Effect of Mix Composition and RAP Content on HMA Performance

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1

Introduction

- RP 175 developed a mathematical algorithm for determining a Gyratory Stability (GS) index for asphalt mixtures based on the Servopac gyratory compactor
- The GS index describes the ability of asphalt mixtures to resist rutting
- The GS index is determined during the mix design stage without additional required testing
- The GS index was found to have good correlation with the Flow number and APA rutting tests

2

Introduction

- The current GS index algorithm was developed for the Servopac gyratory compactor
- ITD has adopted the use of Pine gyratory compactor in all districts as well as at headquarter labs. **Therefore**, it is essential to develop a modified mathematical algorithm for Pine Gyratory Compactor
- Furthermore, there is a need to examine the sensitivity of GS index to the **binder** and **RAP contents** in asphalt mixtures

3

Study Goal

- Investigate the Gyratory Stability and or other gyratory compaction indicators to detect the variability of RAP content and binder content in HMA mixes
- Evaluate the effect of mix composition (binder and RAP content) on mix performance

4

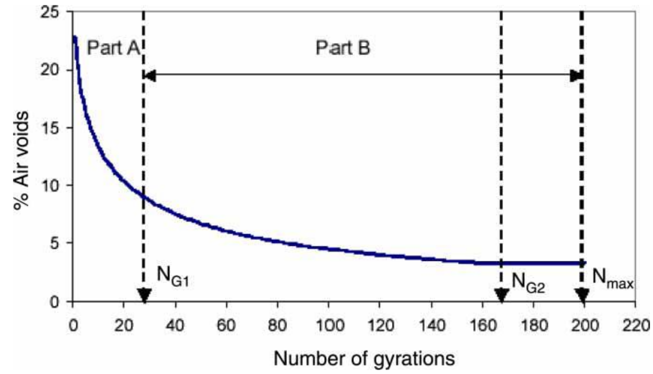
Compaction Curves

Part A

- represents densification of loose mixes (steep change in slope)
- aggregates do not experience significant amount of shear forces

Part B

- **height** does not change significantly and **air voids** relatively **constant**.
- aggregates experience more particle contacts and shear stresses.
- Most of the energy is dissipated through aggregate sliding. Consequently, it increases sample shear strength.
- Therefore, Part B is of interest to calculate the mix stability at ambient temperature



Typical Compaction Curve

5

Compaction Indices

- Various compaction indices were investigated including:
  - Gyratory Stability (GS)
  - Construction Densification Index (CDI)
  - Laboratory Compaction index (LCI)
  - Compaction Force Index (CFI)
  - Locking Point (LP)
  - Compactability Energy Index (CEI)
  - Workability Energy Index (WEI)
- Different studies showed that some indices are more sensitive to the change in mix composition than others.

6

Development of Testing Matrix

Laboratory-Mixed Laboratory-Compacted (LMLC) Test Specimens

Mix type	SP5			
RAP	0%	25%	50%	
RAP Sources	1	2		
AV%	4%	7%		
Aggregate Type	Basalt	River Gravel		
Binder Grade	PG 76-22	PG 64-28	PG 58-34	
Binder Content	OBC	OBC+0.75%	OBC-0.75%	
Anti-Stripping agent	0%	1.50%		

7

Development of Testing Matrix

Plant-Mixed Laboratory-Compacted (PMLC) Test Specimens

Mix #	District	Project ID	Construction Year	Project Key No.	Location
1	1	D1-P1-b1	2020	20794	US-95, JCT SH-53 OIC, UPRP BR Kooteai Co.
2		D1-P1-b3			
3		D1-P1-b3			
4	3	D3-P5-b1	2020	21858	US20/26, SH16 to Linder Road, sh55 Marsing to SR
5		D3-P5-b2			
6		D3-P5-b3			
7	6	D6-P1-b1	2019	19711	US-Ashton Bridge to Dumpground Road
8		D6-P1-b2			
9		D6-P1-b3			
10	1	D1-P2-b1	2020	20795 & 19794	US-95, Garwood Rd GS 4 Frontage Rds & H-57, Priest River Boat Access
11		D1-P2-b2			
12		D1-P2-b3			
13	4	D4-P1-b1	2020	18881	I-84/I-86 Interchange System
14		D4-P1-b2			
15		D4-P1-b3			
16	4	D4-P2-b1	2020	20170	Sh-81, Declo to Burley
17		D4-P2-b2			
18		D4-P2-b3			

8

Task 2: Development of Testing Matrix

Plant-Mixed Laboratory-Compacted (PMLC) Test Specimens

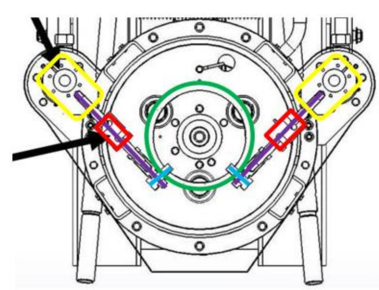
Project #	District	Project ID	Mix Type	Specified Binder PG	Virgin Binder PG	Binder Content Pb (%)	RAP (%)	NMAS	Theoretical Specific Gravity (Gmm)	Bulk Specific Gravity (Gsb)
1	D1	D1-P1	SP3	PG64-28	PG 58-34	5.2	30	1/2”	2.473	2.646
2	D3	D3-P5	SP3	PG64-34	N/A	5.4	0	1/2”	2.430	2.571
3	D6	D6-P1	SP5	PG64-34	PG64-34	5.9	16	3/4”	2.382	2.481
4	D1	D1-P2	SP3	PG64-28	PG 58-34	5.3	30	1/2”	2.476	2.654
5	D4	D4-P1	SP5	PG70-28	N/A	5.1	17	3/4”	2.414	2.559
6	D4	D4-P2	SP3	PG64-28	N/A	6.2	17	1/2”	2.293	2.417

9

Develop Mathematical Algorithm for GS

Load cells measure force vector in the actuator arm.

Actuators apply angle of gyration and drives the gyrations.



Generating a Value for Gyratory Shear
Pine’s Gyratory Shear Measurement

10

Develop Mathematical Algorithm for GS

$$\Sigma M_O = 0$$

$$2R \cdot e\cos(\delta) - (F_g \cdot {}^{h}/_{2}) - ({}^{w}/_{2} \cdot {}^{h}/_{2} \sin(\delta)) = 0$$

Since δ is small angle, we can assume $\sin(\delta) = 0$ and $\cos(\delta) = 1$

$$2R \cdot e - F_g \cdot {}^{h}/_{2} - 0 = 0$$

$$F_g = \frac{2R \cdot e}{{}^{h}/_{2}} = \frac{4R \cdot e}{h} \text{ at half of the sample}$$

So, the shear force (Fg) can be calculated at any gyration number.

$$F_g = \frac{2R \cdot e}{h}$$

$$M = R \cdot e$$

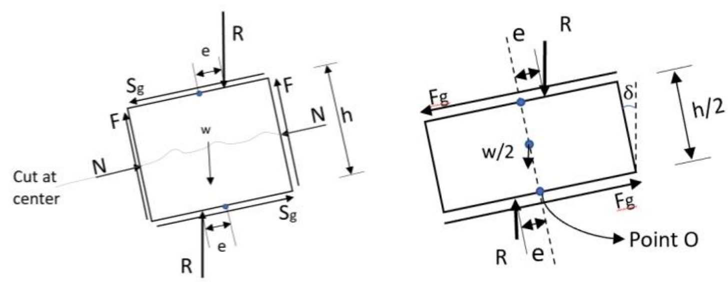
$$\mathbf{F_{gi}} = \frac{\mathbf{2M_i}}{\mathbf{h_i}}$$

The shear stress (Sg) can be calculated an any gyration number as following:

$$S_g = \frac{F_g}{A}$$

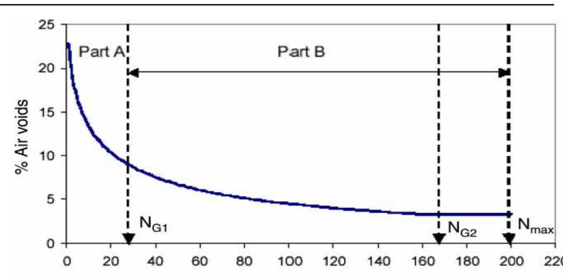
$$\mathbf{S_{gi}} = \frac{\mathbf{2M_i}}{\mathbf{Ah_i}}$$

Calculate shear stress during compaction through conventional static equilibrium analysis



Develop Mathematical Algorithm for GS

GS: the summation of shear energy increments between N_{g2} and N_{g1}



$$GS = \sum_{N_{g1}}^{N_{g2}} \{(2M_i/h_i)(\Delta h_i)\}$$

where:

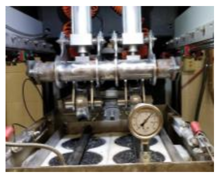
N_{g1} = the number of gyrations at which the second derivative of the air voids function with respect to the number of gyrations is zero. It is assumed that particle contacts are developed at N_{g1}.

