Evaluation of Mechanistic Properties of Hot-Mix Asphalt Containing Recycled Shingles (RAS)

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Green Pavement Technologies - Overview

- Green pavement technologies include innovative pavement materials, as well as pavement rehabilitation methodologies
- On the pavement rehabilitation side, green technologies have included pavement recycling such as:
  - Hot in-place recycling
  - Cold in-place recycling
  - Full depth reclamation
  - CIREAM
  - Stabilization of soils
  - Concrete pavement rubbilization
  - Concrete pavement restoration

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Introduction

- Green pavement technologies have been successfully used for more than 30 years

- **Materials**
  - RAP and RAS in HMA
  - Crumb rubber in HMA
  - Recycled concrete as aggregates
  - Steel slag, crushed glass and ceramic as HMA aggregates

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Introduction

It is generally agreed that the main purpose for the use of green technologies is to make pavements more sustainable in terms of:

- **Economics**: cheaper material sources; in situ vs. plant materials; use of waste and by-products
- **Environment: r**educed use of scarce resources; lower GHG; lower energy usage; less trucking; less waste generation
- **Social:** faster construction/less disruption; more public money for other projects

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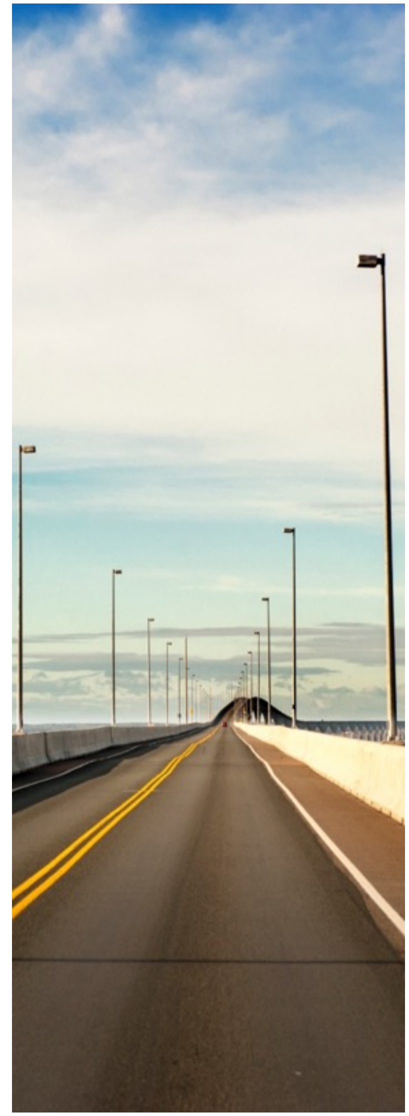
Pavement Sustainability

Effectively designed sustainable pavements should aim to:

- Minimize the use of non-renewable natural resources
- Reduce energy and fuel consumption during construction and operation
- Minimize GHG emissions
- Reduce waste generation
- Reduce frequency and extent of maintenance interventions
- Improve health and safety and reduce risk
- Lower cost
- Ensure a high level of user comfort and safety
- Provide long term value for money



Recycled Asphalt Shingles (RAS)

Roofing shingles consist of:

- High quality fine angular aggregate and filler (50-60%)
- Asphalt cement (20-30%)
- Fibers (5-15%)
- Source
  - Post-manufactured
    - PG High Temp Grade: 115-140
  - Post-consumer
    - PG High Temp Grade: 160-215

Process

- Industrial grinder
- Typically 100% passing from 12.5 mm (1/2 inch)
- Finer grind performs better
- Sorting by hand needed for QC on supply to remove nails, wood, paper, etc.

Image source: Williams et al, 2013

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Introduction

- 10 million tones of post consumer shingles go to landfill in the U.S. every year
- Represents 3% of municipal waste
- ~20 states have specifications for use of RAS in HMA
- Typically allow 5% post-manufactured or 3% post-consumer in asphalt mixes

References

- AASHTO MP 23-14: Standard Specification for Reclaimed Asphalt Shingles in Asphalt Mixtures
- AASHTO PP 78-14: Standard Practice for Design Considerations When Using Reclaimed Asphalt Shingles (RAS) in Asphalt Mixtures

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Evaluation

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Project Objectives

- Evaluate the feasibility of adding RAS and RAP to asphalt mixes used in Vancouver
  - 80,000 tons of shingles to landfills each year
- Sustainability analysis
- Evaluate laboratory performance
  - Determine method of performance evaluation
  - Select mix types
  - Addition should not compromise pavement performance
- Determining the optimum amount of RAS and RAP
  - Performance
  - Cost effectiveness

Mix Evaluation

- Laboratory performance evaluation
- Mechanistic properties

  a) Rutting resistance

  b) Dynamic modulus

  c) Resilient modulus

  d) Susceptibility to low temperature cracking

  e) Fatigue endurance
- Asphalt cement testing
  - PG grade verification

Mix Additives

- Post-consumer shingles used
- RAS ground to 6-7 mm chips
- RAS added to mixes by weight of mix
- Rejuvenator (Cyclogen) used to soften the asphalt cement in mixes containing recyclables
- Conventional City of Vancouver binder course mix used with PG 64-22

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Ground RAS Gradation

Sieve Size (mm)	% Passing
19	100
12.5	99.7
9.5	99.2
4.75	86.0
2.36	80.3
1.18	58.8
0.6	30.0
0.3	15.0
0.15	4.9
0.075	0.5

Trial Mixes

Mix	RAS (%)	RAP (%)	Rejuvenator* (%)
1	-	-	-
2	-	15.0	0.3
2B	-	15.0	-
3	3.0	-	0.3
4	5.0	-	0.3
5	3.0	15.0	0.3
6	5.0	15.0	0.3

