Recycling Asphalt Shingles in Asphalt Pavement

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INTRODUCTION

- Recycling of asphalt pavements extensively used over the world.
- Asphalt roofing shingles also contain asphalt binder.
- Minnesota DOT has sponsored several research studies on recycling shingles
- In 1996, Mn/DOT adopted specification allowing up to 5% Manufacturer Waste Shingle Scrap (MWSS).
- Recent research showed that > 90% roofing waste in Twin-Cities represents potentially recyclable Tear-Off Shingle Scrap (TOSS).
- TOSS asphalt binder has considerably aged, becoming significantly more brittle at low temperatures.
- At the beginning of 2010, Mn/DOT released a draft specification proposing a limit of up to 5% for TOSS.

INTRODUCTION

- Recent research focused on low temperature properties of asphalt mixtures containing different amounts of RAP, MWSS and TOSS.
- Study performed in conjunction with work conducted by MnDOT

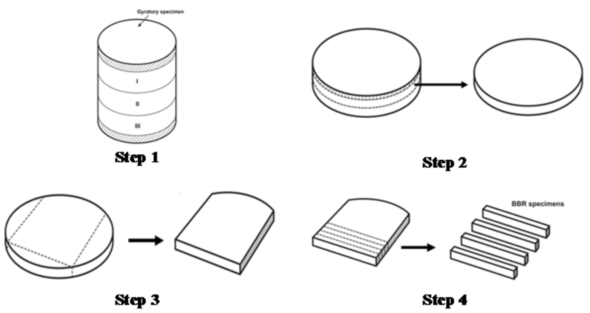
Objectives

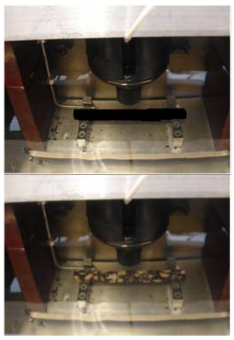
- Investigate influence of RAP and RAS addition on creep stiffness, *m*-value, thermal stress and critical temperature.
- Obtain and compare spatial information of internal structure of asphalt mixtures and determine noticeable changes
- Back-calculate binder creep stiffness using Micromechanical and Analogical Models
- Evaluate environmental impact of shingles recycling

MATERIAL AND TESTING

Test Methods for low temperature characterization of asphalt mixtures

NCHRP IDEA 133 (*Marasteanu et al.*, 2009)





Testing performed according to *AASHTO T 313*-02 and using higher loads due to the higher stiffness of the mixtures.

ASPHALT MIXTURES TESTING MATRIX

Mix		Recycled Material			Binder PG		VMA	VFA	Air Voids
ID	**Description**	**RAP (%)**	**TOSS (%)**	**MWSS (%)**	**58-28**	**52-34**	**%**	**%**	**%**
1	PG 58-28 Control	0	0	0	x		15.9	76.6	3.7
2	15% RAP	15	0	0	x		15.2	72.9	4.1
3	25% RAP	25	0	0	x		15.3	73.0	4.1
4	30% RAP	30	0	0	x		15.0	45.4	3.7
5	15% RAP 5% MWSS	15	0	5	x		15.6	75.0	3.9
6	15% RAP 5% TOSS	15	5	0	x		15.9	77.2	3.6
7	25% RAP 5% TOSS	25	5	0	x		15.4	73.9	4.0
8	25% RAP 5% MWSS	25	0	5	x		14.8	72.5	4.1
9	25% RAP 5% TOSS	25	5	0		x	15.8	71.8	4.5
10	25% RAP 5% MWSS	25	0	5		x	15.0	73.5	4.0
11	25% RAP 3% TOSS	25	3	0	x		15.5	75.3	3.8
12	25% RAP 3% MWSS	25	0	3	x		15.3	73.7	4.0
13	15% RAP 3% TOSS	15	3	0	x		16.1	79.4	4.0
14	15% RAP 3% MWSS	15	0	3	x		16.1	73.8	4.2
15	10% RAP 5% TOSS	10	5	0	x		16.6	75.0	4.2
16	15% RAP 5% TOSS*	15*	5	0	x		16.7	77.2	3.8
17	5% TOSS	0	5	0	x		16.6	76.3	4.0

Binder BBR Creep Stiffness testing performed on extracted binder from mixtures 2, 3, 5, 6, 7, and 8 (MnDOT)

Analysis of Variance: Mixture Creep Stiffness and *m*-value

Response: Creep stiffness S e *m*-value @ t=60s

- Factors: RAP, TOSS, MWSS, Binder PG, Temperature
- Four groups of asphalt mixture considered based on RAP, TOSS, MWSS, Binder PG.

