Customized LCCA, a Practical Guide and Critical Tool: Case Study at TUS Airport

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ABSTRACT

The Tucson Airport Authority (TAA) has developed an Airfield Safety Enhancement Program for Tucson International Airport (TUS) which includes the design of a new parallel Runway 12R/30L with new parallel and connector taxiways. Considering the vast scope for new pavement construction and ultimate cost implications, the development of an appropriate life-cycle cost analysis (LCCA) is a critical tool to evaluate and select viable pavement design alternatives. Following the Federal Aviation Administration guidelines, the LCCA was customized for project-specific conditions to closely represent the anticipated maintenance and rehabilitation measures across the 40-year analysis period. Utilizing the LCCA results, alternatives that involve a combination of flexible and rigid pavement systems are being designed for the project based on future pavement use, typical maintenance practices, and performance history of pavements at TUS. This customized and practical design approach provides a significant benefit to the airport and government agency when providing funding for the recommended pavement section.

INTRODUCTION

Tucson International Airport (TUS) is a joint civil-military airport located approximately 7 miles south of the city of Tucson in Southern Arizona. The airport is owned and operated by the Tucson Airport Authority (TAA). The 2014 Master Plan and Airport Layout Plan update for TUS identified the need to improve the airfield geometric layout due to existing hot spots and historical safety concerns. Through previous planning studies, the TAA developed the Airfield Safety Enhancement (ASE) Program, the largest in the airport's history, to update the TUS airfield to current geometric design standards, mitigate runway incursions and improve the operational safety of the airport. The ASE program is comprised of four projects; one of which will be procured through a Construction Manager at Risk (CMAR) and three which will be procured through Design-Bid-Build (DBB) contract method. This paper discusses the customized Life-Cycle Cost Analysis (LCCA) approach employed for the CMAR project in selecting the pavement design alternatives for the construction of a new parallel Runway 12R/30L, a centerline parallel Taxiway B and an outboard parallel Taxiway C. The new runway will replace an existing general aviation runway with a new 10,996-foot commercial runway. Figure 1 shows the airport layout and the general project limits.

Considering the vast scope for new pavement construction and the ultimate cost implications, the development of an appropriate and representative LCCA was identified as a critical tool in evaluating and selecting the viable pavement design alternatives throughout the project limits. The general guidelines and recommendations provided in Federal Aviation Administration (FAA) Advisory Circular 150/5320-6F, *Airport Pavement Design and Evaluation* and the

Airfield Asphalt Pavement Technology Program (AAPTP) Report 06-06, *Life Cycle Cost Analysis for Airport Pavements* referenced in the FAA Advisory Circular were used for performing the LCCA for this project. Following the guidelines set forth and in coordination with the CMAR, the LCCA was customized based on local maintenance needs with considerations for major rehabilitation requirements across the analysis period.

