High Strain Asphalt Interlayers Using Aramid Polymer Fibres to Mitigate Reflective Cracking in Asphalt Pavements

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ABSTRACT

Reflective cracking continues to be a concern for pavement materials and design practitioners for overlays on asphalt and primarily concrete pavements. Over the years, various materials and techniques have been used to mitigate reflective cracks to varying degree of success. Stress Absorbing Membrane Interlayers (SAMI'S) have been used as a practical method to retard reflective cracking on pavements that have adequate structural support since the early 1970's. Other products have shown mixed results in their ability to retard cracking. Improvements in materials (i.e., mostly the use of polymers) saw the development of engineered asphalt interlayers the 1990's. This was the introduction of performance-based specifications based on the four-point flexural beam fatigue test to control reflective cracking. These systems were designed to be relatively impermeable with high asphalt content (typically >8 %) and low air voids (2-3%) and were placed 25 mm thick with a 4.75 mm nominal aggregate size. The overall early performance of this technique also varied to some degree mostly to due climate and availability of appropriate material.

Research continued and by 2006 consistent performance of the high-polymer design improved significantly with a performance-based specification. Koch Materials Company reported an average of 71% improvement in reflection cracking resistance on their high polymer, performance-designed interlayer projects as compared to control sections measured on 18 projects built with control sections that were up to 4 years old. Increased cracking resistance was documented with the addition of a complementary crack-resistant overlay. The advancement of high-strain asphalt interlayers continues, and ongoing research clearly shows that the use of interlayers has become a common method to reduce reflective cracking. This research has also advanced the use of newer and alternative cracking tests (e.g., IDEAL-CT, SCB-IFIT and DCT) for design and acceptance.

More recently, the application of aramid polymer fibres has been successfully used as a viable and local alternative. This paper discusses the design of the high-strain asphalt interlayer using the aramid polymer fibre reinforcement and the associated performance testing based on IDEAL-CT testing. A 2019 case study is presented to illustrate the ease of design, production and laydown of this advanced material that essentially uses locally available materials and generic performance-based specifications.

Keywords: aramid, overlay, interlayer, polymer modified, crack resistance, reflective cracking, SAMI

OBJECTIVE

The objective of this paper is to provide a brief history on the development and field performance of the high-strain asphalt reflective crack relief interlayer (RCRI) along with innovative developments in the RCRI technology using aramid fibre and newer test approaches (balanced mixture design) and tests such as the indirect tensile test (IDEAL CT) using ASTM D8225 coupled with a rutting test such as the Hamburg Wheel Tracker (AASHTO T324), all with climate adjusted test temperatures.

PARA-ARAMID FIBRES IN ASPHALT MIXTURES

The addition of fibre additives to asphalt mixtures has been practiced for many years and is well documented by McDaniel in NCHRP Synthesis 475 [1]. Natural, mineral, and synthetic fibres of different types have been added to improve various aspects of the performance of asphalt mixtures. Cellulose fibre is used widely to reduce drain down of asphalt cement in coarse graded asphalt mixes (SMA and OGFC), but this material is not acting in a manner to reinforce the asphalt mix. Synthetic or engineered fibres have been used to improve the mechanical properties of asphalt mixtures as it relates to rutting, cracking, modulus, and fatigue performance. Asphalt mixtures made using these synthetic fibres are referred to as fibre reinforced asphalt pavements (FRAP).

Numerous studies [1], [2] have shown that adding synthetic polymer fibres to asphalt mixes can improve their mechanical performance. One of these fibres, aromatic polyamide, is proving to be superior as a reinforcing fibre due to a high strength-to-low-strain ratio, resistance to heat, and polymer-like performance. Aromatic polyamides, or aramids, are a class of synthetic fibres that are heat resistant and strong. Aramids are used in many industries as a replacement to steel and asbestos. Aramids can be used to manufacture high tensile strength and heat resistant fabrics that are used in ballistic protection, thermal protection, and marine applications. As a synthetic fibre, the production of aramid can be manipulated to create specific properties for end use application. Meta-aramids are typically used for heat resistant applications, such as thermal protective clothing, electrical insulation and as a replacement to asbestos. Para-aramids are used in applications where strength and heat resistance are required [3].

Para-aramid has been used to reinforce asphalt mixes for the following reasons:

1. Non-absorptive to asphalt cement
2. High tensile strength (>2750 MPa)
3. High melting temperature (>425°C)
4. High modulus

Para-aramid fibre reinforced asphalt pavements were introduced into Canada in the early 2010’s in Quebec. The Ministère des Transports (Québec) and various municipalities in Quebec started trial projects in 2012 (A20 Saint-Jean-Port-Joli) [4] and 2013 (R227 Marieville, Route Marie Victorin, La Prairie) [5].