Mixture ID	**RAP %**	TOSS %	MWSS %	Binder PG	Description Statistics
1	**0**	0	0	58-28	Control
2	**15**	0	0	58-28	Test
3	**25**	0	0	58-28	Test
4	**30**	0	0	58-28	Test

Group 1

Mixture ID	RAP %	**TOSS %**	**MWSS %**	Binder PG	Description Statistics
2	15	**0**	**0**	58-28	Control
5	15	**0**	**5**	58-28	Test
6	15	**5**	**0**	58-28	Test
13	15	**3**	**0**	58-28	Test
14	15	**0**	**3**	58-28	Test

Group 2

Mixture ID	RAP %	**TOSS %**	**MWSS %**	Binder PG	Description statistics
3	25	**0**	**0**	58-28	Control
7	25	**5**	**0**	58-28	Test
8	25	**0**	**5**	58-28	Test
11	25	**3**	**0**	58-28	Test
12	25	**0**	**3**	58-28	Test

Group 3

Mixture ID	RAP %	**TOSS %**	**MWSS %**	Binder PG	Description statistics
7	25	**5**	**0**	58-28	Control
9	25	**5**	**0**	52-34	Test
Mixture ID	RAP %	**TOSS %**	**MWSS %**	Binder PG	Description statistics
8	25	**0**	**5**	58-28	Control
10	25	**0**	**5**	52-34	Test

Group 4

Analysis of Variance: Mixture Creep Stiffness and *m*-value

Group 1 (0, 15, 25, 30 % RAP, no shingles)

- Increase in stiffness for 25% and higher % RAP and decrease in m-value for all RAP percentages.

Group 2 (15% RAP + TOSS or MWSS)

- Decrease in stiffness for 3% TOSS and increase in stiffness for 5% MWSS. Neither TOSS nor MWSS affect m-value.

Group 3 (25% RAP + TOSS or MWSS)

- TOSS and MWSS do not affect stiffness (25% RAP dominates properties). Increase in TOSS negatively correlated to m-value.

Group 4 (25% RAP + TOSS or MWSS + 58-28 or 52-34)

- Decrease in stiffness for 5% TOSS and softer binder. No binder effect for MWSS.

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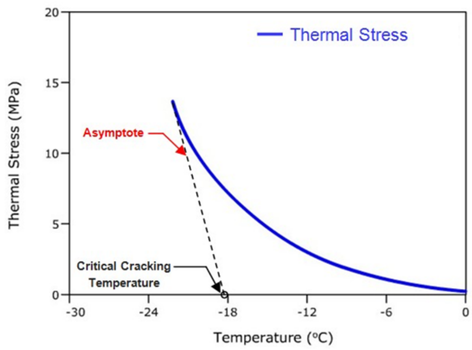
ANOVA: Thermal Stress & Critical Temperature

Critical Temperature - Single Asymptote Procedure (*Shenoy,2002*)



- Response: Thermal stress @ T=-18°C and critical temperature
- Factors: RAP, TOSS, MWSS, Binder PG
- Same four groups of asphalt mixture

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ANOVA: Thermal Stress & Critical Temperature

Group 1 (0, 15, 25, 30 % RAP, no shingles)

- RAP content statistically significant and positively correlated with thermal stress and critical temperature.

Group 2 (15% RAP + TOSS or MWSS)

- Significant increase in thermal stress and in critical cracking temperature only for 3% TOSS.

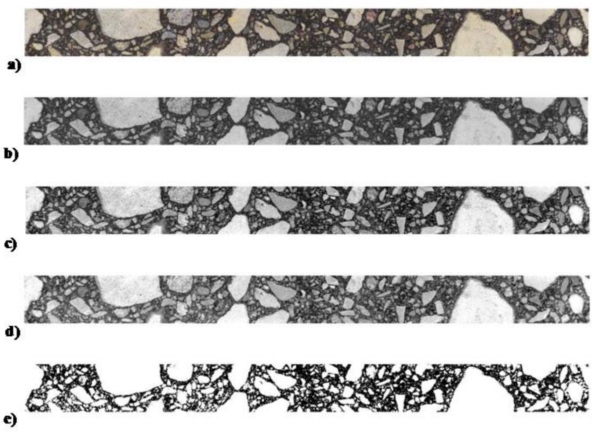
Group 3 (25% RAP + TOSS or MWSS)

- Significant increase in thermal stress when TOSS or MWSS at 3%. Critical temperature increase as shingle content increases.

