CONCRETE RUNWAY RECONSTRUCTED USING RESULTS OF STATE-OF-THE-ART RESEARCH

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ABSTRACT

Colorado Springs Airport is located in the east-central part of Colorado. The airport has 3 runways, with the primary runway being 13,500 feet long and was constructed of concrete in 1993. A pavement evaluation study was accomplished in 2004 which determined that the cause of the deterioration, which included spalling and loose particles, was alkali-silica reactivity (ASR). The consensus was that complete removal and replacement was the only long-term solution. During the design process, industry research was on-going that explored the causes of ASR and recommended steps that could be taken to prevent ASR damage to concrete pavement.

- Local aggregates were evaluated and the evaluation indicated that there were locally available aggregated that were not susceptible to ASR and that the ASR susceptible aggregates would respond favorably to mitigation.

- Local cement and fly ash sources were evaluated to determine if they would meet the criteria included in the bidding documents. On-going research indicated that it was important to limit the amount of calcium oxide in the fly ash, so the limit was set at the amount that was proven to be safe. The research also found that the amount of calcium oxide in the fly ash and the alkali, from fly ash, cement and mixing water, in the concrete mix were critical to controlling the ASR.

- The bidding documents included the standard testing using sodium hydroxide. However, they also included testing using a potassium acetate bath. Potassium acetate is a commonly used pavement deicing agent and has been associated with accelerating the alkali-silica reaction in concrete pavement. Prior to the start of construction, multiple concrete mix designs were developed by the Contractor and the mix design studies indicated that the selected aggregates were susceptible to ASR, but Type F fly ash sufficiently mitigated the ASR. The quality control and quality acceptance material testing has proven that the new steps taken to mitigate the detrimental affects of ASR on concrete pavements are working

INTRODUCTION

The City of Colorado Springs is located in the east-central part of Colorado, and the Colorado Springs Airport (the Airport) is located in the southeast part of the City. The Airport is served by a number of commercial and cargo carriers, as well as by Peterson Air Force Base, which is located on the northerly portion of the Airport and has a variety of assigned military aircraft that use the runways at the Airport. The Airport has three runways. The primary runway is 13,500 feet long and was constructed of concrete in 1993.

Prior to 2004, the concrete pavement on the primary runway was showing signs of deterioration that appeared to be beyond what would normally be expected for a concrete pavement of this age, considering the aircraft loading and environmental conditions that the pavement had experienced. The Airport was required to accomplish maintenance and repair on an accelerated basis due to the deterioration. Due to the presence of excess foreign object debris (FOD), there was concern that the maintenance and repair could not be performed on a timely basis to keep the runway operational.

A pavement condition evaluation was conducted in 2004 [1] to categorize the cause of the deterioration and recommend methods to fix the concrete pavement. The evaluation concluded that the primary cause of the deterioration was alkali-silica reactivity (ASR), which is a chemical reaction between the alkali in the cement and silica in the aggregates. The reaction had taken place within the concrete pavement, and cracks and spalls had formed causing distress in the concrete. This chemical reaction increases with the use of pavement deicers on the concrete pavement.

BACKGROUND

During recent research sponsored by the FAA [2] and conducted by the Independent Pavement Research Foundation (IPRF), a non-profit organization, the details of the chemical reaction were identified and methods to mitigate it were developed. This research recommended changes to the previous FAA specifications, such as more extensive testing of the aggregates; more restrictions and testing of the cement and fly ash; and limitations on the total alkalis allowed in the concrete mix. The Airport decided, and the FAA agreed, that the best solution for bringing the concrete runway back to a fully operational state was to remove the existing concrete and replace it with new concrete. A Pavement Task Force was established early in the design of this project to evaluate the recent research. The Task Force then identified the appropriate changes to the FAA specifications for this project. These changes were incorporated into the project documents. The research shows that these changes should mitigate the increase in the chemical reaction caused by the pavement deicers.

ASR is a distress that is observed in Portland cement concrete (PCC) pavements and is caused by a chemical reaction between available alkalis (sodium and potassium) from cement paste and certain reactive forms of silica within an aggregate. A gel is produced that expands when it absorbs moisture and eventually causes cracks throughout the concrete pavement. These cracks are visible as closely spaced cracking on the pavement surface. The observed crack pattern is commonly referred to as “map cracking.” As the distress progresses, there is an increase in the potential for small pieces of the concrete surface to break loose (spalling). Loose pieces of concrete can be drawn into jet engines or strike aircraft propellers, creating safety concerns for aircraft operating on these pavements.