Laboratory Evaluation Procedures

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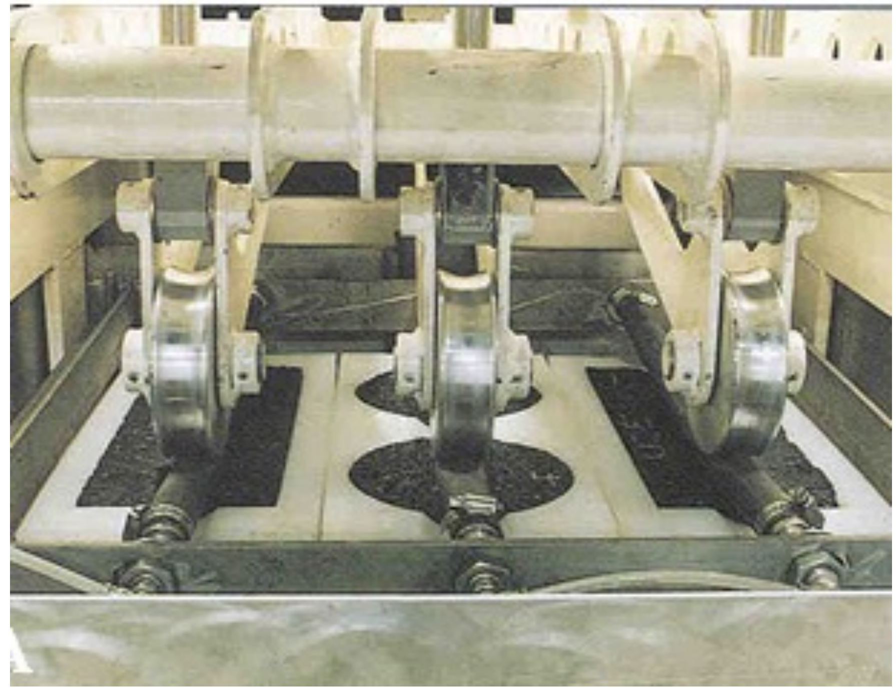
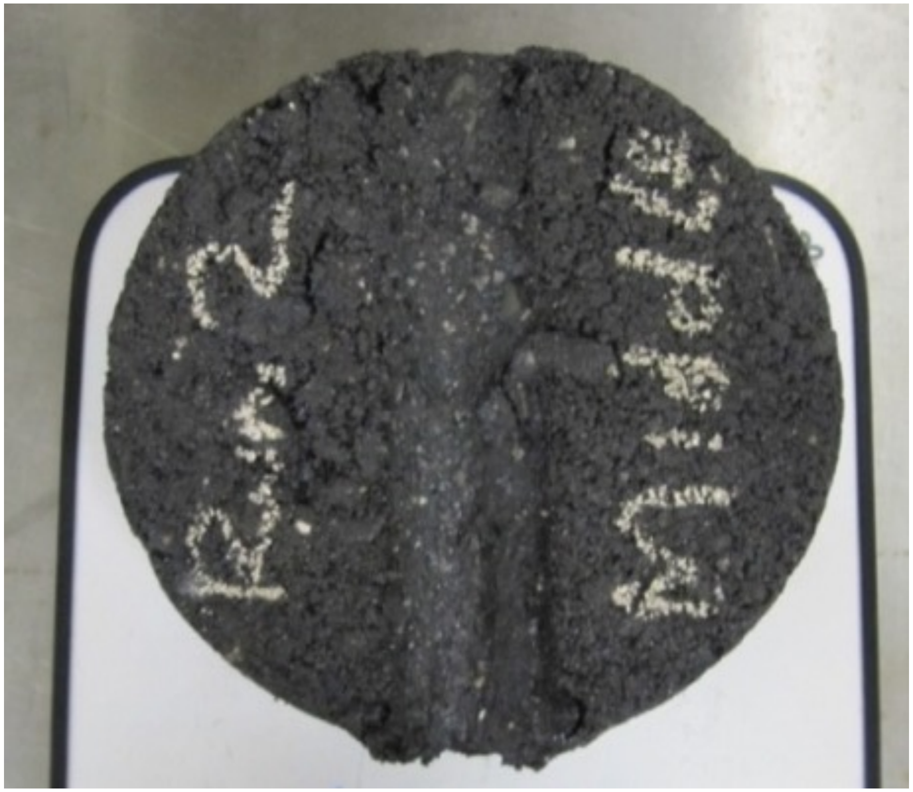
APA Testing

- Asphalt Pavement Analyzer (APA)
- AASHTO TP 63-09
- Loaded wheel runs across sample on inflated rubber hose
- Samples tested in air at 58˚C (136ºF)
- Wheel runs for 8,000 cycles (one cycle is two passes)

