RESEARCH TO IDENTIFY ADVANCED ASPHALT TECHNOLOGY TO ADDRESS SHEAR DISTRESSES ON AIRSIDE FACILITIES

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ABSTRACT

Taking in to account the widespread application of asphalt pavements for airside infrastructure and the very high shear forces at airport pavements, it is critical that these forces and their affect are carefully considered during the design and construction phase of asphalt materials. This paper describes an ongoing research on shear distresses at airside facilities focused on identifying the primary factors in the pavement design and construction phases that affect the development of these distresses in the asphalt layers in airport pavements and how to address them.

Distresses related to application of high shear forces is one of major concerns associated with airfield pavements and has been observed at airports of varying sizes and in varying climates. The recent few examples are Lester B. Pearson International Airport in Toronto, Edmonton International Airport, Halifax International Airport and Quebec International Airport. These particular distressed areas may pose a significant safety hazard and are a challenge for airport operators as well as a continuous economic burden to both airport operators as well as airlines. Due to the complexity of the issue, the current pavement technology does not address it efficiently but rather focuses on short term repairs of the problems areas.

In spite of best practices in pavement structural design and construction being followed, distresses that are consistent with existence of very high horizontal and shear forces frequently occur at certain, critical locations on airside pavements (stop bars, sharp turns, rapid exits). These distresses appear to be occurring in spite of the pavement and asphalt mix being structurally adequate to accommodate vertical loads. The research goal is to identify the flexible pavement failure mechanism at high shear areas and through laboratory testing and finite element modelling to identify asphalt mix and other material adjustments that can be made to achieve pavements with sufficient shear resistance. The behaviour of the asphalt materials is being modeled using finite element methodology to evaluate its response to applied shear stresses. The model is then used to evaluate the effect of asphalt mix and materials characteristics on the shear resistance of airfield asphalt mixtures. Finally, a test or tests is being identified that can be used to evaluate the suitability of candidate asphalt mixtures based on their resistance to development of shear distress.

INTRODUCTION

Canada has a very rich history of aviation that started in 1909 with the first airplane flight in the country which was piloted by J. A. D. McCurdy and took of from Bras d'Or Lake, Baddeck Bay, Nova Scotia. The total distance flown was about a kilometre and the plane took of on and landed on frozen water. Since then, the aviation industry has developed significantly. The aircrafts, the navigation systems, the safety protocols and the airport infrastructure have changed significantly. The first airfield in Canada was Long Branch in Toronto which was built in 1915 and was operated by Curtis Flying School. In its early days and pre World War I, the Canadian government was oblivious to the importance of air travel and the role it could play in the country; however, this attitude changed both during the war and significantly after the war. From its humble beginnings in 1909 the Canadian Aviation industry has flourished to 26 airports in the National Airport System (NAS), 726 certified airports and 1,700 aerodromes. (McGrath, 1992)

A very large portion of airport infrastructure and associated expenditures are associated with the airside pavements and their continual maintenance and rehabilitation. At a minimum every airport will have one runway, a single taxiway and an apron. Generally, as the traffic at airports increases, more taxiways such as high speed exit taxiways and parallel taxiways will be added to minimize runway occupancy times. Following the addition of the taxiways and as traffic increases further, a cross wind runway and parallel runways will be added to increase the percentage of time that the aircraft departures can take place. Once additions to the taxiway and runway infrastructure have been made, only then will area to the apron and terminal buildings be added. The sequence of infrastructure improvements to accommodate increasing traffic is primarily governed by the fact that the capacity of the majority of airports is a limited by the runway capacity rather than the apron or terminal building capacity.

The largest airport in Canada is the Lester B. Pearson International Airport in Toronto (Pearson) which had a total of approximately 433,900 aircraft movements and 34,900,000 passenger movements in 2012 (GTAA, 2012). The airside pavement at the airport consists of five runways, numerous taxiways and aprons, a central deicing facility and airside roads. Of all the major airside pavements (runway and taxiways) the majority of the pavements at Pearson are constructed either as a flexible pavement or as an asphalt surfaced composite pavement. Generally, composite and concrete pavement structures at Pearson are limited to the aprons that experience very large magnitude static loads. The large proportion of asphalt surfaced airside pavements at an airport like Pearson with a very large traffic volume clearly shows the widespread use of asphalt for this application. This is further proven by the fact that 80 to 85 percent of the airfield pavements in the United States are surface with asphalt concrete.

Taking in to account the widespread application of asphalt pavements for airside infrastructure and the very high shear forces that the asphalt layers have to accommodate at some locations, it is critical that these forces and their affect are carefully considered during the design and construction phase. This research will attempt to identify the primary factors in the design and construction phases that affect the development of shear related distresses in the asphalt layers in airport pavements.