ASR is not a new distress to concrete pavements. Until recently, ASR was effectively controlled by selecting quality aggregates and limiting alkali content in the cement. However, over the last few years, certain concrete airfield pavements have been observed experiencing distress that is similar to ASR but not entirely consistent with known ASR distress manifestation. Upon investigation, it has been determined that the distress is indeed a new variation of ASR [2].

Several documented field observations indicated an increase in ASR activity in the presence of deicing chemicals that are commonly used on pavements. These observations prompted the FAA to investigate the cause of the ASR activity that was occurring on pavements that previously had passed the administration’s construction specification material requirements [2].

Through the IPRF, the FAA sponsored research to determine the severity of this new distress and to evaluate procedures for mitigating it in new concrete pavements. Early findings indicate that distress in the surface of the concrete pavement is caused by exposure to pavement deicing chemicals such as potassium acetate. These chemicals provide high levels of alkali and accelerate alkali-silica reactions at the pavement surface. The Airport uses potassium acetate as a deicer on all of its concrete pavements.

It is not the FAA's policy to avoid deicing chemicals for existing pavements. The increase in winter operational safety created by their use far outweighs the pavement concerns [2]. The P-501 specification for this project was published on November 18, 2005. The following discussion items have been incorporated into that specification.

PCC MIX DESIGN

AGGREGATES

- A Request for Information (RFI) for data on local aggregates was published by the City of Colorado Springs prior to the bid date. The purpose was to evaluate the ASR potential of the local aggregates. Six aggregate suppliers submitted a response; however, only three suppliers were responsive, with a fourth being partially responsive. The information submitted was a variety of items, with none of the suppliers having 28-day American Society of Testing and Materials (ASTM) C 1260 test results. Three of the suppliers indicated they were currently running the 28-day tests and agreed to share the test results. No results were ever received. It was assumed that the suppliers did not want to share the information because it may have taken away their competitive advantage in the pricing process.

- There were 14-day ASTM C 1260 tests submitted for the coarse aggregate that had results in the range of 0.023 to 0.09 percent of expansion, with most being in the 0.07 or 0.08 range. The fine aggregate has a range of 0.03 to 0.10 percent of expansion, with most being in the 0.03 or 0.04 percent range. The combined aggregate tests were submitted by only one firm and were all 0.06 percent.

- It was also discussed with the suppliers that they may want to do modified ASTM C 1260 tests that use potassium acetate as a soak solution instead of sodium hydroxide because there is a movement in the industry to require such [3]. Two of the suppliers were interested and one obtained potassium acetate from the Airport. No test results were ever submitted. The suppliers were confident that the aggregates will meet the tests or can be mitigated with fly ash to meet the criteria.

- The project construction P-501 specification required that the aggregates be less than 0.10 percent of expansion ASTM C 1260 tests at 28 days using sodium hydroxide soak solution. The standard FAA specification was modified to require testing to be done using potassium acetate instead of sodium hydroxide and to provide results for guidance in evaluating the materials but not for acceptance.

- It is interesting to note that the results of the tests taken on the actual material used in construction show that the expansion was greater in the sodium hydroxide soak solution than in the potassium acetate soak (see Table 1). It was expected that the potassium acetate would produce the higher expansion based on previous information.

Table 1.
Test Results for Sodium Hydroxide and Potassium Acetate Soak Solutions

Field Tests	Expansion at 28 Days	Expansion at 28 Days
	Sodium Hydroxide	Potassium Acetate
	0.04 percent	
	0.01 percent	
Same Sample	0.04 percent	0.01 percent
	0.04 percent	
		0.02 percent
		0.02 percent
Same Sample	0.04 percent	0.01 percent
		0.04 percent
	0.06 percent	

Source: Test Results from Field Tests

FLY ASH

- The fly ash is distributed from the power plants that produce the fly ash to the contractors that use the fly ash. The power plants put the fly ash out to bid and brokers bid on its purchase. Therefore, the fly ash available in the local area may come from different brokers, and thus the price will vary. A single source of fly ash was required for this project; therefore, sources of the acceptable quantity were included in the screening. The common method of delivery is by rail; however, rail connections can cause difficulty for timely supply and an increase in the cost depending on the location of the plant. For example, if no rail line is available to a power plant, the ash will need to be hauled by a truck, thus increasing costs.