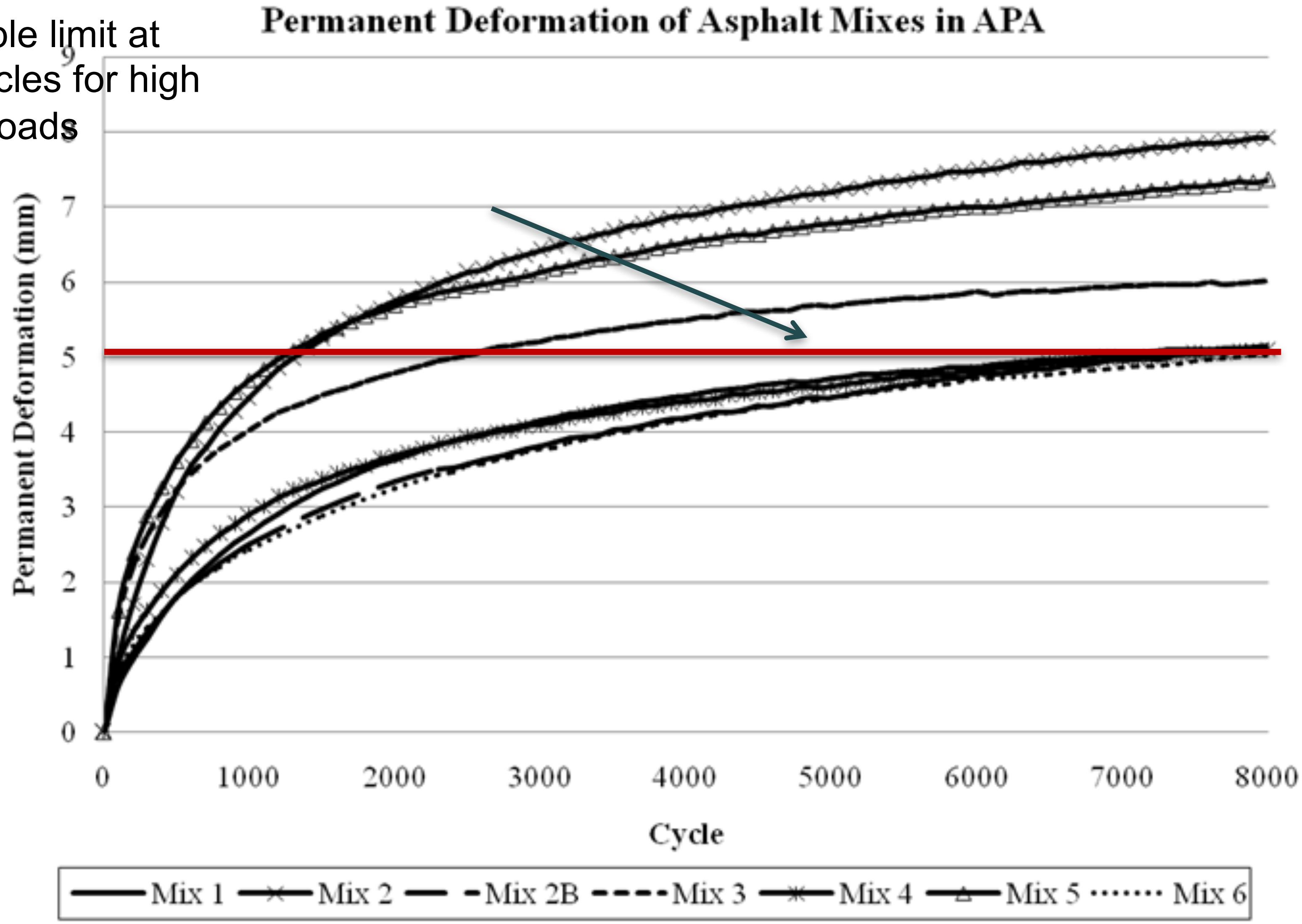


Observed Rutting



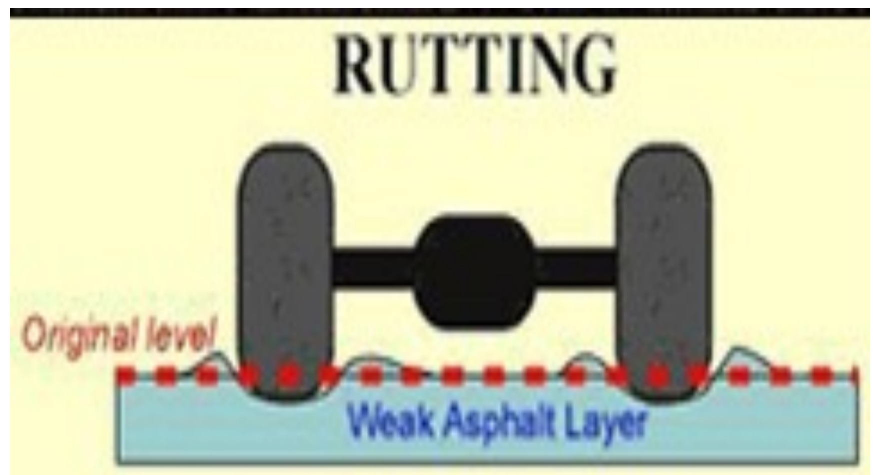
APA Results

Acceptable limit at 8,000 cycles for high volume roads



Rutting Resistance

Number of Cycles	Average Permanent Deformation in APA (mm)						
	Mix 1	Mix 2	Mix 2B	Mix 3	Mix 4	Mix 5	Mix 6
8,000	5.1	7.9	5.1	6.0	5.1	7.4	5.0



Findings From APA

- Best rutting resistance for Mix 1, 2B, 4 and 6
- Mixes 2 and 5 had most deformation indicating substantial affect of rejuvenator with lower amount of RAS
- Mixes 4 and 6 showed that when rejuvenator was added, rutting resistance could be brought to original level by adding enough RAS (i.e. 5%)

Mix	RAS (%)	RAP (%)	Rejuvenator* (%)
1	-	-	-
2	-	15.0	0.3
2B	-	15.0	-
3	3.0	-	0.3
4	5.0	-	0.3
5	3.0	15.0	0.3
6	5.0	15.0	0.3

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Dynamic Modulus Testing

- Evaluates modulus of mix under various temperatures and traffic loads
  - 14, 39, 70, 99 and 129˚F
  - 25, 10, 5, 1, 0.5 and 0.1 Hz
- AASHTO TP 62-07
- Higher frequencies = fast moving traffic
- Lower frequencies = slow moving or static traffic
- Modulus is a function of the stress and strain experienced