BACKGROUND

Airfield pavements experience a variety of different loading conditions depending on the designation of the facility i.e. runway, taxiway or apron. Some of the pavements that are located on the airfield may only be used by the ground support vehicle and emergency vehicles and therefore the loading on such pavements is quite similar to that experienced by highway pavement. Airside pavement can be categorized as apron, taxiways and runway. On the aprons, taxiways and runways the pavements have to accommodate the loads that are applied by a wide variety of aircrafts at varying speeds. Aprons are located directly adjacent to the terminal or hangars and in these areas the planes are either static or very slow moving. The taxiways are the paved areas that connect the aprons to the runways. The traffic on taxiways is generally slow moving and occasionally static in the holding areas. Runways are the areas where planes land and takeoff and the traffic speed ranges from very high speed to relatively slow moving.

On the runways, the type of loading varies significantly both along its length and its width. At both ends of the runway and at intersections with taxiways the majority of the braking and turning forces are being applied by aircrafts. It should be noted that the direction of traffic switches depending on the wind. The middle portion of the runway along its length generally exhibits very little load related damage, primarily because an aircraft that is taking off already begins to get lift by this section and because the impact loads applied by a landing aircraft tend to be on the outer thirds of the runway length. This outer area of the runways is often referred to as the threshold. Additionally, on the outer quarter of the runway width there is generally no aircraft loading with the exception of loading in the case of emergencies.

The loading patterns described above are critical to understanding the nature of this research. The majority of areas along an airfield pavement tend to experience a large proportion of vertical loading as is also the case with highway pavements. Therefore, all pavement design procedures, asphalt mix design methodologies and performance tests are largely focused on ensuring that the pavement can accommodate these vertical loads. The general assumption through the process is that as long as the vertical loads can be satisfactorily accommodated and that good construction practices are followed then the horizontal stresses will not result in pavement failure.

In spite of best practices in pavement structural design and construction being followed, distresses that are consistent with application of very high horizontal and shear forces have been observed at numerous airports in Canada, the United States and the Caribbean. These distresses are not localized to airports experiencing the heaviest traffic, but on the contrary have been seen at both small and medium sized airports where only a very limited number of jets (narrow and wide body) utilize the airside pavements. These distresses appear to be occurring in spite of the pavement and asphalt mix being structurally adequate to accommodate vertical loads as noted by the lack of these distresses in areas where the loading is generally compressive in nature.

The occurrence of shear distresses on localized areas of airside pavements is of considerable concern within the airport industry due to the significant safety hazard these distressed areas pose and the large economic investment that needs to be made by the airport operators in repairing these locations. The shear distresses and in particular the cracking that develops due to high shear forces has a tendency to break the pavement in to smaller strips that are easily dislodged by the continuous passage of aircrafts over these areas. Once the pieces of the asphalt pavement become dislodged there is a significant potential for the material to be sucked in to a jet engine which in turn may cause damage to the aircraft and in the worst case endanger human health and life. The loose pieces of asphalt material on the pavement surface are referred to as Foreign Object Debris (FOD) in the airport industry and FOD is of great concern to airport operators and airlines alike. The significance of FOD and its damaging capabilities are depicted by the crash of Air France Flight 4590 shortly after take-off from Charles de Gaulle International Airport. One of the primary causes of the accident was concluded to be due to the presence of FOD on the runway from a previous aircraft. The FOD on the runway ruptured the tire on the Concord, setting in to motion the fatal sequence of events.

In addition to the safety concerns stemming from the occurrence of the shear distresses, they also are a large economic burden to the airport operators and airlines. Airfield pavements have a large yearly contribution to the capital and maintenance budgets of airport operators. Therefore the operators take a particular care in ensuring that these pavements are designed and constructed to the highest standards in the pavement industry. In spite of their diligence in utilizing their capital investment, the operators have to spend a large portion of their maintenance budget in addressing areas exhibiting shear related distresses shortly after construction or rehabilitation. This additional maintenance to these newly constructed/rehabilitated pavements is often not anticipated and carried out at the expense of other areas requiring maintenance. Furthermore, the repair of areas exhibiting shear distresses can at best only be considered to be temporary. No established repair strategy in the industry, such as full depth patching, can prevent the reoccurrence of the distresses shortly after the repair is carried out. Sealing or filling of the cracks due to the high shear forces is often not possible due to the close proximity of one crack to the next. When these cracks remain unsealed they provide a location where water can get in to the pavement structure which in turn can lead to the pavement then being structurally deficient as well.

In addition to the direct maintenance cost incurred in repairing these shear distressed locations, the airport operators incur an additional economic burden by the lost revenues from having to close either runways or taxiways to carry out the repair. The closing of some of the facilities reduces the number of operations that the airport can accommodate and therefore reduces there income from landing fees.

The cost to airlines due to the presence of the shear distresses on the airfield pavement in two fold as listed below.

- The increased delays on the ground from facilities at the airport being closed for repairs results in a loss of revenue for the airlines as each aircraft is only considered to be making money when it is in the air.
- The vertical deformation of the pavement surface for the high shear forces results in increased dynamic loads being applied to the aircraft body which in turn reduces its fatigue life and increases the amount of maintenance the aircraft will require.