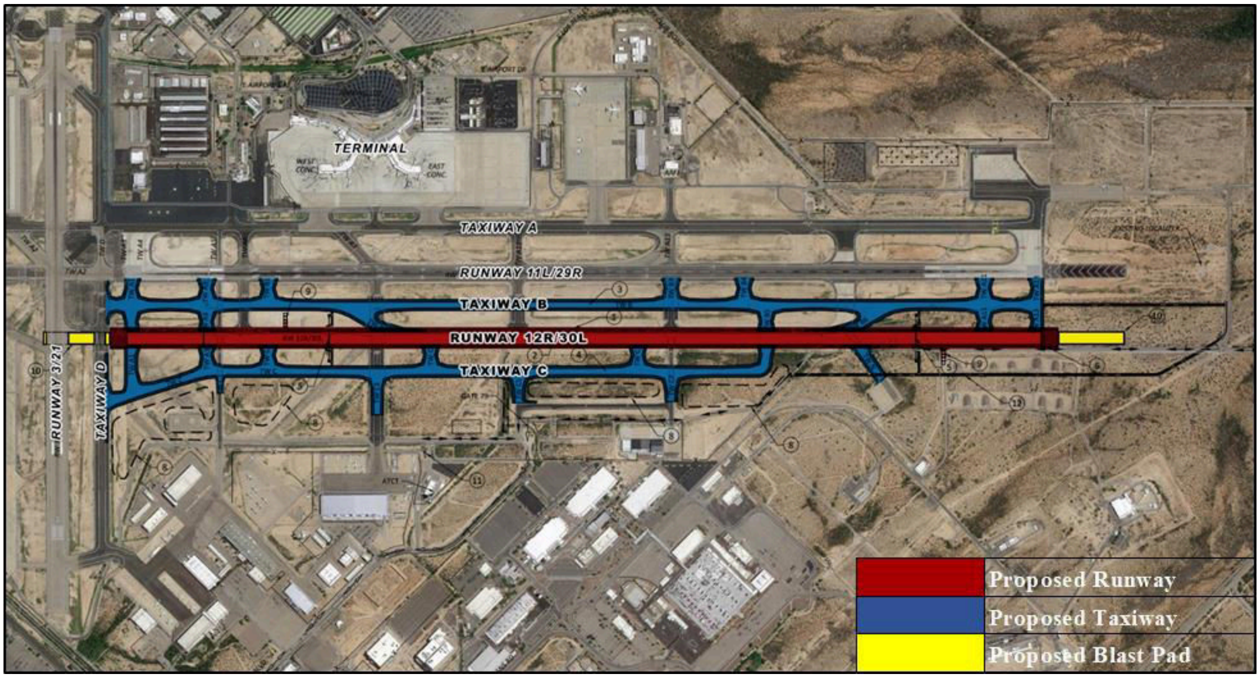

Figure 1. Airport Layout and General Project Limits

METHODOLOGY

The primary objective of performing the LCCA for this project is to provide durable, cost effective pavement design options in terms of pavement construction materials and thicknesses for a desert environment. As a first step, viable pavement design alternatives were developed for the new runway and associated taxiway sections. Pavement design alternatives were developed based on a comprehensive geotechnical investigation, traffic analysis, and consideration of material availability. The following sections describe the overall approach to the LCCA for the project including the factors such as unit cost, material quality, and contractor availability.

Customized LCCA Approach

Both rigid and flexible pavement system alternatives are viable for most pavement applications. The current primary runway at TUS incorporates rigid threshold pavement sections connected with a flexible center portion. In general, flexible pavement systems are designed such that each structural layer is supported by the layer below and ultimately supported by the subgrade. In rigid pavement systems, the load resistance is provided by the slab action of the concrete surface layer and the layer(s) below provide a uniform stable support. With proper design, materials, construction, and maintenance either pavement type can typically provide the desired structural and functional life. Exceptions may include special applications such as parking/apron and fueling areas where a rigid pavement is typically preferred.

For the feasible pavement design options for the runway and taxiways at TUS, several factors including the initial costs, anticipated current and future funding, operational constraints, construction duration, future maintenance, environmental constraints, material availability, and anticipated changes in traffic were considered. As part of the customized and practical LCCA approach, several factors including the material availability, contractor availability, material quality history, unit costs, environmental impacts were evaluated. These factors are discussed in more detail in the sections below.

Material Availability:

The local area has a total of 8 construction aggregate sources within a 50-mile radius of the airport. Additionally, there are a total of 16 aggregate sources within a 100-mile radius. According to the United States Geological Survey (USGS) the quarried construction aggregates in Arizona are predominately derived from granite, limestone, traprock, sandstone and quartzite, and sand and gravel formations. In the Tucson area, granite and sand and gravel formations primarily exist. To produce AC and PCC materials, the local area has approximately 16 plants within a 50-mile radius and 31 plants within a 100-mile radius of the airport. Although all plants may not be capable of typically producing or servicing airfield specified products in accordance with the FAA requirements, given the current number of operations, it is estimated that there will be a sufficient supply for TUS. Table 1 below summarizes the material supplier information compiled for this project. Based on this review, material availability was deemed not a significant factor in choosing one alternative over the other competing ones.

Table 1. Material Supplier Analysis for TUS Airport

Suppliers	Number/Distance from TUS					
	0-25 miles	25-50 miles	50-100 miles	Total	100-125 miles	Total
Construction Aggregates	8	0	8	16	6	22
Asphalt Plants	5	0	5	10	3	13
Ready-Mix Concrete	10	1	10	21	6	27

Contractor Availability:

While TAA has directly contracted this project as a CMAR, the need for future maintenance and rehabilitation still exists. Based on a review of the regional bid tabulation data, it is estimated that there are approximately 20 heavy highway companies bidding on local roadway projects where the scope of work includes grading, utilities, and pavement material placement consisting of Asphalt Concrete (AC) and Portland Cement Concrete (PCC) pavements. While not all contractors may be experienced in airfield paving, it is estimated that 10-12 separate contractors have performed work on airports in Arizona and its surrounding areas. Contractor availability for future maintenance and rehabilitation needs was therefore not deemed a limiting factor in the alternative selection.