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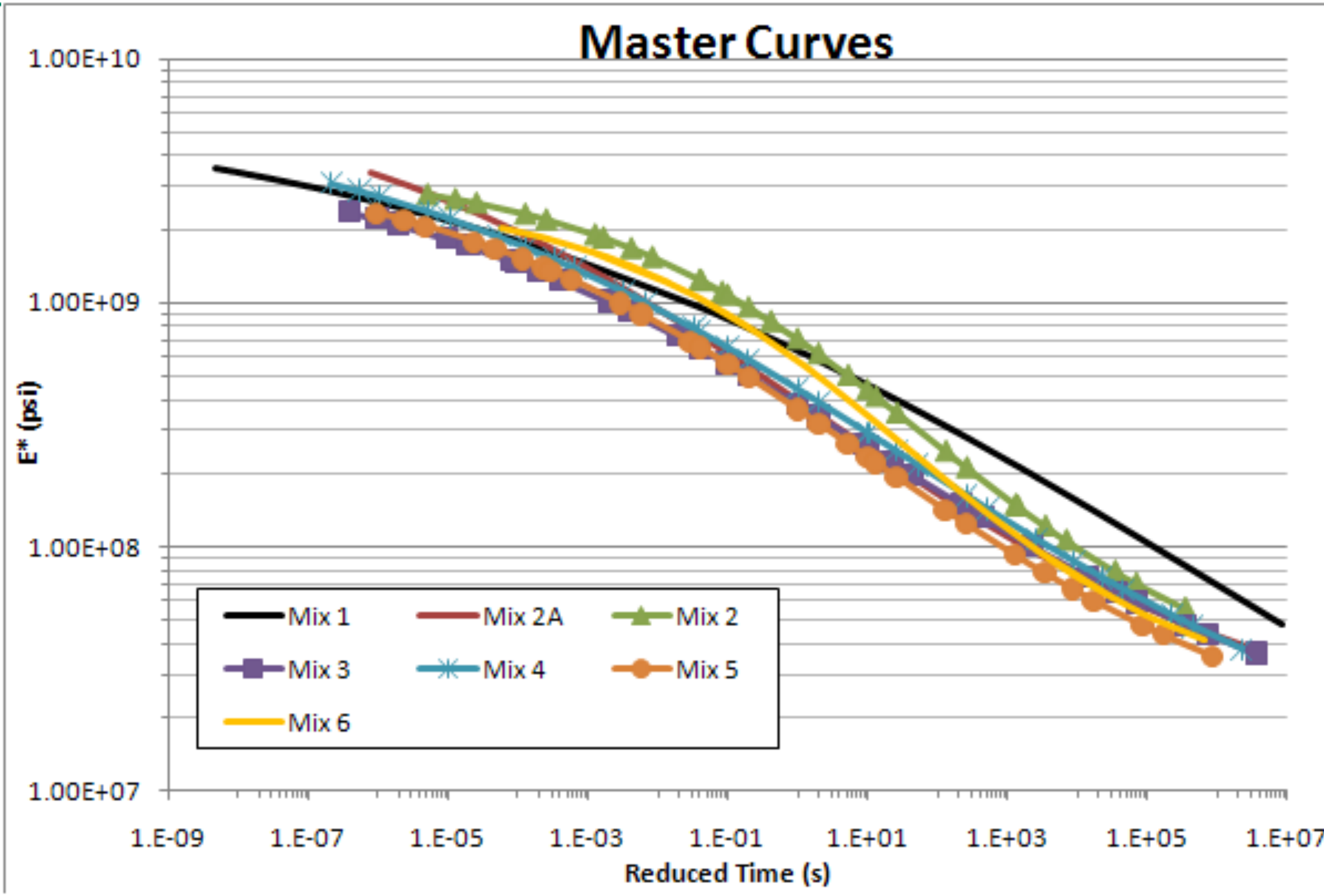
Dynamic Modulus Results



Dynamic Modulus Results

Test Temperature: 70˚F

Dynamic Modulus - MPa

Frequency (Hz)	Mix ID						
	1	2	2B	3	4	5	6
25	5,400	5,000	8,900	4,400	5,200	4,600	7,000
10	6,100	4,400	7,700	4,100	4,800	3,900	6,100
5	6,000	3,800	6,700	3,600	4,200	3,400	5,400
1	4,400	2,600	4,700	2,500	2,900	2,300	3,800
0.5	4,000	2,300	4,100	2,300	2,600	2,100	3,500
0.1	3,200	1,800	3,000	1,800	2,100	1,700	2,600

Dynamic Modulus Results

Test Temperature: 129˚F

Dynamic Modulus - MPa

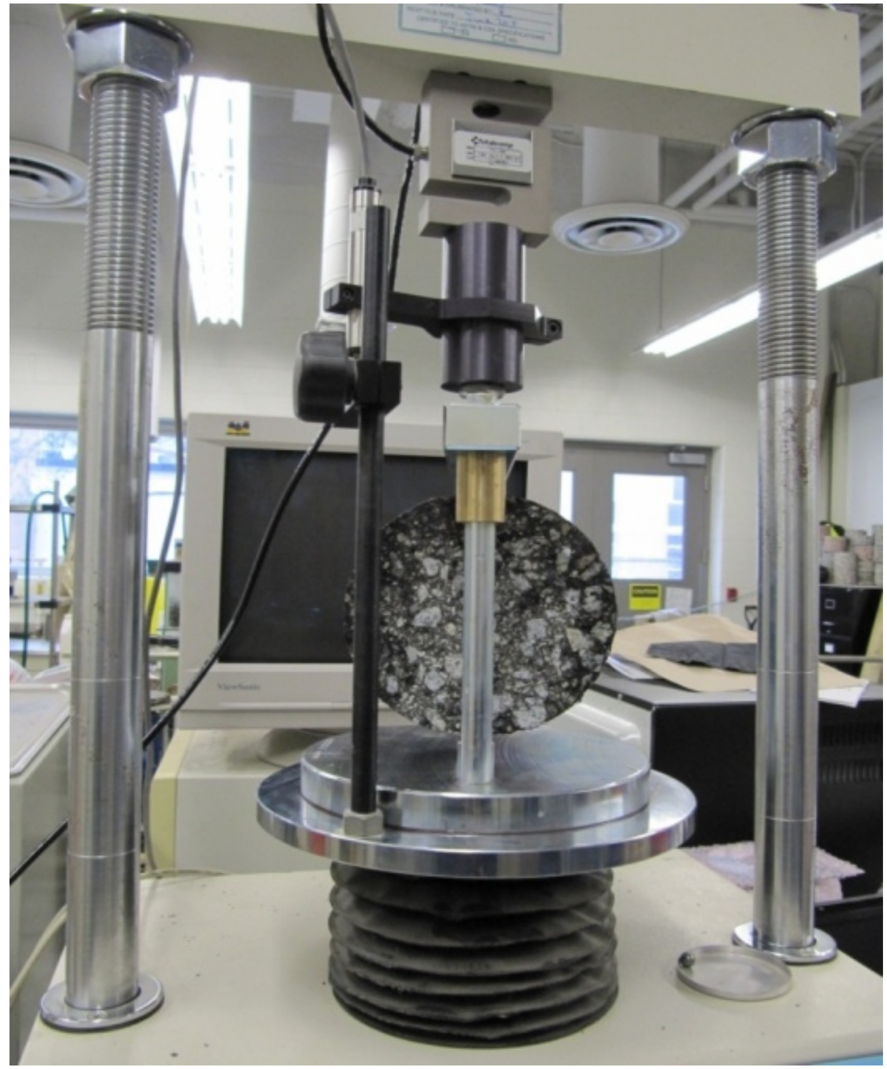
Frequency (Hz)	Mix ID						
	1	2	2B	3	4	5	6
25	940	560	1,140	560	620	590	730
10	750	440	840	450	520	470	570
5	640	390	690	400	450	400	480
1	470	320	500	310	340	310	360
0.5	420	300	450	290	320	290	330
0.1	350	270	380	260	280	250	270