In the foreseeable future it is anticipated that the aircrafts coming on the market will only be larger and heavier and will be exerting higher shear stresses than has ever been applied in the past. Keeping in mind the large economic and safety impact of shear distresses, the fact that they are currently not explicitly taken in to consideration during structural or mix design and the shear stresses are only going to increase in the near future, it is high time that a method be developed to evaluate the resistance of asphalt mixtures to the shear failure. The main objective of this research is to develop a tool that can be used by practitioners in the airfield pavement industry to proactively rather than reactively address these particular distresses.

RESEARCH METHODOLOGY

It is critical to the successful completion of this research that a step wise approach be taken as the outcome from each previous step serves to provide critical information for the execution of the next step in the research. Figure 1 below shows flow chart of the methodology that will be followed during this research. This paper presents the findings of the literature review and preliminary field assessment undertaken as part of Task 1 of this research.

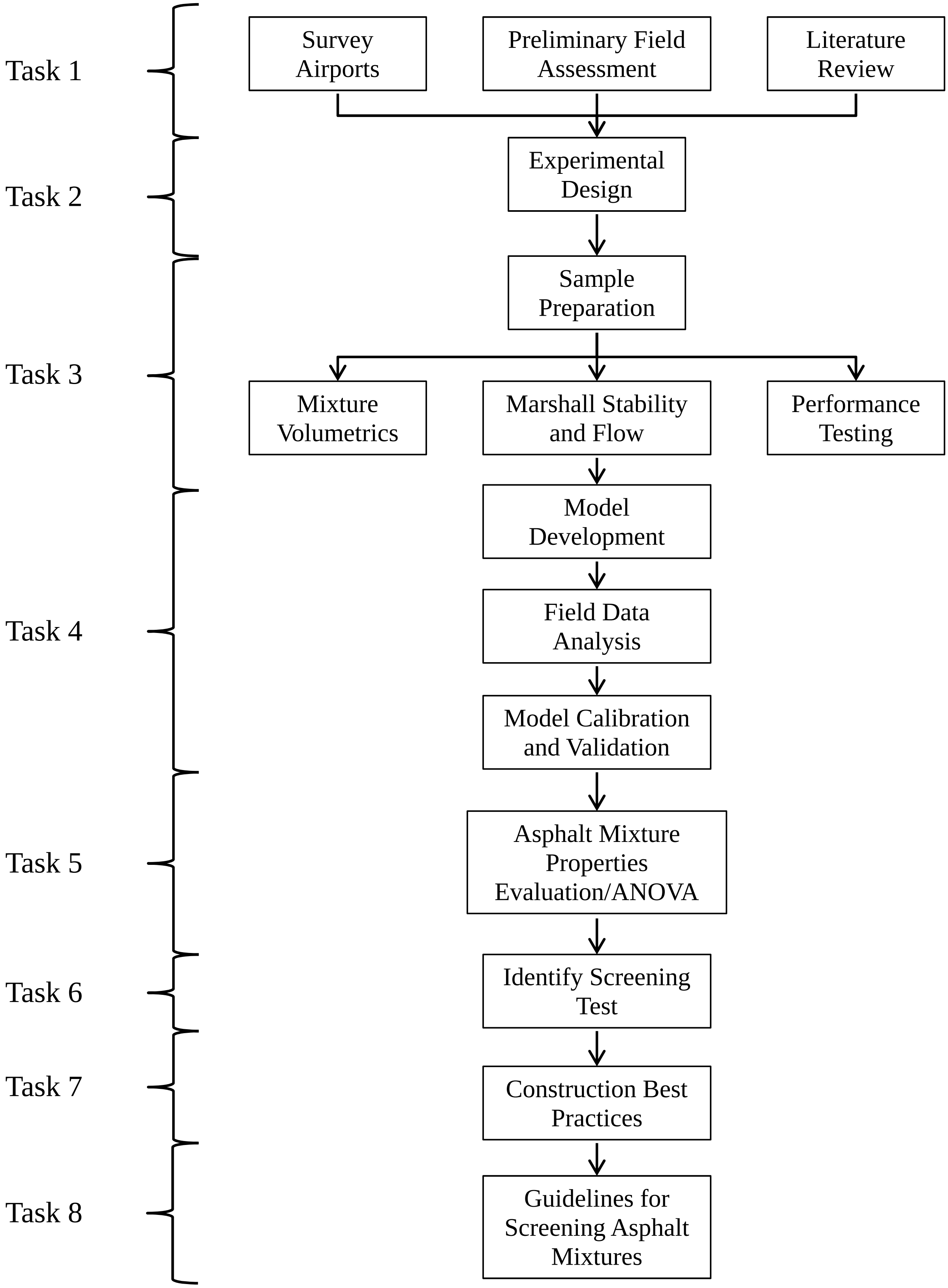

Figure 1 – Research Methodology Flowchart

AIRFIELD PAVEMENT STRUCTURAL DESIGN

The design of airfield pavements differs significantly from the design of road pavements. The primary difference in the design process comes from the differences in the traffic loading and geometry of the pavements.

