Use of Fiber Reinforced Asphalt Concrete as a Sustainable Paving Material for Airfields

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ABSTRACT

Sustainability at airports has received much attention recently as owners work to incorporate sustainable practices into projects and daily operations. In fact, several guides have been published by airport agencies in order to document sustainable practices. One potential sustainable practice involves the use of alternate paving materials for airfield pavements. Specifically, the use of fiber-reinforced asphalt concrete (FRAC) has shown promising results and has most recently been used to resurface Runway 1-19 at the Jackson Hole Airport in Jackson, Wyoming.

This paper explores the feasibility of using fiber-reinforced asphalt concrete as a sustainable paving strategy for airfields. The study included an extensive literature review, performance testing of an asphalt mixture, cost-analysis, sustainable credit summary and CO_2 emission comparison.

Laboratory testing showed that the Jackson Hole Airport mixture performed better than a control mixture produced in the laboratory using similar materials. Further analysis concluded that a fiber-reinforced, porous asphalt friction course can qualify for several sustainable site credits. In addition, the minimal upfront cost of fibers makes this product attractive as the cost can be recouped by approximately a one-year extension in service life.

The pavement design simulations performed indicated a reduction in equivalent CO_2 emissions through extension of service life. Recommendations for the use of FRAC on airfields are provided based on the findings of this study and future research is identified.

INTRODUCTION

Sustainability has gained popularity in the United States and the aviation industry has quickly joined this nationwide effort. A sustainable airport can be defined as one that minimizes short- and long-term impacts of growth on the environment in general and surrounding communities in particular. In 2009, the Chicago Department of Aviation, along with other industry leaders, developed a Sustainable Airport Manual to serve as a working guide for airports nationwide. This guide details a sustainable certification system for airports and allows several credits for the use of alternate paving materials.

Although sustainability credits are important, an alternate paving material must have equal or greater performance than a conventional pavement to be successful and cost effective. Historically, the use of fibers in paving materials has been most popular in Portland cement concrete to increase strength and durability. In comparison, commercially available and recycled fibers have been used to a limited extent in asphalt concrete mixtures on various projects. Most recently, a blend of polypropylene and aramid (Kevlar) fibers has been used in full-scale asphalt concrete projects for streets, parking lots and airfields. With this exception, use of fiber-reinforced asphalt concrete on airfields has been limited or has not been well-documented in literature. Recently, Runway 1-19 at the Jackson Hole Airport in Jackson, Wyoming was resurfaced with a porous friction course that used this blend of fibers. This main runway at the airport is 6,300 feet (1,920.2 m) long by 150 feet (45.7 m) wide and has a pavement section consisting of a 1 inch (2.5 cm) P-402 Porous Friction course on approximately 11-17 inches (27.9–43.2 cm) of asphalt concrete. The main reason for selecting fiber reinforcement was to improve hot-mix asphalt (HMA) performance to better withstand snow plowing, extreme temperature changes and heavy aircraft loading. Typical large aircraft that operate at the airport include the Boeing 757 and 737 along with the Airbus A-319. These aircraft can induce single tire loads upwards of 39,000 lbs (17,690 kg) per tire. In addition, tire pressures can range between 160 -205 psi (1,103 – 1,414 kPa) and can exert large stresses within the pavement structure.

While a majority of large airports use concrete airfield pavements to handle large loading, medium and smaller airports primarily use hot-mix asphalt (HMA). Therefore, improvements in HMA performance can directly benefit airports similar in size to the Jackson Hole Airport by extending pavement service life and reducing maintenance requirements and costs. The inclusion of fibers in HMA has been documented to improve certain aspects of HMA and may be a cost effective solution for airport owners. Therefore, the outcome of this research is intended for medium and small size airports which experience high tire loads and pressures but do not have the traffic volume to justify concrete airfield pavements.

In terms of sustainability, these types of pavements can reduce overall CO_2 emissions by extending service life and reducing maintenance; thus reducing new material production and additional construction or maintenance activities. Also, fiber-reinforced asphalt pavements can provide a use for waste or recycled fibers that may otherwise be discarded. Several sustainability rating systems even provide credits for use of alternate paving materials and inclusion of waste and recycled materials.

OBJECTIVE

The objective of this study is to evaluate the feasibility of using Fiber-Reinforced Asphalt Concrete (FRAC) as a sustainable paving material for airfields. To accomplish this goal, the following areas are addressed in this paper: literature review, material testing of a FRAC and control mixtures, cost analysis, CO_2 emission analysis and recommended airfield applications. Subsequent sections describe how tasks were carried out and the study results.

LITERATURE REVIEW

Fiber reinforcement of concrete has been very popular and a common method to increase the strength and cracking resistance of the material. In fact, fiber reinforcement dates back to the 1950's when modern methods of the practice were first developed (*1*). Although fiber reinforcement has been extensively studied for concrete, these pavements only make up a small portion of the United States infrastructure system. In comparison, hot-mix asphalt (HMA) accounts for approximately 94% of the paved roadways in the United States (*2*) and the trend is similar for airfield pavements. This type of paving material can provide a cost-effective method of surfacing roads, airfields and improving the world's transportation infrastructure system. However, like any type paving material, HMA is subjected to distress mechanisms which lead to deterioration and failure over time.

Distresses are the result of one or more factors, including magnitude of load, type of load, climatic conditions, material characteristics and material interactions. Major pavement distresses that challenge pavement engineers include permanent deformation (rutting), fatigue cracking, thermal cracking and raveling (*3,4*). Hoping to minimize or slow these pavement distresses, research has explored mixture modification through the use of fibers. Inclusion of fibers in paving materials serves to reinforce the material by adding additional tensile strength to the material that results from interconnection between aggregates. This interconnection may allow the material to withstand additional strain energy before cracking or fracture occurs (*5*).