N_{g2} = the gyration number corresponding to 96% Gmm

M_i = the moment at each gyration number, which is readily measured and provided in the Pine Excel spreadsheet.

Laboratory Testing

Gyratory Stability and other compaction Indices



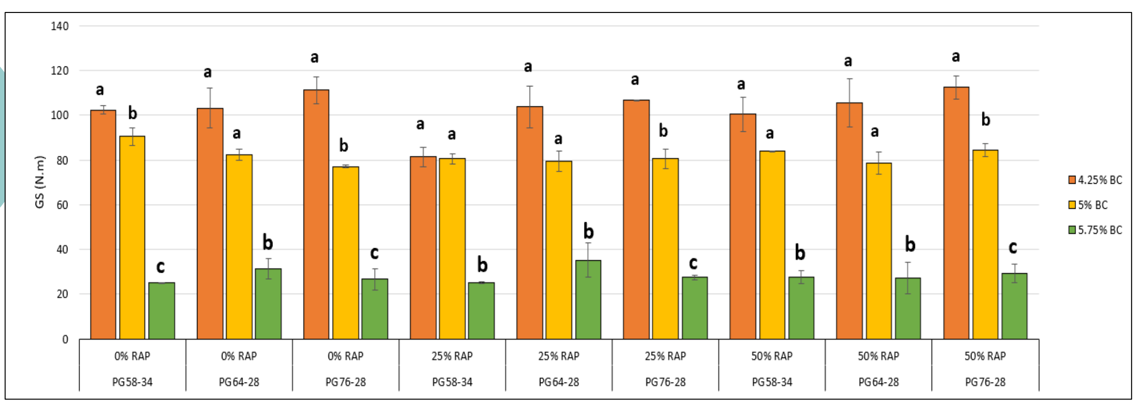
Asphalt Pavement Analyzer (APA-Jr)

Hamburg Wheel Tracking Test (HWTT)

Indirect Tensile Strength (IDT)
Dry and Wet

13

Compaction Indices

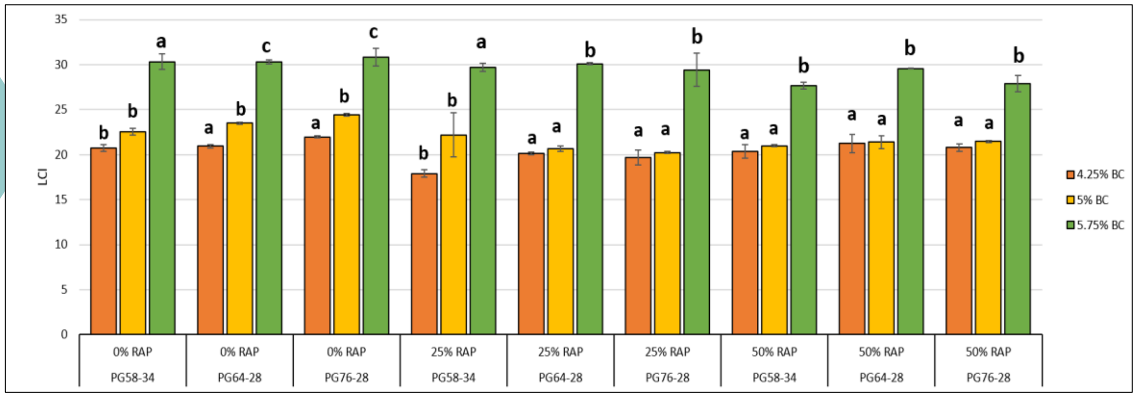


Gyratory Stability (GS) Sensitivity to Different Binder Contents

GS decreased with the increase in binder content; there was statistically significant difference between (dry vs. wet) samples but not between 4.25% and 5% for all cases

14

Compaction Indices

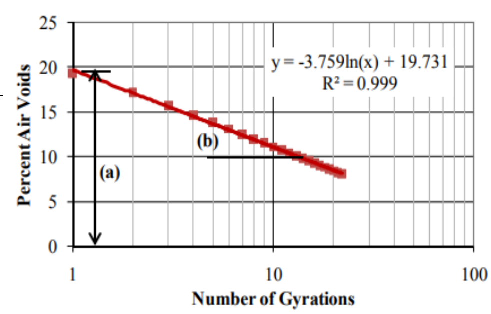


Laboratory Compaction Index (LCI) Sensitivity to Different Binder Contents

LCI increased with the increase in binder content; there was statistically significant difference between (dry vs. wet) samples but not between 4.25% and 5%

Laboratory Compaction Index

$$LCI = 100 * \frac{b^{1.2}}{a}$$



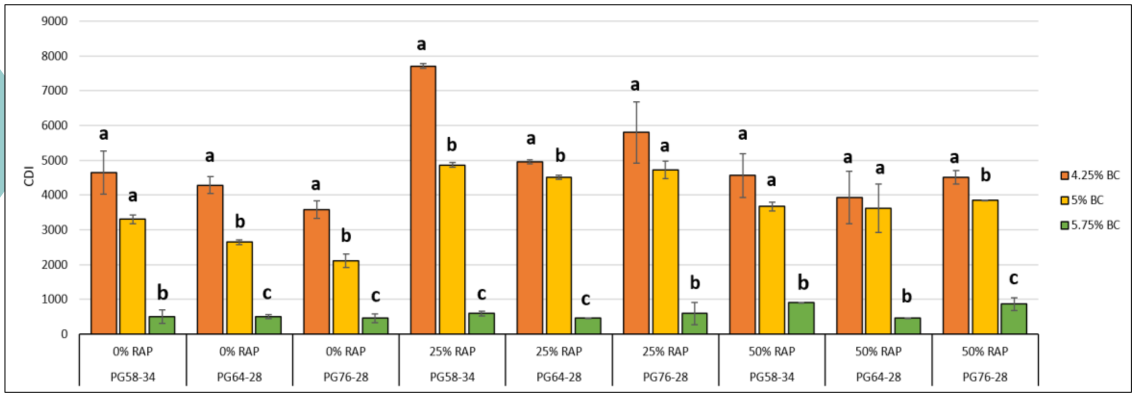
where,

a =The intercept of the compaction curve

b =The slope of the compaction curve (absolute value)

- The LCI: A function of the absolute value of the slope (b) and intercept (a), of the laboratory compaction curve
- Asphalt mixtures with higher LCI values are easier to compact compared to those with lower LCI values

Task 4: Laboratory Testing Compaction Indices



Compaction Densification Index (CDI) Sensitivity to Different Binder Contents

CDI decreased with the increase in binder content; there was statistically significant difference between (dry vs. wet) samples but not between 4.25% and 5% for all cases

17

Construction Densification Index (CDI)

$$CDI = \sum_{N_{=8}}^{N_{92}} \%G_{mm}$$

$\%G_{mm}$ = Percent maximum density

$N_{=8}$ = Gyration number 8

N_{92} = Number of gyrations at 92% Gmm

The CDI: the area measured under the densification curve from the eighth gyration to the number of gyrations at 92% of the theoretical maximum specific gravity (Gmm)