In contrast to road pavement design, the design of airfield pavement is based on the types of aircrafts that are using the facility. Listed below are the primary differences between the aircraft loading and the truck loading:

- Vertical loads applied by aircrafts that contribute to pavement fatigue are much larger than those applied by truck traffic;
- Shear stresses applied by braking and turning aircrafts are significantly greater than those applied by trucks executing the same maneuvers;
- Aircraft traffic is typically a lot more channelized as compared to truck traffic;
- Tire pressures used for aircrafts are larger than those used for trucks;
- Greater variety in the types of aircrafts and their associated loading as compared to truck; and
- There has been a much greater increase in aircrafts loads in recent history as compared to truck loads.

The differences listed above lead to significant difference in the pavement design approach that is used for airfield pavement as compared to road pavements. It is important to understand the structural design methodologies used for airfield pavements and recognize that they do not consider the horizontal loads but rather only the vertical loads. The fact that airfield pavement structural design methodologies do not consider shear stresses is critical at locations where the horizontal forces applied by an aircraft are very large. At these locations although pavement may be structural adequate to accommodate the vertical loads, it may still be structurally inadequate to accommodate the horizontal loads which in turn would lead to failure of the pavement.

Transport Canada Pavement Design Methodology

In the basic pavement design theory, each type of gear type, load and tire pressure is converted to an Equivalent Single Wheel Load (ESWL) which is defined as the load applied by a single wheel that will produce the maximum normal stress that is equal to the stress resulting from the multiple wheel loading (PWGSC, 1995). The ESWL for any gear type is a function of the pavement thickness. From the definition of the ESWL it can be seen that the pavement structural design methodology only considers the vertical loads that are converted to the normal stresses using the contact area.

The ESWL is then utilized to determine the design pavement structure thickness using Equation 1 below (PWGSC, 1995).

$$\boldsymbol{S = \frac{1}{R} \times F \times ESWL \times 10^{-\frac{t}{K}}} \tag{1}$$

Where:
S is the subgrade bearing strength in kN.
R is the overload ratio as discussed below.

K and F are factors that are a function of the contact area associated with the ESWL.
t is the Equivalent Granular Thickness (EGT) as described below.
ESWL is the Equivalent Single Wheel Load.

Federal Aviation Administration Pavement Design Methodology

The design methodology developed by the FAA is more rigorous in how they characterize aircraft traffic for design as compared to the Transport Canada procedures. In the FAA procedure, for each individual aircraft a damage factor is calculated for the location of the main gear from the centreline of the pavement. Once the damage factor for each aircraft has been determined, a cumulative damage factor (CDF) is determined. The maximum allowable damage that a particular pavement structure can accommodate is determined using linear elastic theory. The stresses due to the vertical load applied to the pavement are converted to the vertical strain at the top of subgrade and horizontal strain at the bottom of asphalt layers. The methodology of incorporating traffic loading utilized in the FAA design procedure shows that similar to the Transport Canada methodology the primary loading that is considered are the vertical loads applied to the pavement. No consideration is given to the horizontal component of the load during the pavement structural design. (FAA, 2009)

AIRFIELD ASPHALT MIXES

The asphalt mixes that are used at airports differ from the mixes that are used for road pavements due to the differences in loading patterns and the environmental degradation experienced in the two applications. Listed below are the primary differences between the two applications that affect the asphalt mixes that are used:

- Much higher loads are applied by aircrafts as compared to the loads applied by trucks on road pavements;
- A larger area is exposed to the environmental effects which increases the rate of oxidation of the asphalt mix;
- Increased frictional requirements for airfield pavement to minimize stopping distance;
- Increased durability requirements for airfield pavement to minimize potential for development of FOD due to raveling; and
- Higher smoothness and overall pavement serviceability requirements.

The loading, environmental and level of service differences described above for airfield application are addressed by associated changes to the asphalt mixes utilized for this application. There are two basic mix design methods that are predominantly used for the design of asphalt mixes, namely Marshall and Superpave methodologies.

The Marshall mix design method predates the Superpave (Superior Performing Asphalt Pavement) method which was developed to address some of the issues with the Marshall method (TAC, 2013). In Canada, for road pavements the Marshall method is steadily being replaced with the Superpave design method. Comparatively, for airport pavements in Canada the asphalt mixes are designed exclusively using the Marshall method. The primary reason for the predominant use of the Marshall method of airfield pavement is the limited amount of field experience with the

Superpave method on airfield pavements. Additionally, the development of the Superpave mix design method focused on road pavement applications and therefore the traffic consideration may not be applicable for road pavements.

