Mixtures sensitive to moisture damage could fail across any failure mode including fatigue, rutting, thermal cracking and segregation (Sebaaly et al., 2015). Figure 8 shows that the SMR for the reinforced mixtures is higher than the unreinforced mixture, revealing excellent performance for the reinforced mixtures. The water sensitivity test established that the interior bonding (tensile strength) of the reinforced mixtures was not affected by water.

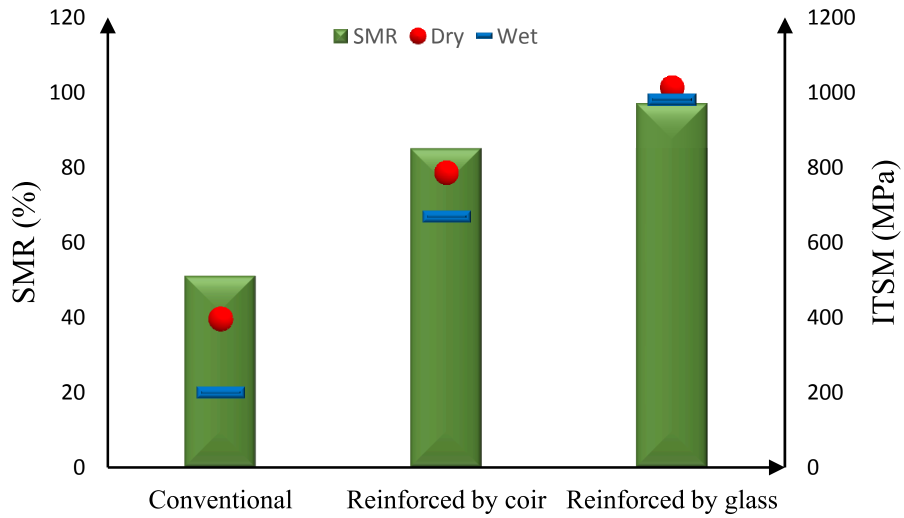

Figure 8. Effect of coir and glass fibers on water sensitivity

4. Conclusions

This study has focused on developing new CMA mixtures, prepared with two different types of fibers, as reinforcement materials. The mechanical properties of each mixture were evaluated under a variety of tests. Based on the results of these tests, the following conclusions can be drawn:

1. Significant improvements were gained in terms of stiffness modulus by using natural and synthetic fibers as a reinforcement material in CMA mixtures.
2. Regarding temperature sensitivity analysis, CMA mixtures with coir and glass fibers show a lower thermal sensitivity than conventional mixtures.
3. Adding coir and glass fibers to the CMA mixtures improve binder drainage resistance.
4. The creep resistance of the reinforced CMA was better than that of the unreinforced mixture.
5. The reinforced CMA mixtures displayed a much-improved service life under the wheel-tracking test when comparing degree of deformation with the unreinforced mixture. This is due to an increase in the tensile strength of the reinforced mixtures. The weak tensile strength of the conventional CMA mixture results in high permanent deformation (rutting) in the wheel-tracking test, reflecting the poor quality of this mixture.
6. Coir and glass fiber reinforced CMA mixtures had a high resistance to the effects of water and can therefore be considered durable. These results are substantially better than those for the unreinforced CMA. There were significant developments for these mixtures in terms of SMR.

7. Based on the above discussion, laboratory investigations indicate that the fiber type, content, length variation and effect of binder content on fiber parameters should be a major research focus regarding the use of fibers in CMA mixtures. However, further work is needed to investigate dynamic modulus, fatigue life and temperature sensitivity. Modelling of the mechanical properties of fiber reinforced CMA mixtures, using finite element analysis, can be considered a new research area for the future.

Acknowledgment

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Use of Permeable Pavements at Airports

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Introduction

By design, airports have vast areas of paved surfaces, most of which consist of impermeable pavement. As has long been recognized, impermeable pavements have the ability to increase both stormwater runoff and the heat island effect. Although many sustainability and low-impact development (LID) manuals include permeable pavement as an alternative to impermeable surfaces, available documentation indicates its use is still very limited at airports, particularly in aircraft movement areas.

Consideration of the use of permeable pavements as a replacement to standard impermeable pavements has increased dramatically over the last 10 years. Permeable pavements are an alternative to impermeable pavement surfaces (conventional pavements) that encourage infiltration and/or filtration of stormwater runoff while still providing structural capacity. Infiltration and filtration eliminate or reduce stormwater runoff volumes discharged to storm drains or combined sewer systems as well as pollutants contained in the stormwater as it discharges to the final nearby water bodies or resource areas.

