Developing Shear Resistant Asphalt Mixes for Roundabout Pavements

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ABSTRACT

On roads that carry heavy traffic and where higher speed is allowed on the roundabout, conventional mixes may not work well. In the roundabout approach zone the forces due to braking can be very significant. On the roundabout itself, shear stress due to centrifugal forces can be high and regular asphalt mixes may not be able to cope with them. The pavements may shove in the roundabout approach zone and deform and shove and crack within the roundabout. Frequent maintenance including emergency repairs may be required. Frictional characteristics of the pavement in the approach zone can also be of concern.

The asphalt mixes to be used at roundabouts should offer better resistance to horizontal shear force than those used in other conventional roadway applications. Unfortunately, the shear resistance testing method for asphalt mixtures is limited in both laboratory and field work. An advanced asphalt technology developed for race track pavement appears to address high shear stresses successfully. A team including the University of Waterloo, Greater Toronto Airport Authority (GTAA) and Golder Associates Ltd. is carrying out a research project on evaluating airport asphalt mixes that can offer superior shear resistance. At minimum, the team will use a Uniaxial Shear Tester (UST).

The above mentioned research is focused on optimizing three main components that impact shear resistance: characteristics of asphalt cement; gradation of aggregates; and aggregate angularity. At the same time the mix is also required to offer good frictional characteristics. It is anticipated that as the results of this research, a mix design procedure can be developed that will allow the design of cost effective asphalt mixes that will offer superior shear resistance which could be beneficial to the performance of pavements at roundabouts.

1.0 INTRODUCTION

Roundabouts are used in many municipalities and cities in Canada. Typically, conventional asphalt mixes are used on roundabout pavements. On low volume and low speed applications, these mixes can likely provide satisfactory performance. However, on roads that carry heavy traffic, and when higher speeds are allowed on the roundabout and in the approach zone, conventional mixes may not work well.

Typical structural design of a pavement takes into account only vertical load application on the pavement from passing traffic. In the roundabout approach zone the forces due to braking can be very significant. Within the roundabout turning circle, on the other hand, shear stress due to centrifugal forces can be high and regular asphalt mixes may not be able to cope with them. There are known examples from the field that are discussed in this paper, where pavements shove in the roundabout approach zone and deform and shove and crack within the roundabout turning circle. Frequent maintenance including emergency repairs may be required. There can also be a concern with frictional characteristics of the pavement in the approach zone.

The asphalt mixes to be used at roundabouts should offer better resistance to horizontal shear force than those used in conventional applications. Unfortunately, shear resistance testing methods for asphalt mixes is limited, in both laboratory and field applications. A device that can be used for this type of testing in the laboratory is the Superpave Shear Tester (SST). The Repeated Shear at Constant Height (RSCH) test and the Simple Shear at Constant Height (SSCH) test can be used in the SST. However, there are only a few SST units available and all of which arelocated within the United States. Additionally, currently the units that are available are used minimally and the testing is primarily carried out for research purposes.

A team including University of Waterloo, Greater Toronto Airport Authority (GTAA) and Golder Associates Ltd. (Golder) is carrying out research on asphalt mixes that can offer superior shear resistance. The team will use a Uniaxial Shear Tester (UST) to evaluate and characterize the shear resistance of asphalt mixes. Research and field applications have been completed regarding the development of advanced asphalt technology race track pavements that has addressed high shear stresses successfully in this application. Also, there are mixes being used in Europe that incorporate epoxy binder and synthetic aggregates that can offer excellent shear resistance and frictional characteristics. However, the price of these European mixes is very high, which would make them prohibitive for more common applications.

The above mentioned research is focused on optimizing three main components that impact shear resistance, as follows

- Characteristics of asphalt cement;
- Gradation of aggregates; and
- Aggregate angularity.

