Asphalt mixture performance and testing

HiMA experiences in cold climate conditions

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Abstract

Studded tires are commonly used in some countries around the world for improved traction on roads in icy conditions. While they improve traction, the metal studs cause abrasion rutting on both asphalt and concrete pavements. Standard approaches do not show sufficient improvement in heavily-trafficked areas such as the City of Anchorage, Alaska, especially on higher speed roads and highways, where the resultant rutting from studded tire wear is one of the most persistent pavement distresses. In the fall of 2014, the Alaska Department of Transportation and Public Facilities (Alaska DOT&PF) undertook a trial in the City of Anchorage using a novel approach to improved resistance to studded tire wear. The approach was to use a standard mix design with a hard aggregate along with an exceptionally soft, tough asphalt binder with an AASHTO M332 grade of PG 64E-40. In laboratory Prall testing, this new mixture gave less than half the volume loss of a typical good-performing mix. Binder design, mixture testing, construction and performance are discussed. To date, performance has been sufficiently impressive to warrant further projects. A follow up major project resurfaced 25 km of highway from 2016 – 2018 and is performing well. A trial project on the Ring Road around St. Petersburg, Russia is also meeting expectations. To date, projects are showing one third less deformation that previous solutions.

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1.0 INTRODUCTION

1.1 Studded Tire Damage

Studded tires are commonly used around the world for improved traction on roads in icy conditions [1]. Regions include the United States and Canada, Scandinavia, northeastern Europe, and Japan. While they improve traction, the metal studs cause abrasion rutting on both asphalt and concrete pavements. Standard approaches do not show sufficient improvement in heavily-trafficked areas such as the City of Anchorage, Alaska, especially on higher speed roads and highways, where the resultant rutting from studded tire wear is one of the most persistent pavement distresses.

Figure 1 shows standard tire studs while Figure 2 shows the resulting abrasion that occurs at varying vehicle speed.

As shown, the vehicle speed greatly influences the scratch and impact on asphalt pavement (aggregate and bituminous binder matrix). If the binder matrix is brittle during the studded tire wear season, it will shatter. The goal of using a modified binder matrix is to create a resilient material that will absorb the impact forces of tire studs (like a shock absorber) and also provide the bonding strength to aggregates to resist the scratching aspect of studded tire wear. At the same time, the pavement must still resist conventional rutting through plastic deformation.