Over the years, researchers have experimented with many different types of fiber reinforcement, including polyester, asbestos, glass, polypropylene, carbon, cellulose, Kevlar and recycled waste fibers (*1,5,6,7,8*). In addition, fiber-reinforcement of HMA has evolved to include a blend of different fibers to achieve different performance aspects (*9,10*).

Overall, the performance of fiber-reinforced HMA has received mixed reviews in research studies; however, Abtahi and Sheikhzadeh (*6*) reported that inclusion of fibers mainly increased dynamic modulus, creep compliance, rutting resistance, moisture susceptibility and freeze-thaw resistance. These researchers also reported a reduction in reflection cracking when HMA was modified with fibers. It is important to note that aforementioned fiber types did not always improve HMA performance in all distress categories. Discussion of different fiber types along with general performance characteristic summaries are described by Abtahi and Sheikhzadeh (*6*).

Kaloush and Biligiri (*11*) performed a laboratory performance evaluation of a dense-graded, fiber-reinforced asphalt mixture and control mixture from a field test section in Tempe, Arizona. This mixture included a blend of polypropylene and aramind (Kevlar). Authors reported increased shear deformation resistance and residual strength in the triaxial strength test. Permanent deformation tests indicated that FRAC mixtures accumulated less permanent strain and exhibited much higher flow numbers than the control mixture. Dynamic modulus values of the FRAC mixture were similar to the control mix at lower temperatures but a notable increase was observed at high temperatures. Also, FRAC mixtures exhibited higher tensile strength, total fracture energy and slower crack propagation according to the Indirect Tensile Strength test (IDT) and C* line integral test, respectively. Finally, the FRAC exhibited better fatigue resistance at 40° F (4.4° C); however, at 70° F (21.1° C) the control outperformed the FRAC mixture at high strain levels.

Su and Hachiya (*12*) conducted a study examining the use of fiber-reinforced, recycled asphalt pavement for airfield surface course pavements constructed with virgin and modified binders. Authors noted that in all mixtures, the addition of cellulose fibers increased the optimum binder content, improved Marshall stability and showed less mass loss by the Cantabro test. The benefit of fibers was more pronounced when modified binder was used. Authors concluded that the fiber addition to RAP containing modified binder increased the dynamic stability (wheel tracking test) making it suitable for airports with heavy loading.

Mahrez and Karim (*7*) reported that the inclusion of glass fibers into stone mastic asphalt (SMA) produced variable Marshall stability data and a decrease in stability and stiffness was observed after inclusion of fibers into the mixture. In a subsequent study, Mahrez and Karim (*13*) used the wheel tracking test to evaluate creep and rutting resistance of glass fiber-reinforced SMA mixtures. They reported higher resilient modulus and more resistance to rutting for mixtures containing glass fibers.

Jahromi and Khodai (*1*) evaluated the properties of asphalt mixtures modified with carbon fibers according to the following tests: indirect tension, creep, repeated load indirect tensile test and Marshall stability. Authors reported a decrease in flow and increased air voids as a result of adding carbon fibers. However, the addition of carbon fibers improved Marshall stability, increased fatigue life and reduced permanent deformation.

A study was conducted by Putman and Amirkhanian (*8*) conducted to evaluate the feasibility of using waste carpet and tire fibers in asphalt concrete. This study compared asphalt containing commonly used cellulose and polyester fibers with mixtures modified with waste carpet and tire fibers. They reported that mixtures containing waste fibers showed improved toughness. However, similar permanent deformation and moisture susceptibility performance was reported between waste fiber mixtures and mixtures containing cellulose and polyester fibers.

Gordon and Holmquist (*14*) summarized another study in which cellulose, polyester and recycled/waste fibers were added to dense graded HMA. Researchers noticed an increase in optimum binder content across all fiber types which can be beneficial to mixture performance. According to the Lottman test for tensile strength, the polyester fiber performed the best; however, the control mixture outperformed other recycled fibers. The polyester fiber had the highest resilient modulus values of all mixtures however; all mixtures exhibited similar resistance to fatigue cracking. Finally, authors concluded that fibers included in this study generally do not increase the stripping resistance of HMA. They also included a similar study comparing asphalt modified with carpet fibers to a control mixture. Researchers noted that the addition of fibers only increased the indirect tensile strength at 77° F (25° C). In the Hveem and Marshall Stability tests, fiber mixtures outperformed the control mixtures. Gordon and Holmquist (*14*) concluded that mixes containing recycled fibers performed as well as, if not better, than mixtures modified with commercially available fibers. Also, no significant performance decrease was noted in mixtures containing either type of fibers when compared to control mixtures.

Sustainable Credit Summary

Sustainability of our nation's infrastructure has received growing attention and the aviation industry has joined this nationwide effort. The Los Angeles World Airports published Sustainable Airport Planning, Design and Construction Guidelines in 2008 to encourage the use of sustainable practices at airports (*15*). In 2009, the Chicago Department of Aviation, along with other industry leaders, developed a Sustainable Airport Manual to serve as a working guide for airports. This guide details a sustainability certification system specific for airports which allows several credits for the use of alternate paving materials (*16*). At the present time, a universal sustainability rating system for airports has not been developed. The authors suggest that the development of these criteria or sustainable design guidelines for airfield pavements should at least consider the following categories: performance and durability, safety (as in adequate frictional resistance), ride quality, impacts on air quality that may be generated from tire wear, urban heat island effect, storm water mitigation, energy savings, cost effectiveness and recyclability of the paving materials. The following paragraphs describe limitations of the existing rating systems, which only address certain aspects of a sustainable pavement design.