Other parameters will also be analyzed during the research, as required. It is anticipated that the practical experience from race track pavements and the results of the airport focused research will lead to the development of a mix design procedure can be used to design cost effective asphalt mixes that will offer the performance needed in roundabout applications.

2.0 PAVEMENTS AT ROUNDABOUTS

The typical geometry of roundabouts in Ontario is shown in Figure 1. The roundabout shown in the figure was recently constructed by the Regional Municipality of Waterloo in Cambridge, Ontario. Since the radius of the roundabout is relatively small the anticipated centrifugal forces are high. Also, due to braking at the stop bar in the approach zone, the horizontal forces in this area are expected to be high. Good friction is required, particularly before the stop bar.

The high horizontal forces may cause pavement distresses such as shoving, cracking, slippage and ravelling. Figures 2 and 3 show typical distresses observed in asphalt pavements at another roundabout in Ontario.

Similar pavement distresses have been observed by Golder on race track pavements, particularly at sharp turns. Also, the shoving, cracking and slippage distresses due to high horizontal forces and resulting shear stresses were observed on numerous airport pavements. The critical locations are shown in Figure 4. The shear distresses are observed at the critical locations primarily due to departing aircrafts braking at taxiway hold lines; fully loaded aircrafts turning from taxiways onto runways; and fully loaded aircrafts turning at runway threshold. Figures 5 and 6 show examples of shoving and cracking distresses on airfield pavements.

3.0 LITERATURE REVIEW

A literature review was undertaken to evaluate the methods used previously to address the issues associated with the application of high shear stresses on asphalt pavements. Based on our literature review, we noted that the shear resistance of asphalt mixes is not a topic that has been extensively researched in the past. Typically, the only context in which shear strength for flexible pavements has been considered was the asphalt resistance to rutting and interlayer bonding.

The Superpave Shear Tester (SST) [1, 2] is a device that was developed by the Strategic Highway Research Program (SHRP), as part of the Superpave mix design methodology, to evaluate the resistance of mixes to permanent deformation. The SST can be used to carry out a variety of different tests: shear at constant height; frequency sweep at constant height; simple shear at constant height; and repeated shear at constant stress ratio. Although the SST was developed to be used in the Superpave mix design methodology, only a very limited number of these testing devices are in use today, and primarily only for research applications.

In the recently published paper "Uniaxial Shear Tester – Test Method for Determine Shear Properties of Asphalt Mixtures" [3] a new piece of equipment called a Uniaxial Shear Tester (UST) was identified as a relatively cost efficient piece of equipment that can be used to carry out similar tests as those carried out by the SST. Good correlations have been observed between the UST and SST results. The University of Waterloo, GTAA and Golder team is purchasing a UST and will carry out the shear resistance testing of the asphalt mixes that are being evaluated in our research regarding superior performing airfield asphalt mixes. The UST is shown in Figure 7.

4.0 ASPHALT MIXES FOR ROUNDABOUT PAVEMENTS

In a great majority of cases, road and other pavements are designed for vertical loadings only. Also, asphalt mixes in conventional mix design procedures such as Marshall or Superpave, are designed only for vertical loadings and typically are not able to cope with high shear stresses.

There are mixes used in Europe that incorporate epoxy binder and synthetic aggregates that can offer excellent shear resistance and frictional characteristics. However the price for such mixes is high, and this would make them cost prohibitive for many common applications. Therefore, it is important that the currently used technology is improved to deal with more challenging conditions, including roundabout pavements.

Golder has developed a mix design procedure for a race track in Ontario. Horizontal stresses applied to the pavement on race tracks are extremely high. Serious asphalt pavement deterioration was observed at Mosport Race Track in Bowmanville, Ontario a few years ago. It is a Formula One Track where the speed of the race cars is very high. A number of the turns are very sharp, some close to 180 degrees. It was observed that the distresses at these turns primarily included severe shoving, cracking and raveling due to high centrifugal forces. Conventional asphalt mixes or concrete surfacing, that was newly placed, failed within a short period of time, sometimes as short as a few weeks.

