RowanUniversity

CENTER FOR RESEARCH & EDUCATION IN ADVANCED TRANSPORTATION ENGINEERING SYSTEMS

ERDC

Engineer Research and Development Center

Development of a Balanced Mix Design for Cold In-Place Recycling Mixtures

US Army Corps of Engineers

CRREL

Research Team:

Yusuf Mehta Ph.D P.E.

Ayman Ali Ph.D

Ahmed Saidi

94th Annual NESMEA/ NEAUPG Conference, Atlantic City (October 17-18, 2018)

Acknowledgement

- Dr. Wade Lein
- Dr. Ben Cox
- Dr. Jeremy Robinson
- Dr. Jeb Tingle
- Mr. Jared Oren
- US Army Engineer Research and Development Center (ERDC)

In This Presentation...

- Background and Problem Statement
- Study Goals and Objectives
- Overall Work Plan
- Balanced Mix Design for CIR Mixes
- Preliminary Results
- Performance Comparison of balanced CIR mixtures
- Future Activities
- Questions

Background & Problem Statement

Background

- Cold In-Place Recycling (CIR) has a number of construction, environmental, and economic benefits.
- Benefits Include:
  - Improves construction conditions
  - Shortens lane closures
  - Maintains height clearances

Problem Statement

- Despite these benefits, use of CIR is limited (low to medium traffic levels).
- Therefore, there is a need to develop a mix design for cold in place recycling, that balances between rutting and cracking performances.

Study Goals & Overall Approach

Research Goal and Objectives

- The goal of this study is to develop a mix design for CIR using a balanced mix design approach.
- Construct and test full-scale CIR pavement sections using a Heavy Vehicle Simulator (HVS).

Rowan University

CENTER FOR RESEARCH & EDUCATION IN ADVANCED TRANSPORTATION ENGINEERING SYSTEMS

ERDC

Engineer Research and Development Center

Balanced Mix Design for CIR Mixes

94th Annual NESMEA/ NEAUPG Conference, Atlantic City (October 17-18, 2018)

Balanced Mix Design Approach

Balanced CIPR Design Approach

Step 1: Obtain Representative RAP Materials and Select Recycling Agent
- RAP Materials: mill or take cores. Determine general gradation and binder content of RAP materials.
- Recycling Agent: foamed or emulsified asphalt.

Step 2: Select Water Content and Dosage of Other Additives
- Water: constant content ranging between 1.5–3%.
- Additives: cement or lime at a constant dosage ranging between 1–1.5%.

Step 3: Mix Components and Produce CIR Mixtures
- RAP, Water, and Additives: mix in a bucket mixer for 3–5 minutes.
- Recycling Agent: add recycling agent at varying contents (i.e., 1–5% with 1% increment). Mix components for 5–8 minutes.
- Note: for high contents (>=4%) of emulsified asphalt, mix the components thoroughly for up 20 minutes.

Step 4: Compact, Cure, and Determine Volumetrics of CIR Samples
- Compaction: compact using the Superpave Gyratory Compactor (SGC) at 30 or 70 gyrations.
- Curing: Dry curing for 3 days at 140°F (60°C).
- Volumetrics: bulk and Rice gravities using CoreLok method

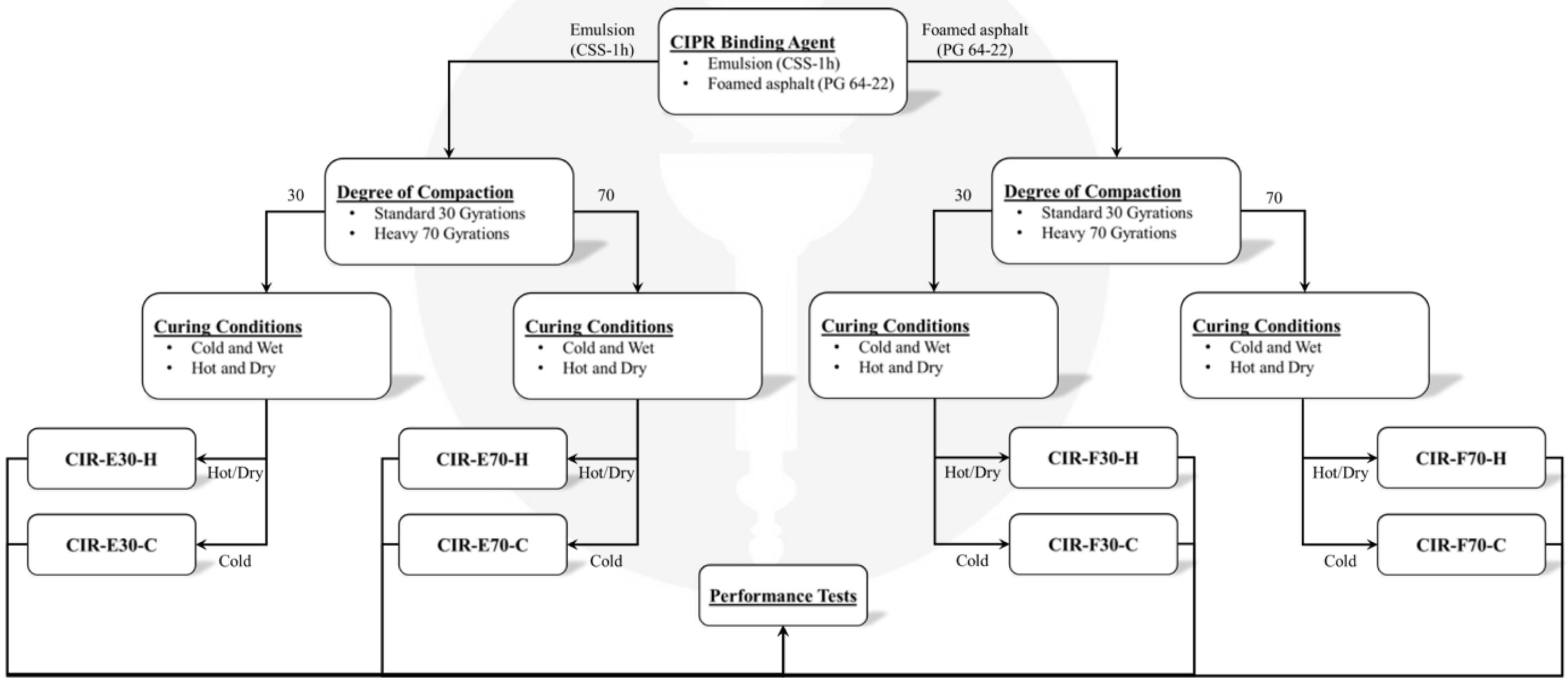
Volumetrics Within Typical CIR Field Densities (i.e., 10–18%)

No, evaluate RAP gradation

Yes

Step 5: Conduct Performance Testing and Determine Optimum Binder Content
- Rutting: APA and DCM.
- Cracking: ITS and SCB.
- Optimum Binder Content: one that balances both rutting and fatigue cracking.

Experimental Plan



Experimental Plan

Mix Design	Characteristics
Aggregates	• 100% RAP
Binding Agent	• CSS-1h Emulsion • Foamed Asphalt (PG 64-22)
Recycling Additives	• Cement • Water
Gyration Level	• 30 • 70
Curing Process	• 3 days at 140°F • 3 days at 50°F

Obtaining RAP

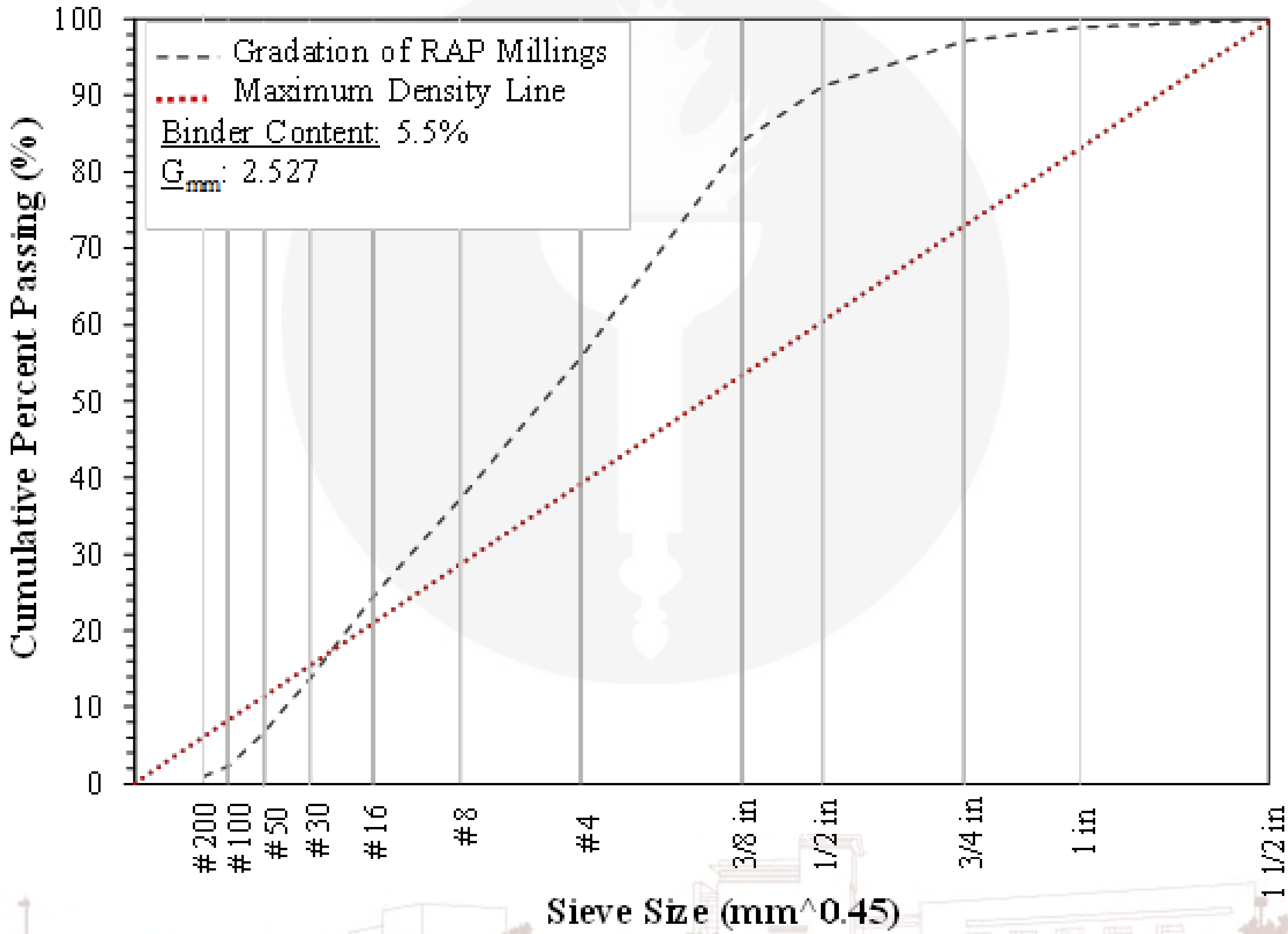
- RAP was obtained by milling a portion of a HMA pavement section at RUAPTF: **12 ft**. wide by **15 ft**. long by **4 in.** deep.