Under the current rating systems, the use of fiber-reinforced asphalt pavement can receive sustainability credits for material reuse and recycled content if recycled or waste fibers are specified in design (*16,17*). Under the Chicago Department of Aviation Guide, a credit may be obtained for innovative design and construction strategies if an environmental benefit can be quantified (*16*). Also, several credits may be achieved for using innovative pavement treatments to improve durability and increase the life cycle (*15*). Finally, if fiber-reinforced, porous friction course (PFC) is specified for airfield paving, sustainability credits may also be achieved for storm water management and urban heat island mitigation (*16,17*).

For example, under the Chicago Department of Aviation criterion (*16*), FAA P-402 FRAC placed on the Jackson Hole Airport runway in lieu of runway grooving could possibly receive but not limited to three points; one point for Section 2.6.1 "Sustainable Sites – Landscape & Exterior Design to Reduce Heat Island, Non-Roof," one point for Section 8.1 "Innovation in Design/Construction," and another point for Section 2.5.1 "Sustainable Sites – Storm Water Design, Quality Control." It is important to note that current criteria for airport sustainability points or credits are vague and can vary depending on the creativity of the applicant. Therefore, this example serves only as a hypothetical situation and actual sustainability credits may vary depending on the reviewing agency and application process.

LABORATORY EVALUATION OF FRAC

Fiber-reinforced asphalt concrete mixture samples were obtained from a runway resurfacing project at the Jackson Hole Airport in Jackson, Wyoming. Specifically, this fiber-reinforced, porous friction course (PFC) was designed to provide friction and surface drainage on the runway. The performance of this mixture was evaluated in the Advanced Pavement Laboratory at Arizona State University (ASU) using the following tests: dynamic modulus (E*) tests, four-point bending beam tests for fatigue life, indirect tensile strength tests for thermal cracking and the Cantabro test for raveling.

Mixture Properties

The location and climate of the Jackson Hole Airport brought numerous maintenance challenges for airport personnel and the asphalt pavement surface on Runway 1-19 needed replacement earlier than expected due to issues with raveling from environmental conditions and snow plowing. Jackson Hole Airport only has one runway and therefore cannot afford to have additional long-term runway closures to maintain or replace failed asphalt pavement. In order to minimize the possibility of premature failure of the new open-graded, porous friction course, the airport decided to specify a fiber-reinforced asphalt mixture for the resurfacing of Runway 1-19.

Mixture properties and aggregate gradation of the Jackson Hole Airport (JAC) Mixture are summarized in Table 1. It is important to note that the FAA P-402 (Porous Friction Course) specification does not have a density requirement (*18*). A target air void level of 14% was chosen since a contractor tends to over compact an open-graded friction course during construction if density control is not required.

Fiber reinforcement of the HMA consisted of a blend of 0.75 inch (19 mm) long aramid (Kevlar) and polypropylene fibers which was manufactured by the FORTA Corporation. To avoid losing fibers during bag house suction, fibers were introduced into the batch plant hopper after the bag house.

A control mixture without fiber reinforcement was not produced during the Jackson Hole Airport project and thus direct comparison cannot be made. Fortunately, a subsequent project using the FAA P-402 specification and the same fiber reinforcement was constructed in 2011 at the Sheridan County Airport (SHR) in Sheridan, Wyoming. Laboratory specimens without fiber reinforcement were prepared from these raw materials as a control mixture and properties are included in Table 1.

TABLE 1 Mixture Properties and Aggregate Gradation

Mix Property	JAC Mixture	SHR Mixture (Control)
Gradation	Open	Open
Binder	PG 64-34	PG 64-34
Asphalt Content	5.70%	5.60%
Laboratory Target Air Voids	13,15%*	15,17%*
G_{mm}	2.416	2.540
Hydrated Lime (%)	0.75%	-
Fiber Reinforcement	1 lb/ton (0.5 kg/MT)	None
Mixing/Compaction Temp, °F (°C)	325/300 (163/149)	325/300 (163/149)

Sieve Size (US)	Sieve Size (SI)	JAC Mixture % Passing	SHR Mixture % Passing	FAA P-402 Control Points
1"	25.4	-	-	-
3/4"	19	100	100	100
1/2"	12.7	82	85	70-90
3/8"	9.5	57	52	40-65
No. 4	4.76	22	19	15-25
No. 8	2.38	12	13	8-15
No. 30	0.6	6	7	5-9
No. 200	0.074	2	2.5	1-5

**Air voids for cylinder and beam samples, respectively (Corelok Method)*

E* Test Results

Dynamic Modulus laboratory test specimens were compacted with a Servopac Gyratory Compactor into a 150 mm diameter mold. Test samples, 4 inches (100 mm) in diameter by 6 inches (150 mm) high, were cored from the center of the gyratory specimens and prepared for testing according to AASHTO TP 62-03.

