

**Laboratory Evaluation of Rubber & Polymer Modified
Bituminous Mixtures Constructed in Stockholm
(E18 Highway between the Järva Krog & Bergshamra Interchanges)**

Executive Summary

Prepared by

Kamil E. Kaloush, Ph.D., P.E.
Associate Professor

Jeffrey Stempihar, P.E.
Graduate Research Assistant

Submitted to

Swedish Road Administration
Vägverket
405 33 Göteborg
Kruthusgatan 17, Sweden

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Ira A. Fulton Schools of Engineering
Department of Civil, Environmental and Sustainable Engineering
Tempe, Arizona 85287-5306, United States of America

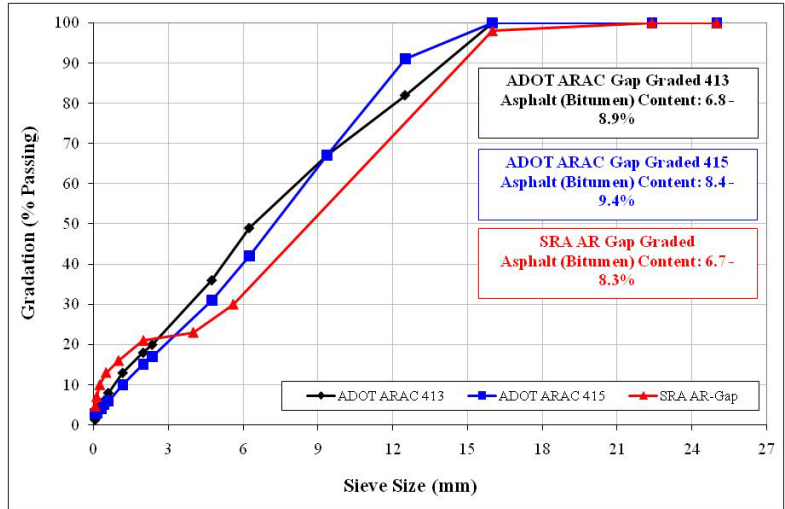
EXECUTIVE SUMMARY

In 2009, Swedish Road Administration (SRA) and Arizona State University (ASU) undertook another joint effort to test three types of gap-graded asphalt mixtures: reference (unmodified), polymer-modified and Asphalt Rubber (AR) - modified mixes; placed on the E18 highway between the Järva Krog and Bergshamra interchanges in Stockholm, Sweden. The accompanying technical report provides documentation of the various mechanical tests conducted on these mixes in order to evaluate the pavement materials' laboratory performance characteristics. The report describes detailed mechanical test results for each of the three mixtures along with a comparative performance discussion. This executive summary provides a brief overview of the study and test results along with a performance comparison of the asphalt rubber mixture to typical Arizona Department of Transportation (ADOT) asphalt-rubber mixtures found in the State of Arizona, United States of America.

The mechanical tests conducted on the three asphalt mixtures included: triaxial shear strength, dynamic (complex) modulus, repeated load for permanent deformation characterization; indirect tensile creep and strength tests for thermal cracking characterization; flexural beam tests for fatigue cracking, and C*-Line Integral for crack propagation evaluation. In addition, conventional binder consistency tests were performed on three different binders: virgin binder with no modification, polymer modified binder, and crumb rubber modified binder.

Aggregates Gradation

A comparison of the SRA AR gradation to similar ADOT mixtures is presented in the adjacent figure. From the comparative figure, the SRA mix gradation has a lower percentage passing all sieve sizes greater than 3 mm and a