Prior to 2016, para-aramid dry polymer fibres treated with the addition of polypropylene and polyethylene fibres were used. These projects used a combination of 65g/t (0.0065%) of para-aramid fibres and 435g/t (0.044%) of polypropylene and polyethylene fibres. The use of this technology in Canada appears to have been sporadic, with some projects in Quebec, Ontario, and British Columbia.

Para-aramid fibre treated with Sasobit® wax was introduced to Canada in 2016 [6]. The first project paved using this combination of materials was completed in 2017 in the District of North Vancouver, on a portion of Mountain Highway in Lynn Valley. As of Spring 2021, there was no observed cracking of the aramid fibre reinforced section of road.

Use of aramid fibre reinforced pavements started to increase in 2017, with the Ontario Ministry of Transportation, and municipalities in British Columbia, Ontario and Saskatchewan running trial projects. In 2018, the Ministries of Transportation in BC, ON and SK used para-aramid fibre reinforced asphalt pavements on bus stop and bus loop projects; asphalt overlays over concrete pavements; and a low volume rural highway. Municipalities in Alberta, British Columbia, Manitoba, Northwest Territories, Ontario, and Saskatchewan began trialing the technology on urban road projects.

BACKGROUND

It is well known that the Superpave mix design system does not address reflective cracking in flexible or composite pavements. A typical treatment for restoring deteriorating Portland Cement Concrete (PCC) and asphalt concrete (AC) pavements is the use of AC overlays. Overlays are needed to protect the existing pavement structure and provide a new, smoother, skid resistant riding surface. According to the American Society of Civil Engineers (ASCE) 2021 report card, the U.S. highway system has been underfunded, resulting in $786 billion backlog of road and bridge capital needs. The bulk of the backlog ($435 billion) is in repairing existing roads [7].

The solution to rehabilitate the pavement is not easy. PCC is a rigid pavement while asphalt concrete is a flexible pavement. This mismatch of modulus (strengths) results in cracks forming in the asphalt concrete because of the underlying concrete pavement joints. The cracks are commonly called reflective cracks or reflective cracking as shown in Fig - 1. Reflective cracks usually begin to appear in the asphalt concrete surface (overlay) within one or two years depending on the thickness of the overlay [8]. It is common to see all cracks reflect through the new overlay in three to five years. It is common to see cracks re-appear at a rate of 25% per year after the first year. As a rule of thumb, it is commonly said, "cracks move upward at about one inch per year."

Asphalt rubber interlayers, fabrics [9], geogrids, and more recently aramid fibre have been used to address reflective cracking. An Army Corp of Engineers Study concluded that while some of the methods work well over flexible pavements in warm climates, the performance has been generally unsatisfactory in cold climates, and the use of asphalt rubber membranes is not effective over PCC in any climate [9]. Most of the existing reflective crack relief methods and their specifications mainly address tension, that is controlling the horizontal movement at the crack or joint interface [10]. There are three forces that need to be addressed: horizontal non-load movement (tension), vertical (shear) load induced movements, and bending or parallel movement under laterally unstable conditions [11]. The shear movement is usually the movement that causes the quickest reflective cracks. This movement is caused by lack of load transfer in the PCC joint.