Confined dynamic modulus tests were conducted for the open-graded friction course. Research has shown that confined testing is necessary to capture the true properties of surface course mixes that experience high confining stresses in the field (*19*). Samples were wrapped with a latex membrane and placed in a triaxial cell where a 20 psi (138 kPa) confining air pressure was applied. Each specimen was tested at 14, 40, 70, 100, 130°F (-10, 4.4, 21.1, 37.8 and 54.4 °C) with 25, 10, 5, 1, 0.5 and 0.1 Hz loading frequencies. A controlled sinusoidal stress was applied and micro-strains were kept below 150 micro-strains in order to stay within the visco-elastic range of the materials. Figure 1 presents dynamic modulus data at 10 Hz and 1 Hz. These frequencies represent typical aircraft speeds of approximately 100 mph (45 m/s) on runways and less than 20 mph (9 m/s) on taxiways (*22*). The Jackson Hole Airport mixture is considerably stronger at higher temperatures for both frequencies which is due to the fiber modification. This additional stiffness may help to reduce permanent deformation. The dynamic modulus test was not able to capture substantial differences between the two mixtures at the lower temperature.

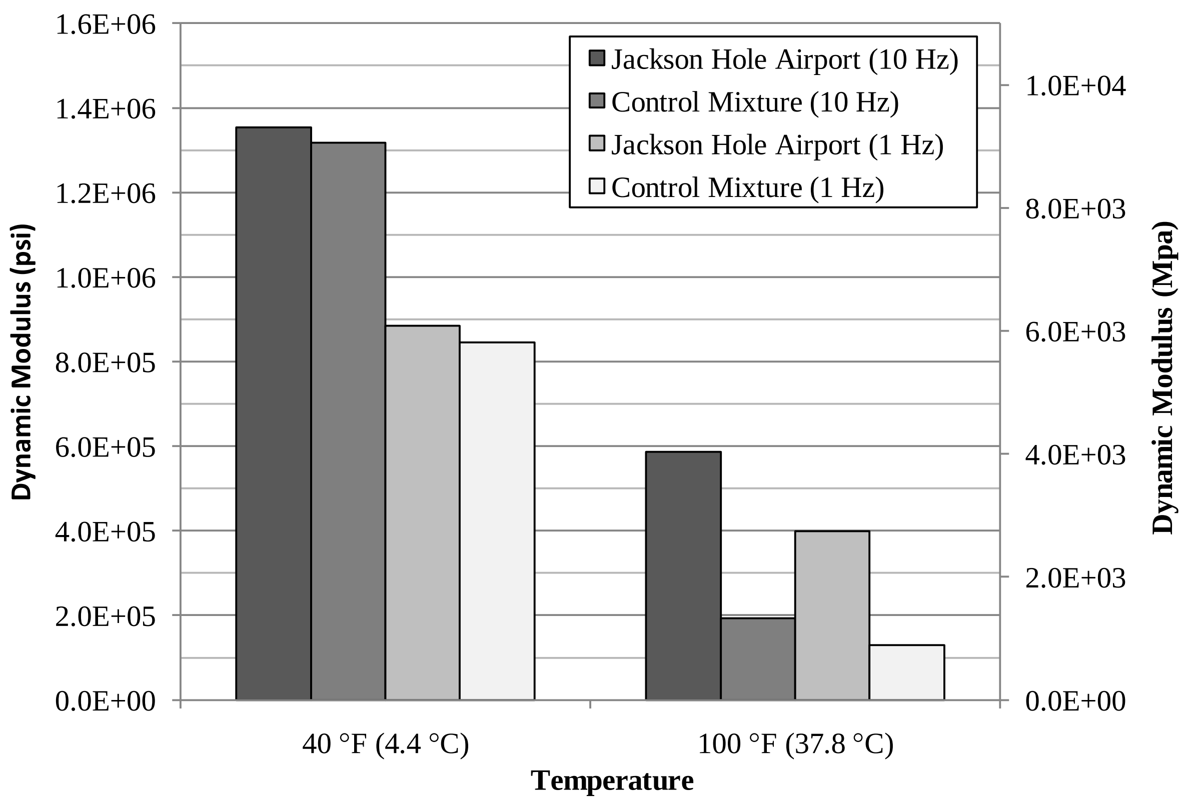

FIGURE 1 E* comparison for Jackson Hole Airport and control mixtures

Fatigue Testing

Fatigue cracking is a common distress in HMA pavements and is a result of stresses and strains developed from repetitive loading. Cracks will develop at areas of critical stresses and strains and will eventually propagate through the HMA layer. While fatigue cracking is not of a major concern for the open graded mixtures, it was of interest to see if differences of fatigue life could be captured from the four point bending fatigue tests.

Beams were compacted to the required air voids and cut to final dimensions of 15 inches (380 mm) by 2.5 inches (63 mm) by 2 inches (50 mm). They were subjected to the four-point bending beam test according to AASHTO T321-03. Each beam was subjected to a different controlled strain rate at 40°F (4.4°C) to simulate colder climate conditions in Wyoming. A 50% reduction in initial stiffness was used as the criteria to determine the number of cycles until failure (N_f). Initial stiffness was recorded as the stiffness of the beam at 50 loading cycles in accordance with SHRP M-009 (*20*). Figure 2 presents a fatigue comparison between the FRAC and unmodified laboratory mixture at 40°F (4.4°C). The FRAC mixture shows substantial performance improvement over the control mixture at 400 and 600 microstrain levels, 2 million versus 3.2 million cycles and 42,000 versus 280,000 cycles, respectively. At the 800 microstrain level, no difference in performance is observed. It is important to note that this comparison is valid since the initial stiffness of the beam samples for both mixtures was approximately 406 ksi (2,800 MPa).