Characterizing RAP

- RAP characteristics were determined:

- Gradation (**AASHTO T27**)
- Aged binder (**AASHTO T319**)
- Rice specific gravity (**ASTM D6857**)

RAP Characteristics



Producing Foamed Asphalt

- Wirtgen WLB 2S laboratory-scale foamed asphalt machine

Characterizing Foamed Asphalt

- Asphalt foaming process was tested at different process water contents (2% - 3.5% with increments of 0.5%) and at three temperatures (155°C, 165°C, and 175°C).

Temperature (°C)	Half-Life (s)	Expansion Ratio	OWC (%)
155	8	8	2.5
165	10.5	10	2.5
175	7.5	9	3

Laboratory Testing Design

- Four performance tests

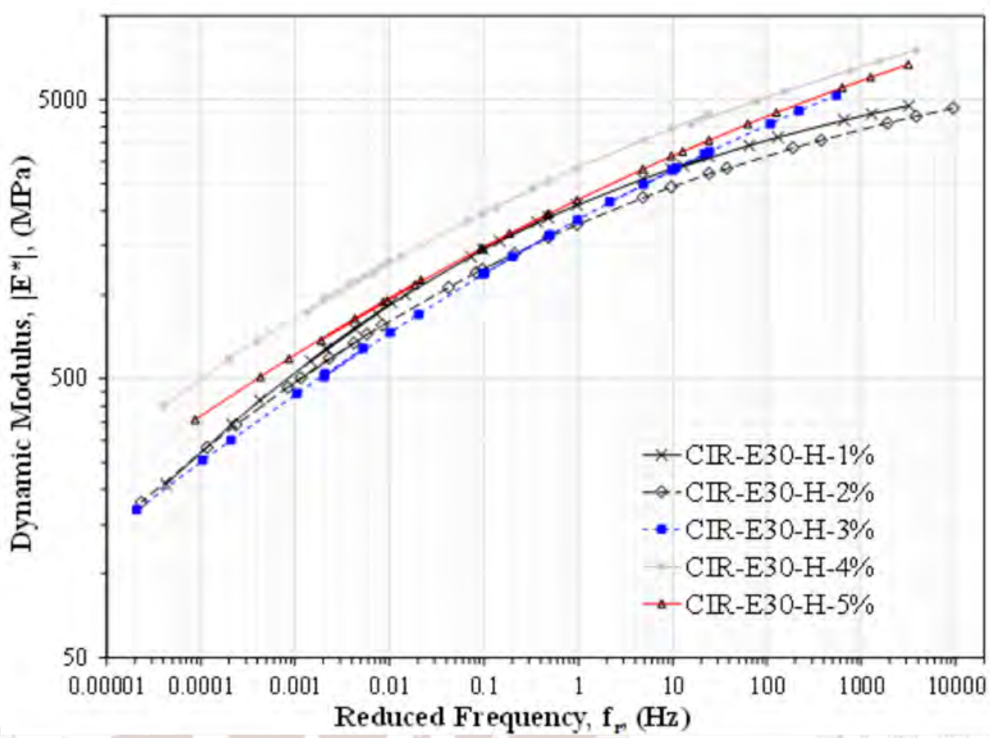
1. Asphalt Pavement Analyzer (APA)
2. Dynamic Complex Modulus (DCM)
3. Indirect Tensile Strength (ITS)
4. Semi-Circular Bend (SCB)

Laboratory Testing Design

Test	Mixtures	Binder contents	Temperature (°C)	Replicates	Total
APA	8	5	64	6	240
DCM	8	2	4, 21, 37 and 54	3	48
ITS	8	5	0	3	120
SCB	8	5	0	4	80
				Grand Total	**488**

Laboratory Testing Design

- The binder content had little to no impact on |E*| of CIR mixtures. Therefore, only two binder contents were tested: 2% and 4%.

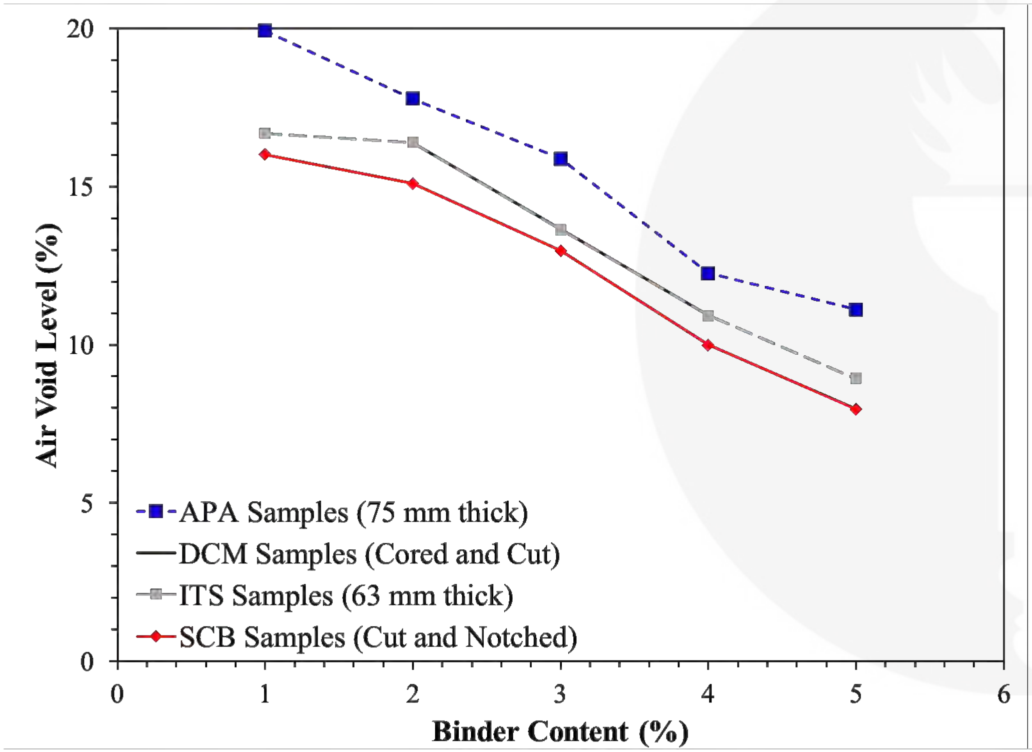


Preliminary Results

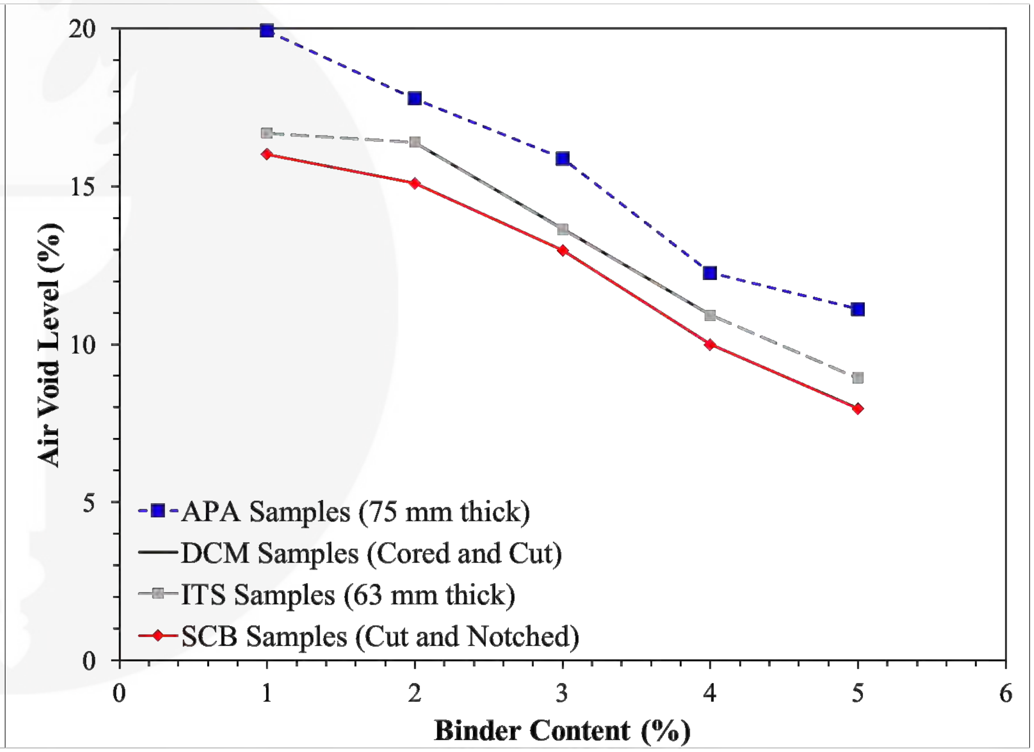
Volumetric Results

- CoreLok was used to determine:
  1. Rice Specific Gravity (G_{mm}) in accordance with ASTM D6857
  2. Bulk specific Gravity (G_{mb}) in accordance with AASHTO T331