Group 4 (25% RAP + TOSS or MWSS + 58-28 or 52-34)

- Using softer binder negatively correlated with thermal stress.

DIGITAL IMAGE PROCESSING



Original image 300dpi

Gray scale

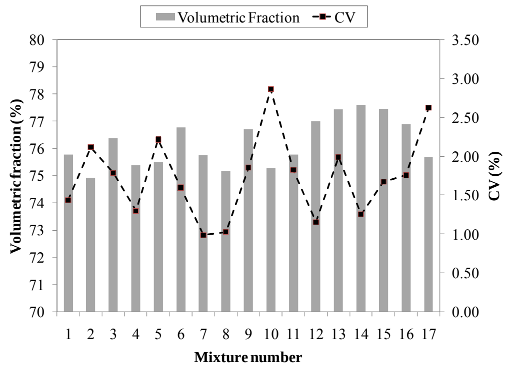
enhance contrast between two phases by histogram equalization

Noise reduction spatial filter

Gray scale to binary image (threshold= 0.35)

DIGITAL IMAGE PROCESSING – Volume Fraction

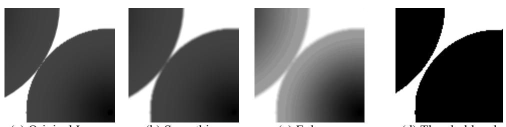
Mixture ID	Volumetric Fraction %	CV %
1	75.8	1.43
2	74.9	2.12
3	76.4	1.78
4	75.4	1.30
5	75.5	2.21
6	76.8	1.60
7	75.8	0.99
8	75.2	1.03
9	76.7	1.85
10	75.3	2.86
11	75.8	1.83
12	77.0	1.15
13	77.4	1.99
14	77.6	1.25
15	77.5	1.67
16	76.9	1.76
17	75.7	2.62



The 17 asphalt mixture present similar volume fraction

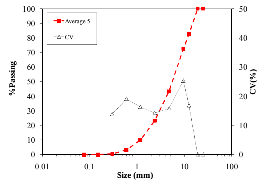
DIGITAL IMAGE PROCESSING – Grain Size Distribution

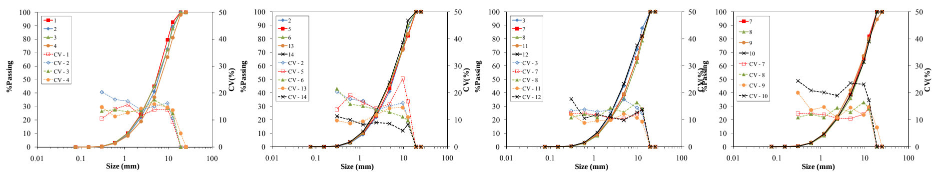
ImageJ v.1.43



(a) Original Image (b) Smoothing (c) Enhance Contrast (d) Threshold and Erosion

Velasquez et al. (2010)



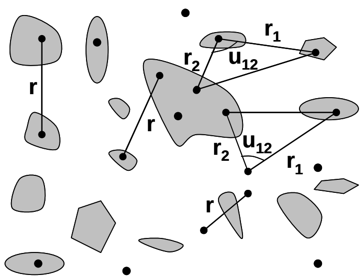


Based on average values of particle size distribution from two-dimensional images, mixtures show similar gradation curves

DIGITAL IMAGE PROCESSING – Correlation Functions

High order microstructural information

n-point correlation functions



Velasquez (2009)

S_1- probability that a randomly selected point in material belong to phase of interest, volumetric fraction of phase

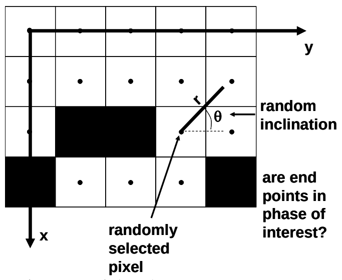
S_2- probability that two points separated distance *r* are located both in phase of interest

S_3- probability of finding all vertices of triangle defined by r_1, r_2 and u_{12} in phase of interest

DIGITAL IMAGE PROCESSING – Correlation Functions

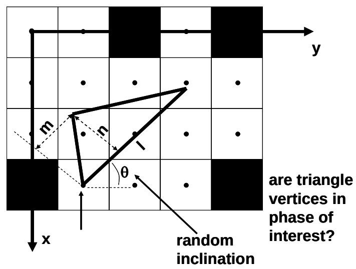
Monte Carlo simulations used to estimate 2- and 3-point correlation functions