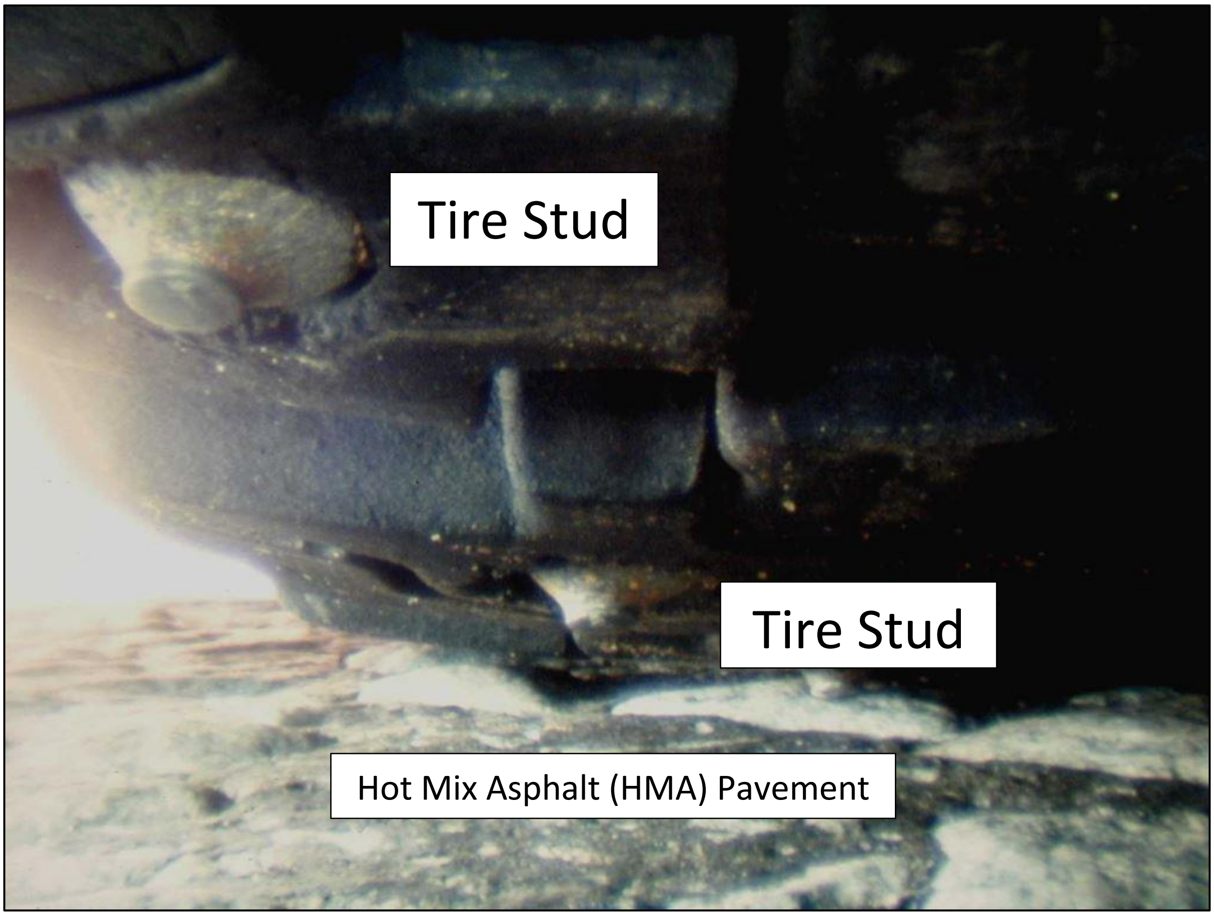

Figure 1. Typical Tire Studs

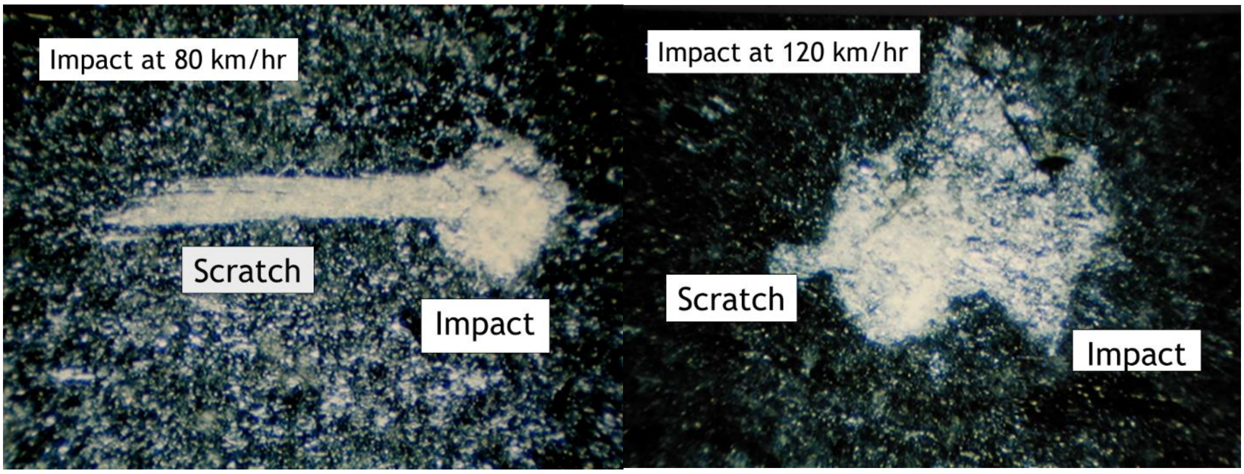

Figure 2. Damage to Hot Mix Asphalt Pavement at Varying Vehicle Speed

Over the years, numerous approaches have been tried to mitigate studded tire damage on asphalt pavements, which is shown in Figure 3. These methods, detailed in the previous report [2], include Stone Mastic Asphalt (SMA), pre-coated chip seal, dry process rubber modification, hard aggregates and polymer modified bitumen (PMB). None was particularly effective.

Figure 3. Resulting Abrasion Rutting

1.2 Highly Modified Bitumen (HiMA)

While Styrene-Butadiene-Styrene-modified bitumens have been used in paving for over 30 years, the typical levels of modification have remained low in most of North America. More heavily modified bituminous binders have been used for many years in Japan and also in parts of Europe and in Australia. Development work in the United States began in 2009 with a study at the National Center for Asphalt Technology (NCAT) in Auburn, Alabama. A thinner, highly modified structural pavement out-performed six thinner sections over a five year period [3, 4, 5]. Since 2009, over 20 states have conducted trials in a variety of mixture and pavement applications and half a dozen have full, commercial specifications. Applications include reduced thickness structural pavements, high durability thin overlays, Stress Absorbing Membrane Interlayers (SAMI), waterproof bridge decking, and high durability micro surfacing.