The available manuals and specifications for permeable pavements cover parking lots, light-duty roadways, and pedestrian areas, but there is little to no guidance for permeable pavements associated with aircraft operations, nor does there appear to be a reference that is all inclusive of the broad range of paved areas that fall within the jurisdiction of an airport. Because of the environmental and sustainable goals supported by the use of permeable pavements, there is a need to develop a concise practical document that airport designers and operators can turn to for guidance on the use of permeable pavement systems.

The objective of the Airport Cooperative Research Program (ACRP), Project 02-64, *Guidance for Usage of Permeable Pavement at Airports* (Bruinsma, et al. 2017), was to develop guidance information that airport agencies need to better assess the option of incorporating a permeable pavement system at their facilities. As part of the ACRP project, data was collected to gain an understanding of industry experience with permeable pavements and to document the use of permeable pavements in the aircraft environment. The following sections summarize the industry perspective on the use of permeable pavements at airports and an overview of case studies developed as part of the ACRP project, highlighting where permeable pavements have already been used in aircraft movement areas as well as vehicular applications.

Industry Survey

One of the initial tasks of ACRP 02-64 was to obtain industry input on the level of experience with and number of permeable pavement projects at airports. The survey consisted of 15 questions relating to the planning, design, and implementation of permeable pavements and the availability of project documentation. The project team received 72 responses, representing 41 airports or agencies and 23 consultants or industry groups. The following discussion summarizes the responses related to experience and implementation.

Does the airport have permeable pavement experience in relation to the following (please select all that apply)?

- Project selection.
- Pavement design.
- Hydrological design.
- Materials selection.
- Specification development.
- Construction.
- Maintenance.
- Performance and durability.
- Development of low-impact design or sustainability manuals.

There is very little reported experience with permeable pavements in an airport environment: responses in the various above categories varied from approximately 5.5 to 22 percent of respondents, depending on the category. As summarized in figure 1, the greatest experience (16 respondents) is in pavement design, and the least experience (4 respondents) is in the development of low-impact design (LID) or sustainability manuals. However, these results may not be entirely representative. Several of the respondents were considering permeable base/subbase layers or porous friction courses that are not part of a complete permeable pavement system.

If the airport has constructed a permeable pavement, where was it applied (please select all that apply)?

Airside:
- Runways.
- Taxiways.
- Aprons.
- Roadways.
- Parking lots.
- Runway shoulders.
- Taxiway shoulders.
- Apron shoulders.
- Roadway or parking lot shoulders.

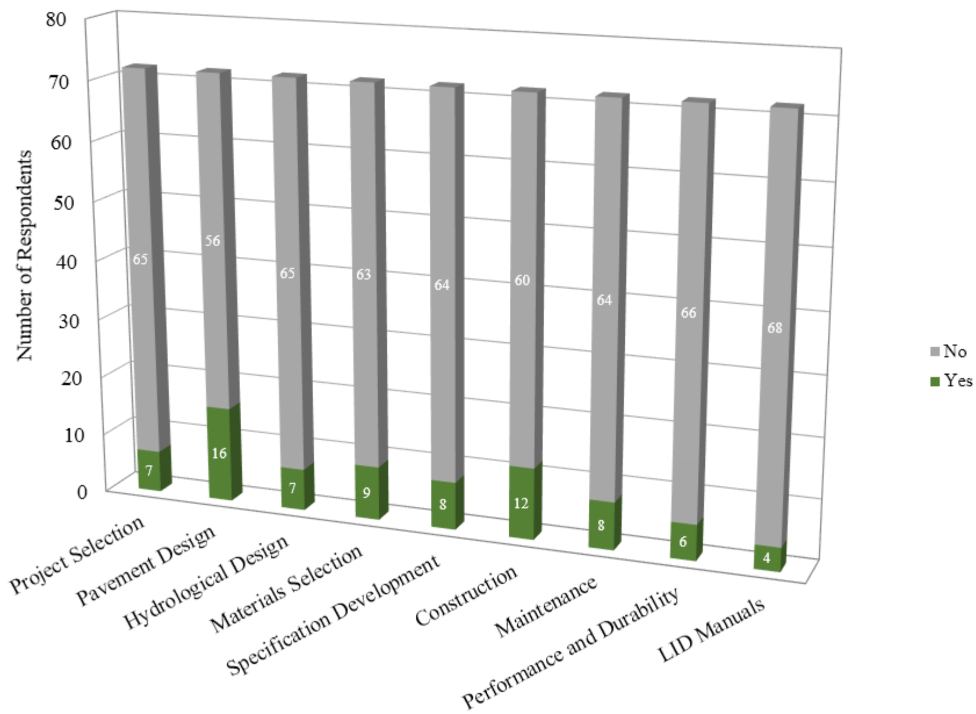

Figure 1. Summary of permeable pavement experience.