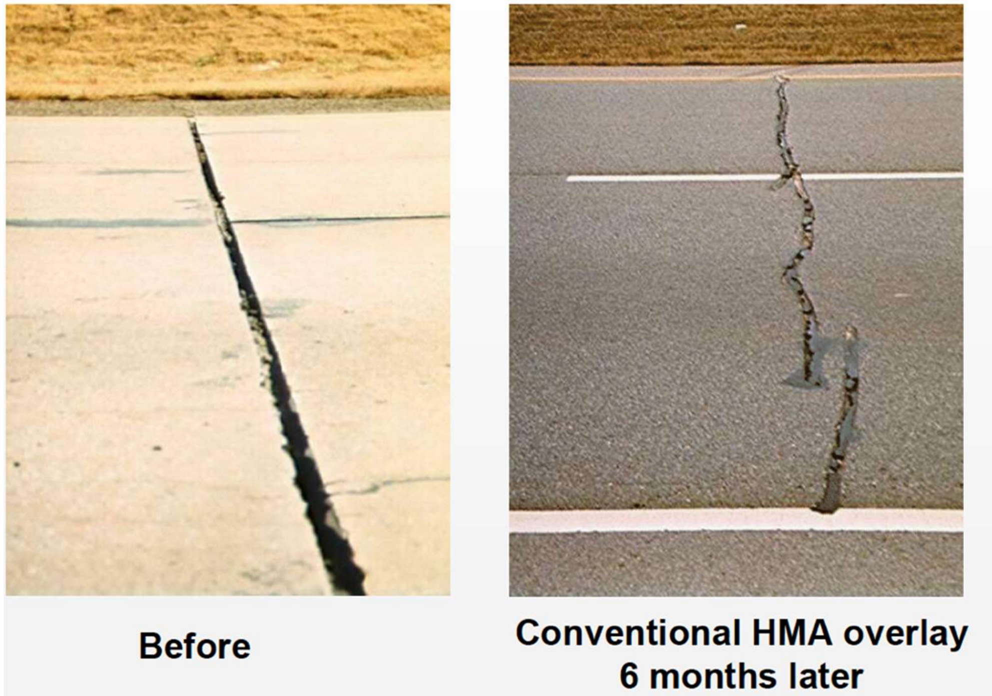

Fig - 1. Reflective Cracking in Asphalt Overlay Caused from Underlying PCC Joint in the US [12]

Stress Absorbing Membrane Interlayers (SAMI'S) have been used as a practical method to reduce reflective cracking on pavements that have adequate structural support since the early 1970's. Other products have shown mixed results in their ability to delay reflective cracking. Improvements in materials (i.e., mostly the use of polymers) saw the development of engineered asphalt interlayers in the 1990's.

Early applications of asphalt interlayers known as Sand Anti Fissure or Fracture (SAF) were developed in France and used with varying levels of success. Conventional specifications were used for the liquid asphalt (minimum performance grade (PG) of asphalt, elastic recovery, and separation) and volumetric mix design (Table 1). The Superpave gyratory compactor is used to compact volumetric samples to an N_{design} of 50 gyrations. Once the volumetric requirements are met, optimum volumetric properties are selected, like the Superpave mix design system. Crushed and natural sands were used to meet the gradation in Table 1. A sand equivalency of 45+ specified to ensure clay free materials. These systems were designed to be relatively impermeable with high asphalt content (typically >8 %) and low air voids (2-3%) and were placed 25 mm thick with a 4.75 mm nominal aggregate size. The overall early performance of this technique also varied to some degree mostly to due climate and availability of appropriate material. After seven SAF projects were completed, the introduction of a performance-based specifications based on the four-point beam fatigue test was selected to control reflective cracking.

Table 1. Mix Design Characteristics for Reflective Crack Relief Interlayer (RCRI)

Gradation	
Sieve	% Passing
3/8" (9.5 mm)	100
No. 4 (4.75)	80 – 100
No. 8 (2.36)	60 – 85
No. 16 (1.18 mm)	40 – 70
No. 30 (600 mm)	25 – 55
No. 50 (300 mm)	15 – 35
No. 100 (150 mm)	8 – 20
No. 200 (75 mm)	6 – 14
Volumetrics ($N_{\textbf{design}}$ = 50 gyrations)	
Asphalt Content (Pb)	7.0 – 10.0%
Air Voids (AV)	2.0%
Voids in Mineral Aggregate (VMA)	16.0% min
Voids Filled with Asphalt (VFA)	70 – 95%

This concept of a highly flexible asphalt interlayer produced a composite pavement design with a layer designed specifically to absorb movement, prevent water intrusion, while structurally stable to withstand traffic. While it seems intuitive, it is in fact counter-intuitive to conventional hot mix construction to have a high-asphalt, high-dust, and low air void mixture.

Other benefits are that the high strain asphalt inlayer is relatively easy to produce using 'locally' available materials and can be placed and compacted with conventional or standard paving equipment. Other advantages include speed of construction, (i.e., quick construction time) and the mix can be opened to traffic in need during staging. Three Wisconsin asphalt interlayer projects from 2001-2002 have been documented with standard HMA construction and no problems mentioned [13].

The SAF technology was introduced in the US by Koch Materials Company (in 1990's and early 2000's). Koch Materials Company began product development of an engineered interlayer that was heavily modified to address concerns with site specific distresses. The interlayer performance specification was based four-point flexural beam fatigue with varying climate requirements. The testing was conducted at 2000 $\mu\varepsilon$ to ensure reflective cracking performance. The test temperature was 10°C, 15°C, or 20°C based on climate temperature.