Golder completed an extensive literature review, stress analysis, and advanced laboratory testing regarding asphalt mixes for race track applications. As a result, an innovative asphalt technology was developed to address the observed issues. It included advanced modification and testing of asphalt binder, incorporating high quality aggregates, including specifying required gradations and physical characteristics, and a mix design procedure that included advanced mechanistic performance testing. The testing required to be carried out on the asphalt mix included rutting resistance and cracking endurance. The Cantabro Loss Test, Texas DOT designation: TEX-242-F was used to evaluate the durability of the mix. The gradation of the mix was fine tuned to provide good macrotexture and frictional characteristics. As a final result, a specification for the race track asphalt pavement was developed. However, during the completion of that assignment, the resistance of the asphalt mix to shear stresses was not able to be directly tested.

The main Formula One Race Track at Mosport was paved in July 2013, using a mix design developed from the technology discussed above. Figures 8 and 9 show the track after paving and in use during a race, respectively. The part of the pavement paved in 2013 is in very good condition. The drivers praise the new pavement not only for the improved ride quality, comfort and safety, but also because they were able to reduce the race time for a loop.

The excellent performance of the innovative race track pavement technology encouraged Golder to investigate other opportunities of using the mix that offers superior resistance to cracking, raveling and shoving. The current primary focus of the research is for airfield pavement application. A team that includes University of Waterloo, GTAA and Golder is carrying out research on airfield mixes that will deal with the observed shear related distresses.

The asphalt mixes to be used at airfields should offer better resistance to horizontal shear force. Unfortunately, the shear resistance testing is not included in the traditional Marshall or Superpave mix design methodologies during the laboratory testing phase. Also, there is no commonly used field test for shear strength evaluation. The Repeated Shear at Constant Height (RSCH) test and the Simple Shear at Constant Height (SSCH) tests were defined as the ones to be used in the investigation of the shear resistance of asphalt mixes. The UST device mentioned in Section 3 of this paper will be used for this testing during our research for airfield asphalt mixes, as a reasonable alternative for the SST.

The above mentioned research is focused on optimizing three main components that impact shear resistance: characteristics of asphalt cement; gradation of aggregates; and aggregate angularity. Other parameters will also be analysed including asphalt mix durability. The research is ongoing. It is anticipated that as the results of this research, a mix design procedure will be developed that will allow the design of cost effective asphalt mixes that will offer required performance at roundabouts.

5.0 SUMMARY

Asphalt pavements at race tracks experience very high shear stresses at sharp turns. The distresses often observed at those locations include severe shoving, cracking and slippage. Conventional asphalt mix design methodologies deal with vertical loading only and are not able to address the observed issues. An innovative asphalt mix design procedure was developed that successfully addressed the observed distresses.

Successful application of race track asphalt technology encouraged the investigation of other applications of the methodology that addresses very high shear distresses applied to asphalt pavements. These applications include heavily loaded airfield pavement and asphalt pavements at roundabouts. A team of University of Waterloo, GTAA and Golder Associates carries out a research of identifying the characteristics of the mix that control its resistance to shear. The investigated testing includes the use of Uniaxial Shear Tester.

6.0 REFERENCES

1. **AASHTO, American Association of State Highway and Transportation Officials, 2013.** Standard Test Method for Determining the Permanent Deformation and Fatigue Cracking Characteristics of Hot Mix Asphalt, (HMA) Using the Simple Shear Tester (SST) Device. 33rd Edition, 2013. ISBN: 1-56051-565-4.

2. **Abd El-Naby, R.M., Abd Al-Aleem, A.M. and Saber , S.H. 2002.** Evaluation of the Shear Strength of Asphalt Concrete Mixes: Experimental Investigation. Annual Conference of the Canadian Society of Civil Engineering, Montreal, Quebec: s.n., June 2002.