In spite of the limited usage of the Superpave method in the airfield pavement industry, there have been a significant number of research studies that have been dedicated to incorporating this method in to the airfield pavement industry ((Cooley, et al., 2009), (Brown, 2012), (Tighe, et al., 2003)). Although the majority of the Superpave mix design methodology is yet to gain wide spread acceptance in the airfield pavement industry, the use of performance graded asphalt cements (PGAC) as was developed within the Superpave system is exclusively used to specify asphalt cement to be used rather than the penetration or viscosity grading system. Due to the higher loads applied by aircrafts as compared to vehicular traffic, research had to be conducted for determining the appropriate PG binder to be used (Advanced Asphalt technologies, LLC, 2008).

In order to decrease the potential for oxidation and to increase the durability of the airfield asphalt mixes, they are generally designed at higher asphalt cement content and lower air void content as compared to comparable road mixes. Additionally to increase the frictional properties of the surface course mix for airfield applications, these mixes tend to be slightly coarser than surface course mixes used for roads. Also for enhanced frictional properties and increased durability, airfield asphalt mixtures are required to use aggregates with higher crushed particle content and higher resistance to polishing. In order to provide greater durability and load bearing capacity to the pavement the stability requirement for airfield mixes tends to be greater than for road mixes. It is also believed that this increased stability provides airfield asphalt mixes with an increased resistance to rutting. The asphalt cement grade used for airfield pavements is typically stiffer than road pavement to provide increased resistance to permanent deformation. Table 1 shows an example of a typical airfield asphalt mix requirements as compared to a premium road paving asphalt mix.

Table 1 – Comparison of Asphalt Mix Requirements for Airfield and Road Pavements

	Airport Surface Course Mix	**Road Paving Surface Course Mix** (MTO, 2010)
Asphalt Cement Content	Minimum 5.3 %	Minimum 5.0 %
Target Air Void Content	3.5 %	4.0 %
Minimum Stability	14 kN	12 kN
Flow	2 mm – 4 mm	Minimum 1.6
Asphalt Cement Grade	PG 70-28 Polymer Modified	PG 64-28

In general, there is some amount of reservation in using innovative technologies in airfield asphalt mixes. The primary reason or the reservation against the use of new technologies is the limited experience, minimal knowledge regarding long term field performance and the belief that the potential risk on airfield pavements in higher. Airfield pavements are generally constructed in an atmosphere of very high performance standards and under very tight timelines and budgetary restrictions. Therefore, most airport operators are unwilling to take the inherent risk that is associated with the use of the new technologies. In spite of the reservations, numerous new asphalt technologies including Warm Mix Asphalt (WMA), asphalt mixtures containing RAP and Stone Mastic Asphalt (SMA) have been researched for their potential use at airports.

SHEAR RESISTANCE OF ASPHALT MIXTURES

The shear resistance of asphalt materials is not a topic that is has being extensively researched in the past. The only context in which the shear strength for flexible pavements has been considered was the asphalt resistance to rutting and interlayer bonding.

Ullidtz in his 1987 book entitled “Pavement Analysis” provides a detailed discussion regarding the material properties of asphalt and the assumptions that are made during the structural design of asphalt pavements (Ullidtz, 1987). In assuming the asphalt materials have a linear elastic response to applied loads two of the most critical aspects of asphalt behavior that are disregarded:

- The shear modulus of asphalt (G) and the dynamic modulus (E) does not follow the relationship for ideal elastic material of E/G = 2*(1+Poisson ratio), but rather the E/G ratio was found to be as high as 6.0 (Misra , 1979); and
- Asphalt materials can be considered to be anisotropic and therefore the modulus of the material in compression is different to the material in bending and this is critical as the majority of pavement design theories utilize the modulus of asphalt determined through application of compressive loads rather than bending or shear loads.

Considering that asphalt materials are both anisotropic and are shear sensitive, assuming that these material properties are insignificant to pavement performance is not accurate. Although the simplifying assumption may result in pavement designs providing adequate performance in most applications, it likely leads to under designed asphalt layers for the applications being researched.

In a study conducted at the Shoubra Faculty of Engineering in Cairo, Egypt, the researchers concluded based on laboratory testing conducted on multiple asphalt types that both the asphalt cement content and type, and aggregate type have an impact on the shear resistance of asphalt (Abd El-Naby, et al., 2002).