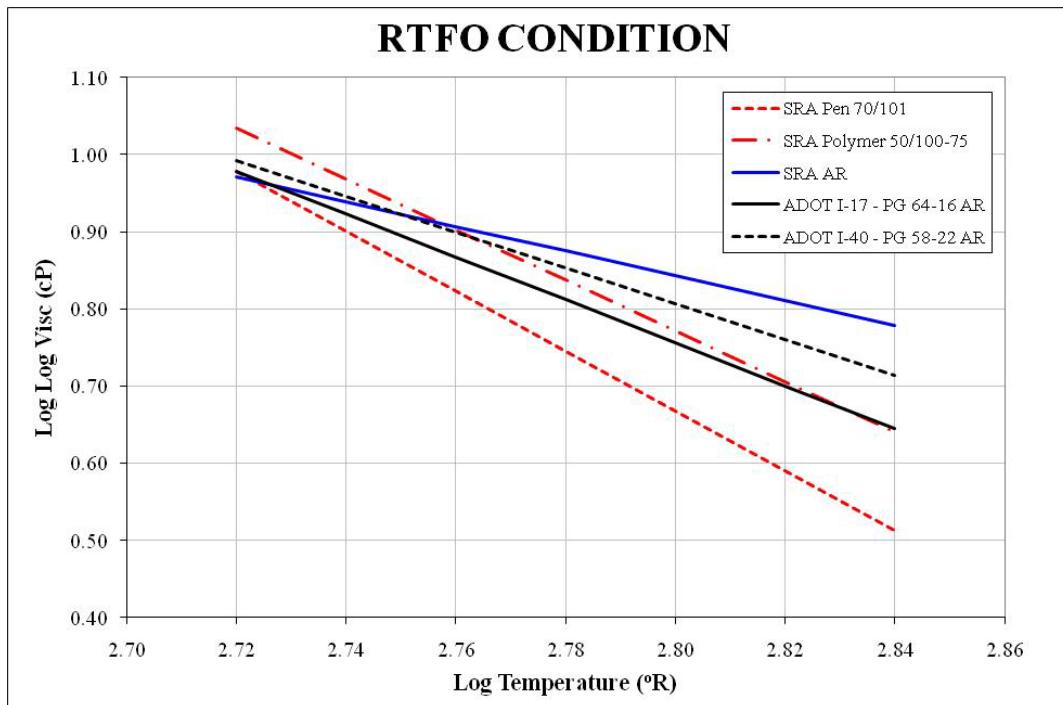
higher percentage passing sieve sizes less than 3 mm. This indicates a larger overall aggregate gradation with more fine content than similar ADOT mixtures. The larger aggregate sizes may provide better wear resistance to studded tires commonly used in Sweden.

In the table below, typical binder contents and air voids range for the ADOT AR Gap graded mixes are presented along with those mixtures included in this study.

Mix	Binder Content (%)	Air Voids (%)
Reference ABS 16 70/100	5.9	2.6
Polymer ABS 16 Nypol 50/100-75	5.9	2.6
Rubber GAP 16	8.7	2.4
Range of ADOT AR Gap Mixes	6.8 – 9.4	7 - 9