Material Quality History:

The Arizona Department of Transportation (ADOT) requirements for the physical properties of the proposed aggregates utilized in the granular bases, AC bases, AC surfaces and PCC surface layers were evaluated and compared to the FAA specification requirements. The ADOT material quality requirements for crushed faces, soundness and wear were generally comparable to the FAA requirements. However, the deleterious material requirement for the aggregate sources used in AC and PCC materials was less restrictive for ADOT and generally allowed more clay lumps and lightweight particles in the prescribed mixes. Given the FAA requirements, an increased unit cost from the average ADOT bid tabulation data is expected. In summary, local ADOT approved aggregates may not meet the requirements set forth by the FAA and can require alternate sources or additional processing requirements.

Environmental Impact Analysis for Emissions and Recycling:

For the environmental impact analysis, potential material hauling distances and the feasibility to recycle or reuse the constructed materials were considered. Upon review of the availability of construction aggregate materials and AC and PCC production facilities within a radius of 25 miles of TUS, high amount of emissions from hauling were not expected to be a major concern. In addition, both the ADOT and FAA specifications allow for use of both recycled asphalt and concrete materials. It was therefore determined both the flexible and rigid pavement alternatives can be viable for TUS airport from an environmental impact standpoint.

Unit Costs:

Cost estimates were developed for each pavement design alternative primarily using costs provided by the CMAR contractor for the project. Coordination with the CMAR contractor allowed for a more accurate and reliable initial construction cost estimate for the project. In addition to the inputs provided by the CMAR contractor, historical bid tabulations and back checking with RSMeans were also taken into consideration in developing the representative unit costs for various construction items. Unit costs for various pavement design alternatives and rehabilitation cycles were further customized based on pavement section location, construction quantities, and constructability factors.

Other Considerations:

The impact of pavement type selection as it relates to the pavement use, future maintenance, operational constraints, and performance history was also analyzed. Both AC and PCC pavement systems have been utilized at TUS and the airport has experience constructing, maintaining and rehabilitating both pavement types. Overall, it was determined that both flexible and rigid pavement systems were viable alternatives that can be adequately designed and constructed to meet the project objectives.

Pavement Design

The FAA pavement design guidelines and procedures detailed in the FAA's Advisory Circular 150/5320-6F, *Airport Pavement Design and Evaluation* were followed and the FAA Rigid and Flexible Iterative Elastic Layer Design (FAARFIELD) computer program was used to compute the required pavement layer thicknesses. Sensitivity analysis for varying traffic and subgrade conditions was also performed to arrive at the potential pavement design alternatives. Overall, four (4) traffic scenarios and three (3) subgrade conditions were analyzed as part of the sensitivity analysis. The pavement design efforts resulted in the following options, which were advanced to the LCCA.

- Flexible Pavement Option: 5.0 in. P-401 Hot Mix Asphalt (HMA) Surface Course /5.0 in. P-401 HMA Stabilized Base Course /9.0 in. P-209 Crushed Aggregate Base Course
- Rigid Pavement Option: 15.0 in. P-501 Portland Cement Concrete (PCC) Surface Course /5.0 in. P-304 Cement Treated Base or 5.0 in. P-403 HMA Stabilized Base Course /6.0 in. P-209 Crushed Aggregate Subbase Course

In addition to the above two pavement design options, the CMAR contractor also proposed a value engineering (VE) alternative to evaluate the use of P-304 Cement Treated Base for the flexible pavement design option for Taxiways which resulted in the following pavement design section.

- Value Engineering Option: 6.0 in. P-401 Hot Mix Asphalt (HMA) Surface Course /6.0 in. P-304 Cement Treated Base/6.0 in. P-209 Crushed Aggregate Base Course

Life-Cycle Cost Analysis (LCCA)

The LCCA process broadly includes the steps below.