18

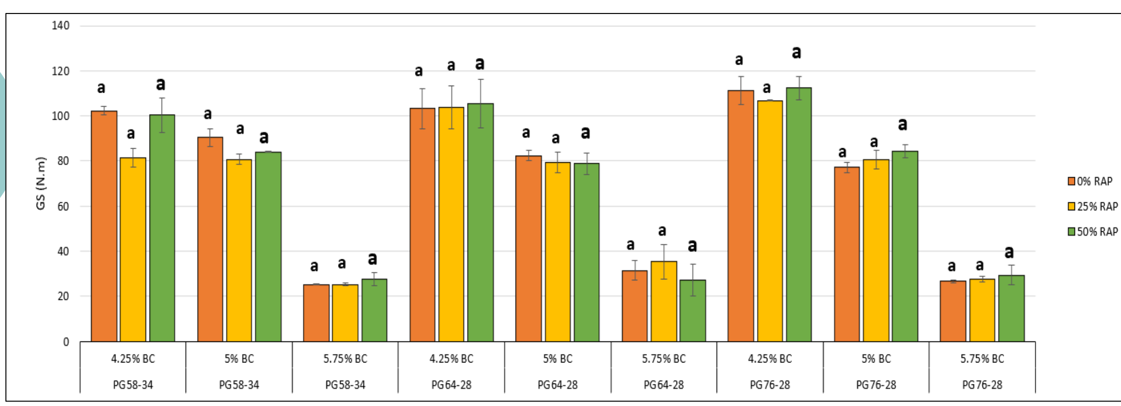
Compaction Indices

Other compaction Indices .....

- Compaction Force Index (CFI)
- Locking Point (LP)
- Compactability Energy Index (CEI)
- Workability Energy Index (WEI)

19

Compaction Indices

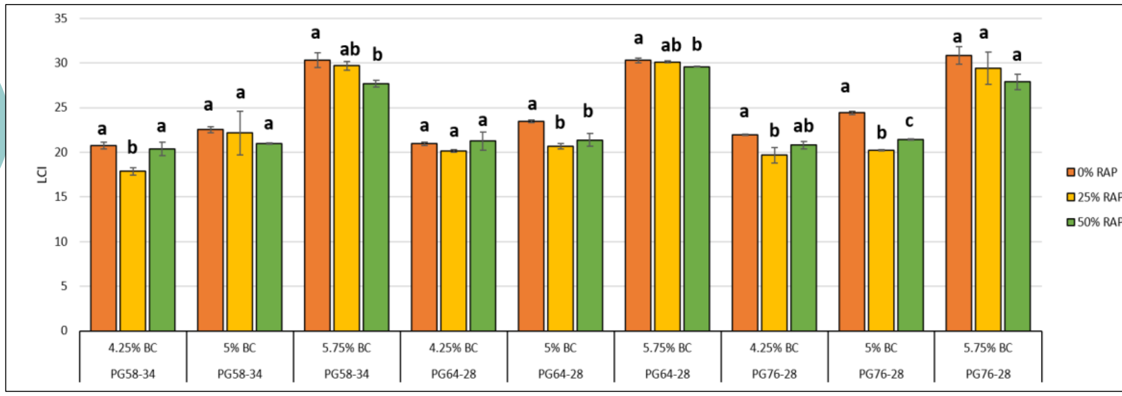


Gyratory Stability (GS) Sensitivity to Different RAP Contents

No consistent trend for the effect of RAP content on GS;
No significant difference in the results

20

Compaction Indices

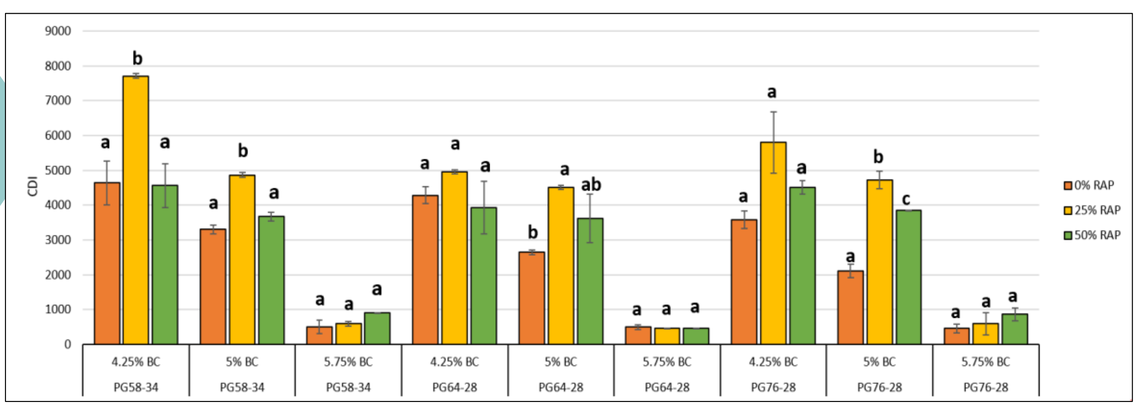


Laboratory Compaction Index (LCI) Sensitivity to Different RAP Contents

No consistent trend for the effect of RAP content on LCI;
No significant difference in the results

21

Compaction Indices

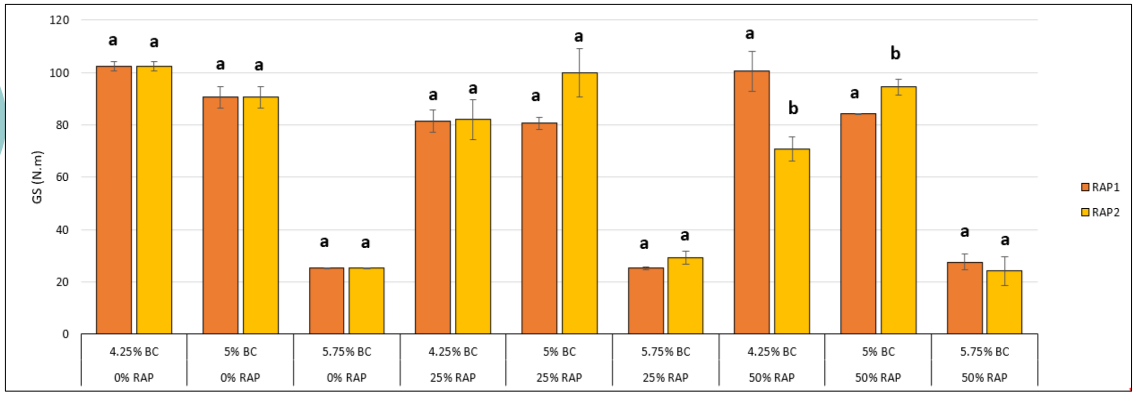


Compaction Densification Index (CDI) Sensitivity to Different RAP Contents

No consistent trend for the effect of RAP content on CDI;
No significant difference in the results

22

Compaction Indices

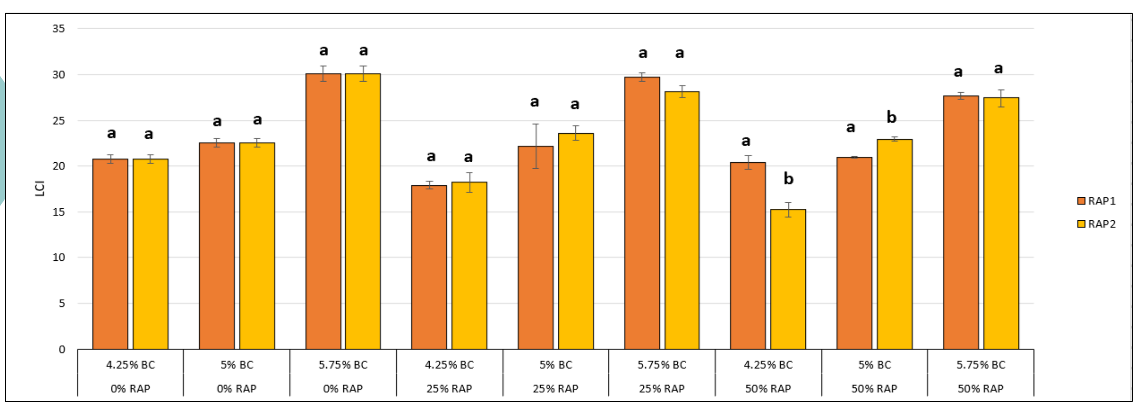


Gyratory Stability (GS) for RAP1 and RAP2

No consistent trend for the effect of binder source on GS;
No significant difference in the results