Dynamic Modulus

- Mixes 1, 2B and 6 had the highest dynamic modulus values
- Mixes 2, 3 and 5 exhibited the lowest modulus values
- When rejuvenator was added to mixes their modulus dropped significantly
- When 5% RAS was added to the mixes (along with rejuvenator) the mix modulus increased again, close to the original level

Resilient Modulus Testing

- Indirect Tensile Strength (IDT) testing carried out to determine loading for resilient modulus
  - ASTM D 7369-09
- All mixes were tested at 18 kN load
- Resilient modulus involves loading samples along the vertical diametral plane
  - ASTM D 6931-07



Resilient Modulus Testing

- Both vertical and horizontal movement were measured
- Each sample was tested twice with a 90˚ rotation in between

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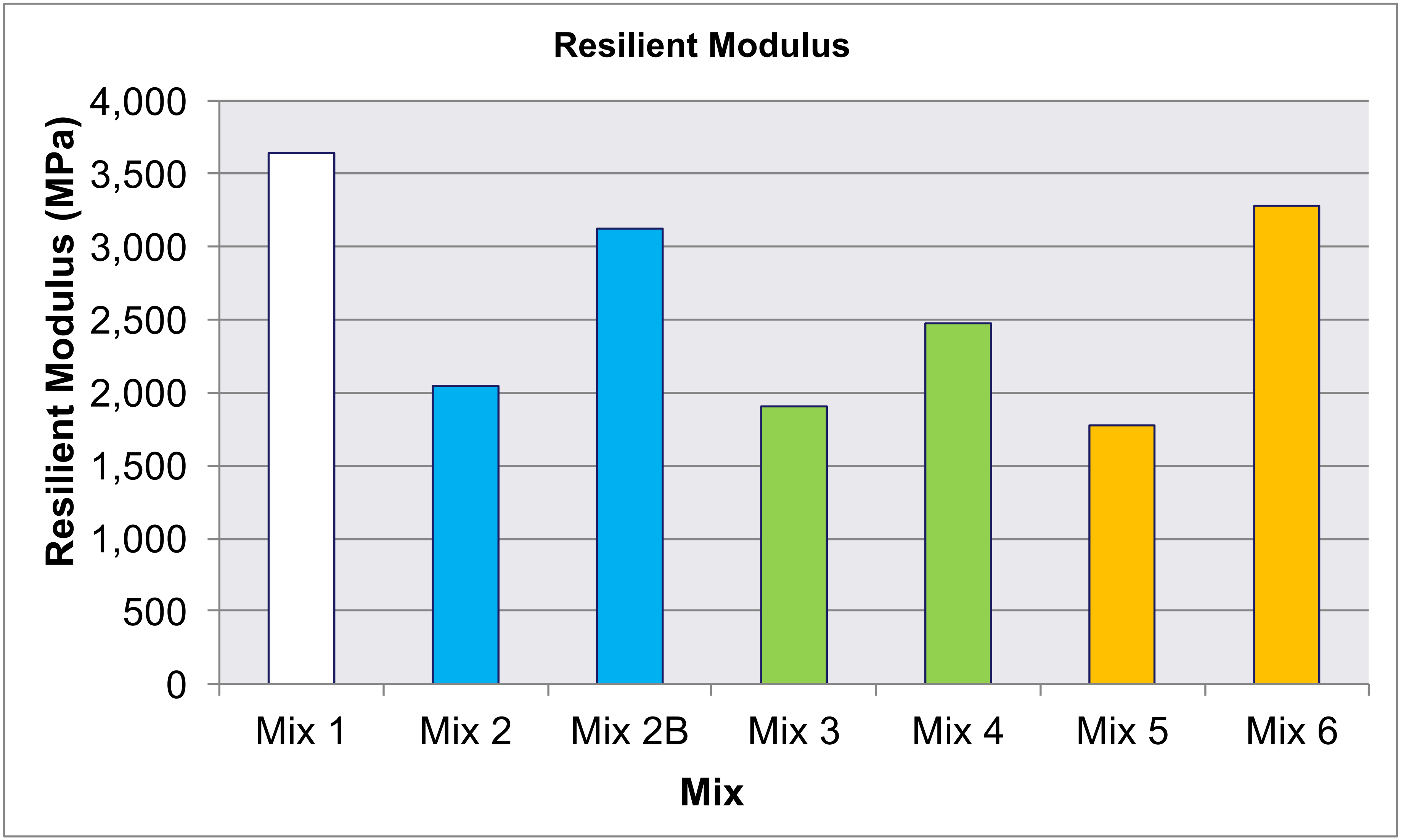
Resilient Modulus Results



Resilient Modulus Trends

- Mixes 1, 2B and 6 had the highest resilient modulus values
- Mixes 2, 3 and 5 had the lowest resilient modulus values

Mix	RAS (%)	RAP (%)	Rejuvenator* (%)
1	-	-	-
2	-	15.0	0.3
2B	-	15.0	-
3	3.0	-	0.3
4	5.0	-	0.3
5	3.0	15.0	0.3
6	5.0	15.0	0.3