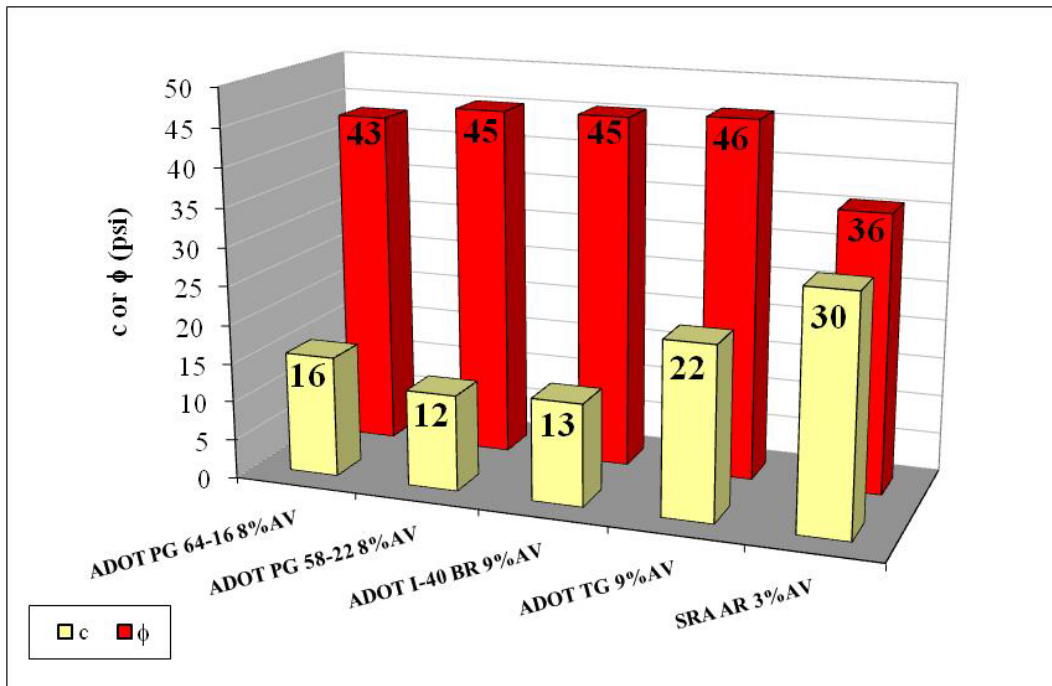
Binder Test Results

A comparison of the viscosity-temperature relationship for the three binders showed that the crumb-rubber and polymer modified binders have much lower slopes across a range of temperatures than the virgin binder, a behavior highly desirable for resistance to permanent deformation. Overall, the SRA crumb-rubber modified binder has the flattest slope amongst the three tested binders, indicating that rubber-modified binder would be least susceptible to viscosity changes across all ranges of low and high temperatures. In comparison to typical ADOT asphalt-rubber modified binders, the SRA AR binder has the flattest slope indicating less viscosity changes across a wide range of temperatures. This property is desirable for Sweden's climate which can see a wide range of temperatures.



Triaxial Shear Strength Test

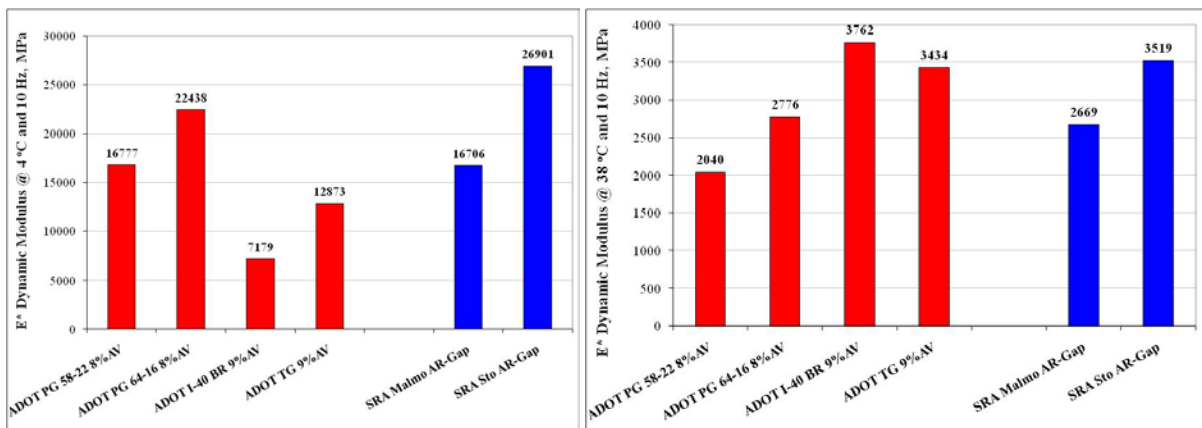
The ASU laboratory test results of the three SRA mixtures indicated that the polymer mixture had the highest cohesion parameter; thus exhibited the highest resistance of the three mixes to shear stress. The angle of internal friction is similar for the three mixes which should be expected given the similar aggregate gradation. In comparison to ADOT mixtures, the SRA AR mix has the highest cohesion parameter but a slightly lower angle of internal friction. This indicates that the SRA AR modified binder plays a significant role in resisting shear stress. However, the lower angle of internal friction of the SRA mix may be the result of less particle contact given the larger aggregate gradation.