Volumetric Results

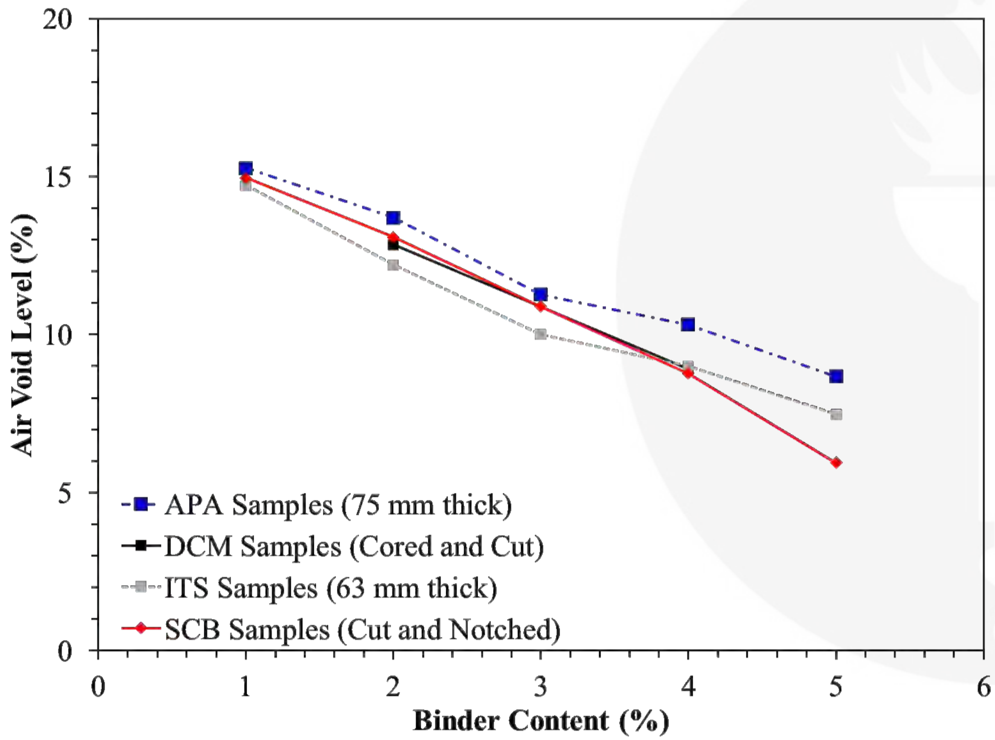


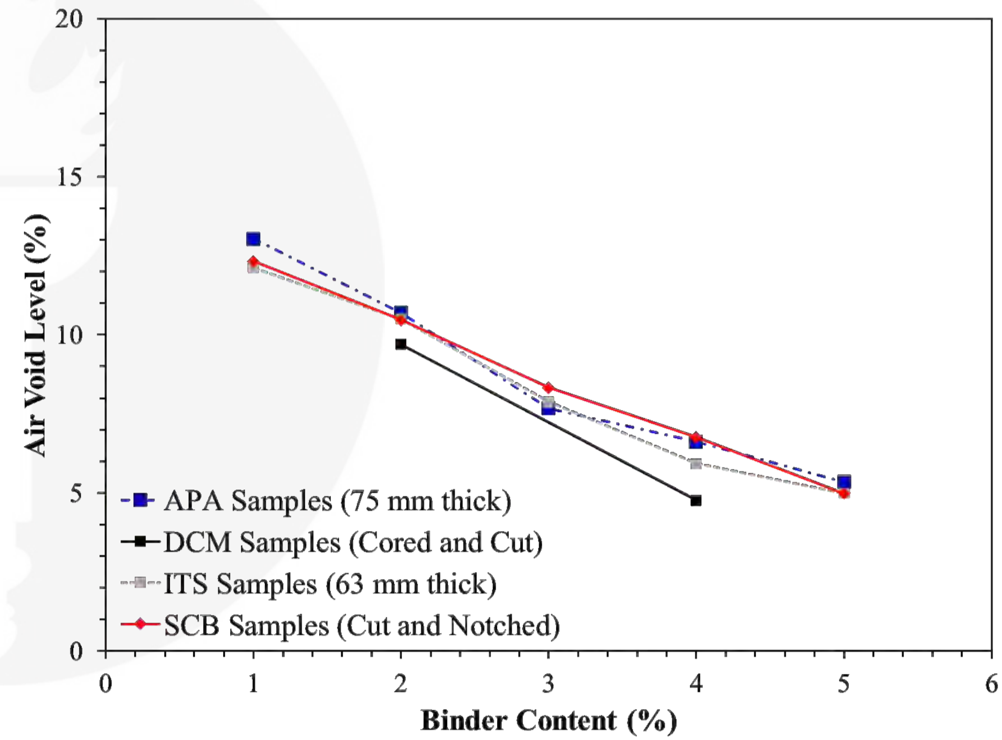
30 Gyrations- Emulsion



70 Gyrations- Emulsion

Volumetric Results





30 Gyrations- Foamed Asphalt

70 Gyrations- Foamed Asphalt

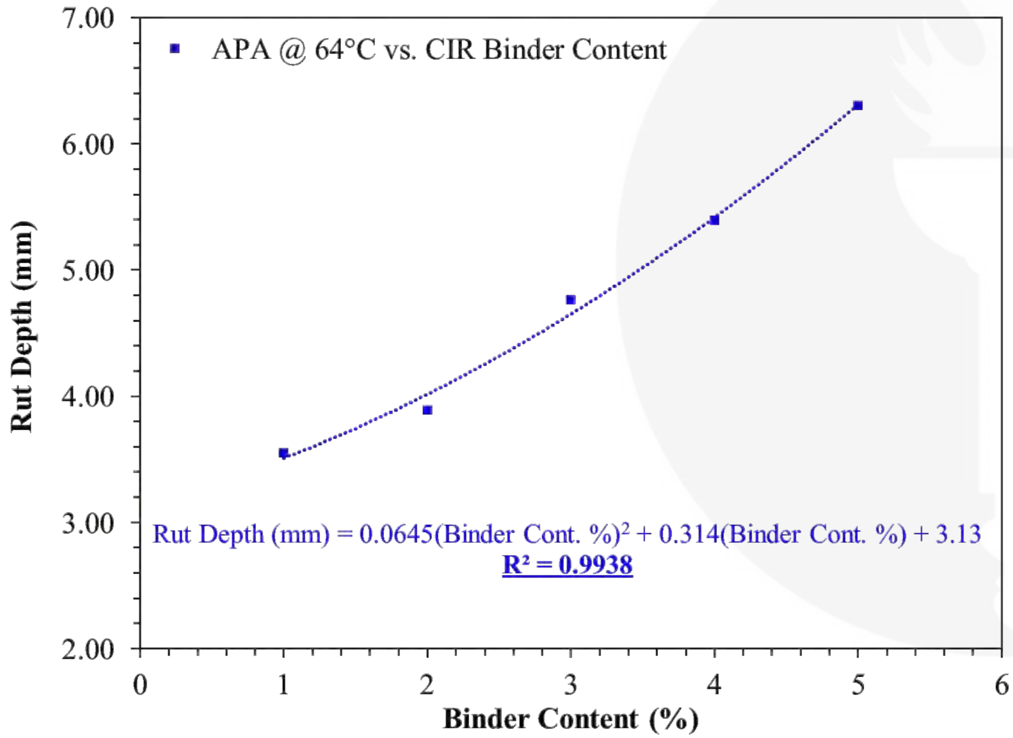
Volumetric Results

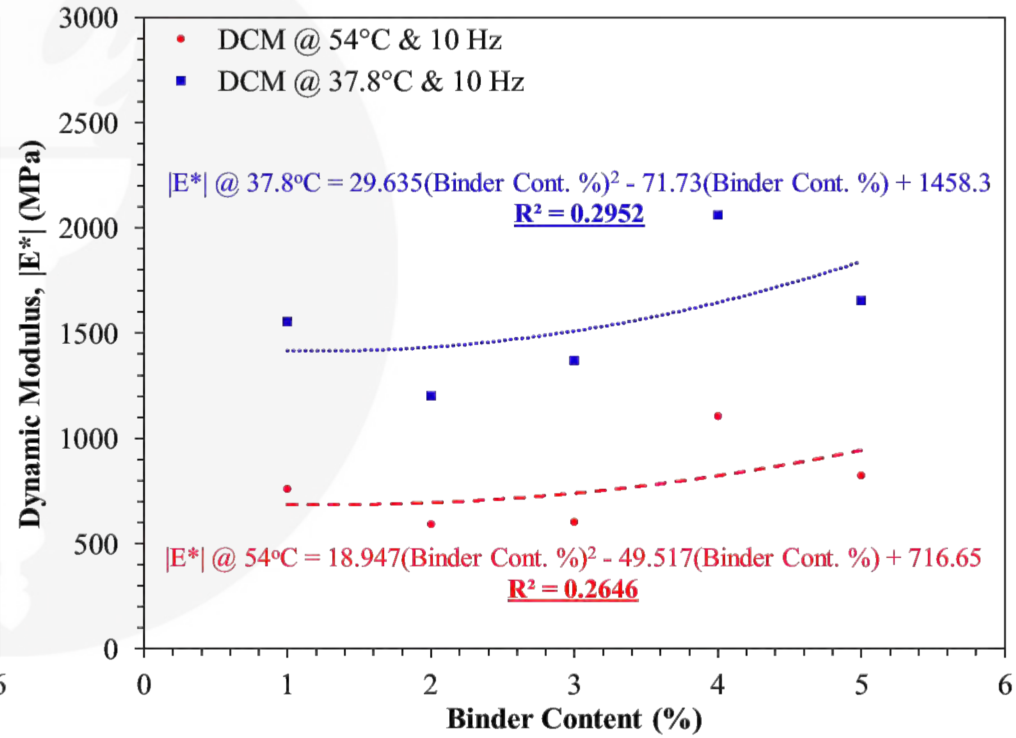
- Increasing the emulsion/foamed asphalt content resulted in a decrease in the air void of CIR Mixes.
- Given the same binder content and curing process, increasing the gyration level caused a reduction in the air void of CIR Mixes.
- At the same gyration level, CIR samples cured at higher temperature presented lower air void values.

Regression Analysis

- It is important to evaluate the applicability of performance tests in designing BMD designs.
- Regression Analysis were performed on CIR samples to assess the performance measures versus CIR binder contents.
- Evaluate the ability of the binder content in predicting CIR rutting and cracking susceptibility