23

Compaction Indices

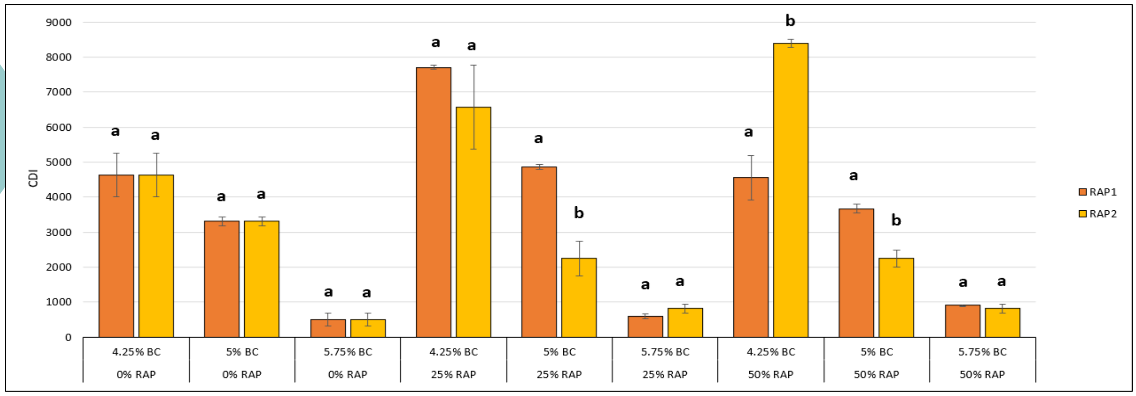


Laboratory Compaction Index (LCI) for RAP1 and RAP2

No consistent trend for the effect of binder source on LCI;
No significant difference in the results

24

Compaction Indices

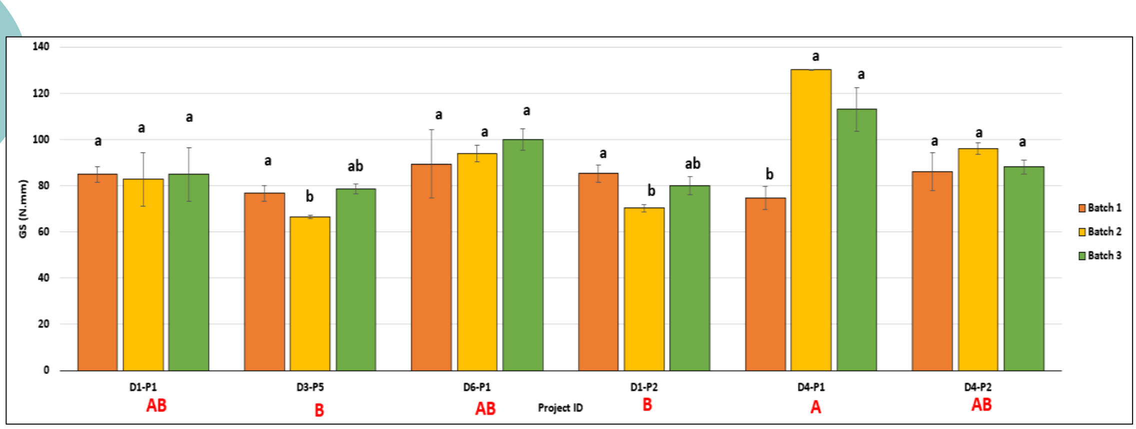


Compaction Densification Index (CDI) for RAP1 and RAP2

No consistent trend for the effect of binder source on CDI;
No significant difference in the results