- The most common local Type F fly ash comes by rail from Texas. There is fly ash available in Colorado from the power plants in Craig and Colorado Springs, but it generally has problems meeting the loss-on-ignition requirements. There is also fly ash available from plants in Bridger, Wyoming, and Coal Creek, North Dakota, but it tends to be higher in calcium than the Texas fly ash. There is also a plant in the Four Corners area (Colorado, New Mexico, Arizona, and Utah) that provides nearly the same quality of ash as that from Texas. However, it is more expensive because it has to be trucked to Gallup, New Mexico, and then loaded on rail.

- The typical calcium oxide for the Texas Type F fly ash is 10 to 12 percent. There are sources of fly ash produced on the east coast that have a range of 2 to 3 percent calcium oxide, but it will be at least five times as expensive to transport to Colorado. The actual test results that were furnished prior to bidding showed that the actual calcium oxide was 10.78 percent and 1.47 percent total alkali.

- The standard FAA P-501 specification was modified to limit the calcium oxide to 12 percent maximum. Tests at Clemson University suggest that fly ash with calcium oxide up to 15 percent can be used to mitigate ASR potential in the presence of pavement chemical deicers.

- The project construction P-501 specification also was modified to require onsite testing of the fly ash to verify the chemical composition delivered to the project site.

- The results of tests on the fly ash that was used on the project show that it was in general conformance to the calcium oxide limit of 12 percent. There were 297 loads of fly ash used, and 28 loads tested slightly over 12 percent. Of those loads, only two were over 15 percent. The average of all the loads was 10.61 percent. Because fly ash is a byproduct of the coal burning operation, it is difficult to get a consistent product. The fly ash supplier would not guarantee that the 12-percent limit could be met consistently.

CEMENT

- There was a much publicized cement shortage during the summer of 2005, and concern was expressed about the availability of cement for this project in the summer of 2006. The cement supplier assured the Airport that there would be sufficient quantity of cement for this project. There are two levels of cement supply: one is to ready mix suppliers and the second is directly to a paving contractor.

- The shortages were in the ready mix suppliers, which operate on the need for cement on a "will-call" basis. Contractors do not commit to buy any specific amount of concrete, so they are at the mercy of the ready mix supplier to give them an allotment of concrete, which is usually based on the quantity they purchased the year before. A ready mix firm may be limited to a percentage of their cement needs; consequently they will limit each of their customers.

- The cement committed directly to paving contractors is called a "no excuses contract," and that quantity is assured to be available. However, the contractor is committed to buy that quantity of cement, even if a specific project is cancelled. The cement industry assured the Airport in writing that the quantity of cement required for this project was set aside in its production for 2006.

- There was some indication that the low-alkali cement (0.6 percent alkali content; 0.8 percent is normal) is somewhat of a problem to manufacture and may be difficult to get. However, the standard FAA P-501 specification requires low-alkali cement at 0.6 percent.

- The specification was modified to require that onsite mortar bar tests be taken for the cement delivered to the site. The results of the mortar bar tests of the material delivered to the site showed that the strength exceeded the project requirements.

GROUND GRANULATED BLAST FURNACE (GGBF) SLAG

- Recent research shows that GGBF slag is not yet proven to be efficient in mitigating ASR for concrete that is exposed to potassium acetate [2]; therefore, the requirement for GGBF has been removed from the project construction P-501 specification.

LITHIUM

- The use of lithium is allowed in the standard FAA P-501 specification. However, it typically is not used because of the significant increase in the cost of the concrete. The minimum dosage recommended is 0.55 gallon per pound of total alkali per cubic yard. The average price of lithium is $18 per gallon. A typical concrete used for airfield pavement that includes low-alkali cement has a total alkali content of about 4.5 pounds per cubic yard. This would increase the cost per cubic yard a minimum of $45. The addition of lithium does not affect the strength of the concrete when used in reasonable quantities. It does mitigate ASR in the presence of deicers.

MIX WATER

- The City of Colorado Springs tested the water from the hydrant on the airfield in the vicinity of the proposed staging area. This sample was tested in the City's laboratory for sodium and potassium. The sample results were evaluated, and the total alkali from the water was approximately 0.03 pound per cubic yard. This result indicates that the water was acceptable to use in the concrete mix.