E* Dynamic (Complex) Modulus E* Test

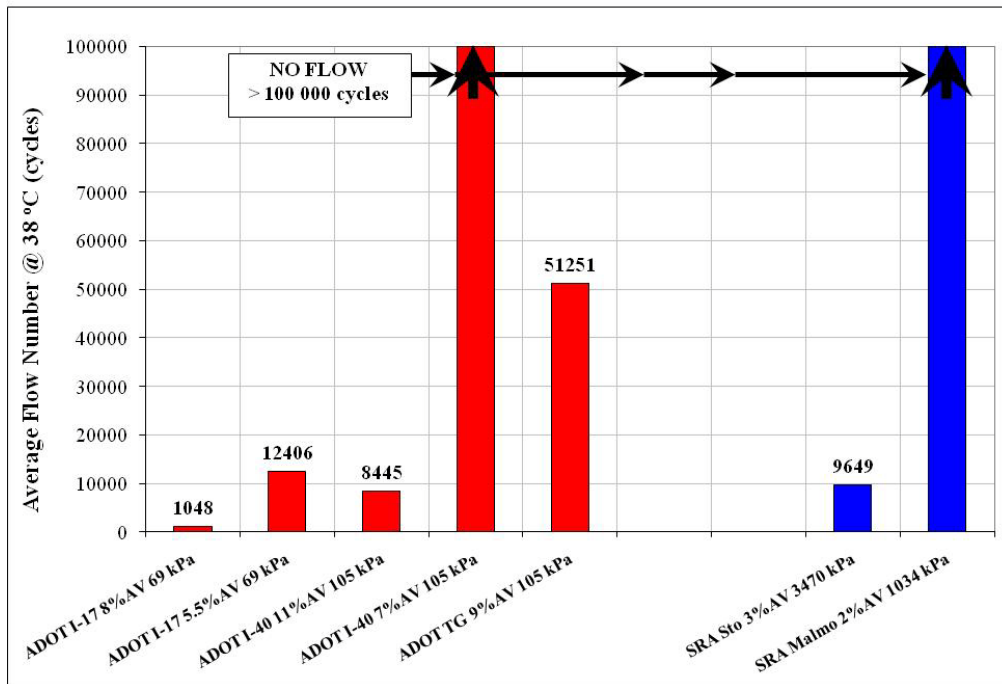
The reference mix showed higher modulus values than the other two mixtures at lower temperatures (-10 and 4.4 °C), while the trend was reversed with further increase in temperature from 21.1 to 54.4 °C. Lower moduli values at cold temperatures are desirable for better resistance of thermal cracking. In comparison, an increase in moduli values as the temperature increases is desirable for better resistance to permanent deformation. The polymer modified mixture exhibited the lowest moduli values at low temperatures and the highest moduli values at high temperatures. The asphalt rubber mixture E* values were very similar to the polymer modified mixture values. In both low and high temperature cases, the asphalt-rubber and polymer modified mixtures had better performance than the reference mix.

In comparison to ADOT AR mixtures, the SRA AR mixture had much higher modulus values at 4 °C. This indicates the SRA mixtures may be more susceptible to thermal cracking than the ADOT mixtures. At 38 °C, the SRA AR mixture had comparable or higher modulus values than similar ADOT mixtures. It is expected that the SRA AR mixture will have similar resistance to permanent deformation when compared to the ADOT mixtures.