2-point correlation function



Velasquez et al. (2010)

3-point correlation function

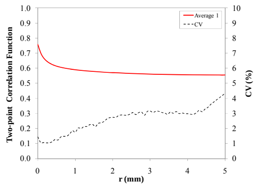


Velasquez et al. (2010)

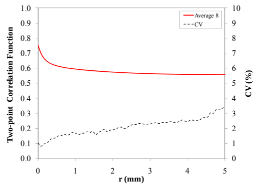
No fluctuation or special pattern were detected by the correlation function investigation

DIGITAL IMAGE PROCESSING – Correlation Functions

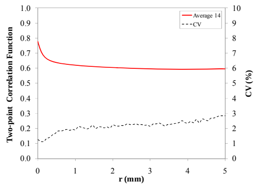
2-point correlation function



Mix 1

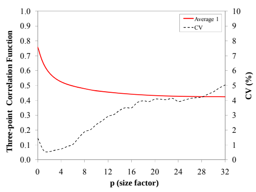


Mix 8

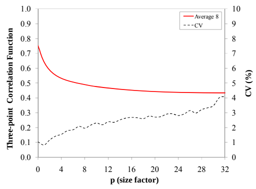


Mix 14

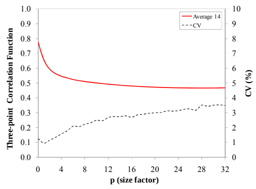
3-point correlation function



Mix 1



Mix 8



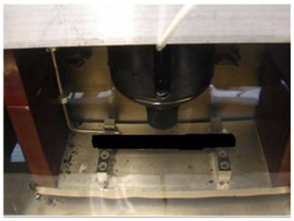
Mix 14

MODELING – Inverse Problem

Evaluation of asphalt binder properties (creep stiffness) using:

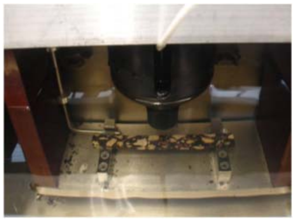
- Experimental data
- Models (micromechanical and analogical)

No chemical extraction



$E_{aggregate}$ +

Inverse Problem



MODELING – Inverse Problem

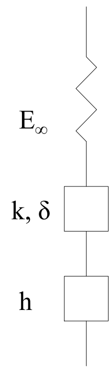
Two models:
- Hirsch model (Christensen et al., 2003)
- ENTPE transformation derived from Huet model (Huet, 1963)

Limited number of mixture analyzed:
- 1, 2, 3, 4, 5, 6, 7 and 8
- Back-calculated values compared with creep stiffness experimentally obtained on extracted asphalt binders (results kindly provided by MnDOT)