Regression Analysis



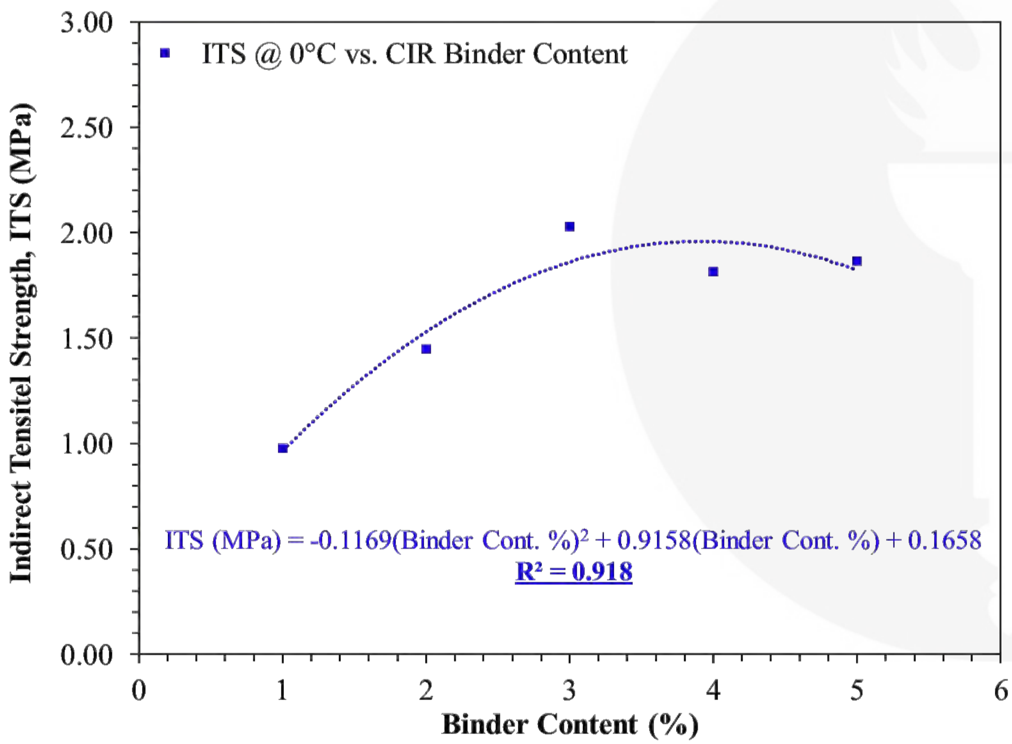


APA vs Binder Content **DCM vs Binder Content**

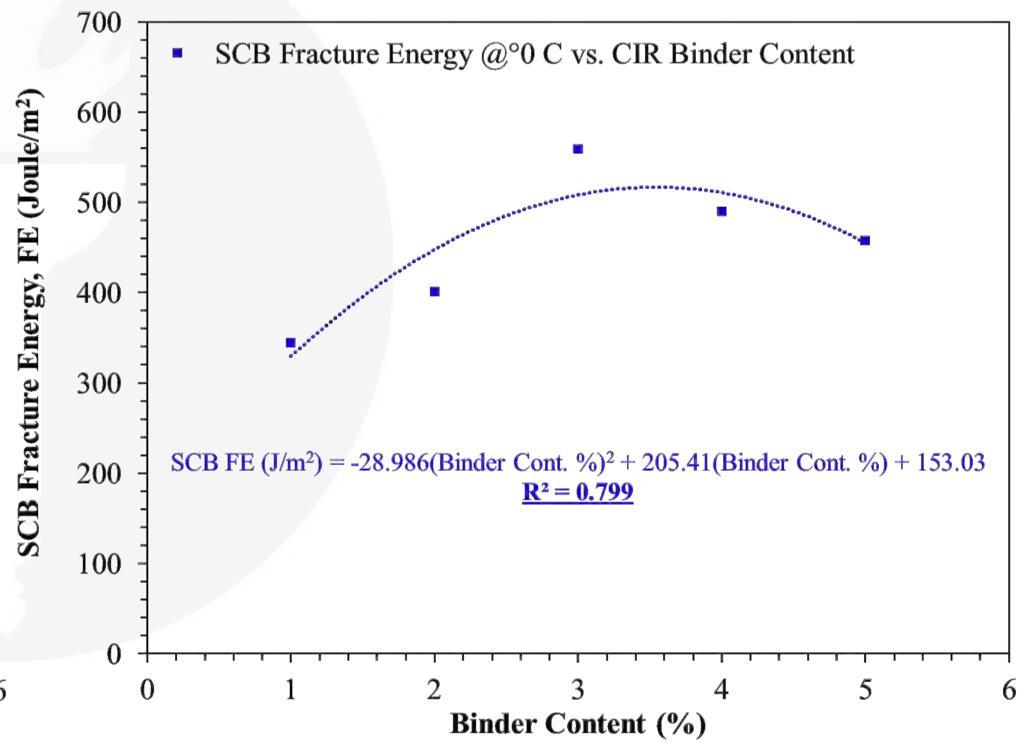
RowanUniversity
CENTER FOR RESEARCH & EDUCATION IN ADVANCED TRANSPORTATION ENGINEERING SYSTEMS

ERDC
Engineer Research and Development Center

Regression Analysis



ITS vs Binder Content



SCB vs Binder Content

CRREL
BUILDING STRONG®

Regression Analysis

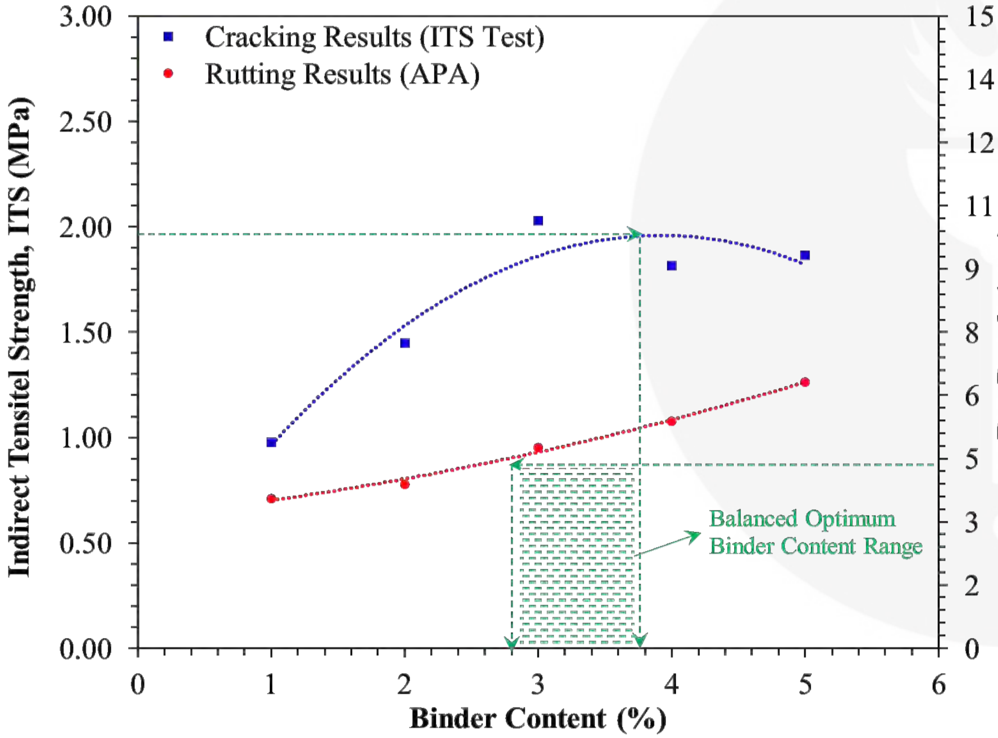
- The binder content of CIR mixes presented strong correlations with:
  - Rut depth (APA)
  - Tensile strength (ITS)
  - Fracture energy (SCB)
- Weak Correlation ($R^2 < 0.3$) observed between the |E*| and CIR binder content. DCM was excluded from the BMD design.

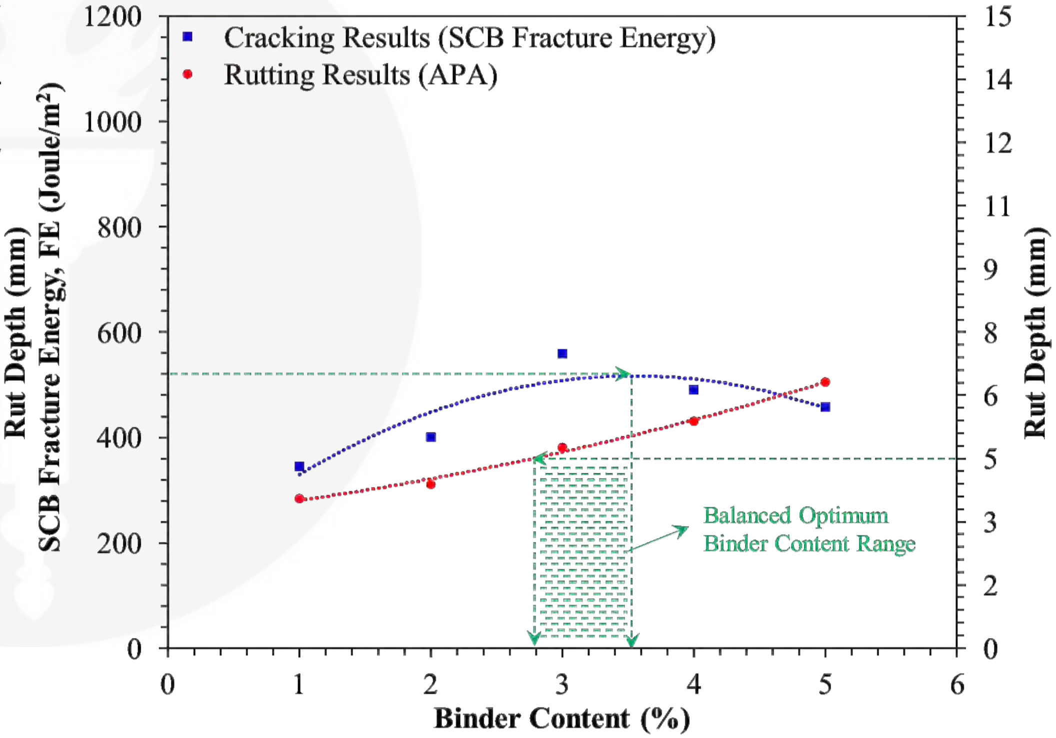
Balanced Mix Design

- The optimum binder content ranges of CIR mixes are determined by establishing relationships between:
  - Rut depth (APA) and Tensile Strength (ITS).
  - Rut depth (APA) and Fracture energy (SCB).
- Balanced mixes will then be evaluated and their performances will be compared at different compaction and curing conditions.