- Establish viable alternative design strategies
- Establish appropriate maintenance and rehabilitation cycles for the various design alternatives
- Estimate direct costs including the initial construction costs and the future rehabilitation costs over the selected analysis period

Initial construction cost estimates were developed for each pavement design alternative primarily using costs developed by the CMAR contractor for the current project. However, additional cost analysis with historical bid tabulations and back checking with RSMeans was also performed. Estimated quantities and unit costs were determined for each pavement material line item. These costs have assisted with developing an understanding for the 'present worth' of all the proposed pavement section considerations. Present worth economic analyses are detailed in Chapter 1 of the FAA Advisory Circular 150/5320-6F, *Airport Pavement Design and Evaluation*.

The LCCA approach utilized the guidelines provided in the Airfield Asphalt Pavement Technology Program's "*Life Cycle Cost Analysis for Airport Pavements*" study (AAPTP 06-06) as the primary reference. The technical guidelines identified within the report specifically address LCCA for airfield pavements and reference airfield, highway and military criteria requirements. The US Office of Management and Budget (OMB) Circular A-94 discount rates were considered and utilized, as appropriate. Following the guidelines set forth in all the referenced documents, LCCA was completed to determine the present worth for each alternative utilizing a real discount rate of 3.5%. Although a 3.5% real discount rate was ultimately selected for the LCCA, a sensitivity analysis was also performed for variable discount rates for comparison purposes as this can have a significant effect on the LCCA results.

The LCCA was performed for an analysis period of 40 years based on the estimated service life for new airfield pavement construction and the recommendations provided in the AAPTP report. General maintenance considerations and timelines were established and generally consisted the factors below.

- AC maintenance cycles
- PCC maintenance – crack sealing, spall repair, joint seal repair cycles
- Pavement markings – Additional repainting of runway pavement markings within the touchdown zone has been programmed. Quantities were established based on one-third of the initial pavement marking quantity. Additional striping was also evaluated based on performance of new materials.
- Major rehabilitation for flexible pavements consisted of a mill and overlay of the surface course on a cycle consistent with the airport practice. Given the 40-year analysis period, a deeper mill and overlay has also been programmed. The timing for the rehabilitation(s) is consistent with the current practice on the existing runway.
- Concrete Pavement Restoration (CPR) cycles for patching, crack sealing, slab replacement, spall repair, joint seal replacement
- Salvage values were established according to the presumed remaining service life of the last major rehabilitation work performed for each option.

The above pavement rehabilitation and maintenance cycles were customized based on the performance history of the pavements at TUS airport as well as the typical rehabilitation cycles, anticipated maintenance needs, and funding availability considerations.

RESULTS

The LCCA was performed for the pavement design options below for the runway and associated taxiways.

- Option 1: 15.0 in. P-501 PCC/5.0 in. P-403 HMA Stabilized Base/6.0 in. P-209 Crushed Aggregate Subbase
- Option 2: 15.0 in. P-501 PCC/5.0 in. P-304 Cement Treated Base/6.0 in. P-209 Crushed Aggregate Subbase
- Option 3: 5.0 in. P-401 HMA Surface/5.0 in. P-401 HMA Stabilized Base/9.0 in. P-209 Crushed Aggregate Subbase

Table 2. Summary of Life-Cycle Cost Analysis Results

Option	40-Year Analysis	Initial Cost		Life-Cycle Cost	
		Total	Square Yard	Total	Square Yard
	Runway				
1	15 in. PCC w/ P-403	$32,231,912	$175.87	$37,829,886	$206.42
2	15 in. PCC w/ P-304	$28,272,110	$154.27	$33,683,399	$183.79
3	10 in. AC	$20,373,916	$111.17	$33,094,017	$180.58
	Centerline Taxiway				
1	15 in. PCC w/ P-403	$16,573,048	$177.57	$17,739,396	$190.06
2	15 in. PCC w/ P-304	$14,714,421	$157.65	$15,880,769	$170.15
3	10 in. AC	$10,519,320	$112.71	$15,575,874	$166.88
	Outboard Taxiway				
1	15 in. PCC w/ P-403	$13,021,681	$177.57	$13,938,097	$190.06
2	15 in. PCC w/ P-304	$11,561,331	$157.65	$12,477,747	$170.15
3	10 in. AC	$8,265,180	$112.71	$12,237,182	$166.87

As noted previously, a discount rate of 3.5% and an analysis period of 40 years was selected for the LCCA. A summary of the LCCA analysis results for the above three options is shown in Table 2.

