better measurement of the air void system in the concrete for durability assessments, but it too has its limitations (Hover 2006).

Measurement of the spacing factor between entrained air bubbles, L-bar, in the cores from Airbase A ranged from 0.18 to 0.26 and averaged 0.23. This is above the conventional criteria of 0.20 mm but within other suggested values for durable concrete as noted above. The USAF considered this indicative of nondurable concrete while the construction agency did not. The impasse between the two government agencies remains unresolved.

CONTINUING ASSESSMENT

The USAF MAJCOM responsible for Airbase A funded a project to conduct further testing of the concrete from the base and also to gather samples from other bases and ascertain some baseline of durability that current specifications used on USAF projects are providing in the field. This project is underway and a final report is expected in September 2008. Initial results of ASTM C-666 accelerated freeze-thaw tests of the concrete from Airbase A are showing accelerated damage from freezing and thawing cycles under these test conditions. These initial, but still incomplete, results, provide corroboration to the USAF's concerns that the damage at Airbase A may be a freeze-thaw durability problem and do not at this point support the contention that the damage is from snow plows.

SPALLING AND DURABILITY

Damage from freezing and thawing requires moisture. In pavements, the areas adjacent to joints are almost invariably the most saturated portion of the pavement surface. This is clearly demonstrated by D-Cracking and alkali-silica reaction distress that often initially develops adjacent to joints (Figure 6). These unrelated distress mechanisms (one from coarse aggregate vulnerable to freezing and thawing and the other a chemical durability issue) both require moisture for the reaction and begin along joints where it is readily available. A similar concentration of damage for freezing and thawing is also reasonable. The joints themselves also allow freezing temperatures to extend back from the face of the joint above the sealant and from the surface. This exposure conditions is only accentuated by use of deicing chemicals.

Figure 7 shows the influence of the spacing factor, L-bar, on spalling at several USAF airbases. As noted earlier, L-bar is neither a complete nor a perfect criterion for freeze-thaw durability, and there is a transition from durable to nondurable concrete. However, the L-bar limit of 0.20 mm or less as a workable criterion to protect against spalling pavements from freezing and thawing for exposure conditions seen by USAF airfields seems quite reasonable.

CONCLUSIONS

The USAF has had ongoing problems with early-age spalling on airfield pavements. Earlier studies found much of the problem lay with poor construction practices that resulted in localized areas of nondurable surface and joint concrete. The USAF implemented requirements for using better concrete mixtures on airfields and increased emphasis and education on the topic. This lessened the problem but never completely solved it.

A renewed round of early-age sliver spalling at an airbase identified as Airbase A for this paper caused a reexamination of the issue and the start of a new ongoing study of the issues associated with early-age spalling. A review of past work and the preliminary work to date suggests that

- early-age sliver spalling along joints is often associated with localized areas of nondurable concrete.
- the maximum spacing factor of 0.20 mm appears effective in discriminating when such spalling appears on USAF airfield pavements and when it does not.

- Damage from freezing and thawing due to Airbase A's low air content and higher than desired spacing factor is the most likely cause of concrete spalling.
- Snow plows are an unlikely cause of the spalling at Airbase A.
- The cause of the low air at Airbase A is not known at this time.

Figure 6. Examples of damage concentrating near joints for durability problems requiring moisture: from left to right (a) D-cracking at Grissom AFB, IN and (b) alkali-silica reaction at Holloman AFB, NM

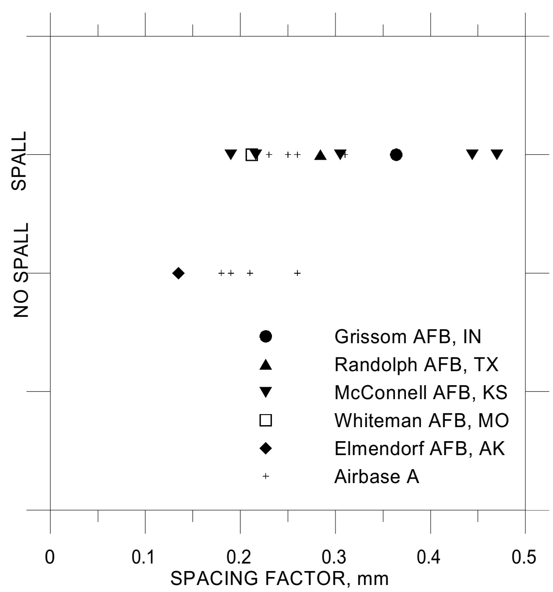

Figure 7. Relation between spacing factor, L-bar and early-age spalling at various USAF airbases

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