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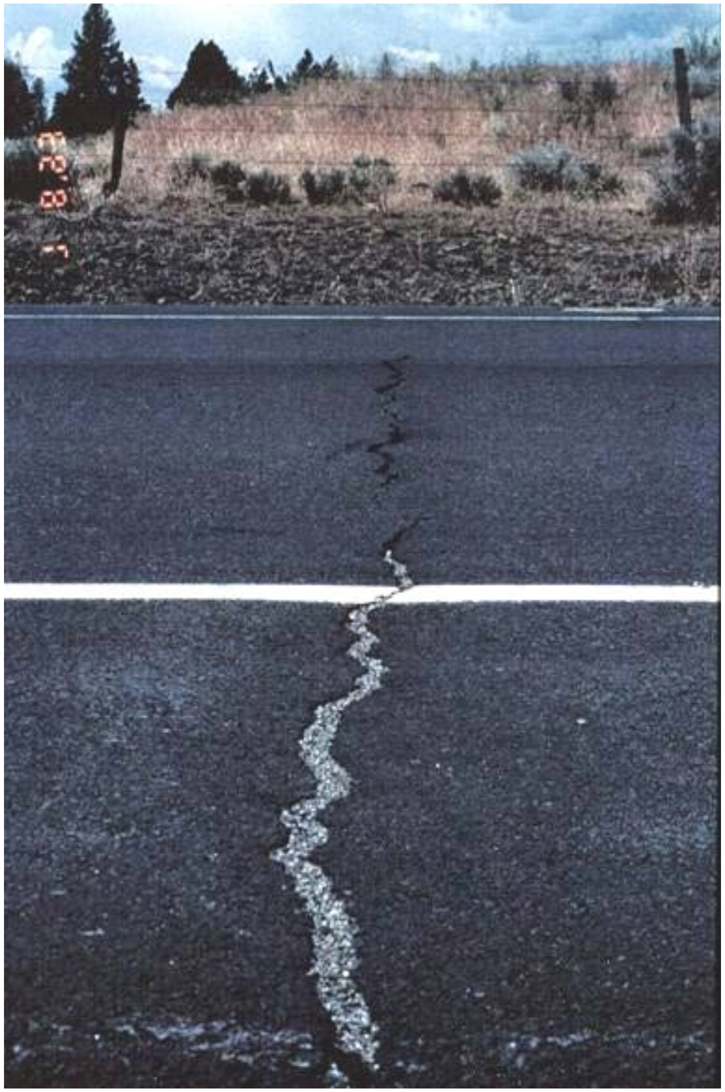
TSRST Testing

- Temperature Stress Restrained Specimen Test
  - AASHTO TP10
- Used to evaluate low temperature cracking susceptibility



TSRST Testing

- Samples held at constant length and cooled at a rate of -50˚F/hour
- As the temperature drops, the sample is maintained in its original length until failure
- The force is monitored and recorded

TSRST Results

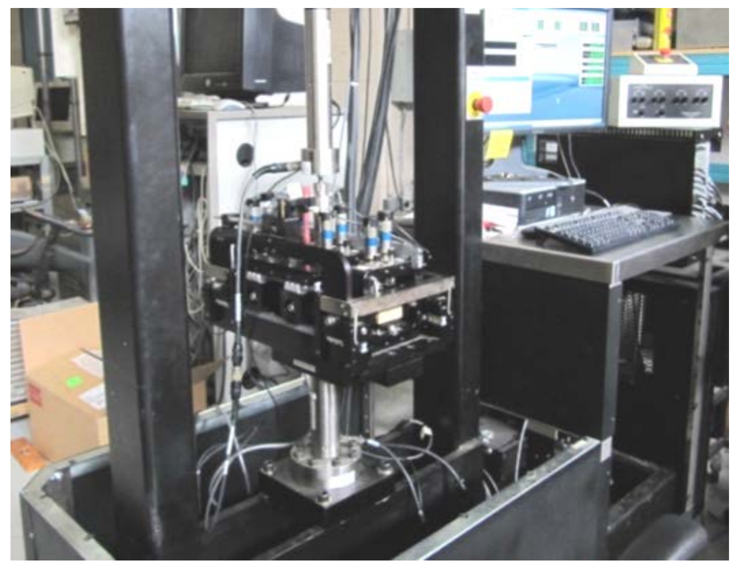
Mix #	Fracture Stress (MPa)	Average Failure Temp (˚F)
Mix 1	2.680	-24
Mix 2B	2.600	-23
Mix 3	2.280	-31
Mix 4	**1.800**	-27
Mix 5	2.460	-28
Mix 6	**1.750**	-24

TSRST Results

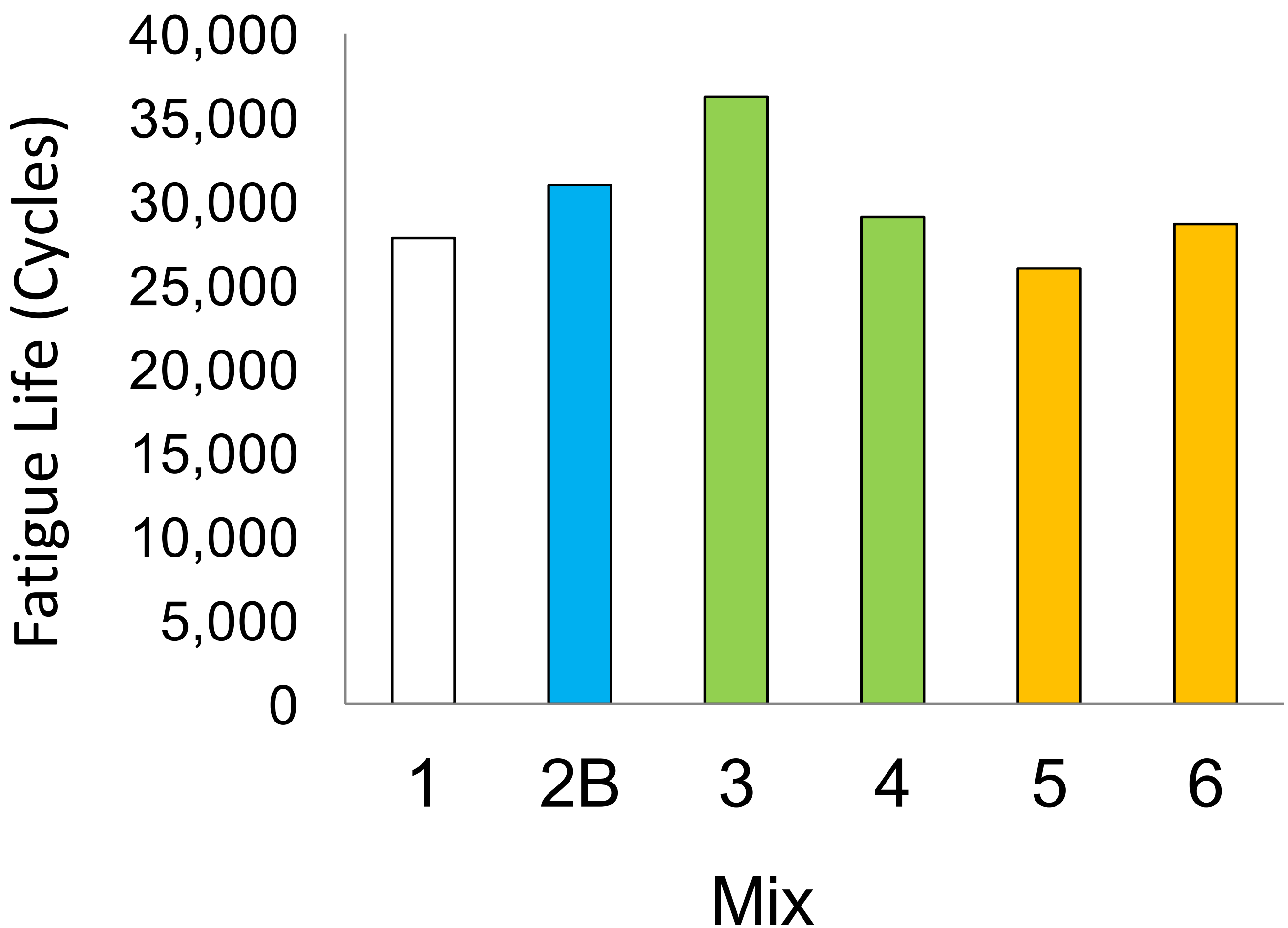
- Narrow range of failure temperatures for all mixes
- Failure temperatures well below the temperatures in the Vancouver area
- Rejuvenator improved low temperature fracture performance
- Mixes 4 and 6 had lower fracture stress resistance
- All mixes acceptable for this criteria