In addition to the three options above, a Value Engineering (VE) option below proposed by the CMAR contractor that included the use of cement treated base under HMA surface was evaluated for only the taxiways. It must be noted however that the potential for reflection cracking was recognized and the LCCA was accordingly customized to account for additional initial construction and future rehabilitation measures.

- VE Option for Taxiways: 6 in. P-401 HMA Surface/6.0 in. P-304 Cement Treated Base/6.0 in. P-209 Crushed Aggregate Base Course

Table 3 shows a summary of the LCCA results for the proposed Taxiway pavement sections along with the VE alternative.

Table 3. Taxiway LCCA Summary with VE Alternative

Option	40-Year Analysis	Initial Cost		Life-Cycle Cost	
		Total	Square Yard	Total	Square Yard
	Centerline Taxiway				
1	15 in. PCC w/ P-403	$16,573,048	$177.57	$17,739,396	$190.06
2	15 in. PCC w/ P-304	$14,714,421	$157.65	$15,880,769	$170.15
3	10 in. AC	$10,519,320	$112.71	$15,575,874	$166.88
VE	6 in. AC w/ P-304	$9,370,765	$100.40	$14,894,554	$159.58
	Outboard Taxiway				
1	15 in. PCC w/ P-403	$13,021,681	$177.57	$13,938,097	$190.06
2	15 in. PCC w/ P-304	$11,561,331	$157.65	$12,477,747	$170.15
3	10 in. AC	$8,265,180	$112.71	$12,237,182	$166.87
VE	6 in. AC w/ P-304	$7,362,744	$100.40	$11,702,858	$159.58

The LCCA computations have identified the rigid and flexible sections are within 2% of each other, when considering a P-304 Cement Treated Base. When considering a P-403 HMA Base, the rigid and flexible sections are within 14% of each other. In section 1.3.3.2 of Advisory Circular 150/5320-6F, *Airport Pavement Design and Evaluation*, the following is noted; "From a practical standpoint, if the difference in the present worth of costs between two design or rehabilitation alternatives is 10 percent or less, it is normally assumed to be insignificant and the present worth of the two alternatives can be assumed to be the same." As such, either the PCC with P-304 cement treated base or the AC section was determined to be a cost-effective design alternative per the LCCA from an overall cost standpoint.

For the taxiway section, the LCCA results indicated that the VE option provides a lower initial and life-cycle cost but overall that cost is within 10% of the AC construction option. Even though the initial cost for the VE option is lower, it is anticipated that the reflection cracking along the longitudinal construction lanes and a potential for 40 to 60 feet spacing of transverse crack development may cause an increase to the TAA maintenance efforts in the future. For the life-cycle cost analysis, maintenance was assumed based on experience and engineering judgement. The VE alternative is currently being evaluated further by the TAA.

BALANCING INITIAL COST IN THE PAVEMENT MATERIAL SELECTION

The LCCA is a valuable tool in the initial stages of a project to determine the viable pavement sections that may be considered per FAA funding requirements. However, the LCCA only quantifies the financial aspects of the pavement material analysis across the analysis period specified. Except for situations where regional circumstances, such as material or contractor availability disproportionally affect the initial costs of a given pavement material, a proper LCCA may determine two or more viable pavement sections that fall within the 10% threshold difference.

While the LCCA provides a financial estimate of the life cycle costs of a given pavement section, the ultimate financial aspect should not be the sole determining factor when deciding to proceed with either a rigid or flexible pavement option. Limitations should be placed on the importance of one section's overall cost versus the another. As stated in the pavement design advisory circular, life cycle costs within 10% should be considered equal. However, selecting a customized design option that balances cost without long term operational impacts for maintenance and rehabilitation should be considered.

In addition, when the life cycle costs of the viable options are considered equal, other factors for the material alternatives must be analyzed to determine if the materials are right for the region, pavement operational use, and airport rehabilitation requirements. This can often be demonstrated by analyzing the existing pavement performance to observe trends for long term closures to rehabilitate the flexible or rigid pavements. Consideration should also be given to the pavements intended operational use. While the lower cost, higher frequency rehabilitations of flexible pavement may be able to be performed on a given taxiway without adversely affecting airport operations, these disruptions can have severe impacts to airport operations when performed on a runway or critical taxiway locations such as entrance points. Stakeholder engagement provides valuable input to the criticality and acceptable level of future disruption for a given pavement area. The airport's ability to properly maintain the pavement once constructed is also a critical factor in the long-term performance of the pavement and in determining the best fit pavement for a given airport application.