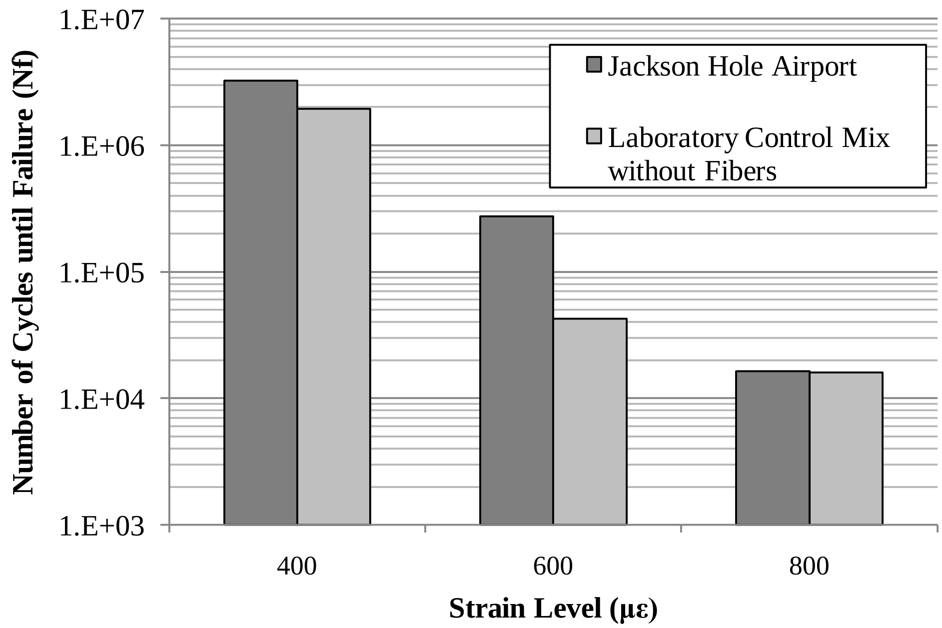

FIGURE 2 Fatigue life comparison at 40 °F (4.4 °C)

Indirect Tensile Strength Testing

One commonly used parameter to evaluate asphalt mixtures is tensile strength which can be used to quantify the effects of moisture and to determine the fracture resistance of an asphalt mixture. Typically, the tensile strength can be accurately determined from an indirect tensile strength test (IDT) carried out in accordance with AASHTO TP9-02*(21).* The test is conducted by applying a constant rate of vertical deformation (2.0 in/min, 50.8 mm/min) until the specimen fails. Two replicates were tested at: 0, 10 and 21.1°C (32, 50 and 70°F)

In addition, energy until failure and total fracture energy were calculated as the area under the stress-deflection plot. Table 2 shows the IDT test results. The Jackson Hole Airport mixture with fibers shows higher indirect tensile strength, energy at fracture and total energy than the control mixture. The increase in tensile strength ranges from 5 to 31%; whereas the energy at fracture range is between 15 and 200%. The contribution of the fibers is evident in the post peak strength of the material as indicated by the total energy. This improvement ranges from 19 to 45%. Although the specimen cracks, the fibers hold the specimen together which, in turn; requires more energy to completely fail the asphalt sample.

TABLE 2 Average Indirect Tensile Strength Test Results

Mixture	Temperature, °F (°C)	Indirect Tensile Strength, psi (kPa)	Energy at Failure, lb-in (J)	Total Energy, lb-in (J)
Jackson Hole Airport	70 (21.1)	75.6 (521.2)	63.5 (7.2)	254.6 (28.8)
	50 (10)	156.3 (1077.7)	149.1 (16.8)	474.5 (53.6)
	32 (0)	272.2 (1876.8)	200.4 (22.6)	532.4 (60.2)
Laboratory Control Mix	70 (21.1)	57.6 (397.1)	48.3 (5.5)	175.5 (19.8)
	50 (10)	138.0 (951.7)	73.7 (8.3)	329.6 (37.2)
	32 (0)	258.8 19.8)	175.0 (19.8)	447.9 (50.6)

Cantabro Abrasion Test

The Cantabro abrasion test was conducted on 4 inch diameter (100mm) by 2.5 inch (63.5 mm) thick specimens using guidance from European test standard EN 12697. A specimen was placed in the LA abrasion machine without the steel balls and rotated for 300 revolutions. The mass before and after was recorded and percent mass loss was calculated. The test was conducted at 25°C using four replicates of each mixture. The specimen was modified with a 1 inch (25mm) hole through the center in attempt to increase the area for particle loss. Test specimens were cut from samples previously subjected to the nondestructive dynamic modulus test.

The average mass loss was 2.6% and 3.7% for the Jackson Hole FRAC mixture and control mixture, respectively. Thus both mixtures exhibit comparable raveling resistance. It was observed that the soft characteristics of the PG64-34 binder at the test temperature prevented excessive mass loss at the edges of the specimens even though loose aggregate was present. It may be beneficial in future analysis to evaluate the raveling potential of porous friction course mixtures at lower temperatures and consider the binder grade as well.

CO_2 EQUIVALENT EMMISSION COMPARISON

Another factor to consider when designing or evaluating a sustainable pavement involves the emission of greenhouse gas emissions resulting from production, mixing and transport of the material. Thus, selection of a pavement that meets design requirements with reduced emissions can provide an environmental benefit. The Global Warming Potential (GWP) was developed by the Intergovernmental Panel on Climate Change (IPCC) to compare the potential of a greenhouse gas, relative to another gas, to trap heat in Earth's atmosphere. GWP measurement uses CO_2 as the reference gas and reports measurements in tetragrams (Tg) of CO_2 equivalent (*23*).