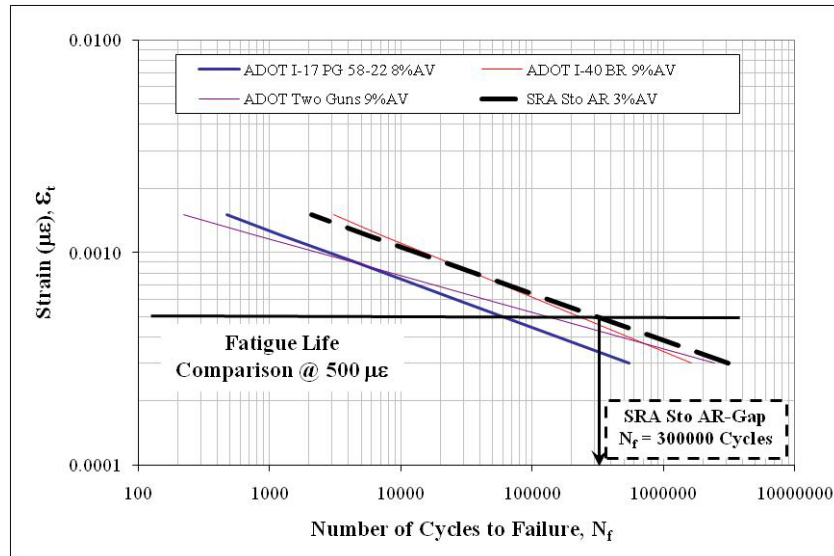
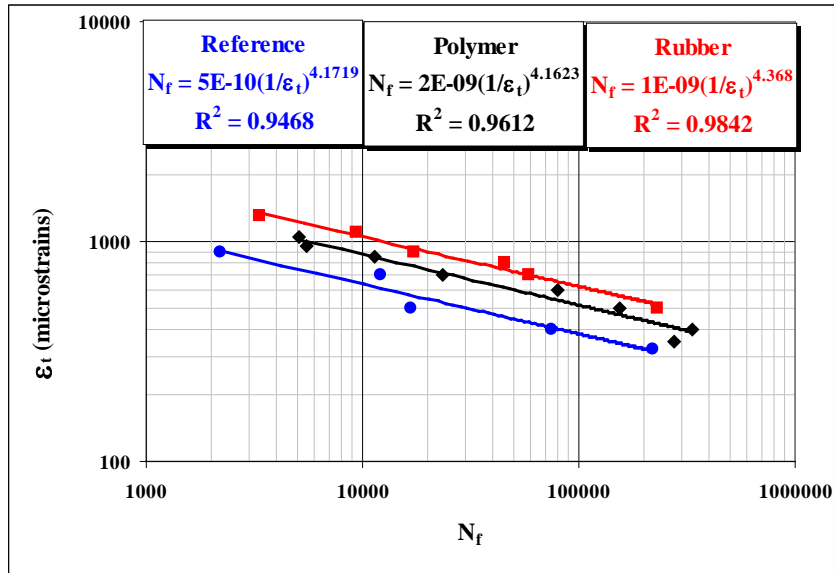
Repeated Load Permanent Deformation Flow Number Test

The unconfined average Flow Number (FN) values for the polymer and rubber mixtures were about 10 times higher than the reference mix. All three mixtures tested at 138-kPa confinement stress condition had no tertiary flow. The rubber mixtures at both unconfined and confined stress conditions had 20-50% higher strains at failure than the reference and polymer mixtures. From these results, it can be summarized that the polymer and rubber mixtures will have good resistance to permanent deformation. However the high strain at failure measured for the asphalt-rubber mix indicates a highly stable mixture. The accompanying chart shows an unconfined flow number test comparison of the SRA AR mixes to typical ADOT AR mixtures. It can be observed that the SRA AR mixture included in this study falls within the range of typical ADOT mixtures.