For a large size project, these factors can result in flexible pavement being appropriate for some areas, while rigid pavements being appropriate for others. For this project, analysis of the existing pavements identified both rigid and flexible pavements typically performed well, with the exception of flexible pavements in areas subjected to low speed channelized traffic. In the hot desert climate this operational constraint creates challenges for long term durability. Review of maintenance capabilities indicated the TAA was equally adept at maintaining flexible and rigid pavements, making maintenance capability a nonfactor. This resulted in the operational requirement and initial cost being the critical factors in determining the preferred pavement materials for the runway and various taxiways.

In reviewing the anticipated operational use of the proposed airfield, the entrance taxiways on both ends of the runway are anticipated to be heavily utilized crossings, subjected to slow moving or standing aircraft as aircrafts queue for departures. Based on the visual inspections conducted during the pavement management system updates in the past, the existing asphalt pavements in a majority of the flexible paved areas are experiencing age/environmental related distresses such as block cracking, weathering, and longitudinal/transverse cracking. However, in the locations similar to these entrance taxiways, additional load related distresses were recorded. Constructing these high traffic crossing / queuing areas with rigid pavement will reduce additional future maintenance caused by the slow-moving channelized traffic and advanced oxidation with the

HMA wearing course. Because PCC is a rigid surface and less susceptible to these types of operational concerns, PCC was recommended for these entrance taxiways. For all other connector taxiways, flexible pavement was recommended due to the lower initial construction costs and the flexibility to perform the required future asphalt rehabilitations without adversely affecting airport operations. Conversely, the importance of Runway 12R/30L to the overall airfield safety and operations meant that an asphalt rehabilitation schedule would be a significant disruption throughout the life of the pavement. Therefore, it was determined that the higher initial investment for PCC was justified for the runway pavement.

By performing a thorough and proper LCCA, multiple pavement sections and materials were able to be identified as viable candidates for use on the project within the requirements for federal funding. This allowed the pavement sections to be tailored to not only the funding aspect for the project, but also the operational aspects of the individual pavement areas. The result of this approach is a balanced pavement design that fits the airport's needs now, and throughout the future life of the pavement.

CONCLUSIONS

Development of a comprehensive Life-Cycle Cost Analysis (LCCA) for feasible pavement design alternatives is a critical tool in the pavement type selection and design process because of the short-term and long-term cost implications for the agency. However, it is critical for the LCCA to be reliable and representative for project specific conditions. Analysis period, discount rate, unit costs and estimated rehabilitation cycles all have a significant impact on the LCCA results. It is therefore important to customize and tailor the LCCA approach to project specific conditions that consider local availability of construction materials, qualified regional contractors, funding mechanisms, project objectives, performance history of pavements, and typical maintenance practices among other factors. If the difference in the present worth of costs between two competing alternatives is 10 percent or less, the results are generally considered similar and the present worth of the two alternatives can be assumed to be the same. A sensitivity analysis of the critical variables such as the discount rate and major rehabilitation activity timing is also recommended to better understand and interpret the LCCA results. This customized and practical design approach for LCCA provides a significant benefit to the airport and government agency when evaluating potential pavement rehabilitation alternatives and providing funding for the recommended pavement design alternative. However, LCCA is not the only tool to managing long term costs. A balance for the operational requirements and future extended closures which disrupt traffic must also be provided. At TUS, the overall size of the project provides locations where initial cost savings can be balanced with the LCCA result.

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Field and Laboratory Characterization of Cement Treated Permeable Base for Flexible Airport Pavement at the FAA's National Airport Pavement Test Facility

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ABSTRACT

The performance of cement treated permeable base (CTPB) material under full-scale aircraft traffic is investigated on two dedicated pavement sections during construction cycle 9 (CC9) at the Federal Aviation Administration's (FAA) National Airport Pavement Test Facility (NAPTF). Laboratory and field characterization of the CTPB material was performed during the construction stage. In addition to testing for compressive and flexural strength, measuring resilient modulus on 28-day cured CTPB cylindrical specimens was experimented as part of the laboratory characterization. Although producing specimens of flat and smooth end surfaces was one of the major challenges in measuring reliable vertical deformations, stress-dependency of CTPB material was captured in the resilient modulus test results. The light weight deflectometer (LWD) was identified as a feasible field alternative for the characterization test on the finished CTPB surface. The CTPB modulus measured in the laboratory was approximately 1.8–2.6 times the field modulus derived from LWD testing. This paper discusses laboratory and field characterization results and provides an overall evaluation of CTPB material properties and anticipated performance under full-scale traffic. The implications of test results for future CTPB material FAA specifications are also addressed.