25

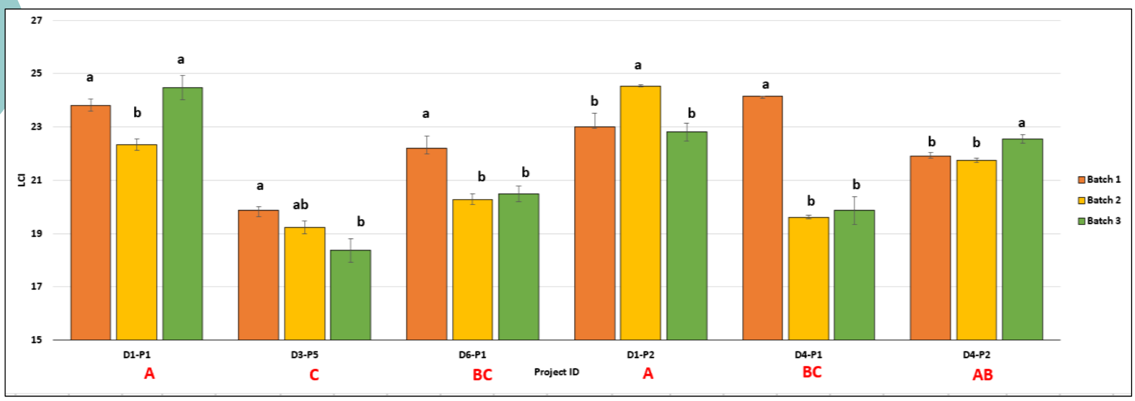
Compaction Indices



Gyratory Stability (GS) of PMLC Mixes

26

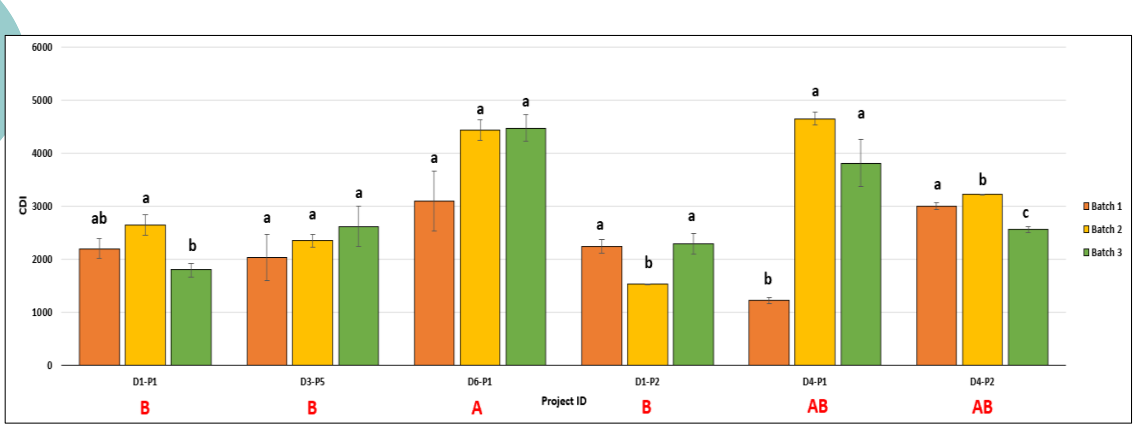
Laboratory Testing Compaction Indices



Laboratory Compaction Index (LCI) of PMLC Mixes

27

Laboratory Testing Compaction Indices



Compaction Densification Index (CDI) of PMLC Mixes

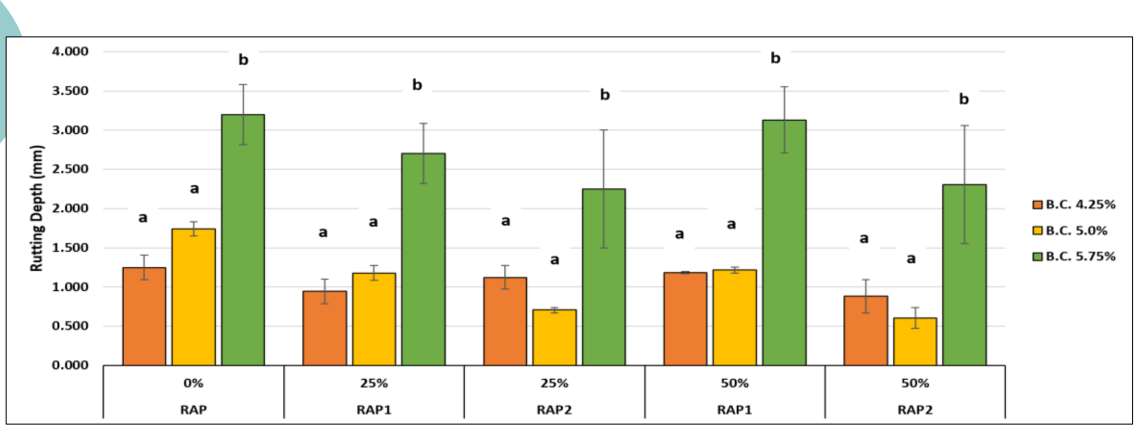
28

Laboratory Testing Rutting

Rutting Performance Results

29

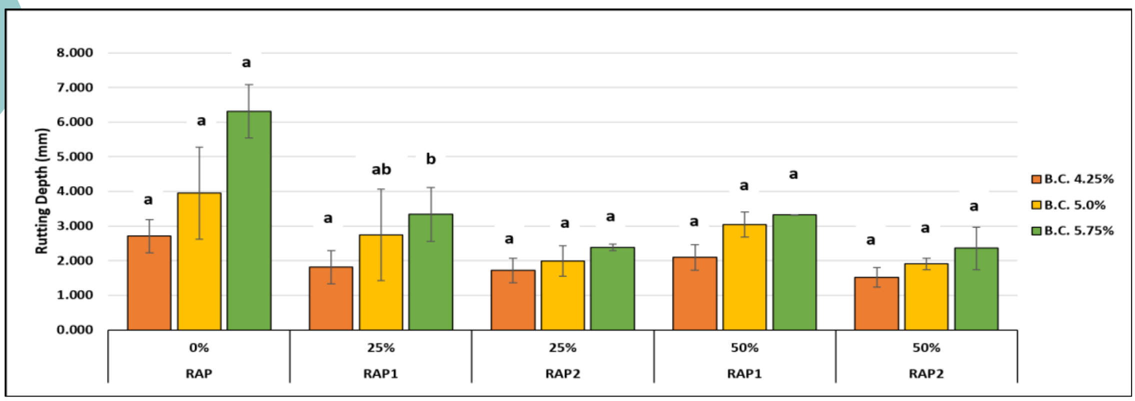
Laboratory Testing Rutting



APA Rutting Depths at Different Binder Contents (PG58-34)

30

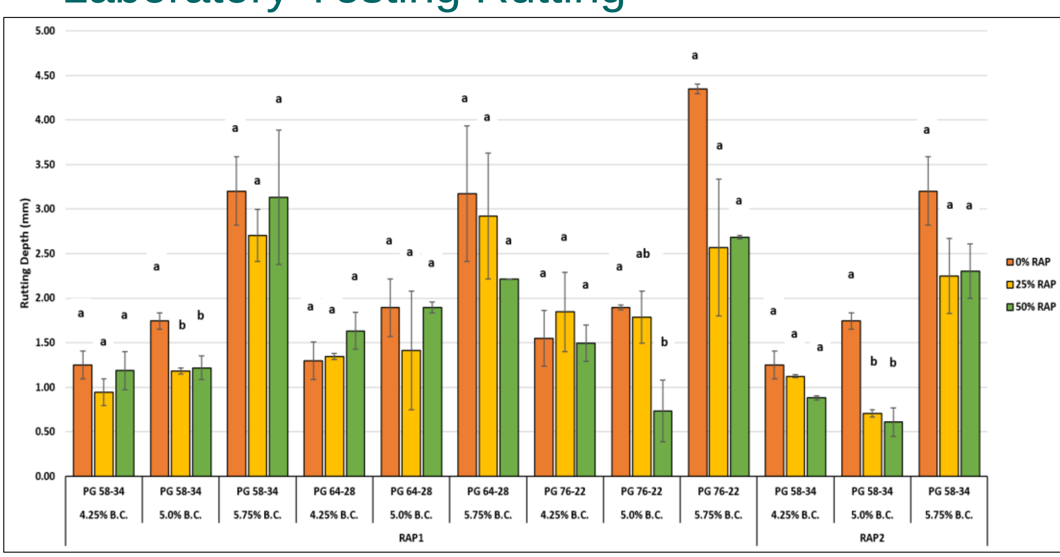
Laboratory Testing Rutting



Hamburg Rutting Depths at Different Binder Contents (PG58-34)