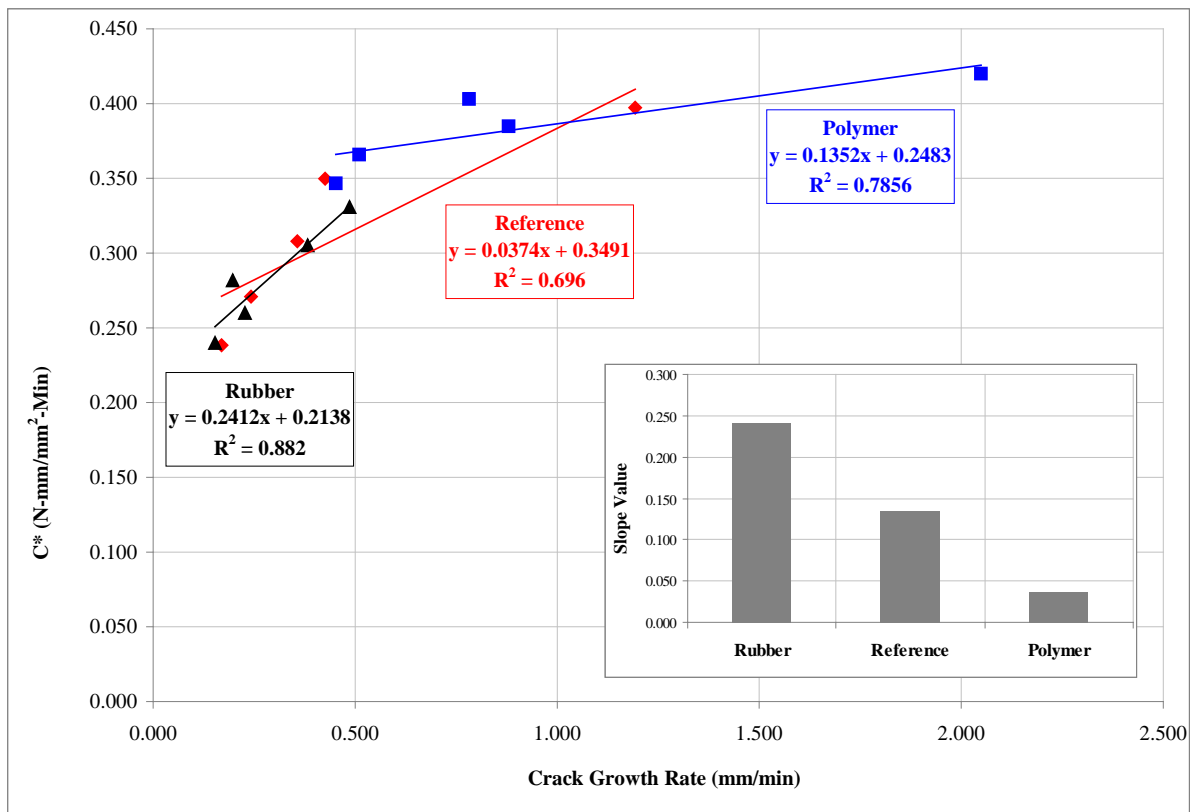
Fatigue Cracking Test

Of the three mixtures included in this project, the asphalt-rubber mix exhibited the best fatigue life (higher cycles until failure) than the polymer and reference mixes, as shown in the below figure. The second figure below shows a fatigue comparison with ADOT mixtures. An example comparison is drawn at 500 micro-strain, and the SRA AR mixture had the best fatigue life, requiring the most cycles until fatigue cracking failure.



Crack Propagation Test – C* Integral

Test results indicated that the asphalt-rubber mix provided the highest potential of resistance to crack growth as determined by the slope values obtained amongst the three mixtures. During testing, the polymer mix required a higher force to initiate cracking, but once the initial crack originated, the crack grew more rapidly than in the other two mixes. The total energy required to propagate the crack was analyzed for all the three mixes at different load displacement rates and it was found that the asphalt-rubber mix samples required higher energy to form and propagate a crack up to 60 mm.



Indirect Diametral Tensile Test (IDT)