Figure 4 shows the change in phase structure going from standard polymer loading to high polymer loading. The schematics on the left show the relative proportions of swollen polymer to bitumen while the images on the right are micrographs of such blends. The light regions are swollen polymer while the dark regions are bitumen. As the polymer content increases, the structure changes from bitumen with a dispersed swollen polymer phase (top micrograph) to swollen polymer with a dispersed bitumen phase (bottom micrograph). In effect, the binder behaves more like bitumen-modified rubber than rubber-modified bitumen.

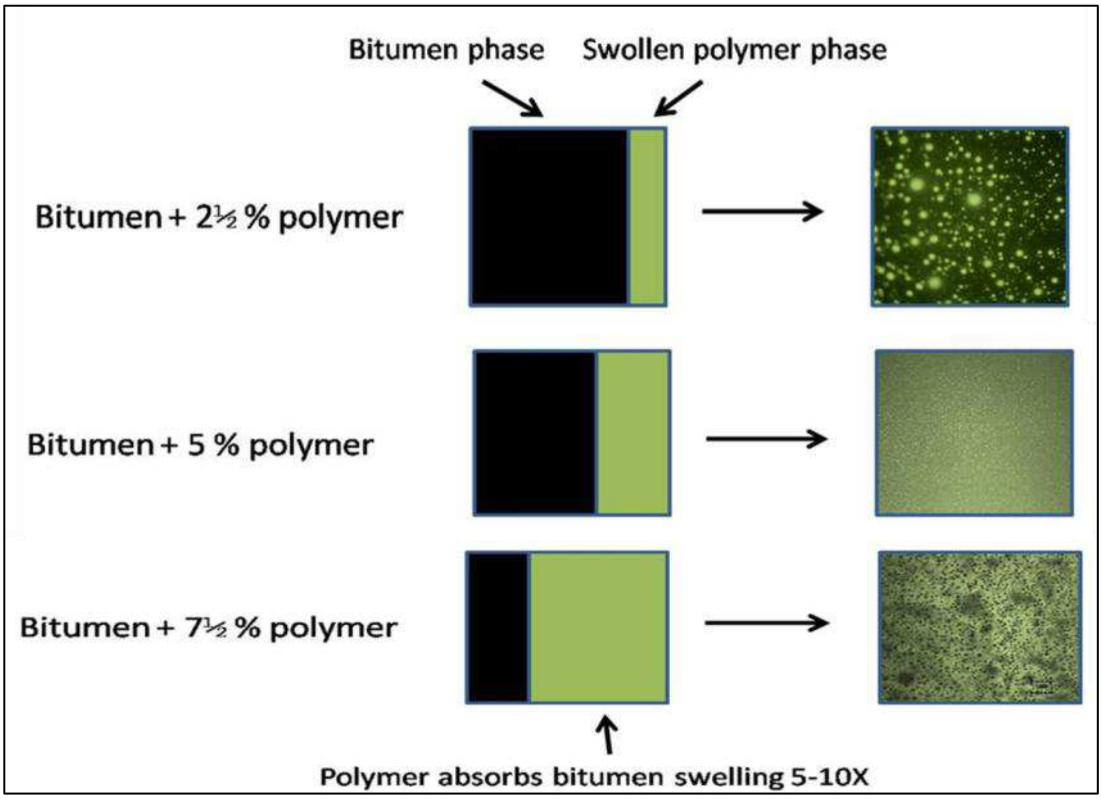

Figure 4. Dispersion of Styrene-Butadiene-Styrene (SBS) Polymer in Bitumen at Different Loadings

This behavior gives a material that combines exceptional resilience and resistance to permanent deformation with exceptional toughness and resistance to cracking. Thus a mixture can be designed that resists both permanent deformation and fatigue cracking without having to sacrifice one to achieve the other.

Conventional design methods such as the 1993 AASHTO Flexible Pavement Structural Design do not recognize increased toughness, relying only on modulus, and so severely underrate the performance of HiMA pavements. However, the current AASHTOWare® Pavement ME Design [6] software does allow for material property input for the damage models. Extensive material property testing was conducted on the binders and mixtures from NCAT and that data has been used in performance comparison of the HiMA and control sections from NCAT. The modeling successfully predicted the relative performance of the HiMA versus the standard material sections demonstrating that the ME Design software can be used for rational pavement design [7, 8].