31

Laboratory Testing Rutting

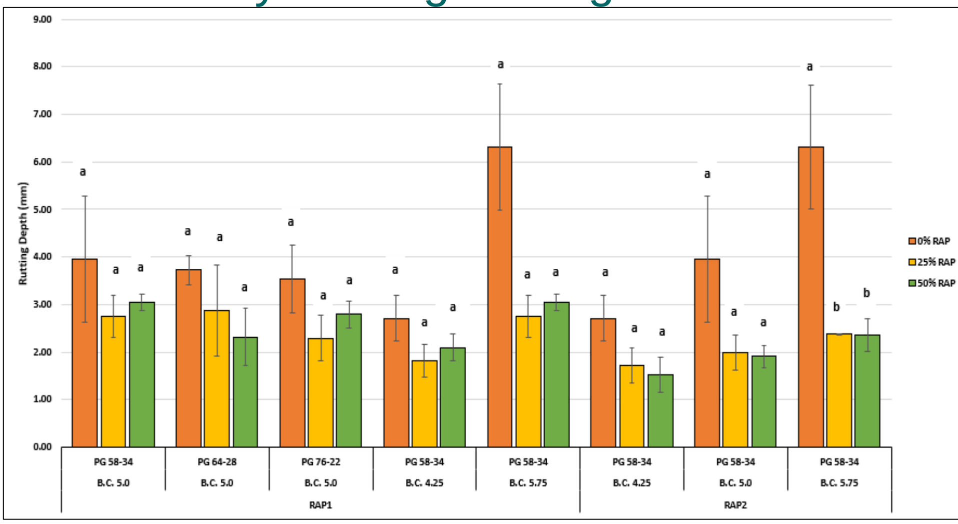


APA Rutting Depths at Different RAP Contents

APA rut depth is less than 5 mm

32

Laboratory Testing Rutting

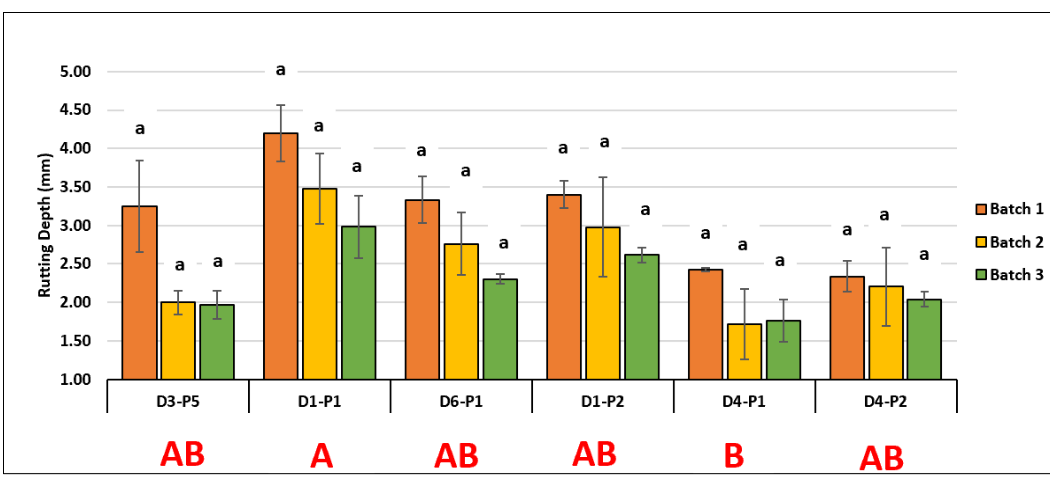


Hamburg Rutting Depths at Different RAP Contents

Overall, mixtures with RAP had less HWTT rut depth; HWTT was less than 12.5 mm

33

Laboratory Testing Rutting

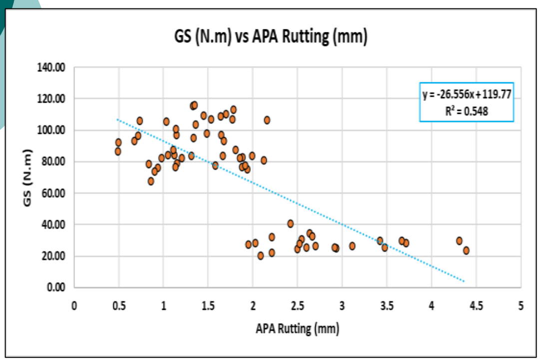


Hamburg Rutting Depths of PMLC Mixes

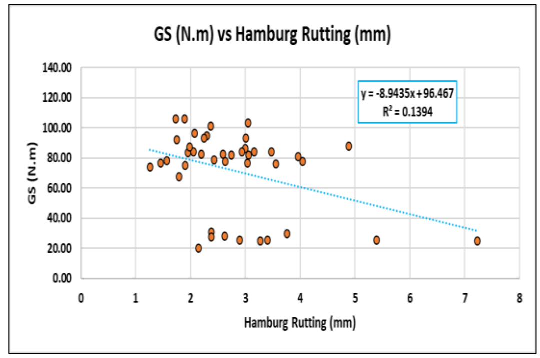
HWTT was less than 12.5 mm after 20,000 passes

34

Laboratory Testing Rutting



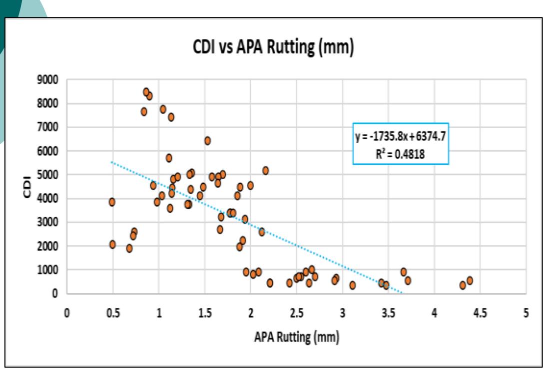
Correlation between GS and APA Rutting Data of LMLC Mixes



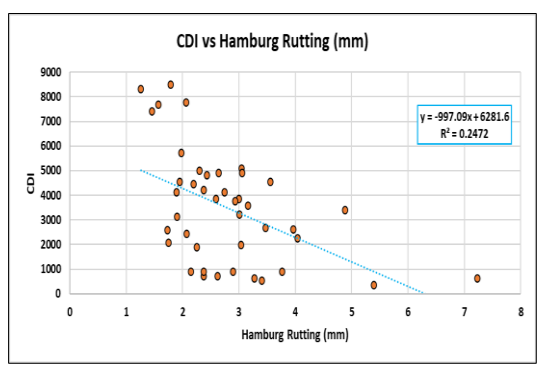
Correlation between GS and Hamburg Rutting Data of LMLC Mixes

35

Laboratory Testing Rutting



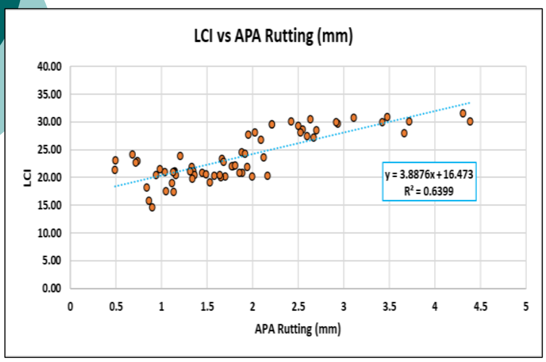
Correlation between CDI and APA Rutting Data of LMLC Mixes

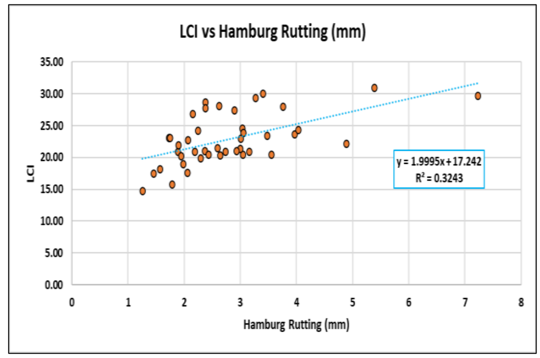


Correlation between CDI and Hamburg Rutting Data of LMLC Mixes

36

Laboratory Testing Rutting



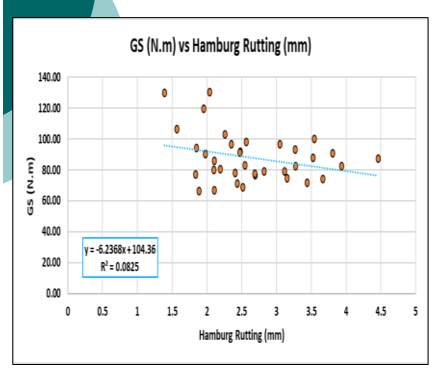


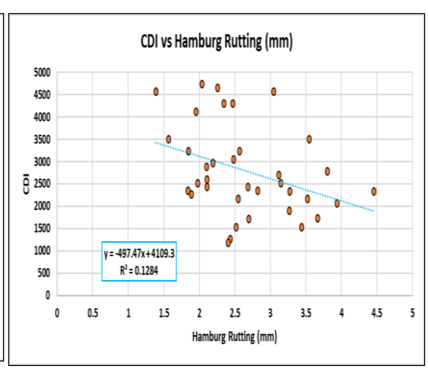
Correlation between LCI and APA Rutting Data of LMLC Mixes

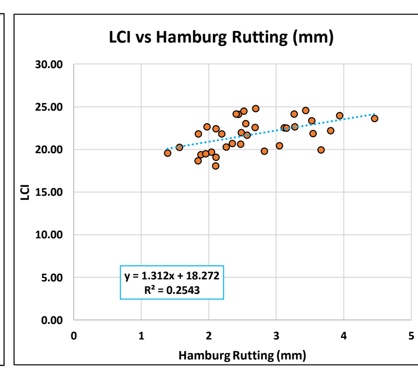
Correlation between LCI and Hamburg Rutting Data of LMLC Mixes

37

Laboratory Testing Rutting







Correlation between GS, CDI, LCI and Hamburg Rutting Data of PMLC Mixes

38

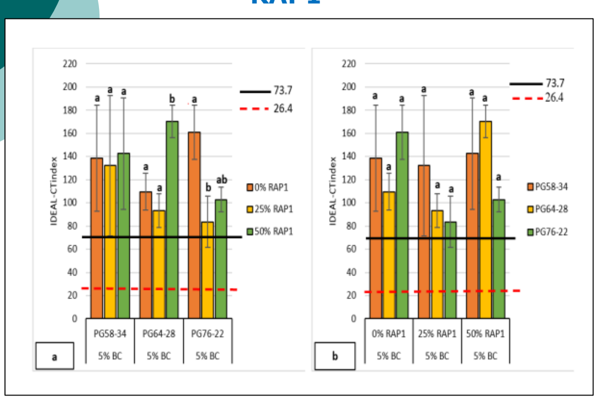
Laboratory Testing Cracking

- Monotonic IDT Cracking resistance indicators
  - IDEAL-CT_{Index}
  - Cracking Resistance Index (CRI)
  - N_{flex}
  - $Weibull_{CRI}$
  - Fracture Energy (G_f)
  - $IDT_{Strength}$,
  - $IDT_{Modulus}$
  - Flexibility Index (FI)