Balanced Mix Design

- CIR-E30-H

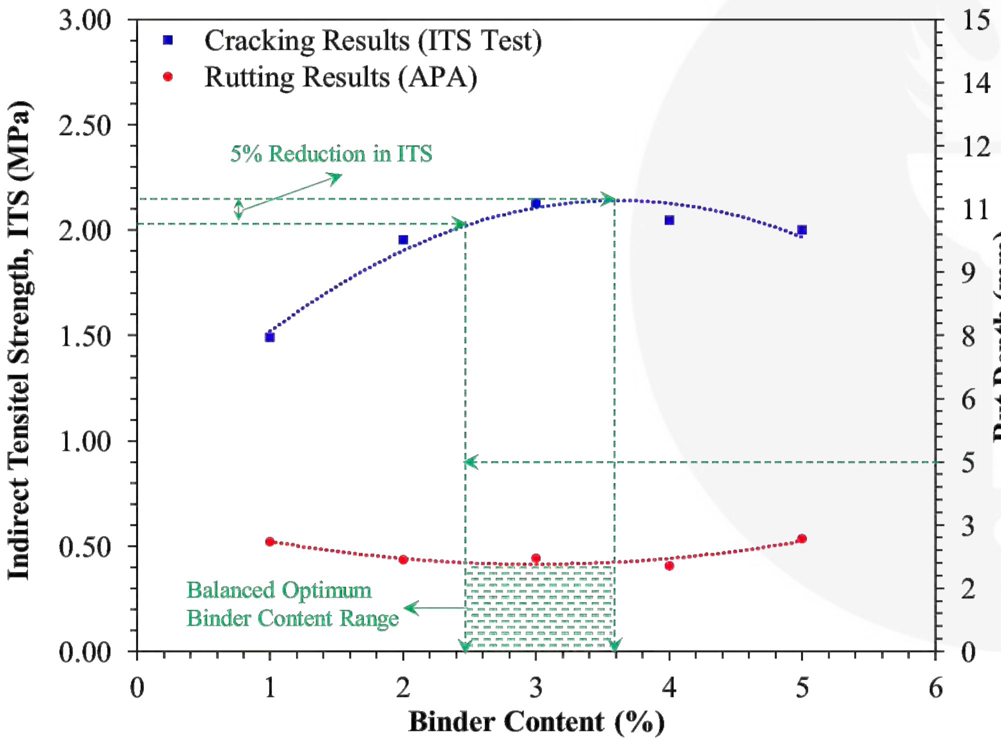


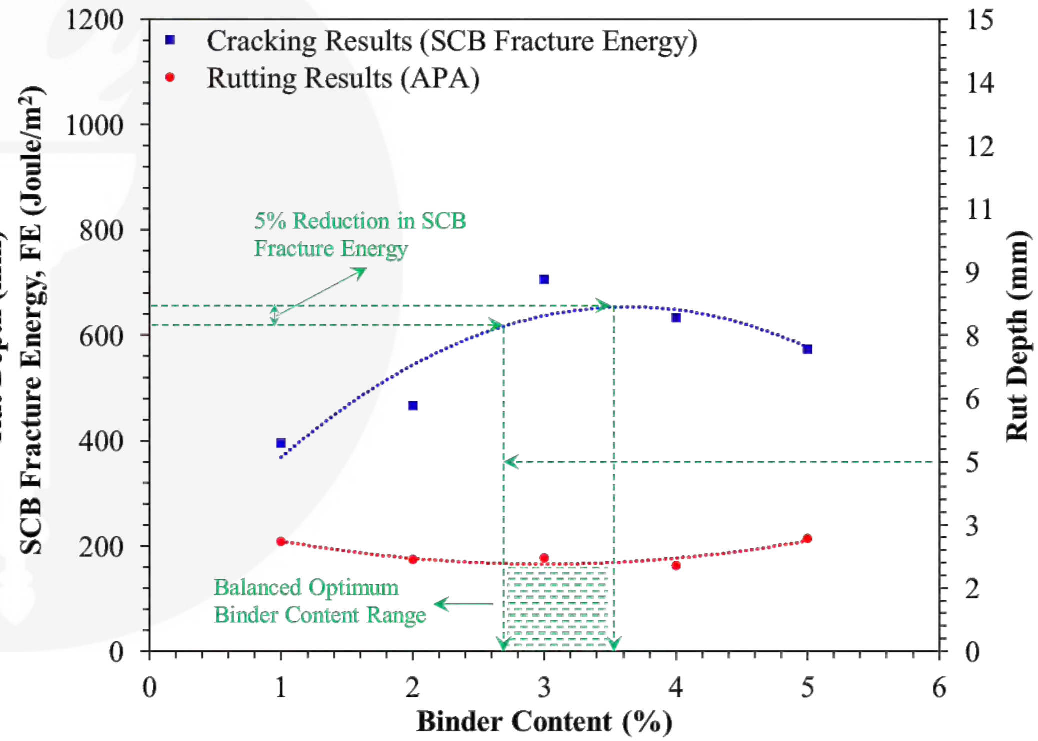


ITS vs APA **SCB vs APA**

Balanced Mix Design

➢ **CIR-E70-H**





ITS vs APA **SCB vs APA**

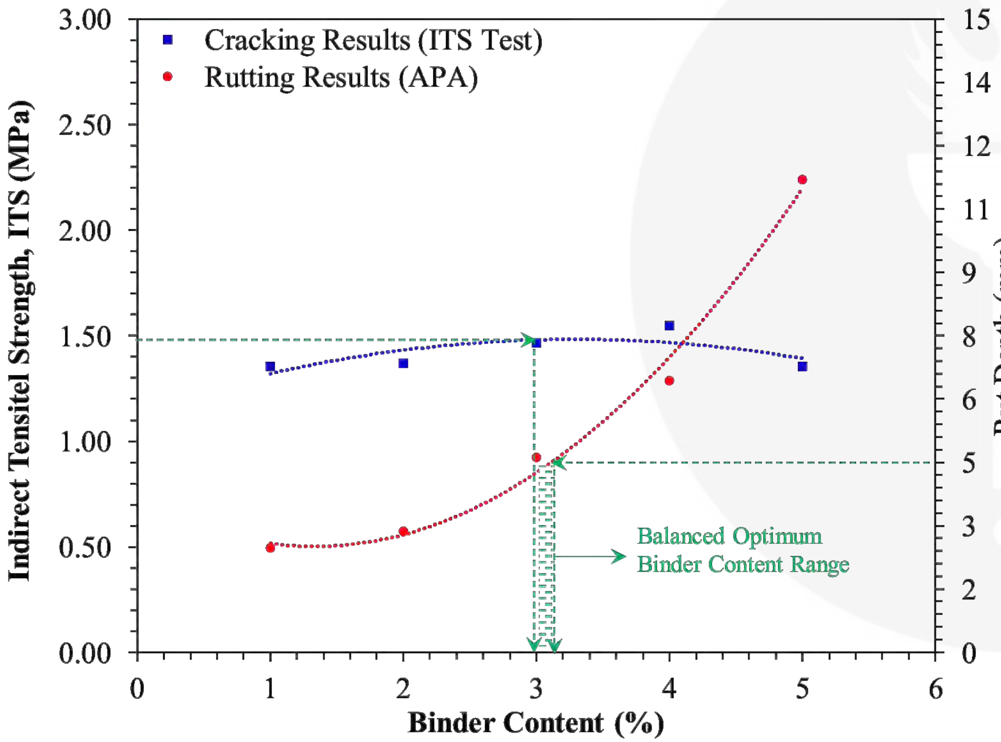
BUILDING STRONG®

RowanUniversity
CENTER FOR RESEARCH & EDUCATION IN ADVANCED TRANSPORTATION ENGINEERING SYSTEMS

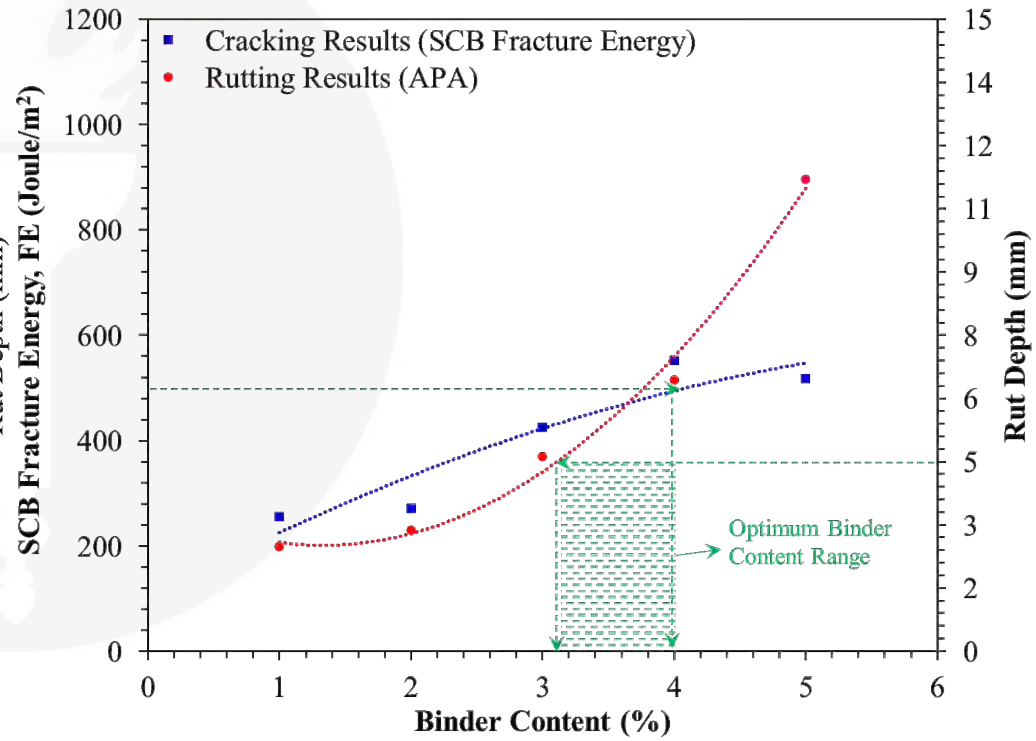
ERDC
Engineer Research and Development Center

Balanced Mix Design

➢ CIR-F30-H



ITS vs APA



SCB vs APA

Balanced Mix Design

- Three cases were observed:

A. Rutting (APA) and Cracking (SCB and ITS) measures were relevant. (Example: CIR-E30-H, CIR-F70-H).

B. Fatigue Measures are more relevant than those of rutting. (Example: CIR-E70-H).

C. Rutting and Fatigues measures present increasing trends. (Example: CIR-F30-C)

Balanced Mix Design

Balanced Mix Designs				
Mix	**OBC (%)**	**Rut Depth (mm)**	**ITS (MPa)**	**SCB FE (J.m^{-2})**
CIR-E30-H	3.11	4.48	1.90	522.05
CIR-E70-H	3.16	2.44	2.13	628.43
CIR-F30-H	3.10	4.29	1.56	431.68
CIR-F70-H	3.78	4.83	1.87	555.31
CIR-E30-C	3.50	5.53	0.40	304.26
CIR-E70-C	3.95	4.09	0.62	523.31
CIR-F30-C	3.38	5.48	0.56	196.60
CIR-F70-C	3.78	4.74	0.73	209.88

Rowan University
CENTER FOR RESEARCH & EDUCATION IN
ADVANCED TRANSPORTATION ENGINEERING SYSTEMS

ERDC
Engineer Research and
Development Center

Performance Comparison of balanced CIR mixtures

94th Annual NESMEA/ NEAUPG Conference, Atlantic City (October 17-18, 2018)

Performance Comparison

- The performance of CIR samples at optimum binder content were evaluated and compared at the following conditions:

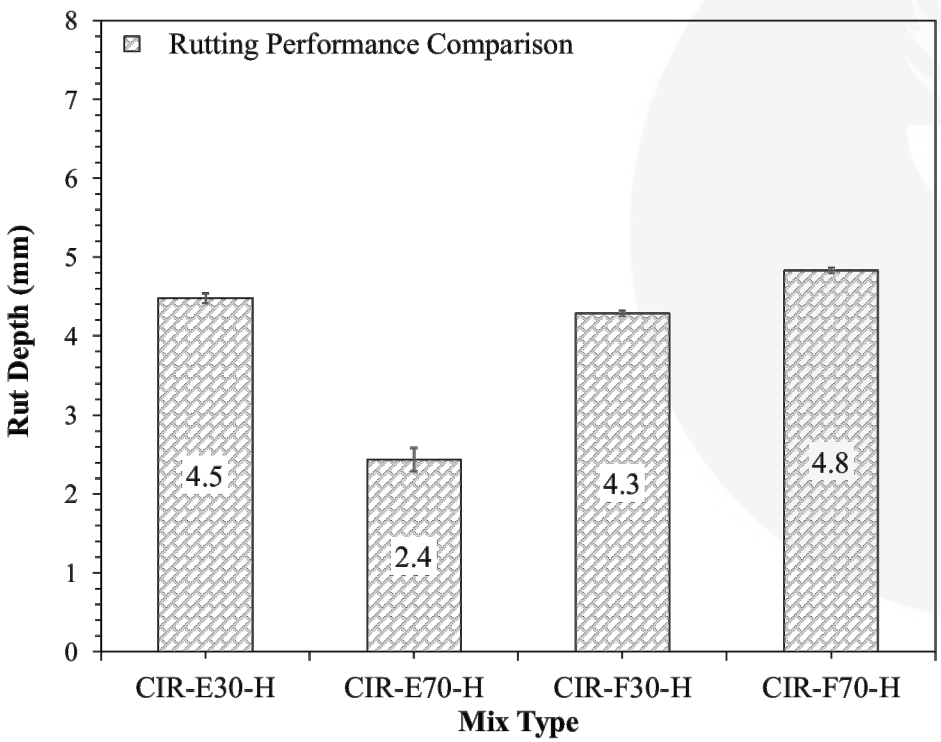
A. Binding agent (i.e. Emulsion or Foamed asphalt).