In 2013, the Alaska Department of Transportation and Public Facilities became interested in the HiMA technology as a possible approach for addressing the abrasion damage caused by studded tires. This paper summarizes the development work of binder formulation and mix design, laboratory testing for damage resistance, and construction and performance to date of the first full scale pavement trial in Anchorage.

2.0 MATERIAL TESTING AND DEVELOPMENT

2.1 The Prall Test

The Prall test for studded tire damage was originally developed in the Nordic countries and is standardized as EN12697-16 in the European Committee for Standardization (CEN). A commercial video demonstrating the test is available online [9]. The Alaska DOT&PF method [10] closely follows EN12697-16 Method A [11].

Test specimens are 100 mm in diameter and 30 mm thick and are tested at 5 ºC. The specimen is loaded in the test device and covered with 40 stainless steel spheres 12 mm in diameter. The test chamber is oscillated with a stroke of 43 mm at a frequency of 950 strikes per minute for a period of 15 minutes.

A schematic of the test device is shown in Figure 5 and a photograph of the test chamber with steel spheres is shown in Figure 6.

The mass of the test specimen is determined before and after abrasion and the material loss is converted to volume and reported as the abrasion value in units of cm^3.

The classification scale for Prall loss is given in Table 1, ranking from Poor (>50 cm^3) to Very Good (<20 cm^3). The typical range for mixtures for Alaska DOT&PF is about 18 to 28 cm^3.

Table 1. Nordic Countries Classification of Asphalt Mixture Wear Resistance

Class	Prall Loss – cm^3	Wear Resistance
1	< 20	Very Good
2	20 – 29	Good
3	30 – 39	Satisfactory
4	40 – 49	Less satisfactory
5	> 50	Poor

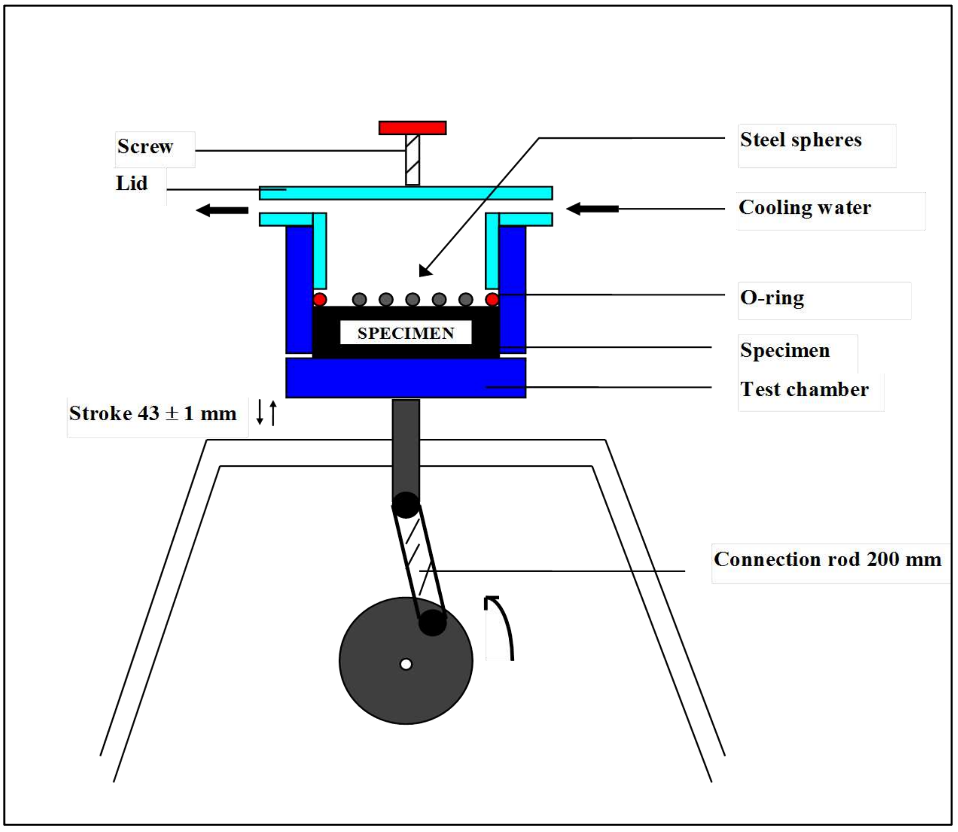

Figure 5. Prall Test Device

Figure 6. Image of Prall Test Chamber

2.2 Binder Formulation and Testing

For the Alaska DOT&PF Prall test, mixtures are prepared with a standard – 19 mm dense mix with a hard aggregate. Base binders that have been used include PG -28 or PG -34 modified with SBS, Nevada Tire Rubber (NVTR), Ground Tire Rubber (GTR), Transoctenomer Rubber (TOR), or combinations thereof. For the first experimental binder, a PG -34 base bitumen was modified with 7.5 percent SBS polymer. This binder gave a very good result of 22 cm^3. With the very high expected rutting resistance for a HiMA binder, a second test was conducted with the same formulation and an even softer PG -40 base. This binder gave an exceptionally good performance at 11 cm^3. The data for several comparative binders is shown in Figure 7.