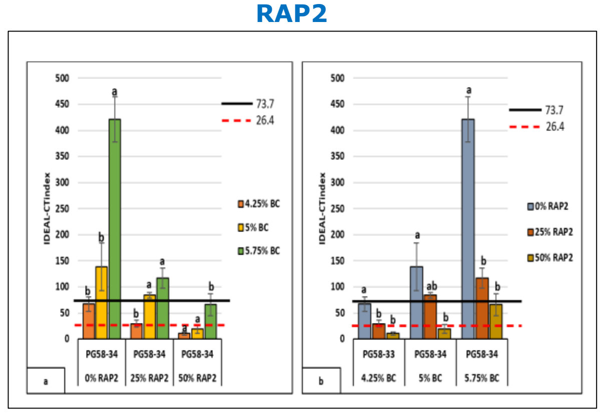
39

Laboratory Testing Cracking

RAP1



RAP2

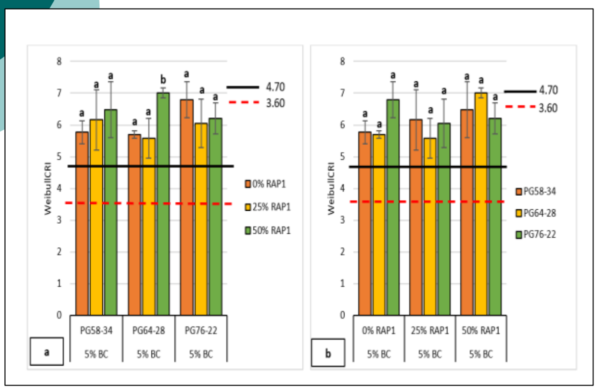


Effect of Binder Grade/Content and RAP Content on IDEAL-CTIndex

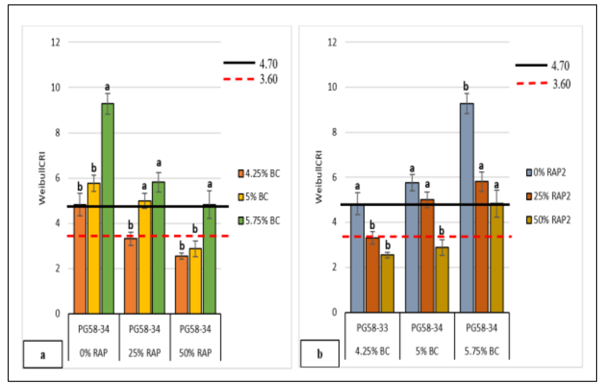
40

Laboratory Testing Cracking

RAP1



RAP2

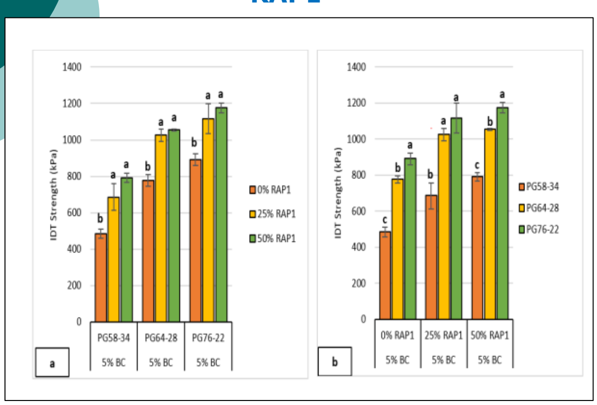


Effect of Binder Grade/Content and RAP Content on WeibullCRI

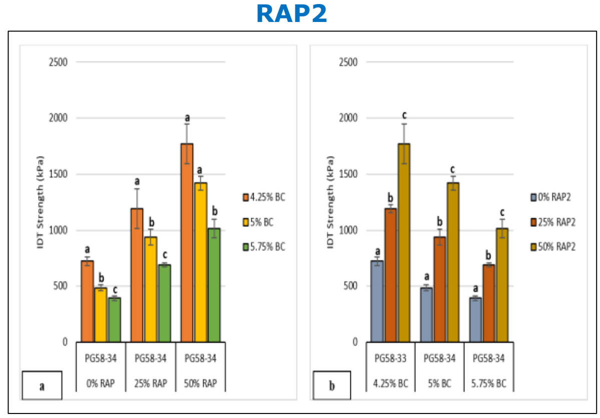
41

Laboratory Testing Cracking

RAP1



RAP2

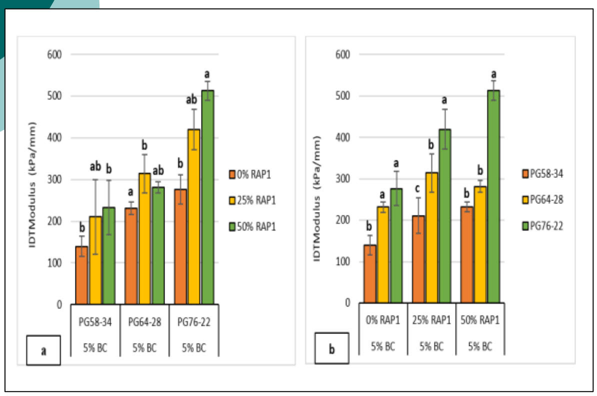


Effect of Binder Grade/Content and RAP Content on IDT strength

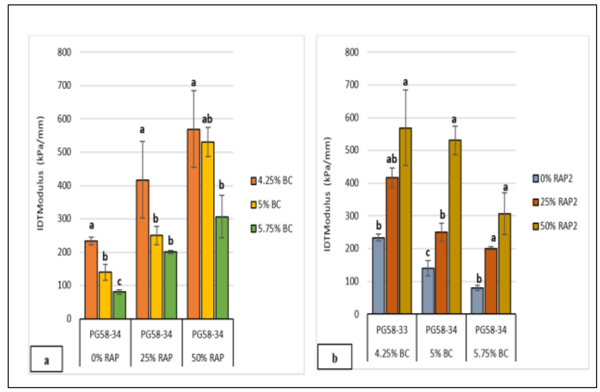
42

Laboratory Testing Cracking

RAP1



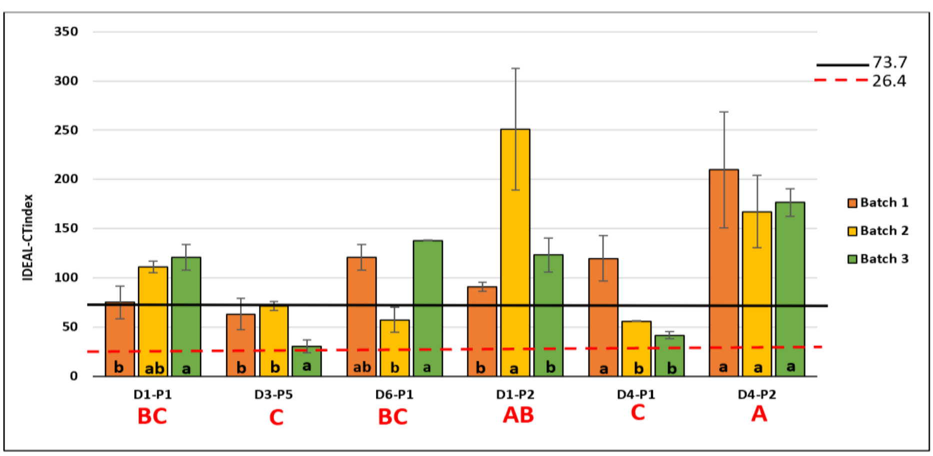
RAP2



Effect of Binder Grade/Content and RAP Content on IDT Modulus

43

Laboratory Testing Cracking

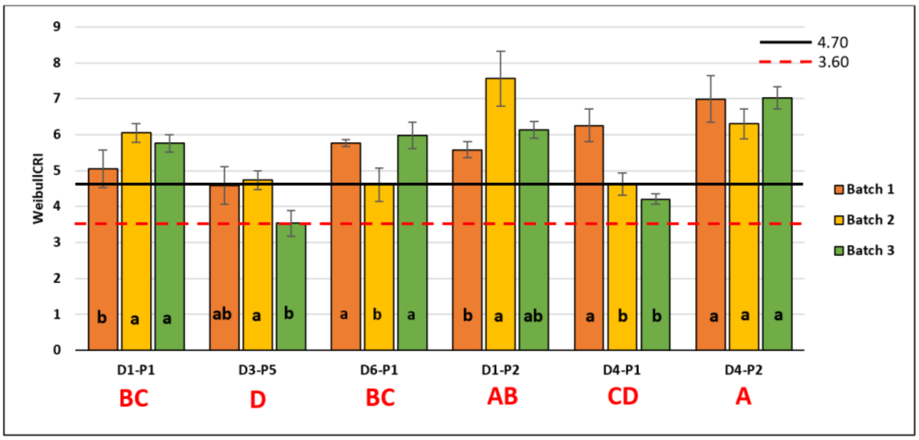


IDEAL-CT Index of PMLC

- D4-P2: higher binder content (6.2%) and lower RAP content (17%)
- D3-P5: 0% RAP and 5.4% binder content; was dry during compaction