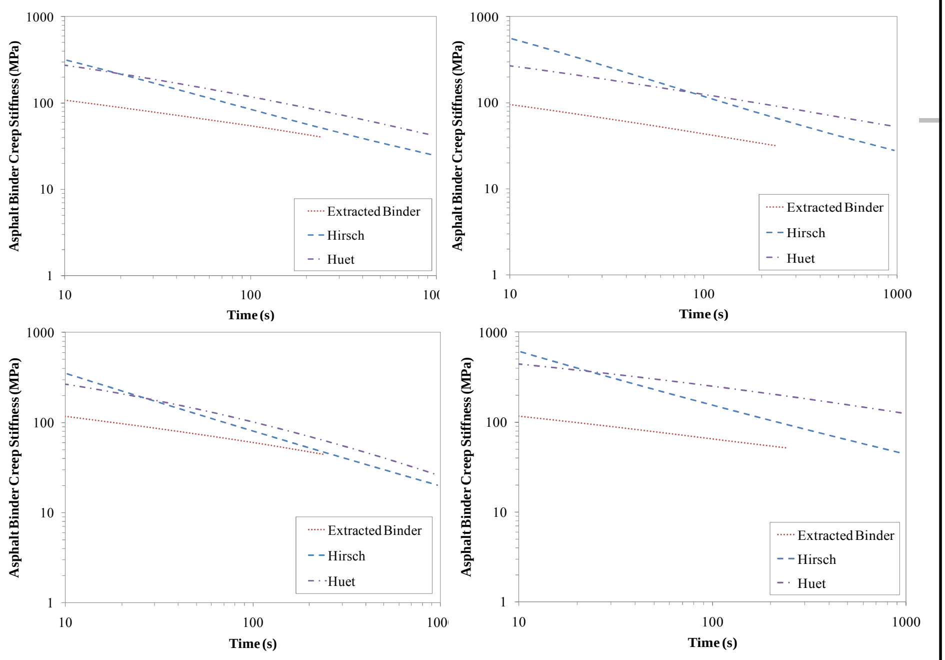
ENTPE Transformation

$$\tau_{binder} = 10^{-\alpha}\tau_{mix}$$

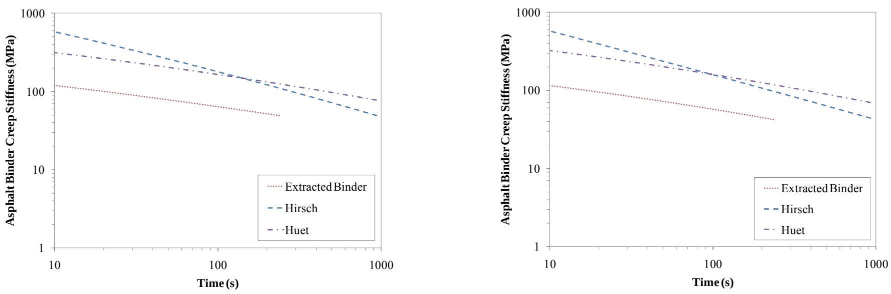
$$S_{binder}(t) = S_{mix}(t/10^{-\alpha})\frac{E_{\infty\_binder}}{E_{\infty\_mix}}$$



$S_{mix}(t)$	creep stiffness of mixture,
$S_{binder}(t)$	creep stiffness of binder,
E_{∞_mix}	glassy modulus of mixture,
E_{∞_binder}	glassy modulus of binder,
τ_{binder}	characteristic time of binder,
τ_{mix}	characteristic time of mixture,
α	regression parameter which may depend on mix design,
t	time.



Binder from Mixture



- Back-calculated binder creep stiffness higher than experimentally measured stiffness on extracted asphalt binders
  - Dry mix?
  - Virgin-aged binder interaction and mix temperature issues?
  - Stiffening effect due to fibers in shingles?

ENVIRONMENTAL ANALYSIS

Life Cycle Assessment (LCA)

1) Goal Definition and Scoping;
2) Inventory Analysis;
3) Impact Assessment;
4) Interpretation

- First two steps considered
- Used Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects (**PaLATE**), an Excel spreadsheet program
- Determined environmental effects of using different quantities of shingles and RAP in pavement

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ENVIRONMENTAL ANALYSIS

Assumptions

- Shingles contribute about 30% asphalt binder of their weight to the mix design
- Use of shingles does not significantly affect performance of asphalt pavement

Calculations

- The potential energy use (MJ) and global warming potential (GPW) (carbon dioxide emissions, Mg of CO_2) for a 1 mile long and 48 foot wide pavement constructed with 5 inches of asphalt mixture and 6 inches of aggregate base

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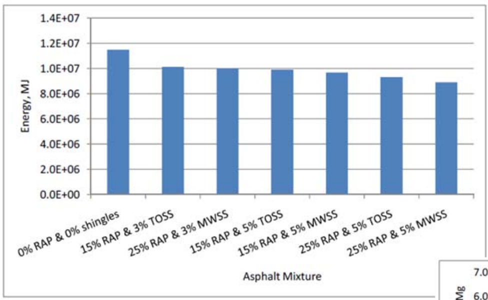
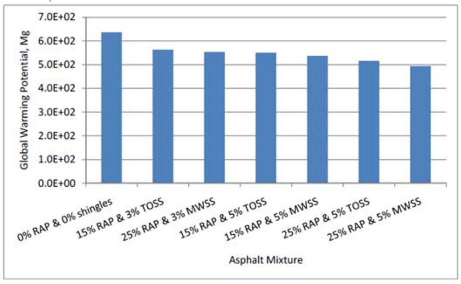
ENVIRONMENTAL ANALYSIS





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ENVIRONMENTAL ANALYSIS

- The maximum reduction is estimated for the mixtures that use the highest amount of recycled materials, 25% RAP combined with 5% recycled shingles.
- The energy reduction is approximately 20% and the global warming potential reduction is approximately 20% as well.
- Using recycled shingles in asphalt pavement construction results in a significant reduction in the amount of shingles that are land filled.
- Effect not considered in the PaLATE calculation (will be done in the future)

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THANK YOU!

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