In addition, research has been conducted related to the shear strength of the bond between two lifts of asphalt mix ((Vacin, et al., 2005), (West, et al., 2005), (Hachiya, et al., 1997)). The Superpave Shear Tester (SST) is a device that was developed by SHRP as part of the Superpave mix design methodology to evaluate the resistance for asphalt mixes to permanent deformation. The SST can carry out three different types of tests; namely shear at constant height, frequency sweep at constant height, simple shear at constant height, repeated shear at constant stress ratio. Although this testing equipment was developed to be used in the Superpave mix design methodology for facilities with very high traffic loading, only a very limited number of this testing device is in use and is used primarily for research applications. It is significantly less common than the performance testing devices applying compressive loads. Additionally, the susceptibility of asphalt mixtures to permanent deformation is generally determined in the industry utilizing simulative devices such as the Asphalt Pavement Analyzer (APA) rather than using the SST. (Pavement Interactive, 2008)

PAVEMENT DISTRESSES

The mode or cause of failure of a pavement determines the types of distresses that develop in the asphalt layers. This research will primarily be focused on distresses in the cracking and surface deformation categories although it is rarely the case that only one particular type of distress in observed on a pavement. For the majority of pavements although there may be a primary distress with an associated cause, a number of other secondary distresses will also be observed.

Surface deformation in the asphalt layers can be caused by both vertical and horizontal movement of the asphalt. There are a number of factors that can cause permanent deformation (rutting) of the asphalt surface, as listed below:

- Inadequate load bearing capacity of the subgrade soils;
- Densification of the asphalt mix due to inadequate compaction;
- Inadequate bond with underlying pavement layers;
- Instability of the asphalt cement in the asphalt mix; and
- Inadequate angularity and interlock between the aggregate particles in the mix.

Some of the factors above such as inadequate bond with underlying layers and densification of the asphalt layers following construction have to be accounted for during the construction phase and can generally be eliminated as potential factors by following best construction practices. The remaining two causes for surface deformation in the asphalt layers has to be addressed during the asphalt mix design stage and will be the primary focus of this research.

Cracking in asphalt pavements can be caused by a number of different factors. The type and pattern of cracking that occurs is based on the primary cause of the crack development. Slippage cracking is caused by the horizontal movement of the asphalt layers. Slippage cracks generally appear as moon shaped or horseshoe shaped cracking with end of the crack pointed in the direction of the thrust of the wheel. Slippage cracking can be caused both by an inadequate bond between the asphalt layer and the underlying layers or due to excessive deflection of the surface asphalt layer as compared to the underlying layers.

In addition to the slippage cracking shown above another type of cracking is shear cracking. Although the two types of cracks looks similar, shear cracking does not necessarily imply that the asphalt layers have debonded from the underlying layers. Additionally, shear distresses as observed in some cores samples can start both at the top and bottom of the asphalt layer.

Although it is likely that a number of the cracking types will simultaneous exist within pavement, this research project will focus on slippage cracking, its mechanism, causes, and how this type of cracking can be mitigated.

ASPHALT MIX PERFORMANCE TESTING

Although Marshall stability and flow are tests that can be used as indicators of field performance by empirical relationships, they are the only tests that are routinely required to be carried out for during the design and selection of suitable asphalt mixes. Marshall stability and flow are carried out as a part of the Marshall mix design process; however, for Superpave mixes, no such performance tests are required. Rather, the Superpave design process relies almost solely on balancing the volumetric properties of the asphalt mixture.

In spite of the fact that it is not common practice in the industry today to evaluate the field performance of an asphalt mixture in the laboratory, a number of tests exist that can be utilized for evaluating asphalt mix field performance prior to its placement in the field. The field performance tests can be grouped in to three main categories (Brown, et al., 2001):

- Tests to determine the fundamental mechanistic properties of the asphalt mixture (for example dynamic modulus);
- Empirical tests that can be used to estimate field performance e.g. Marshall stability; and
- Tests that simulate the loading patterns that are applied to the asphalt layers by traffic (for example the Hamburg Wheel Rut Tester).

Complex Modulus Testing

The two main properties of the asphalt mixture that are of concern in determining the field performance of the mixture is the modulus of the mixture and it resistance to fracture. The modulus or stress-strain relationship of an asphalt mixture is referred to as a complex modulus and it is a complex number with a component for the elastic modulus and another component for the viscous modulus.

The modulus values can be determined in a number of ways and two of the most common ways differ primarily in the loading pattern that is applied to the test samples. To determine the dynamic modulus (E*) of an asphalt sample, as per the standardized procedure described by the American Society of Testing Material (ASTM) in ASTM D3497, the sample is subjected to uniaxial compressive stress at varying frequencies (ASTM, 2003). To determine the complex shear modulus (G*) of the asphalt mixture, as per the standardized test described by the American Association of State Highway and Transportation Officials (AASHTO) in AASHTO TP7, the samples are subjected to a shear stress at varying frequencies that are applied to the bottom of the sample (AASHTO, 2013). Figure 2 depicts the loading pattern that is applied during the dynamic modulus test (left) and the loading pattern that is applied during Frequency Sweep Constant Height (FSCH) shear test (right).