3. **Josef Zak, Carl L. Monismith, Erden Coleri, John T. Harvey. 2017.** "Uniaxial Shear Tester – Test Method to Determine Shear Properties of Asphalt Mixtures", 2013.

FIGURES

Figure 1. Roundabout constructed in the Regional Municipality of Waterloo in Ontario.

Figure 2. Example of distresses of asphalt pavement at roundabouts.

Figure 3. Example of distresses of asphalt pavement at a roundabout. Asphalt shoving, cracking and slippage are clearly visible.

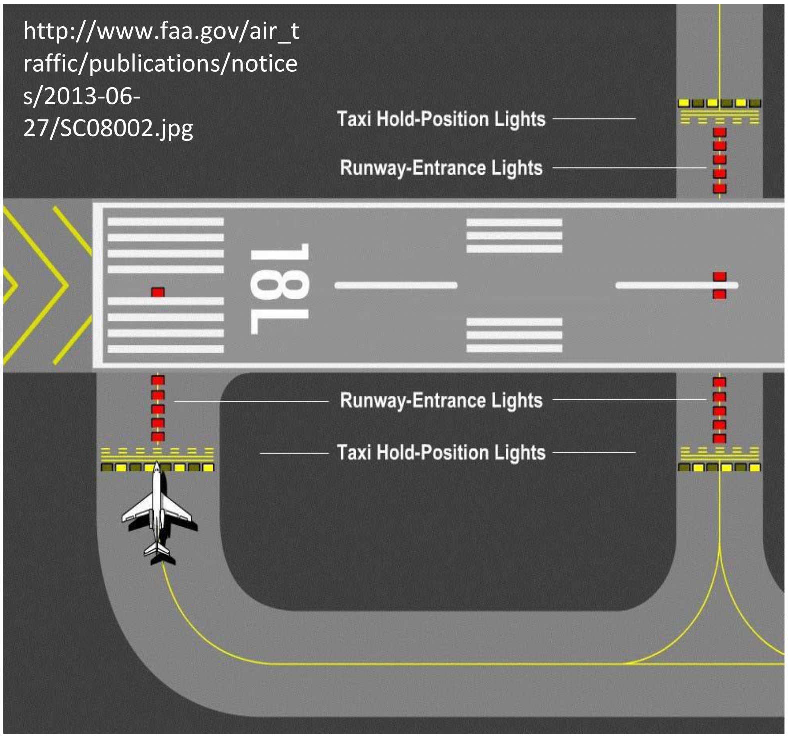

Figure 4. Locations where shear distresses (shoving, cracking and slippage) typically occur on airfield pavements.