44

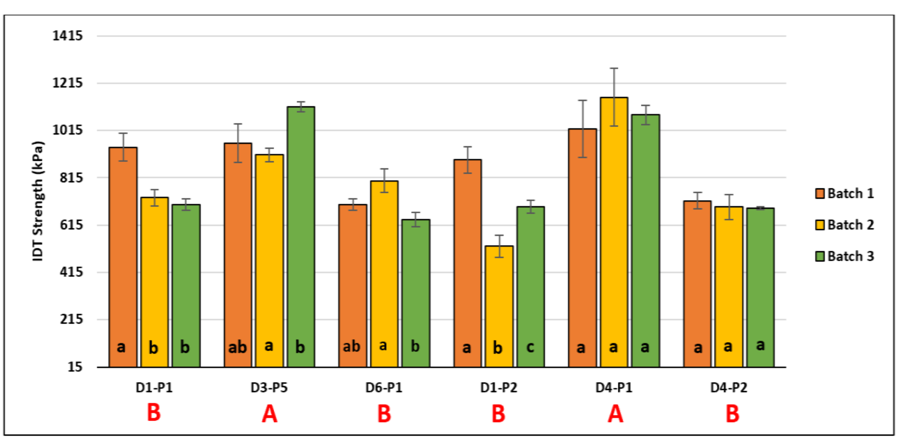
Laboratory Testing Cracking



WeibullCRI of PMLC

45

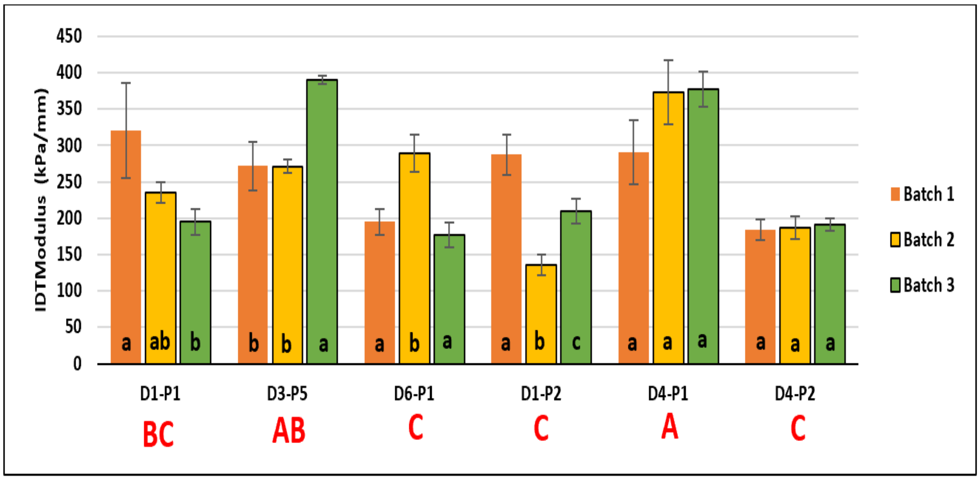
Laboratory Testing Cracking



IDT Strength of PMLC

46

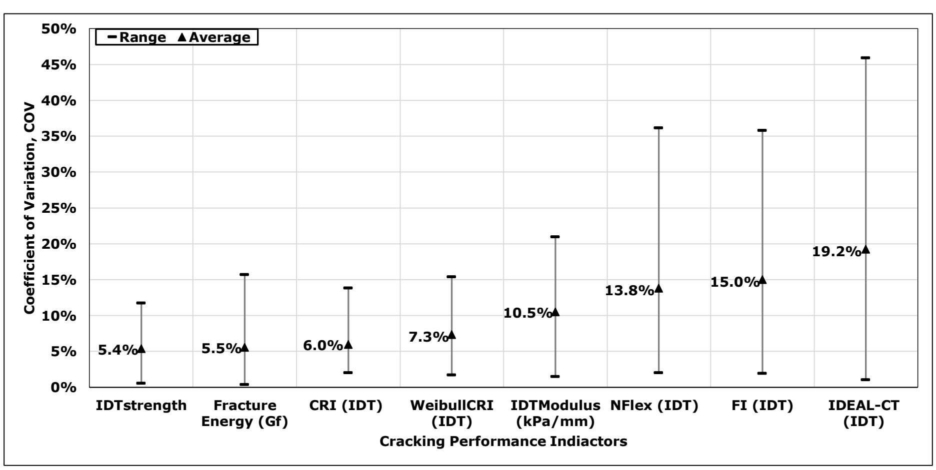
Laboratory Testing Cracking



IDT Modulus of PMLC

47

Laboratory Testing Cracking



Coefficient of Variation (COV) in Cracking Performance Indicators of Mixes

48

Evaluation of Compaction and Stability Indices

- Based on the comprehensive evaluation of the results of the compaction indices, the GS, CDI, and LCI were found to be sensitive to binder content; however, all the compaction indices were less sensitive to the change in the RAP content and binder grade.
- The GS decreased with the increase in binder content for all mixes (with and without RAP) for different binder grades. Drier mixtures required more energy needed for compaction than softer mixtures.

49

Evaluation of Rutting Performance and Moisture Susceptibility

- The rutting performance evaluation using the APA rut test and HWTT showed that all LMLC and PMLC had good resistance to rutting. In addition, there was no sign for moisture damage for all mixtures tested using HWTT.
- The APA and HWTT rut depth increased with the increase in binder content as expected. However, there was a statistically significant difference in the APA rut depth results between mixtures with 5.75% binder content and 4.25% binder content, while the difference in the HWTT results was not statistically significant between 5.75% and 4.25% binder content.

50

Evaluation of Rutting Performance and Moisture Susceptibility

- Overall, mixtures prepared with RAP tended to have slightly less rutting compared to mixtures without RAP at the corresponding binder contents, but the difference was not statistically significant.
- The LCI showed a better correlation with the APA rut depth (R^2 = 0.64).

51

Evaluation of Cracking Performance

- The results demonstrated that the IDTModulus and IDTStrength were able to capture the change in binder content, binder grade, and RAP content. Other indices including IDEAL-CT Index, WeibullCRI, CRI, and Nflex factor were sensitive to binder content and RAP contents from the second source of RAP. Overall, the cracking resistance improved with the increase in binder content as expected. Also, all mixtures prepared at different RAP contents (up to 50%) from the first source of RAP had good resistance to cracking; however, the mixtures prepared with the second source of RAP did not show this trend.

52

Evaluation of Cracking Performance

- The results also illustrated that the cracking performance of mixtures prepared with RAP (up to 50%) from the second source of RAP can be improved by increasing the binder content. This indicates the importance of the balanced mix design when incorporating RAP materials in asphalt mixtures.

53

Implementation

- ITD may consider implementing and applying a balanced (engineered) mix design concept for asphalt mixtures prepared with high RAP content to ensure that such mixtures have adequate resistance to cracking and rutting comparable or superior to the control mix. The results of this study showed that adjusting the binder content improved the cracking performance of mixtures prepared with up to 50% RAP.

54

Questions…….

55