Landside:
- Roadways.
- Parking lots.
- Shoulders.
- Patios/plazas.
- Sidewalks.

Eight airside permeable pavement projects were identified through the survey, with the greatest number being shoulders (see figure 2) (Note: permeable base/subbase and porous friction course projects are not included). Two apron projects were also identified.

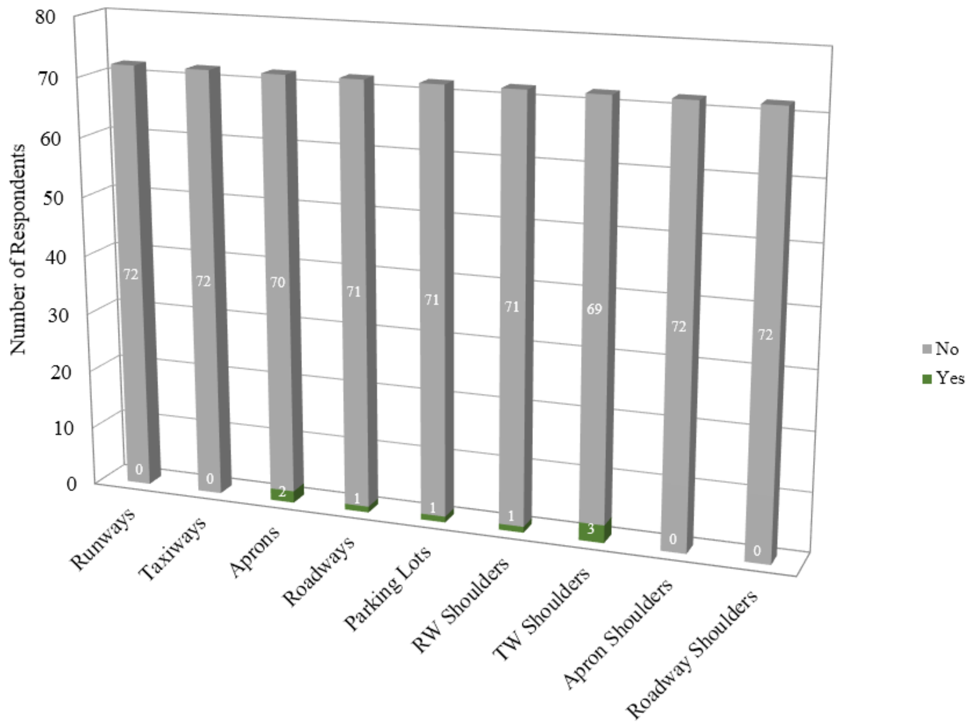

Figure 2. Summary of airside permeable pavement applications.

As summarized in figure 3, the majority of landside applications (67 percent of respondents) are parking lots. While permeable pavements have been considered by some agencies and consultants, many of the respondents decided to use conventional pavements.

If the airport was able to participate in a permeable pavement project, where would it consider applying it (please select all that apply)?

The majority of interest in future airside applications (see figure 4) are in areas that do not receive aircraft traffic or would receive limited aircraft traffic, such as parking lots, shoulders, and roadways. Only 12 percent of the respondents have interest in applications that would have aircraft loadings (runways, taxiways, and aprons), with the greatest interest being aprons. Several respondents indicated they would not use permeable pavements anywhere on the airside.

Parking lots also have the greatest level interest for landside applications, as summarized in figure 5. The use of permeable pavement for landside roadways has the lowest interest (12 percent of respondents).