While not directly related to the interlayer, the overlay needed to be addressed since this is a composite system. The overlay thickness was based on traffic level to protect the interlayer. Koch internal research recommended that the overlay asphalt binder ~~to~~ use a styrene-butadiene-styrene (SBS) modified asphalt binder with a PG+ specification (elastic recovery or force ductility). LTPPBind software was to be used to select the 98% PG reliability binder to provide overlay consistency and to assist with cracking resistance. The following overall thickness requirements in Table 2.

Table 2. Minimum Overlay Thickness Recommendations for RCRI **[14]**

Traffic Level	Thickness (mm)
< 3 million ESAL's	40
3 to 10 million ESAL's	65
10 to 30 million ESAL's	75
>30 million ESAL's	90

Hveem Stability (AASHTO T246) was selected to address rutting resistance and in some cases, New Jersey DOT for example, selected the asphalt pavement analyzer (AASHTO T 340) to address rutting resistance. A minimum Hveem Stability value of 18.0 at 60°C was selected or a maximum 10-mm rut depth in the asphalt pavement analyzer. This was the minimum value needed to support construction equipment/traffic and to minimize rutting during construction. The RCRI is designed to accommodate construction traffic, but it is highly recommended to place the overlay within a 5-day period.

The four-point beam fatigue (AASHTO T 321) was selected to address the three forces: horizontal non-load movement (tension), vertical (shear) load induced movement, and bending or parallel movement under laterally unstable conditions [12] and [11]. The four-point beam fatigue test was found to be a good predictive tool for reflective cracking based on 150 combinations of sites and field observations of cracking data and layered elastic properties up to 15 years of age by Sousa et al [15]. During the development of the flexural fatigue specification, the strain was set to 2000 $\mu\varepsilon$ to simulate the movement at a joint. The test temperature was selected according to the project climate and ranges from 10 to 20°C. The minimum cycles to failure (N_f) for the RCRI performance-based specification (Fig - 2) was a minimum of 100,000 cycles based on the analysis method of Rowe and Bouldin [16]. This analysis method was recently adopted by American Association of State Highway and Transportation Officials (AASHTO) and included in AASHTO T 321. The loose mixture was conditioned for four hours at 135°C following AASHTO R30 prior to compaction in a linear kneading compactor. The target air voids for the beam specimens are 3 ± 1.0% air voids which is the target in place air void level.

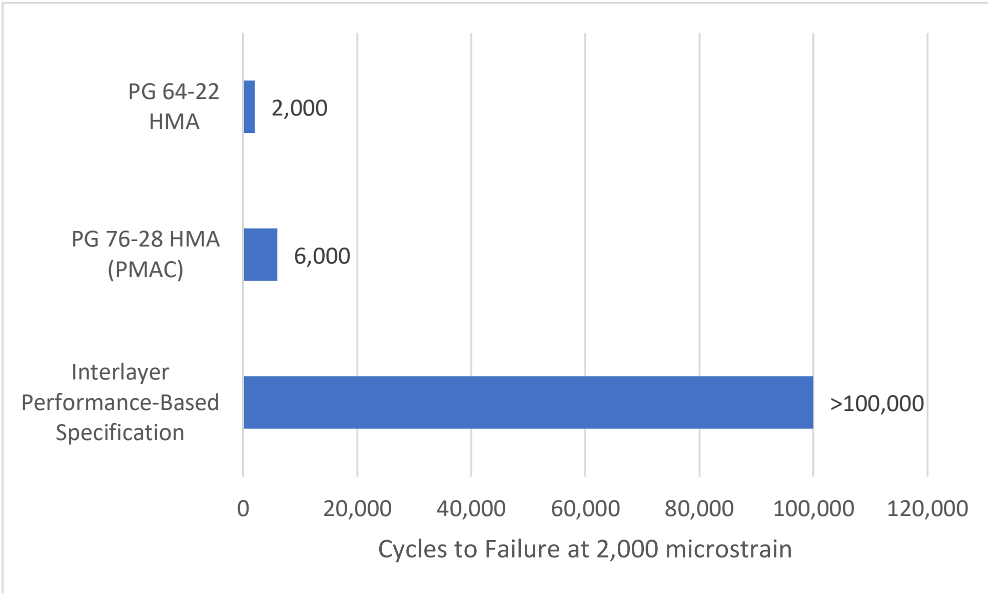

Fig - 2. Flexural Beam Fatigue Cycles to Failure (Proposed Specification)

This performance-based specification (Hveem Stability and Flexural Beam Fatigue) was used on several projects (2000 to 2002) in various states (Kansas, Missouri, Virginia, Wisconsin, Iowa, Illinois, Louisiana, Kentucky, Texas, Arkansas, South Dakota, Michigan) with better field performance test results. All mixtures were designed with a performance-based specification while maintaining volumetric requirements. Volumetric targets were useful especially for quality control of the interlayer. Koch's internal research on field data shows that designing the mixtures using a performance-based approach resulted in improved resistance to reflective cracking. On average, there was a 71% improvement in reflective cracking based on crack count surveys performed annually. The crack counts were manual crack counts using a measuring wheel where a control section was compared to a trial section over about 330m. Only transverse cracks (full to partial) were measured.