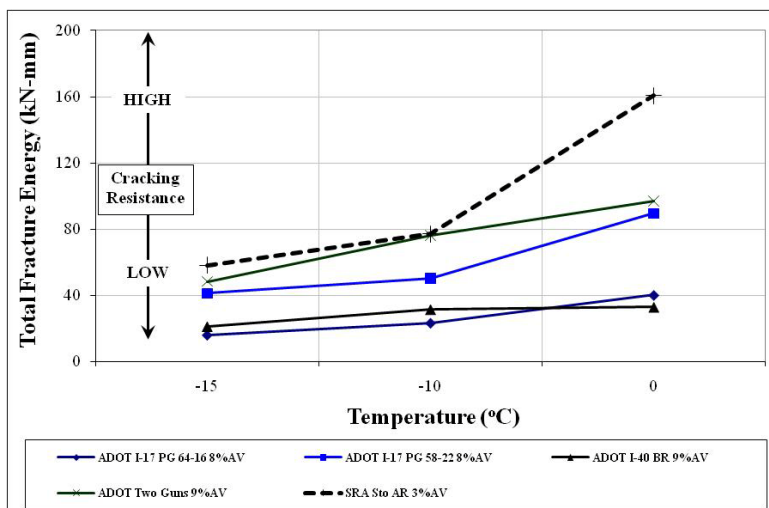
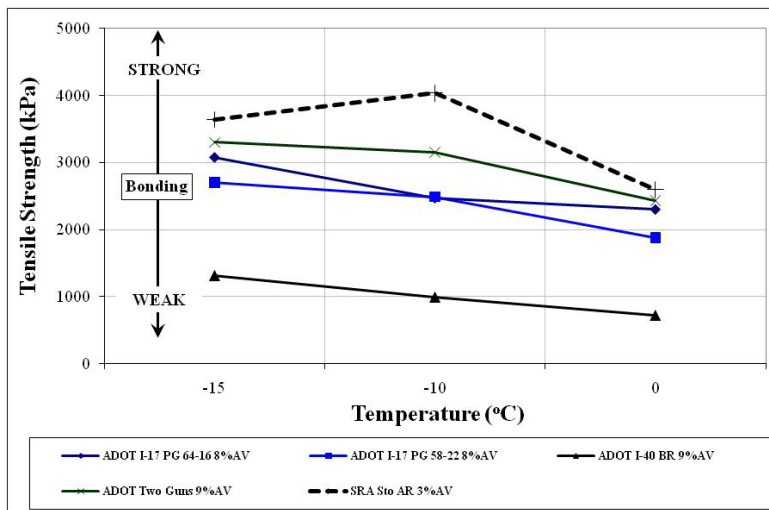
Higher creep compliance values were exhibited by the rubber mixture, followed by reference and polymer mixtures. Since the creep compliance is inversely proportional to the stiffness modulus, it is desirable to have high creep compliance when thermal cracking is of concern.

In terms of tensile strength, the polymer mix had 10 to 20% higher values than the reference mix; while the strength of the rubber mix was lower (20-30%) than the polymer and reference mixtures.

However, the rubber mixture required the highest peak energy at failure when compared to the other two mixtures at 0 °C (~1.6 times higher), but very similar values were observed at the other lower temperatures.

Finally, the rubber mixture required the highest total fracture energy of the mixes 0 °C (~1.5 times higher), and about 10% higher values at the other two lower temperatures. At the lowest temperature (-15 °C), it was observed that the rubber mixture had higher energy values than the other two mixtures. Generally, less thermal cracking should be expected as the energy at failure or fracture energy is increased. These test results indicate that the asphalt-rubber mixture will require the most energy to fully develop thermal cracking. These results correspond well with the C* line integral test results where the asphalt-rubber mixture required the most energy of the three mixtures to propagate a 60 mm crack.

In comparison to ADOT mixtures, the SRA AR mixtures exhibited a much higher tensile strength than typical ADOT mixtures at 0, -10 and -15 °C. Also, in comparison to ADOT mixtures, the SRA AR mixture required the highest total fracture energy to develop thermal cracking in the specimens. This trend was most evident at 0 °C but at -10 and -15 °C, the SRA mixture shows similar results to the ADOT Two Guns 9% AV mixture, which is also designed for a cold climate location in northern Arizona. Given the colder climate design considerations of Sweden, this trend is not surprising. The SRA mixtures should be designed to have better cold climate thermal cracking resistance than mixtures placed in Arizona. Overall, the SRA AR mixture should have good cold weather thermal cracking performance.



SUMMARY

This executive summary provided a brief overview of the performance test results obtained on the Swedish Road Administration asphalt mixtures. Detailed descriptions of the tests, procedures, and results can be found in the accompanying technical report. In addition, this summary provided a comparison of SRA asphalt-rubber test results to typical mixtures used by the Arizona Department of Transportation.