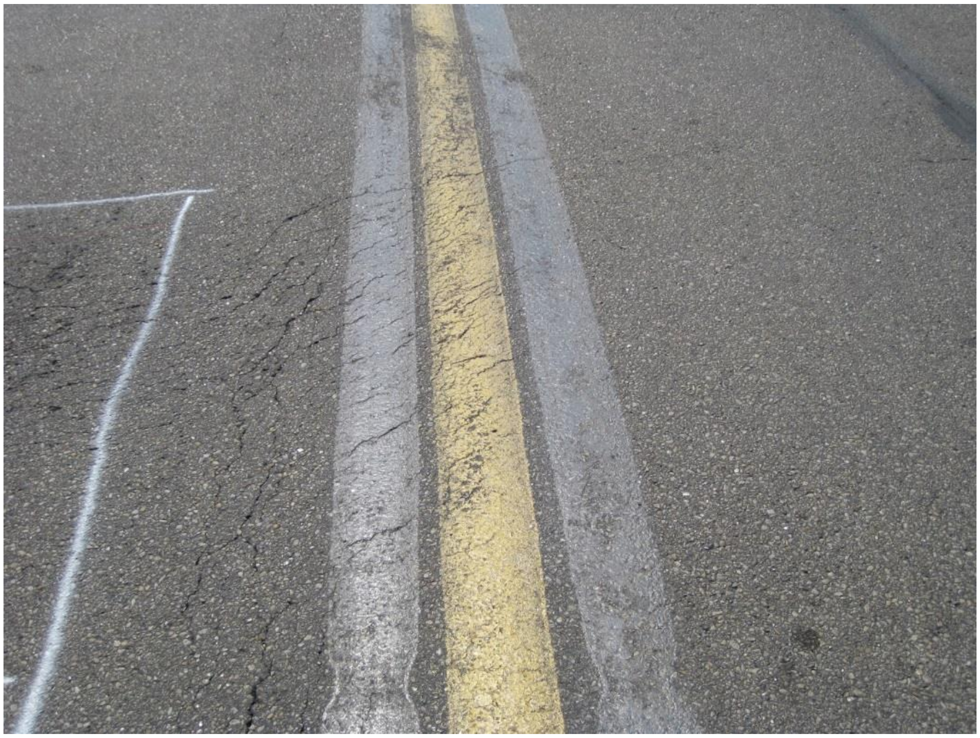

Figure 5. Example of airfield pavement shoving, cracking and slippage.

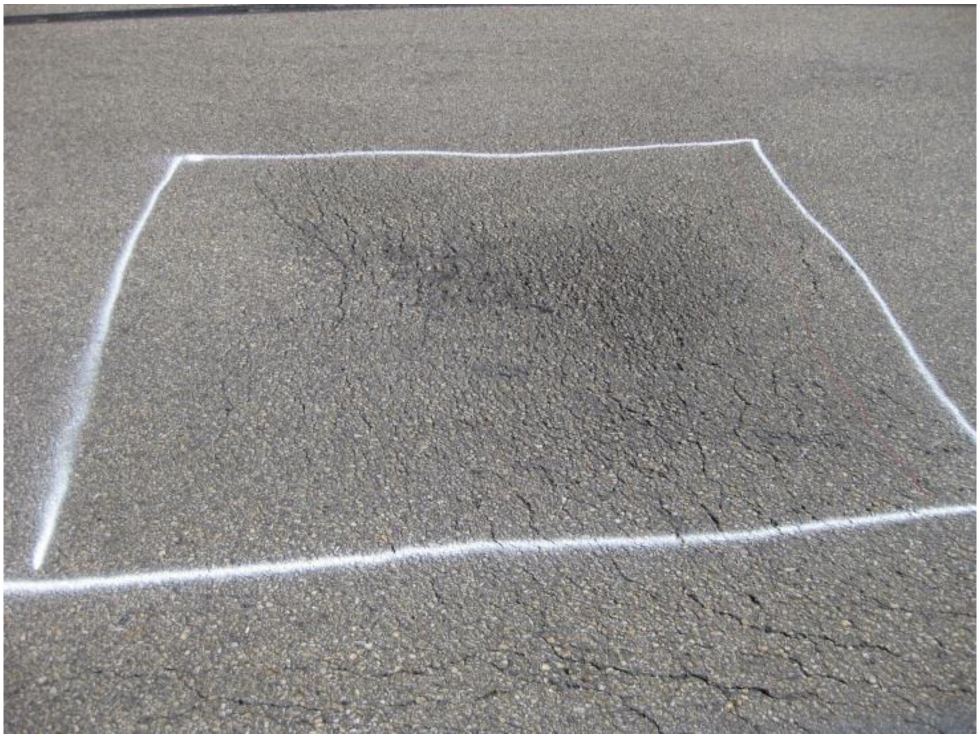

Figure 6. Example of airfield asphalt pavement severe shoving.

Figure 7. The Uniaxial Shear Tester.

Figure 8. Advanced asphalt pavement placed on Mosport Race Track in 2013.

Figure 9. A race car on the asphalt pavement placed at Mosport Race Track in 2013. The pavement is in very good condition.