B. Curing process (i.e. Cold or Hot).

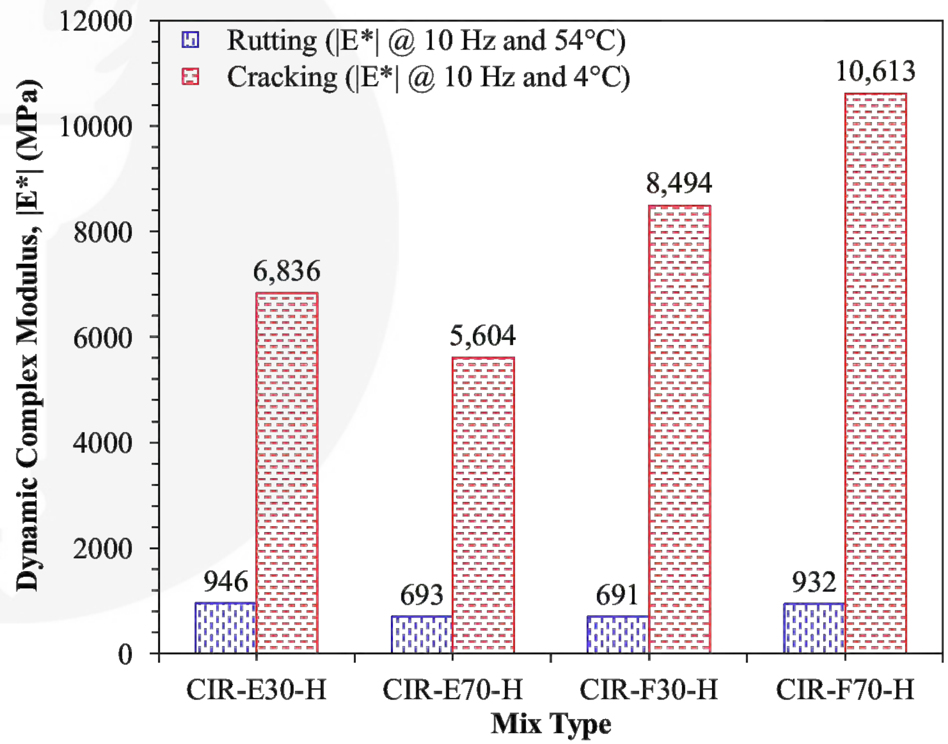
C. Compaction Level (i.e. 30 or 70 gyrations)