White et al (*23*) developed a formula to compute the total annual kilogram CO_2 equivalent per unit length and width of pavement. The use of this equation is applicable to roadways, airfield pavements or parking lots. In development of this formula, the authors used the following greenhouse gasses typically produced from asphalt production, mixing and transport: carbon dioxide (fossil), methane (fossil), carbon monoxide (fossil) and dinitrogen monoxide. In this analysis, the following formula is used to compute the total CO_2 equivalent (*23*):

$$Total\ Annual\ kg\ CO_2\ equiv./km = \frac{\sum\left[T * W * 1000 * D_n * (P_n * M_n) + (D_i * T_p\right]}{Y}$$

Where:

- T = layer thickness (m)
- W = pavement width (m)
- D_n = density of paving material (kg/m3)
- P_n = material production value (kg CO_2 equiv./kg material)
- M_n = material mixing value (kg CO_2 equiv./kg material)
- D_i = distance from material production site to construction location (km)
- T_p = fuel consumption associated with transport from material production site to construction location (kg CO_2 equiv./kg material)
- Y = pavement service life (years)

For asphalt concrete, White et al (*23*) reported values for P_n and M_n of 0.0238 and 0.0663 kg equiv. CO_2/kg, respectively. In one example, the transport value (T_p) was kept constant and reported as 0.0002821 kg equiv. CO_2/kg-km. Detailed discussion on the derivation of these values included the greenhouse gasses used in the analysis is reported in White et al (*23*).

Since the production, mixing and transport of asphalt concrete with and without fibers is essentially the same, the best way to realize a reduction of annual kilogram CO_2 equivalent per kilometer of runway is to increase the service life of the pavement (Y) or reduce the thickness of the material (T). FAA FAARFIELD 1.305 pavement design software was used to run design simulations. However, one drawback in FAA thickness design is that the modulus of asphalt concrete is fixed at 200,000 psi (1,380 MPa) to correspond to an approximate 90°F (32° C) pavement temperature and the primary failure method is subgrade shear (*4*,*24*). Strain in the asphalt layer can be considered but the designer must change a program default (*24*). Therefore, at the present time the FAA design procedures do not consider thickness changes due to improvement in asphalt concrete material properties.

For this FRAC surface course analysis, an undefined layer was created to represent asphalt concrete with varying modulus values. For a dense-graded asphalt, Kaloush et al., (*11*) reported that the inclusion of fibers resulted in approximately a 50% increase in dynamic modulus at 100°F (34.7° C) and 10 Hz frequency which typically represents a 100 mph (45 m/s) aircraft speed on a runway (*22*). Therefore, the dynamic modulus of the FRAC surface course was increased to 250,000 and 300,000 psi (1,723 and 2,068 MPa) for this analysis. This is a conservative increase since the true dynamic modulus may be three times higher as indicated by the testing results in this study.

A typical aircraft fleet mixture at Jackson Hole Airport was created using the Airbus A-320, Boeing 757 and Boeing 737; all with 1,200 annual departures. The designed pavement structure consisted of a 5 inch (127 mm) FRAC surface course, 7.6 inch (193 mm) FAA P-401 base course and 14 inch (356 mm) FAA P-209 aggregate base course on subgrade with a CBR-value of six. Using the life analysis feature in FAARFIELD 1.305, a modulus change to 250,000 psi and 300,000 psi resulted in approximately a 50% and 100% increase in service life, respectively. Since these increases may not be reasonable in terms of practical experience, several design life scenarios were analyzed.

For the CO_2 analysis, the transport distance was assumed to be 25 km (15.5 miles), the density of asphalt concrete was taken as 2,275 kg/m^3 (142 lb/ft^3) and a runway width of 45.7 m (150 feet) was used. Results of the CO_2 analysis are presented in Table 3. Thus, the use of FRAC as the surface course can result in a 33% decrease in total kilograms of annual CO_2 equivalent per kilometer of runway. This is based on the assumption that the dynamic modulus increases by 50% to 300,000 psi (1,723) for FRAC and is also limited by the current FAA design procedures.

TABLE 3 Total kg Annual CO_2 Equivalent / km of Runway

Service life (Y)	Total kg Annual CO_2 Eq. / km runway (lb/mi runway)	% Change
10	128,279 (455,703)	100.0%
15	85,519 (303,801)	33.3%
20*	64,139 (227,850)	0.0%
25	51,312 (182,283)	-20.0%
30	42,760 (151,902)	-33.3%

** Standard FAA design life*

COST COMPARISON

A cost comparison of a FAA P-402 mixture with and without fiber modification was performed for the FRAC mixture placed at the Jackson Hole Airport and a similar project at the Sheridan County Airport in Wyoming. Both projects are in the same geographic region and utilized the same PG-64-34 binder and fiber material. Bid tabulations were obtained from the Wyoming DOT website and the average prices were compiled for the three main line items: 1) P-402a Porous Friction Course; 2) Modified PG64-34 binder; and 3) Fiber Reinforcement Additive. The average unit price from the bidding contractors was used for this analysis. It is important to note that some unit prices were not included in the average because they were much higher or lower which can be attributed to contractor bidding strategies.

Using these prices, total cost was developed along with the cost per ton of FRAC. Next, the fiber reinforcement line item was removed and total cost and cost per ton were reported for unmodified P-402 HMA. Even though the projects included a separate line item for the fiber reinforcement additive it is impossible to determine whether the contractor added additional cost to the P-402 Porous Friction Course line item to account for labor for mixing and construction costs. An easy solution would be to compare prices to similar State of Wyoming jobs which specified unmodified FAA P-402 Porous Friction Course. However, there were no projects constructed in the State of Wyoming during 2009 and 2010, using this unmodified material (*24*). Thus, for this analysis a three percent reduction in the unit price for P-402 Porous Friction Course was used to represent unmodified in-place mixture costs (*26*).