INTRODUCTION

The Federal Aviation Administration (FAA) operates the NAPTF, a state-of-the-art full-scale testing facility located at the William J. Hughes Technical Center in Atlantic City, New Jersey. The NAPTF is a fully enclosed instrumented facility that simulates aircraft traffic of up to 6007 kN in weight. Since 1999, a variety of rigid and flexible pavements structures are cyclically tested at the NAPTF. Construction of the current flexible test pavement (CC9) was completed in December 2019.

Permeable base layers rapidly remove water from within the pavement structure (Hall et al. 2005) while providing additional load distribution capacity for flexible pavements. However, the use of CTPB as stabilized base for flexible pavement design is not currently recommended by the FAA due to its susceptibility to reflective cracking (FAA 2018). CC9 includes two dedicated pavement sections (test items) with identical layer thicknesses but different base course materials to investigate the performance of CTPB under full-scale traffic. These test items are built over a low strength subgrade with California Bearing Ratio (CBR) of 5%. The pavement structure consists of 737 mm of granular subbase (P-154MR), 203 mm of base course and 127 mm of hot mix asphalt surface (HMA) (P-401MR). Conventional crushed aggregate (P-209MR) is used as base course in the control test item while CTPB (P-307MR) is used in the experimental comparison test item.

Materials were sampled during the placement of CTPB to prepare laboratory specimens for compressive and flexural strength testing. In addition, measuring resilient modulus (M_r) on 28-day cured CTPB cylindrical specimens was experimented. LWD testing was performed on the CTPB surface after 7- and 28-days of curing. In this paper, CTPB test results of both laboratory and field characterization are discussed. Also, an overall evaluation of the anticipated performance under full-scale traffic is provided.

CTPB MATERIAL AND CONSTRUCTION

Permeability, initial constructability, and long-term durability are key factors to be considered in the CTPB mix design. The CTPB mix should consist of durable, high-quality mineral aggregate with negligible fines, and sufficient cement paste to uniformly coat the aggregate particles without clogging the pore structure (Hall et al. 2005). Table 1 presents the CC9 CTPB mix design. Figure 1 shows the coarse and fine aggregate combined gradation. All aggregate material requirements are met per FAA's construction specifications (FAA 2018). In addition to the items in Table 1, a water reducer admixture was incorporated into the mix at a rate of 390mL/100kg. The mix design rendered a 7-day average compressive strength (ASTM 2018) of 4413 kPa, meeting the FAA's mix design requirement (i.e., between 2758 kPa and 5516 kPa). The permeability measured during the initial test strip (ASTM 2017) was 615 m/day which exceeds the upper limit per FAA's requirement (i.e., between 150 m/day and 450 m/day).

Table 1. CTPB Mix Design

Material	Type	Quantity per Unit Volume
Portland Cement	Type I	77.1 kg/m^3
Slag Cement	Ground granulated blast furnace slag - grade 120	41.5 kg/m^3
Coarse Aggregate	Stone size 57 per ASTM C33	1364.5 kg/m^3
Fine Aggregate	Sand	194.0 kg/m^3
Water	Potable (water-cement ratio = 0.36)	42.7 kg/m^3
Air Content		35%
Total		1719.8 kg/m^3

Designations for the experimental and control test item are LFS-4N and LFC-4S, respectively. CTPB construction on LFS-4N was completed in two placements using a form riding triple roller paver (figure 2). The placements took place one week apart during October 2019. Figure 3 illustrates the test area layout including details on area coverage per placement. The surface of P-154MR subbase course was dampened shortly before each placement to prevent moisture loss of the CTPB mix from absorption by the underlying aggregate. After initial consolidation with the first pass of the form riding paver, the target thickness of 127 mm was achieved with 4 and 6 additional passes for placement 1 and 2, respectively. P-209MR material was used to complete the base course construction over a width of 0.9 m for the north shoulder