Impact of Compaction Level

➢At Hot Curing



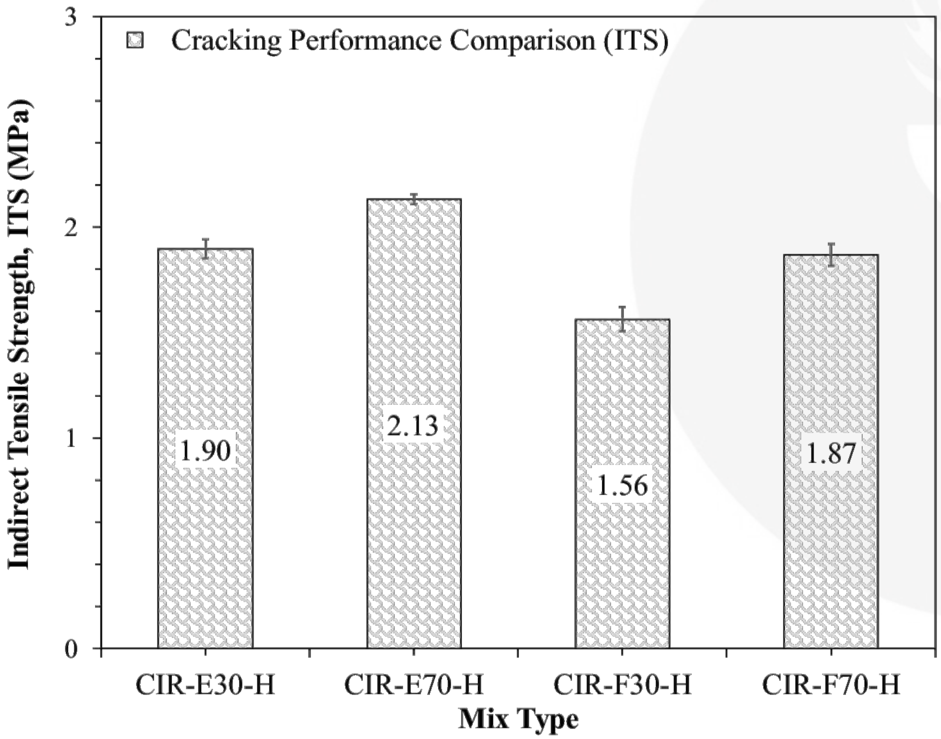
APA rutting



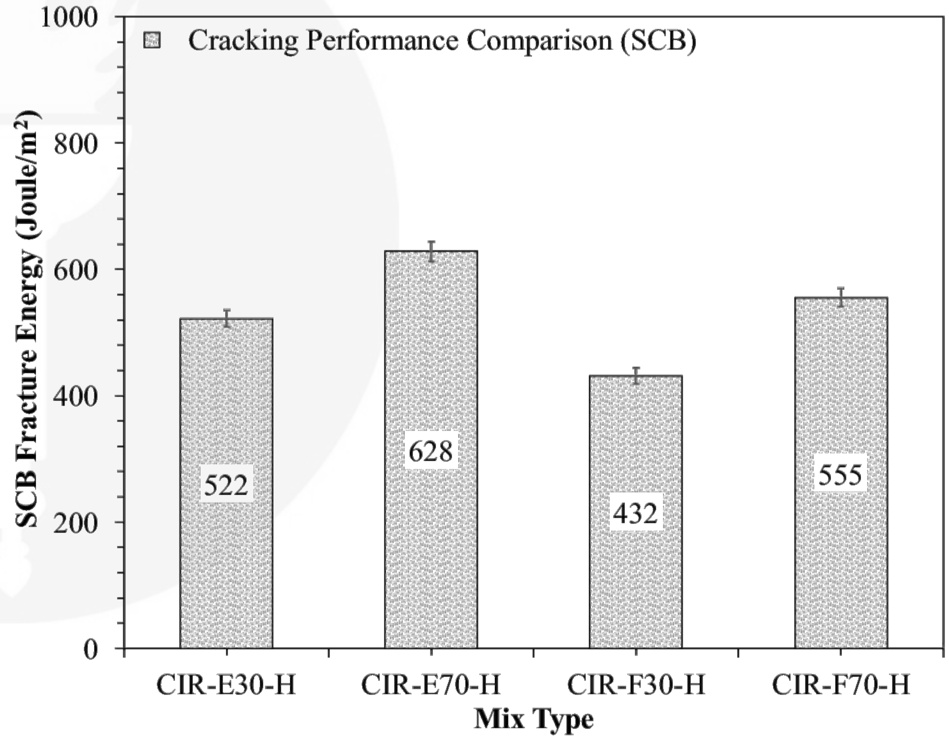
DCM

Impact of Compaction Level

➢At Hot Curing



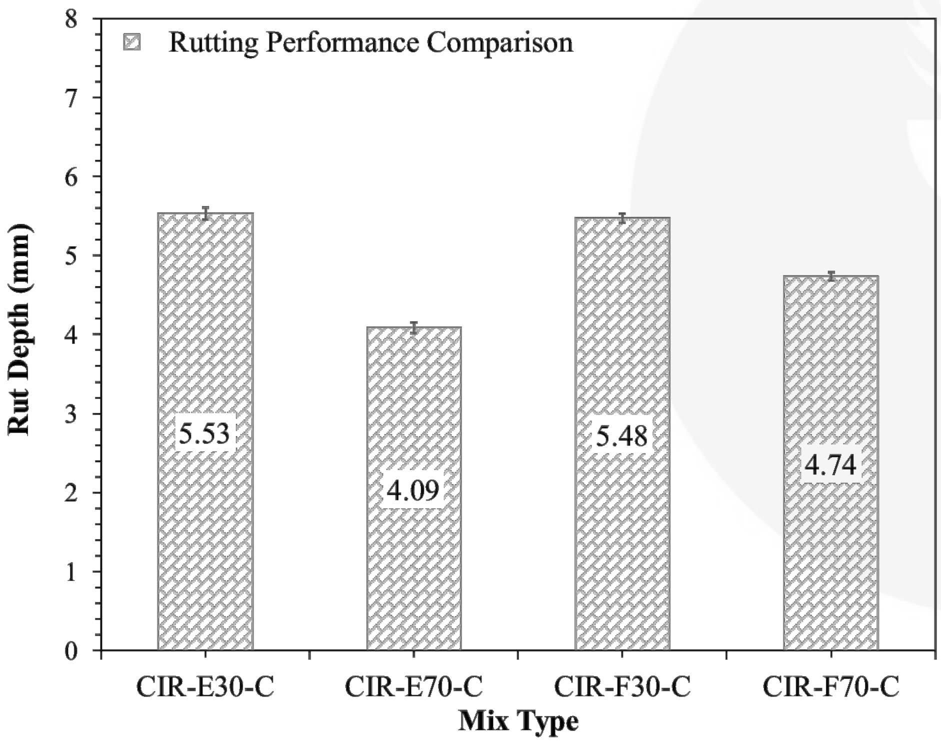
ITS Cracking

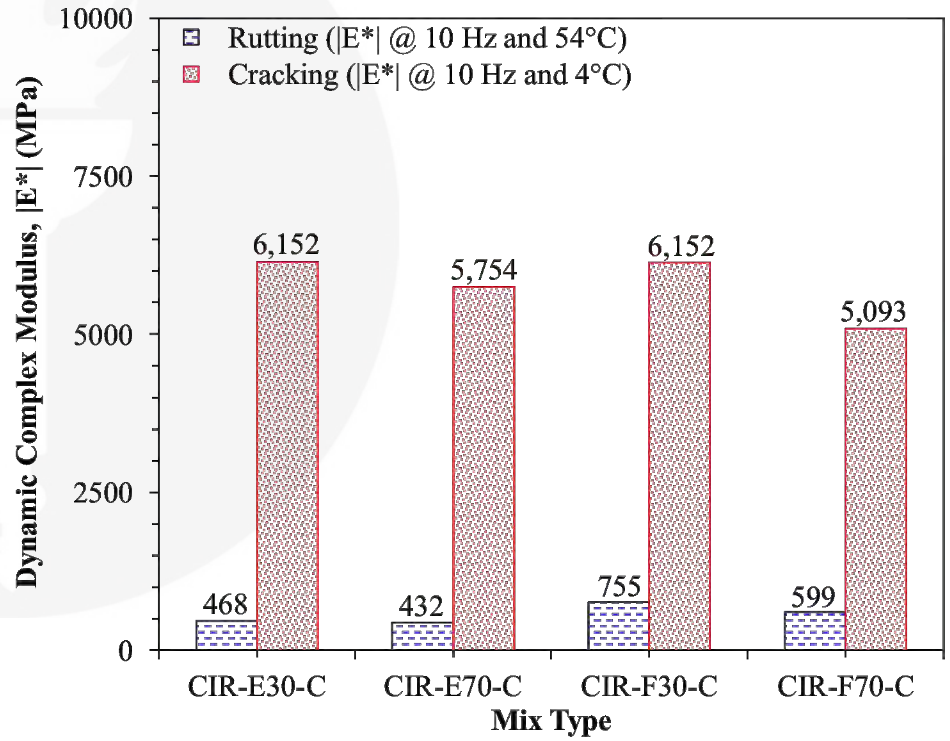


SCB Cracking

Impact of Compaction Level

➢At Cold Curing

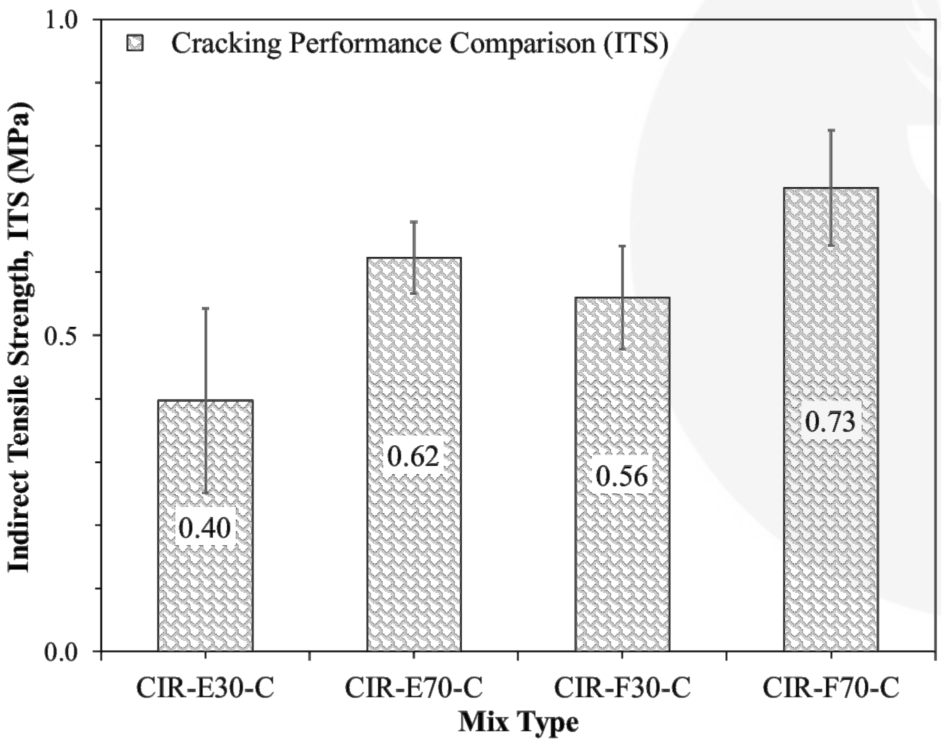


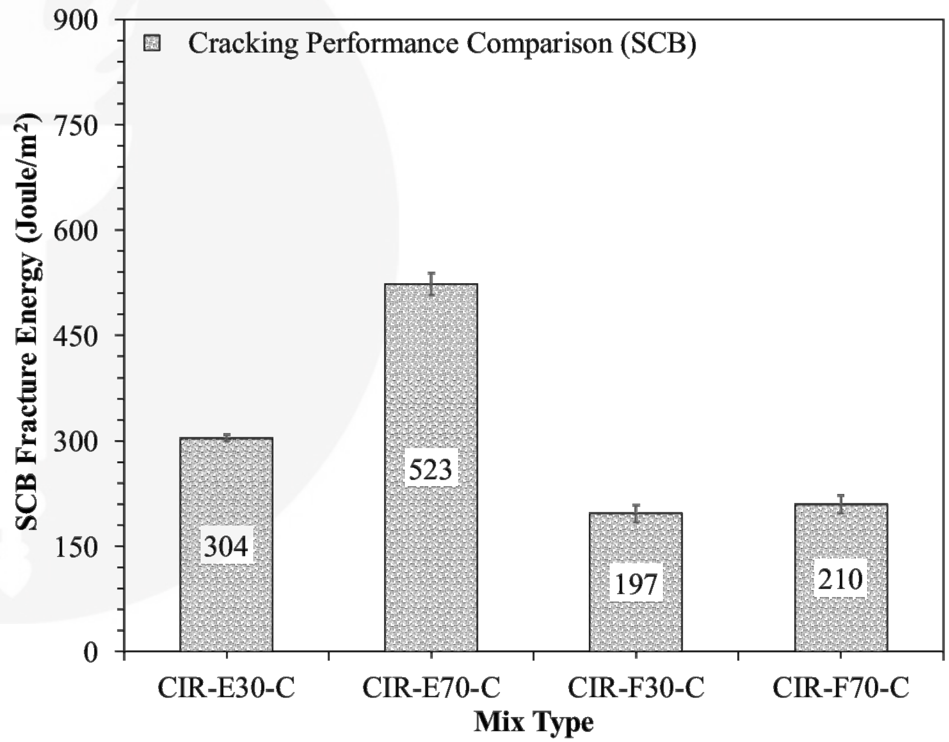


APA rutting **DCM**

Impact of Compaction Level

➢At Cold Curing