CONCRETE MIX DESIGN

- The concrete mix design that was used for this project consisted of:
  - Type I/II, Low-Alkali Cement: 411 pounds
  - Class F Fly Ash: 30 percent, 176 pounds
  - Air-Entraining Admixture: 5.5 percent
  - Water Reducer Admixture
  - Coarse Aggregate that is ASR Susceptible: 1,897 pounds
  - Fine Aggregates: 1,265
  - Water: 211 pounds
  - Water/Cement Ratio: 0.36

TOTAL ALKALI

- The total alkali content of the mix was limited to a maximum of 5 pounds per cubic yard, with a tolerance of 0.5 pound per cubic yard in the modified P-501 specification. A sample calculation of the amount of alkali for a mix of 586 pounds of cemententious material (see below) with 30 percent fly ash (176 pounds), added as an admixture, is as follows:
  - Fly Ash: 586 pounds x 0.30 = 176 pounds x 0.0147 = 2.58 pounds of alkali
  - Cement: (586 pounds - 176 pounds) x 0.006 = 2.47 pounds of alkali

  - Water: 0.03 pound of alkali
  - TOTAL = 5.08 pounds of alkali per cubic yard

- Admixtures can also add slightly to the alkali in the mix, but they were assumed to not contribute to the total alkali. This example shows it is possible to meet the 5 pounds of alkali plus a tolerance of 0.5 pound (5.5 pounds allowed).
- During the project construction, tests were accomplished on the cement and fly ash that were used during production to verify the total alkali (see Table 2).

Table 2.
Test Results for Cement and Fly Ash Total Alkali

Design Mix	Material Certification (pounds/Cy)	Independent (pounds/Cy)
Cement	2.30 (0.56 percent)	2.26 (0.55 percent)
Fly Ash	2.47 (1.40 percent)	2.05 (1.16 percent)
Total	4.77	4.31
Field Check (1)		
Cement	2.30 (0.56 percent)	2.34 (0.57 percent)
Fly Ash	2.47 (1.40 percent)	1.83 (1.04 percent)
Total	4.77	4.17
Field Check (2)		
Cement	2.30 (0.56 percent)	2.34 (0.57 percent)
Fly Ash	2.27 (1.40 percent)	2.20 (1.25 percent)
Total	4.77	4.54

Source: Test Results from Field Tests

PAVEMENT THICKNESS DESIGN

The PCC pavement thickness design is based on the following factors: flexural strength, subgrade strength, base course thickness, and aircraft traffic. These factors are discussed below:

- The flexural strength depends on the components of the mix design discussed earlier. There was concern about using a flexural strength as high as 750 psi because of the amount of cement that is required to achieve this strength. By increasing the amount of cement, the alkali content of the mix is increased, which can cause the ASR potential to increase. Recent research has shown that the strength of the concrete should not govern the mix proportioning. Instead, ASR mitigation and concrete durability should be the primary consideration.
- The cost to increase the flexural strength (from 650 psi to 700 psi) was compared to the cost of adding concrete thickness (from 15 inches to 16 inches based on a reduction in flexural strength), and the cost to add thickness was slightly higher. However, as indicated above, the increase in strength will require more cement, thus increasing the mixture's potential to

develop ASR. The contractor's risk increases more with the added strength than with the added thickness, which will be reflected unfavorably in the bid price. To facilitate variations in the field, the mix designs are always designed to be at least 50 psi higher than the minimum requirement; thus, the effective strength of the concrete is higher than the minimum design strength. A flexural strength of 650 psi at 28 days was used for this project.

- The fly ash should be used as an admixture rather than a cement replacement. The National Coal Ash Association recommends that 15-percent fly ash is the minimum content to be effective for ASR mitigation. Fly ash contents less than 15 percent usually result in concrete mix workability problems. The contractor's mix design for this project used 30 percent fly ash to mitigate the ASR potential in the aggregates that they selected to use. The mix design 28-day flexural strength averaged 765 psi, with the lowest being 720 psi. The average was 70 psi (17 percent) over the required 650 psi. The mix design showed that a minimum flexural strength of 650 psi would not be a concern.