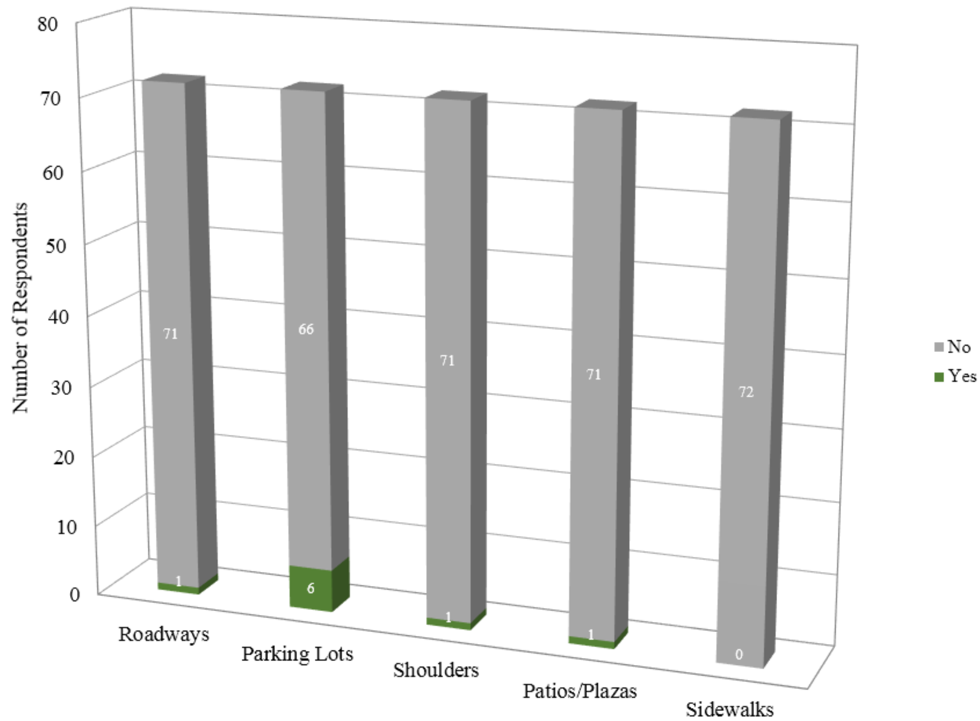

Figure 3. Summary of landside permeable pavement applications.

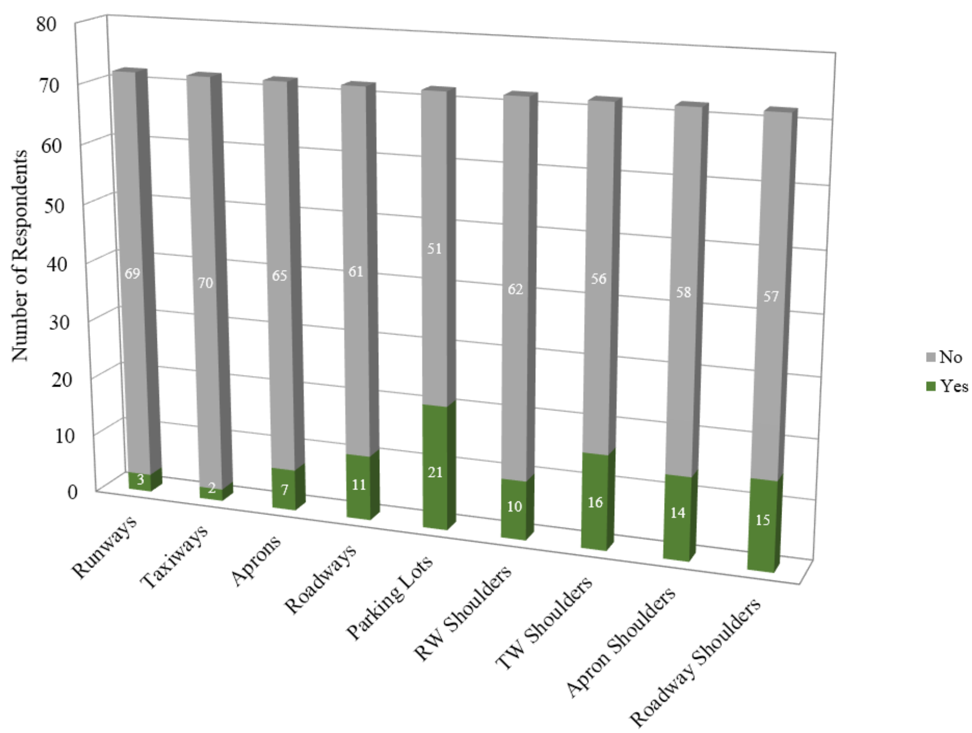

Figure 4. Summary of future airside permeable pavement interest.