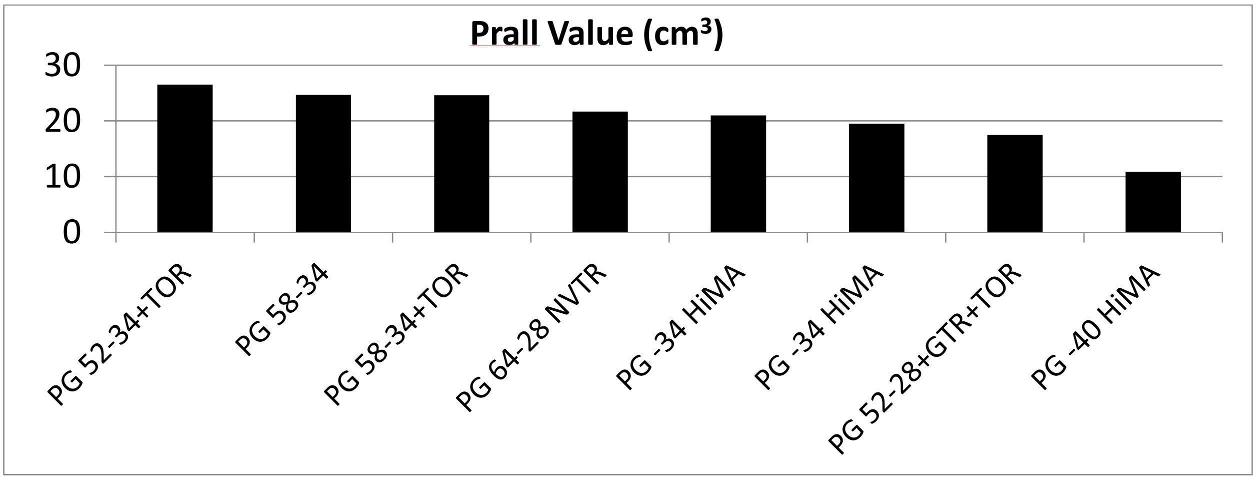

Figure 7. Prall Test Results for a Range of Binders

Comparative Prall specimens are shown in Figure 8. The standard specimen on the right shows typical abrasion with most of the aggregate clearly visible. The steel spheres progressively abrade the binder from the surface, then fracture and abrade the exposed aggregate. With the PG -40 HiMA binder, much less of the binder is abraded due to its resilience and it can continue to protect the aggregate below from fracture.

Figure 8. Abraded Prall Specimens Showing Different Damage Patterns

A PG -40 binder for heavily trafficked city streets in Anchorage sounds like a high risk for permanent deformation, but Figure 9 shows the result of the standard Alaska DOT&PF Georgia Wheel Loader test at 8000 cycles at 41 °C with minimal deformation.