- The geotechnical report recommended that a maximum modulus of subgrade reaction (k-value) of 300 psi/inch should be used for the design of PCC pavement based on the PCA correlation for k value from CBR values. Other correlations typically used in the industry provide values as low as 200 psi/inch. To determine the effect of all the variables on the PCC thickness, a sensitivity analysis was conducted for this project (see Table 3). It was determined that varying the subgrade k-value from 200 to 300 psi/inch had a minimal effect on the minimum required pavement thickness. Therefore, a k-value of 200 psi/inch was used in the design.

- The design aircraft is a 175,000-pound, dual-wheel aircraft B737.

- The expected traffic is equivalent to 11,472 annual departures of the design aircraft. The traffic used for the runway design was based on the assumption that 60 percent of the traffic at the Airport uses this runway.

- The resulting design PCC pavement thickness is 16 inches.

- The moisture content of the subgrade soils ranges from 4.9 percent to 17.2 percent, which is at or above the optimum moisture content. To provide a better construction platform, the top 12 inches of the subgrade will be stabilized with cement.

- The FAA requires a stabilized base course for pavements that serve aircraft weighing 100,000 pounds or more. Recent research has shown that high-strength, cement-treated base courses are a contributing factor to a reduced fatigue life of the concrete pavement above. Therefore, an asphalt-stabilized base course was selected to minimize the potential that the strength of the base was too strong. This base course does not require cement, which could be difficult to get, nor does it require a bond breaker. The thickness is 8 inches.

The pavement section was 16 inches PCC pavement, 8 inches of asphalt-treated base, and 12 inches of cement-stabilized soil.

Table 3.
Pavement Thickness Sensitivity to Subgrade k-Value, Concrete Flexural Strength, and Annual Departures

Subgrade k-Value	Concrete Flexural Strength	Minimum PCC Thickness			
		FAA Design Spreadsheets		LEDFAA	
		60 percent Traffic – 11,472 Annual Departures	25,000 Annual Departures	60 percent Traffic – 11,472 Annual Departures	25,000 Annual Departures
200 psi/inch	650 psi	16 inches	17 inches	16 inches	18 inches
200 psi/inch	700 psi	15 inches	165 inches	15 inches	18 inches
200 psi/inch	750 psi	14 inches	15 inches	14 inches	17 inches
250 psi/inch	650 psi	16 inches	16 inches	16 inches	18 inches
250 psi/inch	700 psi	15 inches	16 inches	15 inches	17 inches
250 psi/inch	750 psi	14 inches	15 inches	14 inches	17 inches
300 psi/inch	650 psi	16 inches	16 inches	15 inches	18 inches
300 psi/inch	700 psi	15 inches	15 inches	15 inches	17 inches
300 psi/inch	750 psi	14 inches	15 inches	14 inches	16 inches
400 psi/inch	650 psi	15 inches	16 inches	n/a	n/a
400 psi/inch	700 psi	15 inches	15 inches	n/a	n/a
400 psi/inch	750 psi	14 inches	14 inches	n/a	n/a
500 psi/inch	650 psi	15 inches	16 inches	n/a	n/a
500 psi/inch	700 psi	14 inches	15 inches	n/a	n/a
500 psi/inch	750 psi	14 inches	14 inches	n/a	n/a

Source: Project Design Report

CONCLUSION

Ongoing research is showing that additional measures need to be taken to produce PCC pavement that is less susceptible to the detrimental affects of ASR aggregates that are causing severe damage to the concrete pavements. This project added those additional measures and has shown that it is practical and cost-effective to include those additional requirements in a normal paving project. The long-term effects of these measures will not be known for some time; however, the results of the testing conducted on the material used in the construction indicate that the additional requirements can be met.

This project was not intended to be a research project. Construction needed to proceed to meet the project delivery schedule; therefore, more extensive testing was not required. As the additional research is completed for the affects of ASR on concrete pavement, those results should be incorporated into future paving projects.

REFERENCES

1. Kimley-Horn and Associates, “ASR Preliminary Assessment for Colorado Springs Airport,” 2004.
2. Federal Aviation Administration, Airport Engineering Division, AAS-110 “Accelerated Alkali-Silica Reactivity in Portland Cement Concrete Pavements Exposed to Runway Deicing Chemicals,” Engineering Brief No. 70, 2005.
3. Rangaraju, P, “Test Method to Assess Potential Reactivity of Aggregates in Presence of Airfield Deicing Chemicals (Mortar Bar Test),” Interim Test Protocol, 2005.