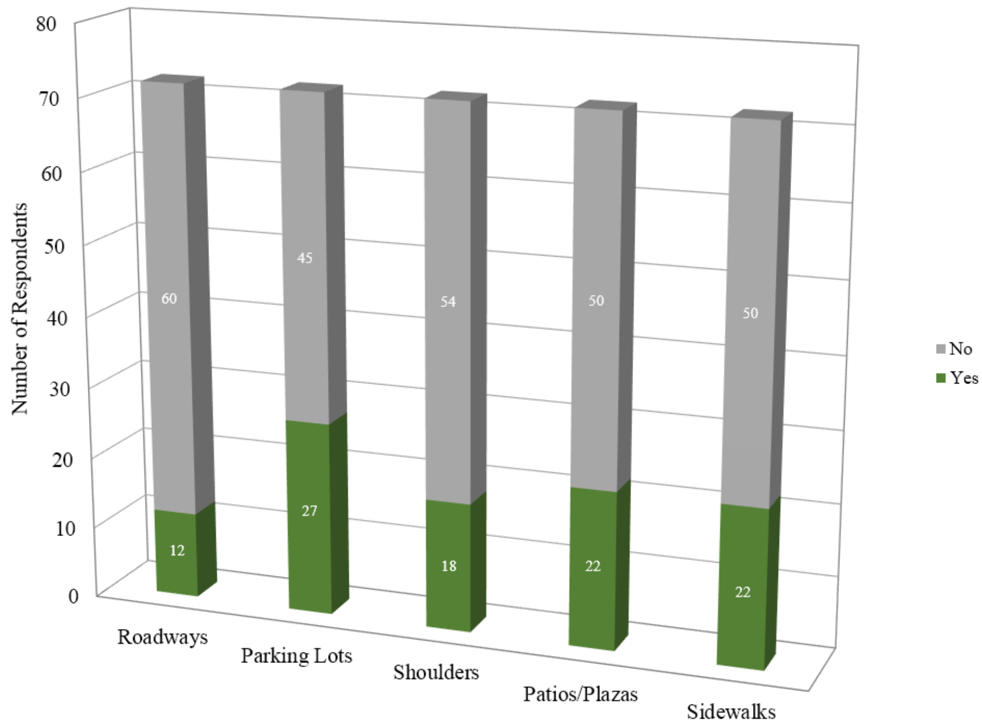

Figure 5. Summary of future landside permeable pavement interest.

Based on answers and comments received from the industry survey, the primary concerns with the use of permeable pavement are generally in the following areas:

- Low infiltration soils.
- Ability to carry aircraft loading with low risk.
- Materials durability/production of foreign object debris (FOD).
- Future maintenance to maintain permeability.
- Subgrade or groundwater contamination from spills.
- Cost of construction and available funding.

Some of these concerns are not unique to permeable pavements.

Airport Permeable Pavement Projects

Through the industry survey and literature review, several permeable pavement projects associated with airports were identified. The locations, and type of project, include the following (note: * denotes ACRP 02-64 case study locations):

- Boston Logan International Airport – Parking lot.
- Burlington International Airport – Parking lot.
- Culpeper Municipal Airport – General aviation apron.*
- Dulles International Airport – Taxiway shoulders and parking lot.

- General Mitchell International Airport – Runway shoulders.
- Los Angeles International Airport – Parking lot.
- Paine Field Airport – Industrial apron*, roadway*, and parking lot.
- Philadelphia International Airport – Parking lot.
- Richmond International Airport – Taxiway shoulders.*
- San Diego International Airport – Parking lot.
- Seattle-Tacoma International Airport – Service road.
- Stewart International Airport – Parking lot.
- Tampa Bay International Airport – Parking lot.
- Wittman Field – Taxiway shoulders and roadway shoulders.

As identified in the above list of airports that have implemented permeable pavements, the applications exposed to aircraft traffic include shoulders for runways and taxiways and aprons. Shoulders have been designed for heavier aircraft, but these areas are designed for infrequent, or even no, load applications. The aprons that have been constructed are intended for lighter loads. The Culpeper apron project also includes taxiing areas, which suggests light aircraft taxiways are potential candidates for permeable pavements. Based on the applications already implemented, other airside areas could be candidates for permeable pavements, such as overruns and taxiway islands. However, because there is no data currently available for the design or performance of permeable pavements under heavy aircraft loading, applications should be limited to shoulders for heavy aircraft areas.

Case Study Projects

Four case studies were developed for ACRP 02-64 to gain insight into the application of permeable pavement in an airport environment. Available project documentation was collected and reviewed, and interviews were conducted with persons involved with the projects. These case studies are summarized below.

Culpeper Regional Airport – Porous Asphalt Apron

Culpeper Regional Airport (Virginia) needed to expand their T-hangar and executive hangar facilities. However, the location site development (see figure 6) and available airport land did not provide sufficient space to meet stormwater detention requirements with conventional designs: land outside the airport would need to be purchased or an extensive storm drain system constructed. Although the costs for these were not determined, both options were deemed too expensive for the Airport's budget. Therefore, an alternative method of addressing stormwater statutes was needed. Campbell & Paris, the Airport's engineer, had previous experience with porous asphalt pavement and recommended its use.

The permeable pavement design was required to detain 100 percent of a 10-year design storm to reduce peak flow rates in the proposed developed conditions. The permeable pavement is designed to provide detention, rather than infiltration, due to