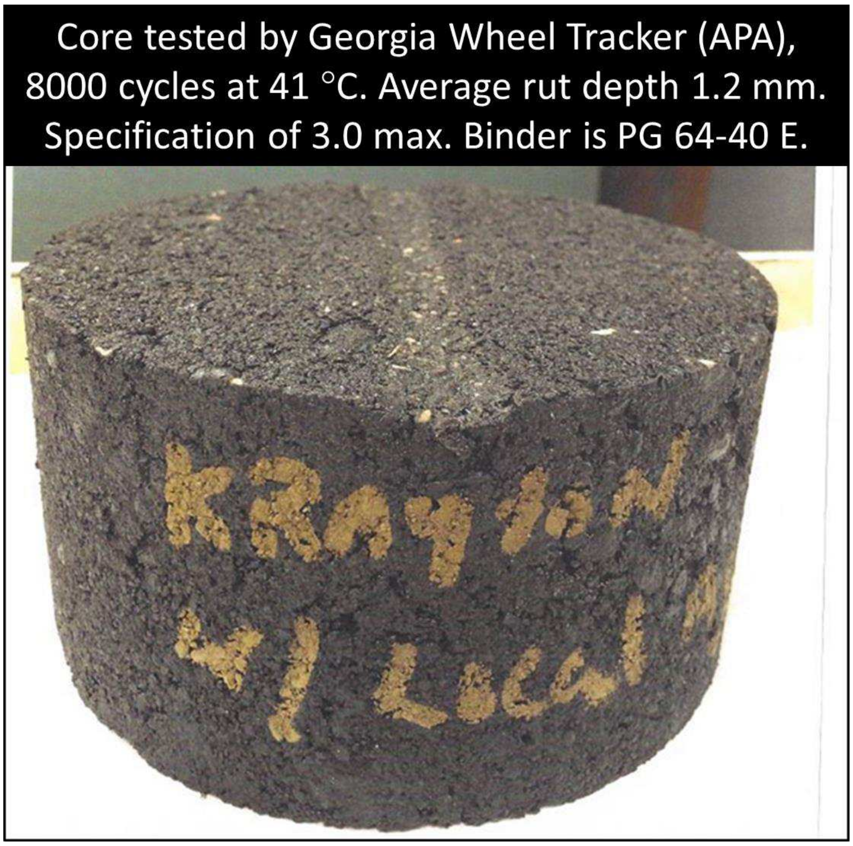

Figure 9. Asphalt Pavement Analyzer (APA) Rut Test Specimen

Binder Specification

The trial binders for Prall evaluation were prescriptively formulated so the question became - what is an appropriate PG binder specification for open bid? In evaluating the binder, it was graded according the both AASHTO M 320 and AASHTO M 332 (MP 19 at the time). The binder met M 320 PG 64 and also M332 PG 64E for high temperature. It maintained PG -40 for the low temperature as well. The binder could not be reliably tested for toughness and tenacity as the tensile strength exceeded the adhesive strength to the tension head.

In intermediate temperature testing, it was noted that the binder was quite soft even at very low temperatures with failure limit for $G^*\cdot\sin\delta$ below 0 ºC.

Based on the experimental binder specification testing, Alaska DOT&PF wrote in Special Provision Section 702 with the following requirements:

- Meet AASHTO M 320 for PG 64-40;
- Meet AASHTO MP 19 (now M 332) for PG 64-40 E; and
- PAV DSR shall not exceed 5000 kPa @ 0 °C.

Since 2014, the PG 64-40 E binder specification has been revised as follows with the new spec being used on subsequent projects:

- MSCR @ 64 °C $J_{NR3.2}$ kPa^{-1} - 0.10 max, % $Recovery_{3.2}$ - 95 min.
- 135 °C viscosity Pa·s – 1.0 max.
- PAV DSR @ 4 °C – 5000 max.

Mix Design

The mixture volumetrics were set at standard Alaska DOT&PF Class A Type II from Table 401-1, as shown in Table 2.

Table 2. Marshal Mixture Volumetric Requirements

Table 401-1 Class A Type II	
Stability, pounds	1800 min
Flow, 0.01 in	8 – 14
Voids in Total Mix	3 – 5%
Compaction Blows	75
Voids Filled with Bitumen, VFA(B)	65 – 75%
Dust/Bitumen	0.6 – 1.4
Voids in the Mineral Aggregate, VMA	13% min

Project and Pavement Design

The project was a standard street resurfacing with a 44 mm mill and 50 mm fill. It comprised 5th and 6th Avenues and cross streets in downtown Anchorage. Traffic is 10,000 – 15,000 AADT. Figure 10 is a map of downtown Anchorage with the project highlighted. For reference, the project name is Anchorage 5th and 6th Avenue Resurfacing L Street to Ingra Street Project No. 59763.

3.0 CONSTRUCTION

The PG 64E-40 binder was supplied by Denali Asphalt, LLC and the project was constructed by Granite Construction. Figure 11 shows the crowded paving conditions and windrow construction.

Construction was started in September 2014 and completed in June 2015. Paving was done at night and static rolling was required due to noise and to sensitive infrastructure. The temperature of the mat averaged 155 ºC. Even with the difficult conditions and lateness in the year for the start, the contractor achieved the required mat density of 95 percent and joint density of 93 percent.

Figure 10. Downtown Anchorage

Figure 11. Windrow Paving

4.0 GLENN HIGHWAY PROJECT

4.1 Project and Pavement Design

With the successful performance of the Anchorage project. Alaska DOT&PF specified the same PG 64E-40 binder for resurfacing of the Glenn Highway. Due to studded tire abrasion, this highway has typically been resurfaced every six to seven years. The project was a five cm mill and fill resurfacing of 24.5 km of Glenn Highway with 45,000 tonnes of asphalt. The project was supplied from two plants with the mix designs and volumetrics shown in Tables 3 and 4. The mix designs were 75 gyration Superpave and a warm mix additive was used. Compaction temperatures were 152 – 157 °C, though the observation was that lower temperatures would have been suitable.