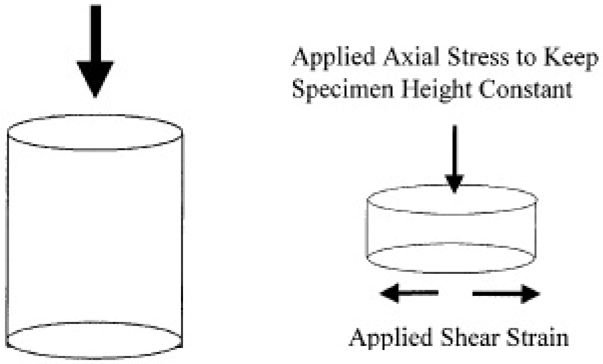

Figure 2 – Loading Pattern for Dynamic Modulus and Shear Modulus Testing

Creep Testing

The two tests that are described in the previous section do not allow for the separation of the time-dependent and time-independent portions of the strain. For a material like asphalt pavement it is critical to also gain an understanding of the time-dependent strain of the asphalt mix. The time-independent is the non-recoverable strain also non as the plastic strain and the time-dependent strain is the recoverable strain, also known as the elastic strain.

The parameter known as compliance (D) is the reciprocal of the modulus and is useful in separating the time-dependent strain from the time-independent strain (Brown, et al., 2001). The compliance versus loading time relationship for an asphalt mix can be determined by carrying out a creep test in which the asphalt sample is subjected to either one of multiple loading and unloading cycles during which the strain response of the sample is measured. The compliance of the asphalt mix can be divided in to three distinct phases based on loading time. During the primary phase the rate of strain development decreases with loading time. In the secondary phase the rate of strain development is constant with loading time and in the tertiary phase the rate of strain development increases with loading time.

The concept of the three phases of compliance for an asphalt mixture is critical to this research project. The time at which the tertiary phase begins is referred to as the flow time. For a constant volume, it is at the flow time that the shear deformation of the asphalt mixture will begin.

FINITE ELEMENT MODELLING

Currently most pavement design methods assume that an asphalt mix is a linear elastic material which allows us to obtain analytical solutions to the mathematical model that governs the response of the system. Use of FEM allows us to discretize the larger asphalt mix system into smaller elements each of which is assigned a set of material properties that govern its response. By dividing the larger system in to smaller elements a numerical solution can be obtained for the more complex mathematical models that would govern the asphalt matrix if it were assumed to be either a viscoelastic or viscoplastic material.

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PAVEMENT CONSTRUCTION PRACTICES

Good construction practices are critical to achieving the desired pavement performance. Numerous texts are available within the industry and training courses that detail the good construction practices that should be followed to ensure that the final product meets the assumptions that were made during the pavement design process ((Epps, et al., 1991), (AI, 1998)). In addition to the general best practices that are recommended for all asphalt pavement construction, research has also been conducted by Auburn University to identify best construction practices that are specific for airfield asphalt pavements (Brown, et al., 2008).

Listed below are some of the construction best practices that should be followed to ensure that the asphalt pavement has maximum resistance to shear distresses.

- Existing asphalt surface should be thoroughly cleaned and any dust, debris and slurry from traffic or milling operation should be completely removed;
- Tack coat should be applied to existing asphalt surfaces after they are completely cleaned and the tack coat should be an emulsified asphalt.
- The tack coat should be allowed to cure prior to placement on any new asphalt and it should be ensured that any and all tack coat that appears to be ponding is removed before asphalt placement;
- If asphalt is being placed on an existing concrete pavement or on a cement treated base (CTB) the surface of the concrete or CTB should be scratched to produce more texture followed by application of tack coat; and
- The new asphalt material should be properly placed and compacted to avoid any bumps and segregation and to meet the required compaction limits included in the specification.

PRELIMINARY FIELD ASSESSMENT

Based on a preliminary field assessment as part of this research, it has been observed that similar distresses related to high shear forces have been seen at airports ranging in size from large international airports accommodating wide body jet aircraft to small regional airports accommodating only narrow body regional jets and turbo-propeller planes. During the course of the research some of the airports where shear related distresses have been observed include Edmonton International Airport, Lester B. Pearson International Airport and Turks and Caicos Island Airport. Also through discussions with the FAA it has been identified that similar shear related distresses have been observed at multiple airports in the United States, for example and Newark Airport in New Jersey.

The distresses that were observed at Edmonton International Airport included shoving, shear cracking and vertical deformation. The distresses were noted primarily at the intersection between one particular taxiway and the runway. The distresses were not observed at the intersection between the other taxiways and the same runway. Based on discussion with the airport authorities and review of existing information, it is understood that all the aircrafts that enter the runway for takeoff do so at the taxiway/runway intersection where the distresses were observed. On the other hand, the aircraft leaving the runway after landing tend to leave exit on the other taxiways. Based on this observation it can be concluded that the shear distresses are primarily caused by the braking and turning action of fully loaded aircrafts prior to taking-off. The same movements of an aircraft that has just landed and burned the majority of its fuel does not cause the same magnitude of damage.