To improve the RCRI system, Koch Materials Company partnered with researchers at the university of Illinois at Urbana Champaign (Dr. Glaucio Paulino, and Dr. William Buttlar). The objective was to understand the fundamental knowledge of the damage mechanism in the RCRI system to improve the RCRI and overlay. This was accomplished over a four-year National Science Foundation (NSF) grant plus matching industry funds under a grant opportunity for academic liaison with industry (GOALI) project titled: Reflective Crack Control Treatment and Design Procedures: A New Integrated Approach, Proposal Number 0219566 [17]. This research developed the disk-shaped compaction tension (DC(T)) test (ASTM D7313), single-edged notched beam test, and the development of the cohesive zone finite element model for modeling reflective cracking. This project conducted fundamental research to understand the damage mechanism of reflective cracking. This fundamental research integrated material property inputs (fracture energy from the DC(T) and low temperature creep compliance (AASHTO T322)) in pavement structures using ABAQUS to model reflective cracking and validated with field performance data [18] - [19]. Fig 3 shows an example of two mixtures comparing the load vs cracking mouth opening displacement (CMOD) at -20°C. The area under the load vs. CMOD is the fracture energy of the mixture. The RCRI interlayer mixture and 9.5-mm PG 64-22 mixture have similar peak loads, but the post peak behavior (ductility) is much larger than the PG64-22 thus increasing the crack resistance of the mixture.

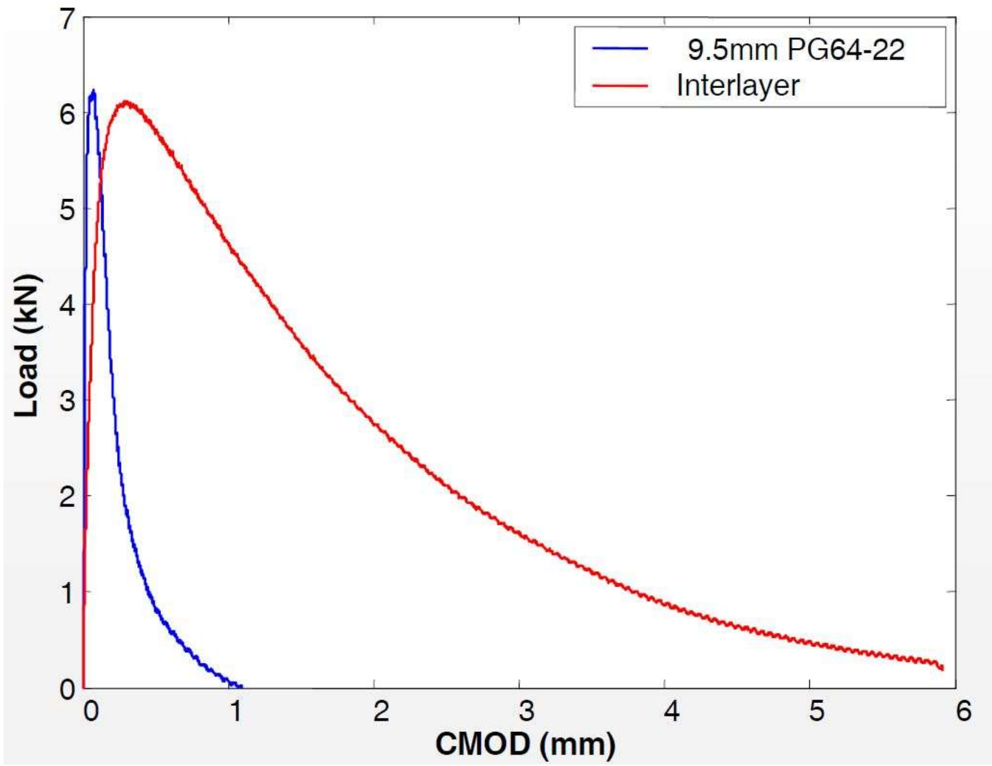

Fig 3. Load vs CMOD of a 9.5-mm PG 64-22 vs RCRI Mixture at -20°C [14]