As a bonus, this project was chosen by the Federal Highway Administration as one of the ten demonstration projects for enhancing pavement durability through increased in-place pavement density. Construction for the whole project went from late season 2016 to early season 2018, with the FHWA monitoring only for the 2016 construction. Density control techniques used on the project in addition to WMA include MOBA Pave-IR, intelligent compaction and a real time rolling density meter. As shown in Table 4, densities of > 95% were consistently achieved. This work is well documented in NCAT Report 17-05 [12].

Table 3. Aggregate Gradations for Mix Designs 1 and 2

Sieve Size	Mix Design 1	Production Avg.	Mix Design 2	Production Avg.
19 mm	100	100	100	100
12.5 mm	90	91	85	87
9.5 mm	73	75	70	72
No. 4	48	47	45	45
No. 8	32	31	31	31
No. 16	21	21	20	21
No. 30	15	16	14	16
No. 50	10	11	9	11
No. 100	7	8	7	8
No. 200	5.2	5.8	5.0	5.3

Table 4. Mixture Volumetric Test Results

	Binder (%)	Va	VMA	VFA	Gmb Lab	Gmm	Gsb	In-place Density
JMF 1	5.6	4.0	16.6	76	2.453	2.568	2.784	
Specs 1	5.2-6.0	4.0	13.0 min	65-78				92.0 min
Test Strip 1	5.5				2.459			95.8
Control 1	5.4				2.455			95.6
JMF 2	5.5	3.7	15.1	76	2.409	2.509	2.703	
Specs 2	5.1-5.9		13.0 min	65-78				96.0 min
Test Section 1	5.3				2.456	2.585		95.0
Test Section 2	5.2				2.412	2.521		95.7

5.0 ADDITIONAL ALASKA PROJECTS

Based on the initial results, Alaska DOT&PF has executed several additional projects in the Anchorage area:

- Parks Highway MP 35 – 40 — 9/2015 – 9/2016
- Tudor Road – Minnesota to 36th Avenue — 10/2017 – 6/2018
- Old Glenn Highway – Artillery Road to Lake Ridge Drive — 8/2019 – 9/2019
- Minnesota Drive – Seward Highway to Tudor Road — 8/2019 – 9/2019

As of October 2019 all of these pavements are performing well.

6.0 ST. PETERSBURG RUSSIA PROJECT

6.1 St. Petersburg Ring Road or KAD (КАД -Кольцевая автомобильная дорога)

The St. Petersburg Ring Road is a 142 km freeway encircling the city of St. Petersburg, Russia constructed from 1998 to 2002. Lane 3, in particular, experiences very high traffic of 30,000 vehicles per day, mostly cars. Wearing courses in lanes 3 and 4 have typically lasted only two to four years and the most recent wearing course, paved in 2016, was already failing after two winters due to excessive abrasion rutting.

6.2 2018 HiMA Trial

A one km section of the KAD was resurfaced August 30, 2018. The binder for the project was produced at the Gazpromneft Refinery at Ryazan, a 900 km haul. The binder was formulated with a blend of 260 pen and PG 64-22 with 7.5% SBS to meet a specification of PG 76-40. The wearing course design was five cm of 19 mm SMA. Prall mass loss on a laboratory specimen was 23 cm^3, somewhat higher than expected. Photos from the project are shown in Figure 12. To date the pavement is performing well.

Figure 12: St. Petersburg Ring Road Paving – August 30, 2018

7.0 PERFORMANCE

The pavement is being monitored for rutting and winter damage. It is premature for full evaluation; however the performance to date is good with no winter damage such as raveling and minimal abrasion rutting. The wheel paths look dark much like the abraded Prall test specimens indicating that roughly the same behavior is occurring in the laboratory and in the field. The Alaska DOT&PF is pleased with the performance and is specifying several more projects with PG 64-40 E binder and hard aggregates. Summer 2020, Alaska DOT&PF will conduct a detailed pavement condition evaluations on both the Anchorage project and the Glenn Highway project below which will be reported later.

In 2015 on 5th and 6th Avenue the PG64-40 E binder was used for the first time. It was used with a Superpave mix that incorporated hard aggregate (Nordic max of 8%). In 2019, after four seasons of studded tire wear, the average rut depth on 5th Avenue is 5.2 mm, and on 6th Avenue is 5.0 mm between L Street and Ingra in downtown Anchorage.