Figure 3 shows an example of the shear cracking and shoving that was observed at Edmonton Airport. The shear cracking is evident in the middle of the photograph. The shoving was noted by the horizontal moving of the crack sealant that was applied to the joints that were sawcut in to the asphalt layers directly over the top of the joint in the concrete base. From the photograph below it can be seen that the original joint that would have been cut relatively straight has moved quite significantly due to the high shear forces applied by turning aircrafts.

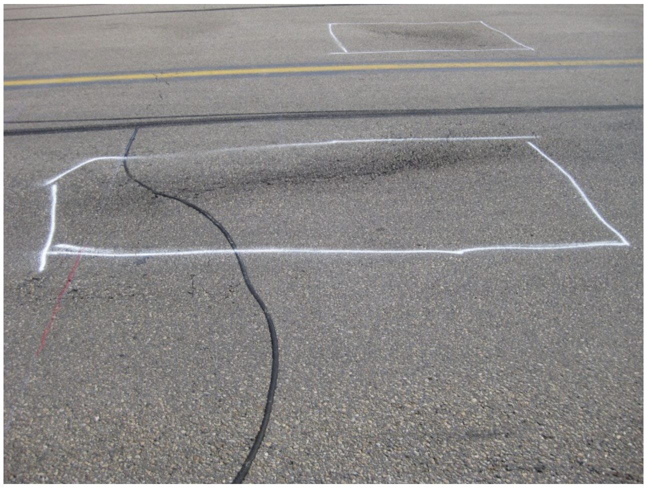

Figure 3 – Shear Cracking and Shoving on Runway at Edmonton International Airport

EXPECTED CONTRIBUTION

The airfield pavement industry is very different than the road pavement industry in terms of both loading, the required level of service and the expectation regarding safety. In spite of the significant economic position and contribution of the aviation industry, the majority of the pavement research and advancements have been focused on pavements for roadway applications. The primary reason for the relative stagnation of the airfield asphalt pavement industry is the hesitation to move away from something that has worked relatively well in past, in spite of some of its short comings, due to the risks involved. This research will be focused on addressing one of the significant short comings within the asphalt technology that is currently used for airfield pavements.

Distresses related to very high shear forces that are exerted on the localized areas of airfield pavements pose a significant safety hazard and economic burden to the airport operators and airlines. In spite of its safety and economic impact these shear forces are not considered during the pavement structural design or the asphalt mix design stages for airfield pavement. In both stages it is only the compressive or vertical loads applied by aircrafts that are explicitly taken in consideration. The primary assumption being made during the pavement design process is that if the structural design and asphalt mix design can accommodate the vertical loads they will perform adequately under the applied horizontal loads. Although this assumption may hold true for some areas of airfield pavements, it is clear that this is in fact not the case for other locations where shear related distresses begin to appear shortly after the pavement is constructed.

Some of the distresses that are observed in areas with extremely high shear forces include cracking vertical deformation and shoving. The cracking in the pavement poses a significant safety hazard as it can lead to development of FOD which as a best case can cause significant damage to an airplane and as a worst case can lead to a fatal accident. The primary economic burden to the airport operators is in the repeated repairs that need to be carried out at these locations as there is no established way that these areas can be permanently repaired. Generally, it can be expected that any repair of these areas will only last a relatively short period of time and will need to be redone continuously through the pavement design life. The repeated closures of facilities that are required to carry out the repair incur an additional cost to the airport operators as it limits that number of operations that the airport can accommodate.

The shear related distresses are also economically damaging to the airlines as the vertical deformations results in additional dynamic forces on the aircraft body which reduces and fatigue life and increases maintenance requirements. Facilities closures for repairs also may increase ground delays for aircraft resulting in lost revenues for the airlines.

Although such distresses have been observed at airports of all sizes and they have such a significant impact on the industry, no effort has been made to address proactively address the cause of these distresses. The approach used to date has largely been reactive with all repair strategies having a very short term life. The primary purpose of this research will be to develop a tool that can be used by pavement and asphalt mix designers to provide airport operators with an asphalt technology that will have provide superior performance in high shear airfield pavement areas.

The research will identify the primary causes and locations of shear distresses observed in asphalt layers in airfield pavements. The asphalt materials will be modeled to evaluate its response to applied shear stresses. The model will then be used to evaluate the effect of asphalt cement grade, aggregate angularity and coarse aggregate proportion on the shear resistance of airfield asphalt mixtures. Finally, a test will be identified that can be used to evaluate the suitability of candidate asphalt mixtures based on their resistance to development of shear distresses.

The overall contribution of this research will be to provide the industry with a guidance document that can be used by pavement designers for designing and selecting asphalt mixtures that will provide desired performance in areas where aircrafts are applying high shear stresses.
It is anticipated that the research findings if implemented will enhance the safety of asphalt pavements in these critical airfield pavement areas. The use of superior asphalt technology can

reduce the economic burden imposed on airport operators if they select asphalt material for these high shear areas. Additionally, the airlines will also be expected to benefit economically from the findings of this research.

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