Table 4 presents a summary of the cost analysis for the two projects. The higher cost per ton in the Sheridan County Airport project is reasonable given the smaller quantity of HMA. However, it is important to note that for both projects, the cost increase of adding fibers to the HMA is approximately 11%.

TABLE 4 Project Cost Comparison for a) Unmodified P-402 Porous Friction Course b) P-402 FRAC

Item	Jackson Hole Airport			Sheridan County Airport		
	Unit	$/unit	Total Cost	Unit	$/unit	Total Cost
P-402 Porous Friction Course, tons	8530	48.5	$413,705	5800	58.6	$339,880
PG 64-34 Modified Binder, tons	640	1000	$640,000	520	890	$462,800
Total Cost of HMA Mixture			***$1,053,705***			***$802,680***
Cost per Ton of HMA Mixture			***$124***			***$138***

Item	Jackson Hole Airport			Sheridan County Airport		
	Unit	$/unit	Total Cost	Unit	$/unit	Total Cost
P-402 Porous Friction Course, tons	8530	50	$426,500	5800	60.4	$350,320
PG 64-34 Modified Binder, tons	640	1000	$640,000	520	890	$462,800
Fiber Reinforcement Additive, lbs	8530	7	$59,710	5800	8.35	$48,430
Total Cost of FRAC Mixture			***$1,126,210***			***$861,550***
Cost Per Ton of FRAC Mixture			***$132***			***$149***

In order to determine the increase in pavement service life for the additional cost of fiber reinforcement to be justified, the equivalent uniform annual cost (EUAC) was calculated for each mixture across different pavement service lives. Since the pavement service life for porous friction course is typically around 8-12 years (*27*), a range of values between 5 and 15 years was included in the analysis. Five years represents a premature pavement failure whereas 15 years represents an exceptional service life.

It is important to note several assumptions made during the cost comparison analysis. Salvage value was taken at $3/ton of asphalt millings, net present value (NPV) was determined using a 5% interest rate and maintenance and operational costs arising from construction and maintenance downtime were not considered.

Results of the EUAC comparison are presented in Figure 3. From this figure, it is evident that the additional cost of fiber reinforcement can be justified in only a short period of time. For example, if the unmodified P-402 Porous Friction Course failed in Year 8, the fiber-reinforcement would need to extend the service life approximately 0.9 years to have equal EUAC values. Any additional service life beyond Year 8.9 would lower the EUAC and provide cost additional benefit to the owner. This example holds true for both projects. However, as service life extends beyond 10 years, an additional 1.1 years of service life is needed to justify the cost of fiber reinforcement.

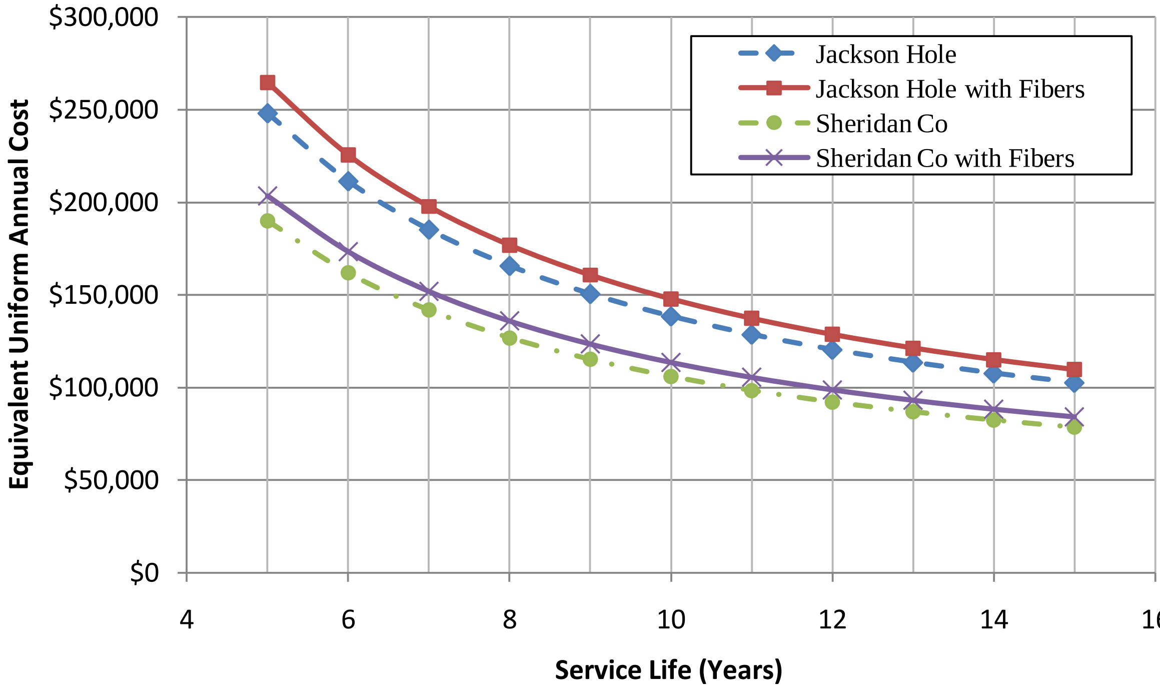

FIGURE 3 EUAC comparison for FRAC and unmodified porous friction course

Overall, given the data and pricing from the Jackson Hole Airport and Sheridan County Airport projects in Wyoming, the low upfront cost of the fiber-reinforcement can be justified by a minimal increase in pavement service life.