Fatigue Testing

- Four Point Flexural Bending Beam Test
  - ASTM D 7460-08
- Cyclical loading applied at constant strain until stiffness decreases significantly
  - Strain 400 µε
  - Temperature 70˚F
  - Fatigue life - failure point when stiffness decreases by 50%



Fatigue Testing Results



Fatigue life

- Mix 3 the best
- Other five mixes exhibited similar fatigue endurance

Asphalt Cement Testing

- PG grade verification
- Virgin asphalt cement PG 64-22
- Asphalt cement recovered from three mixes only
- Increase of high (good) and low (bad) temperature ends in RAS and RAS/RAP mixes

Mix	High Temp Range (ºC)	Low Temp Range (ºC)
4	78	-19
5	70	-20
6	79	-16

Analysis and Summary

Analysis

- Mixes 1 and 2B (conventional)
- Good rutting resistance
- Highest dynamic and resilient modulus
- Good TSRST results (low temp cracking)
- Mixes 4 and 6
- Rejuvenator and 5 % RAS
- Mix 6 also had 15 % RAP
- Exhibited similar performance to conventional mixes but lower low temperature (fracture stress) resistance

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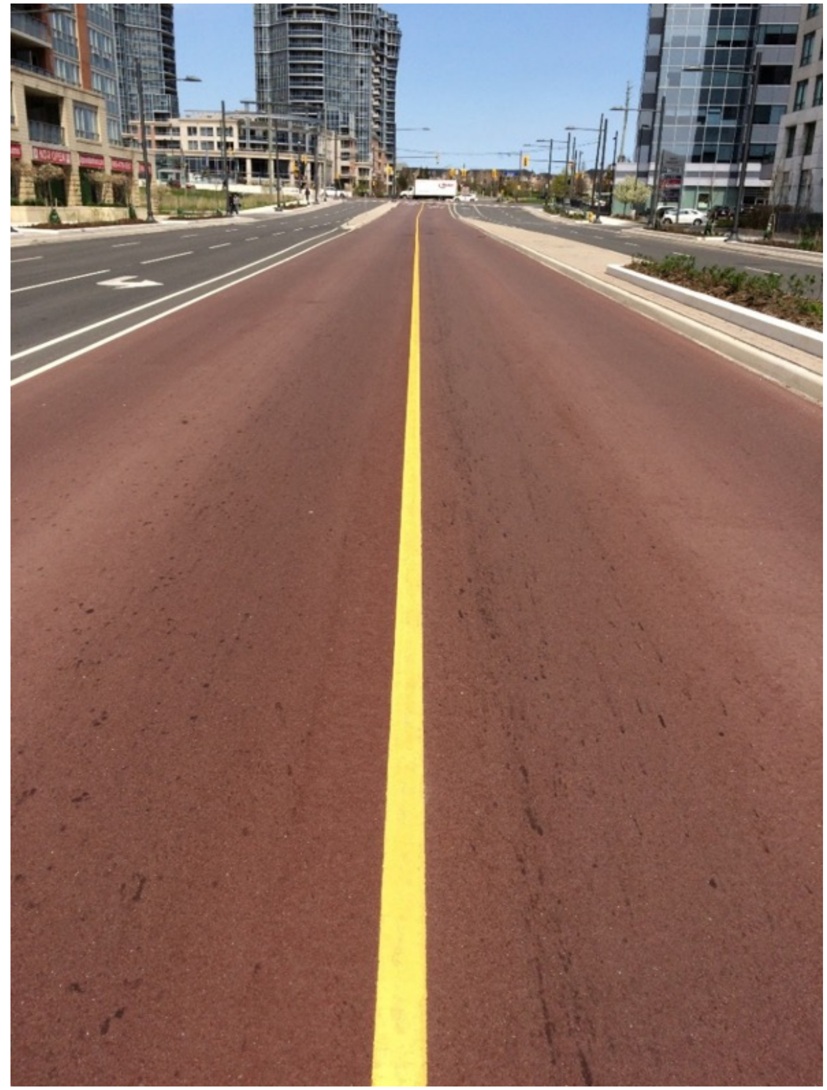
Analysis

- Mixes 3 and 5
- Rejuvenator and 3 % RAS
- Mix 5 also had 15 % RAP
- Exhibited larger rutting depth
- Lower modulus values
- Good TSRST results
- Mix 6 - the optimum for the Vancouver area where low temperature is not an issue



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Premature Cracking with Excess RAS