Phase II of this integrated approach used the tools from the NSF GOALI study to design mixtures for accelerated pavement testing (APT) using the accelerated loading facility (ALF) at the University of Illinois at Urbana-Champaign [20] under the direction of Dr. William Buttlar. Four test sections were constructed in 2007. Each test section was 38 metres in length. The RCRI mixture was designed by SemMaterials and using locally available materials from Urbana-Champaign. The RCRI mixture design met the performance-based approach. Previous data from the GOALI study was used to design the pavement system. Details on the construction, layer thicknesses, instrumentation, loading, can seen in Dave et al. For brevity, the four sections are as follows:

- Section 1 – Control Section
- Section 2 – RCRI Section
- Section 3 – Dual RCRI System
- Section 4 – RCRI with Experimental Flexible Binder (XFB) in the Overlay

Materials were sampled during construction to compact samples to generate fundamental material property inputs (AASHTO T322 and ASTM D7313) to be used in pavement modeling which can then be compared to the field performance. Some promising results were that the crack jumping phenomenon was observed in section 2. The crack jumping mechanism seemed to be mitigated by the dual RCRI system (section 3) [20].

Twenty-three years after the introduction of this technology, the high strain asphalt interlayer is specified in some form by some 20 states (Fig 4) with various performance requirements. Adoption slowed somewhat due to lack of understanding, lack of high polymer modified asphalt, and cost. Polymer aramid fibre seem to be direct replacement for original high-polymer asphalt design.

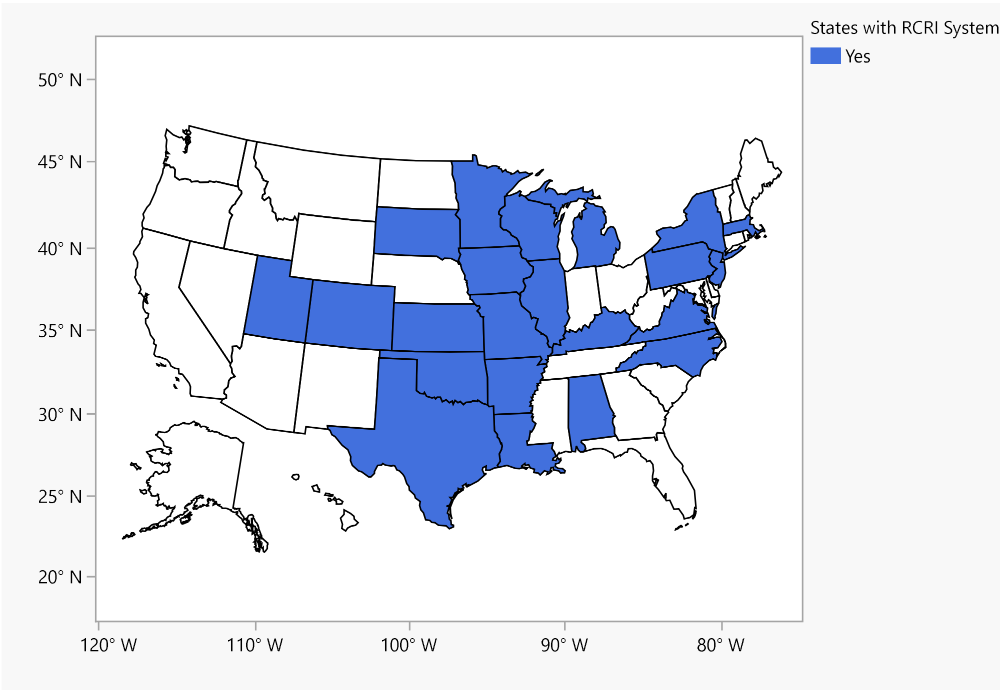

Fig 4. Reflective Crack Relief System in the U.S.

Research on the RCRI has progressed. For example, in 2019 the Wisconsin Department of Transportation (DOT) issued a request for proposals (RFP) titled Interlayer Mixture Design [21]. The objective of this research is to develop an alternative method for accepting interlayer mixture designs without the bending beam fatigue test. Mixtures accepted that use other means are expected to maintain the same level of quality that the beam fatigue test provides.