RECOMMENDED AIRFIELD APPLICATIONS

In the past, use of fiber modification has been limited to smaller scale street or highway projects due to cost concerns and lack of experience with materials. However, the added engineering benefits of polypropylene and aramid fiber-reinforcement, along with the minimal cost increase, make this product viable for airfield pavements that sustain large loading and tire pressures. For example, airports experiencing aircraft loads greater than 60,000 lbs (27,216 kg) and 150 psi (1,034 kPa) tire pressures may consider FRAC. Also, use of FRAC may be most beneficial for the following FAA airport types: non-hub primary, non-primary commercial service, relievers and general aviation utility airports. Typically, these types of airports tend to utilize HMA pavements and can experience wide ranges of load magnitudes and tire pressures.

Specifically, fiber-reinforcement may be beneficial in improving the engineering properties of FAA P-402 friction courses (PFC). PFC's provide a reduction in hydroplaning potential and provide increased surface friction for aircraft (*27*, *28*). However, a major concern with PFC's revolves around a shorter service life of about 8-12 years on highways and airfields (*27*) and raveling can be a contributor to foreign object debris (FOD) on runways. Thus, many airports have decided to use runway grooving as a means of friction improvement in lieu of PFC's.

A 2007 study sponsored by the Airfield Asphalt Pavement Technology Program (AAPTP) (*27*) cited improved surface friction as a main benefit of PFC. However, this study has shown potential problems with the current FAA P-402 PFC material which include raveling, surface deterioration and shoving under heavy aircraft turning movements. This study also recommended the use of modified binders and fibers in PFC's to reduce binder drain down and increase durability as measured by the Cantabro abrasion loss test. Other problems include: low structural strength, patching difficulties and susceptibility to high stresses under loading (*29*).

Based on this information and performance test results from the Jackson Hole Airport FRAC mixture, FAA P-402 may be an excellent candidate to receive polypropylene and aramid fiber reinforcement to improve engineering properties and ultimately, service life.

Fiber reinforcement can also be used, and in fact more effective, in dense-graded or gap-graded asphalt mixtures. For example, dense graded HMA pavements used on airfield aprons are prone to significant rutting as a result of elevated temperatures and high static loading from parked aircraft. On hot days, the aircraft tires may actually settle into the asphalt pavement. Aircraft can sustain major damage while trying to remove tires that have become stuck in the asphalt pavement. Fiber-reinforcement may improve the stability of these apron mixtures and reduce the potential for rutting.

It is important to note that use of fiber-reinforcement is not a substitute for insufficient asphalt mix design. Asphalt material must be properly designed prior to construction and should consider the addition of fiber material in the mixture.

CONCLUSIONS

Sustainability has gained popularity in the United States and the aviation industry has quickly joined this nationwide effort. In recent years, several organizations have published sustainable airport guides in an effort to implement voluntary sustainability rating systems specific for airports. Under these sustainability guidelines, porous or open-graded Fiber Reinforced Asphalt Concrete (FRAC) could qualify for several sustainability credits for storm water control, urban heat island reduction and innovative design materials and techniques. In addition to these credits, the authors recommended that sustainable pavement design should also consider performance and durability, safety (as in adequate frictional resistance), ride quality, impacts on air quality that may be generated from tire wear, energy savings, cost effectiveness and recyclability of paving materials. Fiber reinforced asphalt concrete evaluated in this study meets several if not all of these categories.

The material tests in this study indicated that the dynamic modulus of FRAC is improved over a control mixture especially at 100°F (34.8°C). Beam fatigue test results also showed substantial improvement as a result from the addition of fibers. The strength contribution of fibers was evident in the indirect tensile test, especially when the energy until fracture and total fracture energy were compared to the control mixture. These properties indicated that the FRAC mixture is better able to resist the development and propagation of cracks when compared to the control mixture; however, the mixtures exhibited similar raveling resistance according to the Cantabro Abrasion test.

A cost analysis of the bid quantities and pricing for FRAC placed at the Jackson Hole Airport and the Sheridan County Airports in Wyoming indicated that the low upfront additional cost of the polypropylene and aramid fibers can be recouped by the owner through a minimal increase in pavement service life of approximately one year.

CO_2 analysis of a FRAC surface course can result in a 33% decrease in total kilograms of annual CO_2 equivalent per kilometer of runway during the design service life. This is based on the assumption that the dynamic modulus increases by 50% to 300,000 psi (1,723 MPa) for

FRAC and is also limited by the current FAA design procedures which limit design asphalt modulus to 200,000 psi (1,380 MPa). Also, use FRAC can further reduce CO_2 emissions since this material can be used as recycled asphalt pavement at the end of its service life.

Finally, several recommended airfield applications of fiber-reinforced asphalt concrete were presented. Based on this information and performance test results from the Jackson Hole Airport FRAC mixture, FAA P-402 may be an excellent candidate to receive polypropylene and aramid fiber reinforcement to improve engineering properties and ultimately, service life. Use of the material may also be extended to dense graded asphalt mixtures for airfield pavements.

Overall, the use of fiber-reinforced asphalt concrete can be a suitable candidate as a sustainable paving material for airfields.

RECOMMENDATIONS

It is important to note that conclusions drawn from this study are limited to the materials tested and information obtained for this research. In order to further validate this work, additional dense and open graded airfield FRAC materials should be evaluated and subjected to performance testing. Specifically, the FAA should consider evaluating FRAC mixtures in a full-scale test facility. Finally, the in-place runway pavements at the Jackson Hole and Sheridan County Airports in Wyoming should be surveyed to evaluate field performance and validate laboratory data.

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