The mix placed on the Glenn Highway in 2010 incorporated crumb rubber and a PG 64-34 binder. In 2012, the average rut depth between Airport Heights and Hiland, being the most highly trafficked route in Alaska, was 8.1 mm after two winters of studded tire wear. In 2017 the rubberized mix was milled up and a Superpave mix with PG64-40 E binder and hard aggregate was placed. In 2019, the average wear on this Superpave mix between Airport Heights and Hiland was 5.3 mm after two seasons of studded tire wear. Rut depth on 6th Avenue is shown in Figure 13.

Figure 13: 200 block of E 5th Avenue – October 14, 2019

8.0 CONCLUSIONS

- Studded tire abrasion of pavements, both flexible and rigid, is a persistent problem in many cold climates. Various techniques have been tried over the years but none so far has proved satisfactory.

- Highly modified bitumen or HiMA allows the production of a very soft and resilient binder that can, to some degree, resist abrasion in the Prall test. That, combined with adequate permanent deformation resistance, makes it an interesting candidate to mitigate studded tire damage.

- A PG 64-40 E binder formulated with a high content of SBS gave excellent performance in the Prall test and a robust M320/M332 binder specification was used for a commercial resurfacing project in Anchorage of the summers of 2014-2015. There have been several subsequent projects through 2019.

- Construction went smoothly with no significant issues and high densities, both mat and joint, were achieved despite the requirements for night paving and static rolling late in the paving season.

- It is premature for full performance evaluation. However, performance to date is good with no winter damage and minimal abrasion rutting. Typical abrasion rutting is reduced by about 1/3 over other solutions.

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REFERENCES

[1] Wikipedia the Free Encyclopedia, "Snow Tire", https://en.wikipedia.org/wiki/Snow_tire, accessed August 1st, 2019.

[2] T. Burritt, R. Kluttz and C. Lubbers, "A Novel Approach to Mitigating Studded Tire Abrasion," Proceedings, Canadian Technical Asphalt Association, vol. 61, pp 163-178, 2016.

[3] D. Timm, M. Robbins, J. Willis, N. Tran and A. Taylor. "Field and Laboratory Study of High-Polymer Mixtures at the NCAT Test Track - Interim Report", Report 12-08, National Center for Asphalt Technology (NCAT), Auburn, Alabama 2012.

[4] D. Timm, M. Robbins, J. Willis, N. Tran and A. Taylor, "Field and Laboratory Study of High-Polymer Mixtures at the NCAT Test Track: Final Report", Report 13-03, National Center for Asphalt Technology (NCAT), Auburn, Alabama 2013.

[5] J. Willis, D. Timm and R. Kluttz, "Performance of a Highly Modified Asphalt Binder Test Section at the NCAT Pavement Test Track", Transportation Research Record No. 2575, Transportation Research Board, National Research Council, National Academies, Washington, D.C. 2016.

[6] Association of State Highway and Transportation Officials, "AASHTOWare Pavement ME Design", https://www.me-design.com/MEDesign/, accessed August 1st, 2019.

[7] R. Kluttz, R. Dongré, R. Powell, J. Willis and D. Timm, "Performance and Rational Design of Thin, Highly Modified Structural Pavements", Proceedings of the 2014 International Conference on Perpetual Pavement, Columbus, Ohio 2014.

[8] R. Kluttz, R. Dongré, R. Powell, J. Willis and D. Timm, "Long Term Performance of a Highly Modified Asphalt Pavement and Application to Perpetual Pavement Design", Proceedings of the 6th Eurasphalt and Eurobitume Congress, Paper No. 212, Prague, Czech Republic 2016.

[9] Cooper Research Technology Ltd. "Prall Tester by Cooper Technology", https://www.youtube.com/watch?v=q7VXiR2IkY4, accessed August 1st, 2019.

[10] Alaska Test Method 420, Abrasion of HMA by the Prall Method, 2019 http://www.dot.state.ak.us/stwddes/desmaterials/mat_waqtc/assets/pdf/testman/2018/series_400.pdf, accessed October 28, 2019.

[11] European Standard for Bituminous Mixtures prEN 12697-16 part 16: Abrasion by Studded Tyres, European Committee for Standardization CEN/TC 227 rev. 1997.

[12] T. Aschenbrener, E. Brown, N. Tran and P. Blankenship, "Demonstration Project for Enhanced Durability of Asphalt Pavements through Increased In-Place Pavement Density," NCAT Report 17-05, 2017.