CASE STUDY - TAYLOR COUNTY AIRPORT, KENTUCKY

In 2019 a new version of the reflective crack relief interlayer (RCRI) using aramid fibre was introduced and used on the Taylor County Kentucky airport. The existing overlay on the runway was from 2013 and was showing signs of early raveling. The airport authority wanted to add structure but was concerned about reflective cracking showing up in the overlay. The engineering staff recommended the use of a 25 mm RCRI with a 50mm Superpave overlay.

Due to the lack of a local high polymer modified binder, the contractor chose to use an aramid polymer fibre to meet the design targets. The RCRI mixture was designed using Table 1 to meet the gradation and volumetric requirements but the indirect tensile cracking test (IDEAL CT, ASTM D8225) was used as the performance indicator in lieu of the normal four-point beam fatigue specification (minimum 100,000 cycles at 2,000 $\mu\varepsilon$).

The physical properties of the aramid fibre used in the modified RCRI layer are shown in Table 3. The RCRI mix design utilized 130g/t aramid fibre in conjunction with a PGAC 64-22 binder to achieve an acceptable level of performance. While PGAC 64-22 is not common for the extremely, high flexible interlayer, it worked well for this version of the interlayer over lightly distressed asphalt pavement. It is noted that, the inclusion of aramid fibre was easily observed while the asphalt was being placed at the project site. Fig 5 is a photo from the paver on the Taylor County airport project showing the fine-graded, binder rich, fibre reinforced RCRI.

Fig 5 - Aramid Fibre Reinforced Asphalt

Table 3. Physical Properties of Aramid Fibre Used in RCRI

Aramid Properties	Measure	Standard
Material	Para-Aramid Fibre	Manufacturer Certification
Form (Filament Yarn)	12,000 +/- 100 / bundle	Manufacturer Certification
Tensile Strength	> 2.758 GPa	ASTM D2256
Elongation at Break	< 4.4 %	ASTM D2256
Modulus	> 95 GPa	ASTM D2256
Specific Gravity	1.44-1.45 g/cm3	ASTM D276
Decomposition Temperature	> 426 ˚C	ASTM D276
Fibre Length	38mm	Manufacturer Certification

Further evaluation was important to validate the observed properties or characteristics of the interlayer. While PG 64-22 was good start (and sufficient for a central US climate over lightly distressed asphalt), it was necessary to evaluate the technology with different performance graded binders to provide a better understanding and more options for pavement designers.

To achieve the higher elasticity, a lightly modified asphalt binder was used in conjunction with aramid fibre. Aramid fibre provides the high strain response while the modified asphalt was an excellent base material. The IDEAL-CT test was used to further explore these options of higher elasticity.

When using IDEAL-CT, it should be noted that this is not a flexural fatigue test, but it seems to be a good guidance (index) test that can be used for the design of the asphalt interlayer. Fig 6 shows the average CT_{index} test results for three mixtures at the optimum binder content of 8.2% demonstrating the drastic data response of the asphalt interlayer (CT index=1500+ at various climates) as compared to a very good conventional mix (CT index=153). The IDEAL CT test temperature was adjusted based on the asphalt binder grade to simulate different climatic conditions.

In addition to gaining a better understanding of the material properties, there were various lessons learned with the Taylor County Airport associated with the production, laydown, and placement of the RCRI.

1. The high strain asphalt inlayer is relatively easy to produce using 'locally' available materials.
2. It can be placed and compacted with conventional or standard paving equipment.
3. Quick construction time.
4. The mix can be opened to traffic in need during staging.

The cost for the RCRI asphalt mix for this project was approximately $115/ton USD.

Experience has also shown that the interlayer can milled if required, however it can also be left in-place as part of a long-life or perpetual pavement.