Excessive RAS

Cracking of new binder course that contained high percentage of RAS

Excessive RAS

Repairs of new binder course that incorporated high amount of RAS

RAS Fibers Recovered in Extraction

Potential Performance Issues

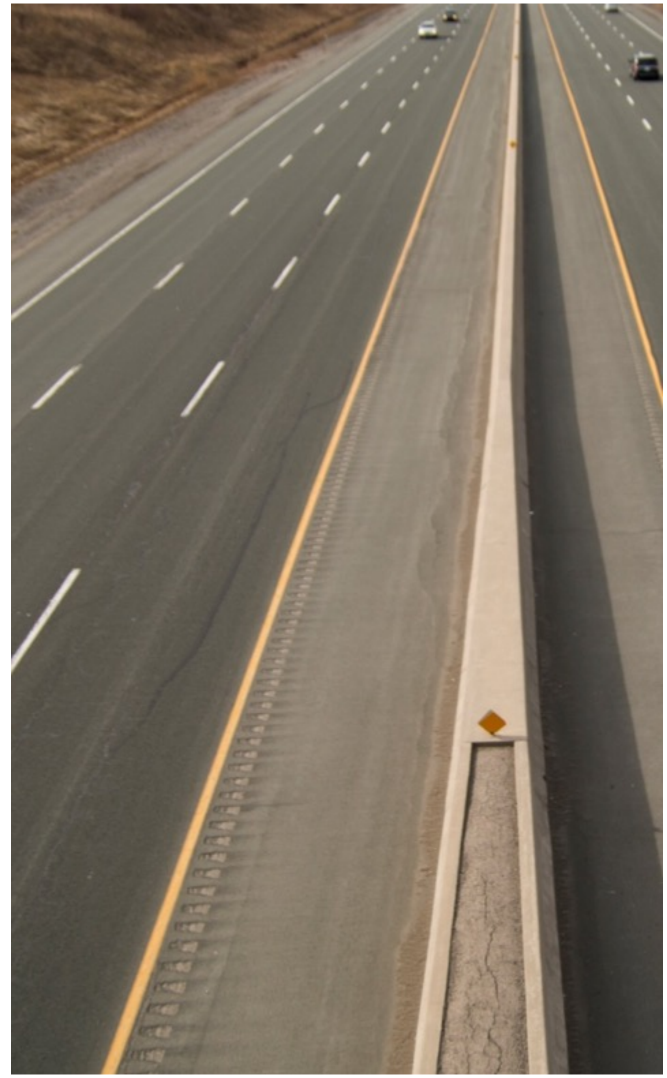
- In low temperature areas RAS to be added to HMA with caution due to potential for cracking and raveling
- Consider:
  - % RAS and %RAP together
  - Using softer asphalt cement grade with higher ratios
  - Using asphalt cement softener (rejuvenator)

Summary

1. 15% RAP does not negatively affect mix performance

2. When rejuvenator added to mixes, rutting resistance and stiffness dropped

3. When 5% RAS was added, mix stiffness and rutting resistance increased to the original level



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Summary

4. It is necessary to achieve a correct ratio between rejuvenator and RAS

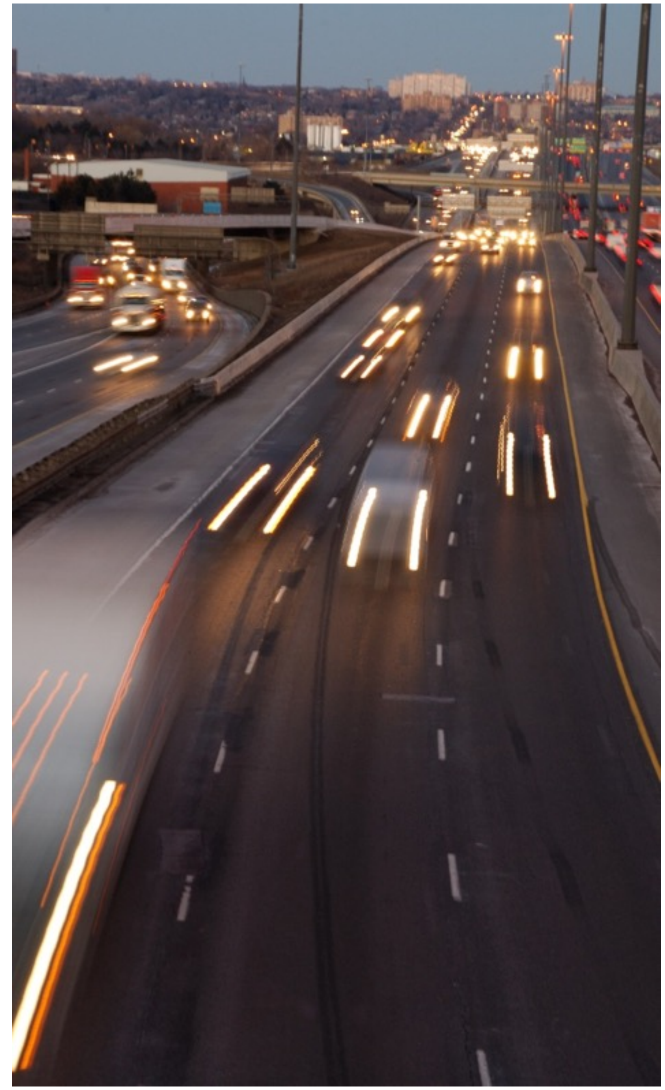
5. Testing shows that some asphalt mixes containing RAS can perform similarly to conventional mixes

6. Optimum mix for Vancouver

   - 15 % RAP
   - 5 % RAS
   - Appropriate amount of rejuvenator

7. **For Ontario (or NE U.S.) this will not work. 3% RAS considered maximum for Ontario (without PGAC adjustment).**

8. Appropriate addition of RAS reduces cost and does not impair performance



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General Comments

- For every 1% of RAS the low temp grade increases by 1.9ºC
- For every 1% addition of RAP, low temp increases by 0.3%
- Rule of thumb – max 20% RAP or 3% RAS before requiring AC grade lowering
- This corresponds to a 14% binder replacement with RAS and a 20% binder replacement with RAP
- Study showed mixes with coarser RAS had more cracking than finer RAS
- Cost savings using RAS ~$7/ton at 5% RAS
- RAS or RAS/RAP blends improve rutting resistance but reduce low temperature cracking performance

Questions?

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