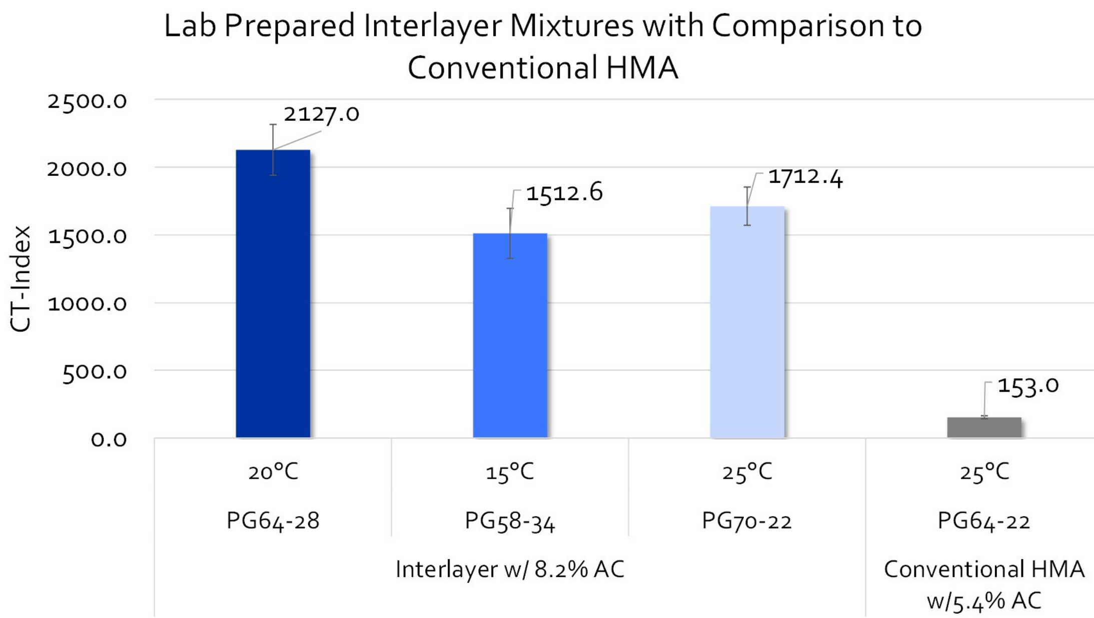

Fig 6 - IDEAL CT Test Results of the Interlayer Designed with Aramid Fiber and Lightly Modified Asphalt Binder

The IDEAL-CT test should be coupled with a rutting test such as the Hamburg Wheel Tracker (HWT). The HWT test is reliable and modern substitute to the older Hveem Stability test that was used in the original early 2000's specification. Early work by Blankenship suggests that values of 5000 minimum (or slightly less) cycles at 12.5mm seem to be sufficient to provide enough rut resistance for a paving platform and construction traffic. It should be noted that rutting has never been reported to the best of the authors' knowledge on any interlayer project since the asphalt interlayer is protected from direct long-term traffic by an overlay.

When the asphalt RCRI is properly designed with tests such as IDEAL-CT (extreme value) and minimum HWT rutting value, one should expect it to be highly flexible to resist cracking while withstanding construction traffic. The flexibility of the RCRI mixture reinforced with aramid fibre is demonstrated in Fig 7. Note that the layer on top is the interlayer that demonstrates the ability of the interlayer to bend as compared to the conventional layer on the bottom.

Fig 7– Asphalt Interlayer in Laboratory

CONCLUSIONS

There are several noteworthy advantages to the more recent developments in the high strain asphalt interlayer discussed in this paper. Most importantly is the improvement performance and the significant delays in cracking. From a design perspective, the mixture is tested and evaluated based on performance criteria and newer, more readily available tests such as the IDEAL CT and DCT tests can be used to measure cracking resistance. The product is 'impermeable' which facilitates the need to provide or force lateral drainage. It is envisioned that these advances will impact on the overall life cycle cost of pavements by reducing the maintenance and rehabilitation costs particularly where the interlayer is used to mitigate reflective cracking, for example over concrete. Based on 20+ projects construction in the US from 2000 through 2006, the high strain asphalt inlayer is relatively easy to produce using 'locally' available materials and can be placed and compacted with conventional or standard paving equipment. Other advantages include speed of construction, (i.e., quick construction time) and the mix can be opened to traffic in need during staging. Experience has also shown that the interlayer can milled if required, however it can also be left in-place as part of a long-life or perpetual pavement.

FUTURE WORK

The advancements with high strain asphalt interlayers discussed in this paper provides owner agencies (provincial and municipal) and the practitioner with engineering solutions to help mitigate a long-standing problem with reflective cracking. Research conducted in 2019 concluded the following:

"Based on the results of the laboratory testing, it appears that applications that might benefit the most from the addition of aramid fibers are those where the asphalt is subjected to high strain levels, such as in overlays of jointed concrete pavements or overlays of pavements with considerable cracking." [22]

It is envisioned that owners will consider the use of fibres in general and particularly the high strain asphalt interlayer to improve fatigue life at high strain levels. It is expected that the improved performance will reduce life-cycle costs, which will also benefit the travelling public. Accordingly, aramid fibres are being evaluated for various applications as engineering solutions to produce long-lasting performing asphalt pavements. The high strain asphalt interlayer should be considered to provide a viable alternative to paving over concrete without having to perform costly concrete repairs before placing the asphalt overlay. It is anticipated that trials will be conducted soon to further evaluate this technology for application across Canada.

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