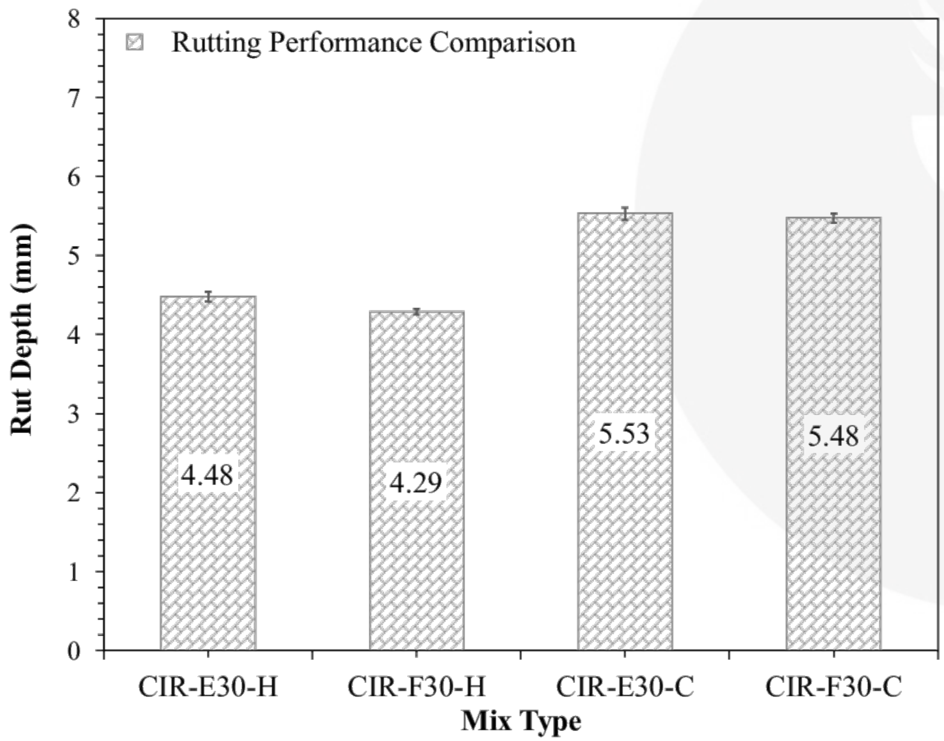




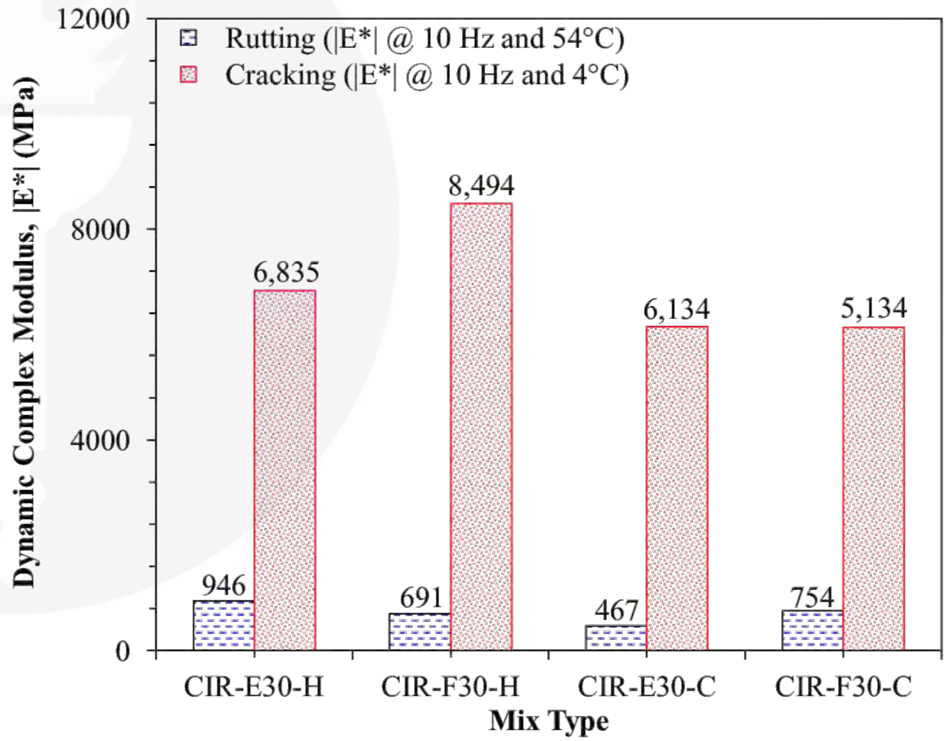
ITS Cracking **SCB Cracking**

Impact of Curing Temperature

- At 30 Gyrations



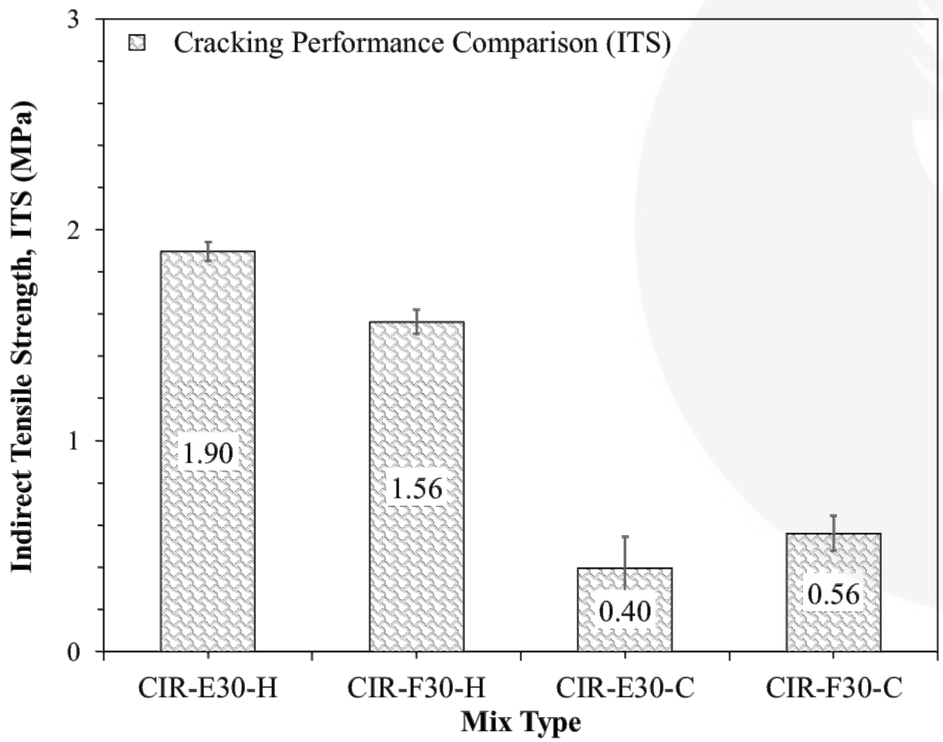
APA rutting



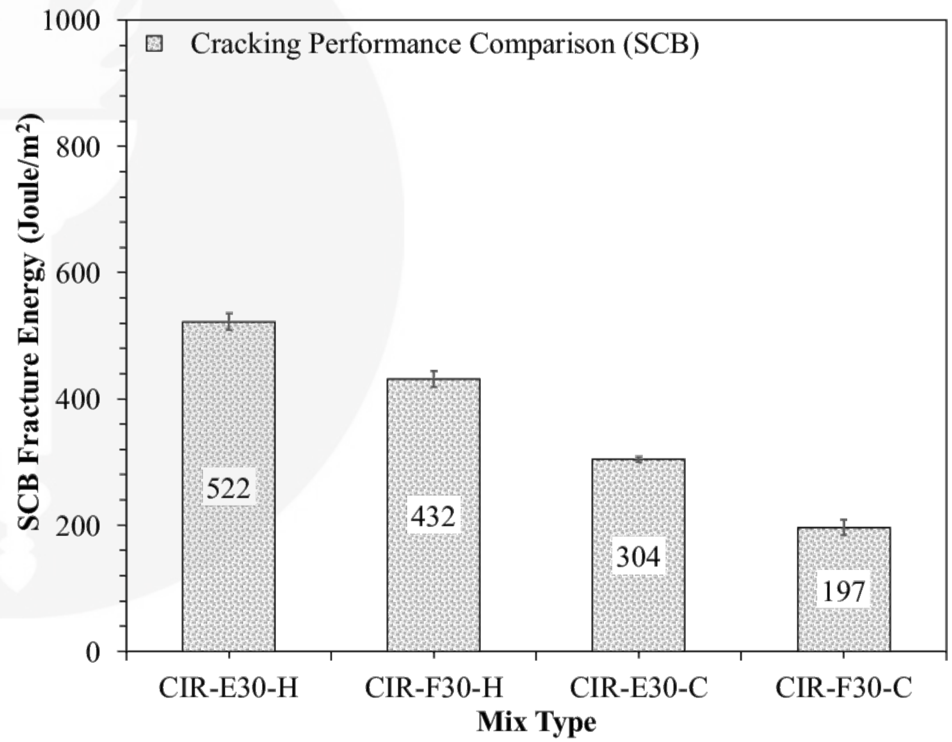
DCM

Impact of Curing Temperature

➢ **At 30 Gyrations**



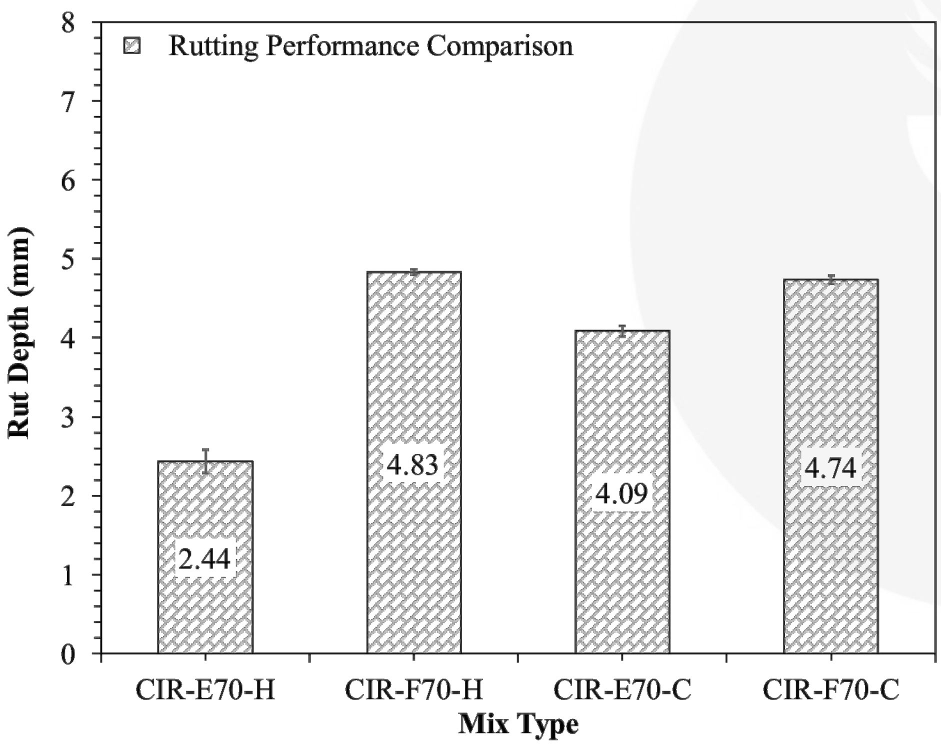
ITS Cracking



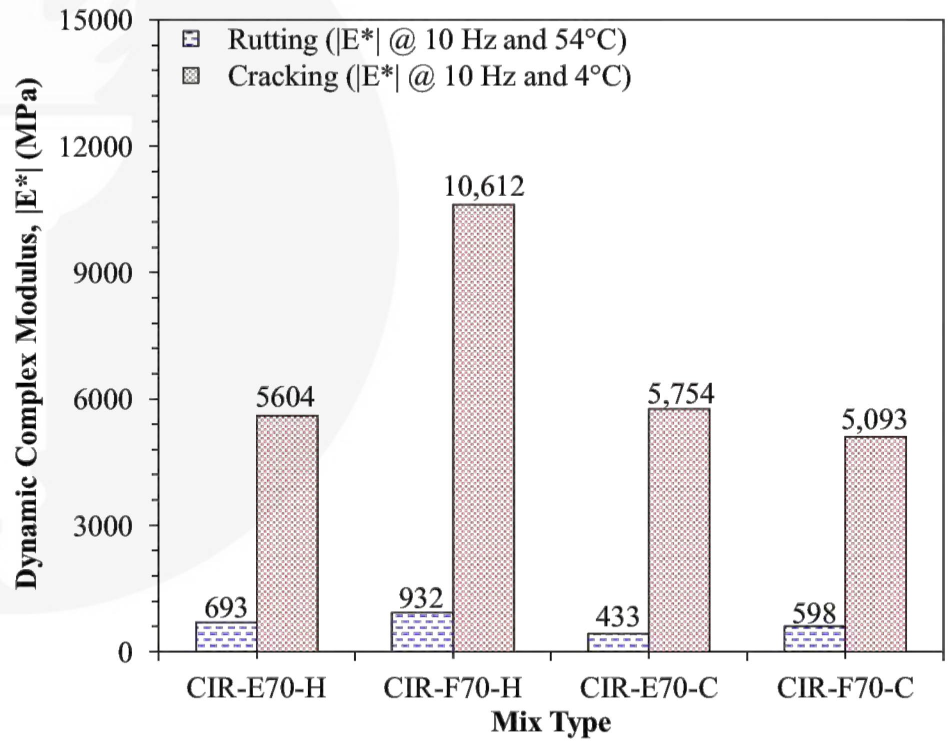
SCB Cracking

Impact of Curing Temperature

➢At 70 Gyrations



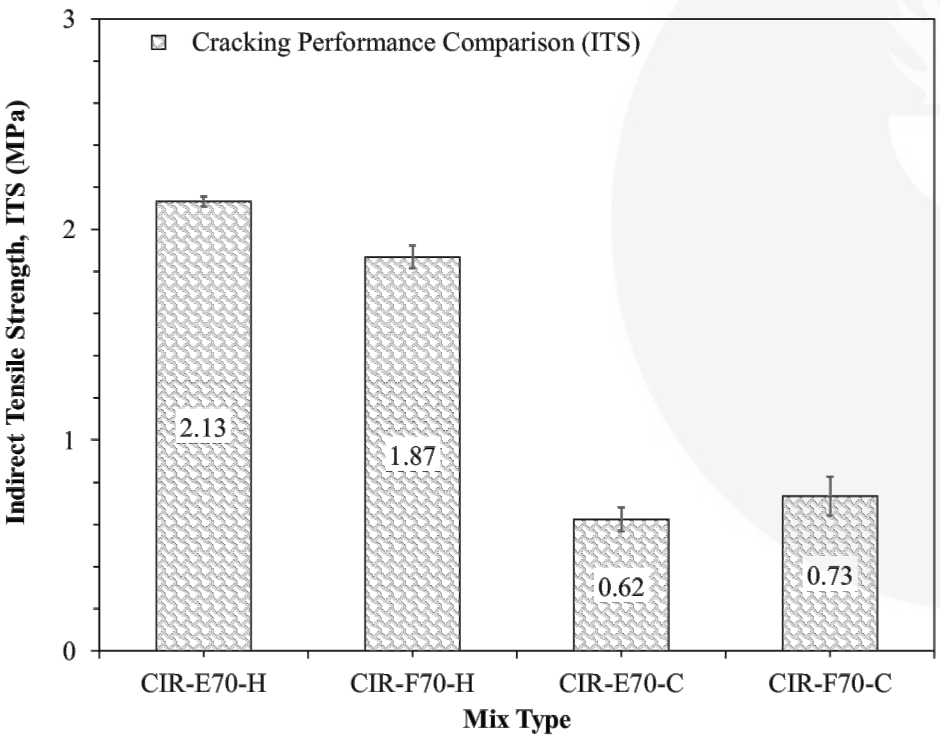
APA rutting

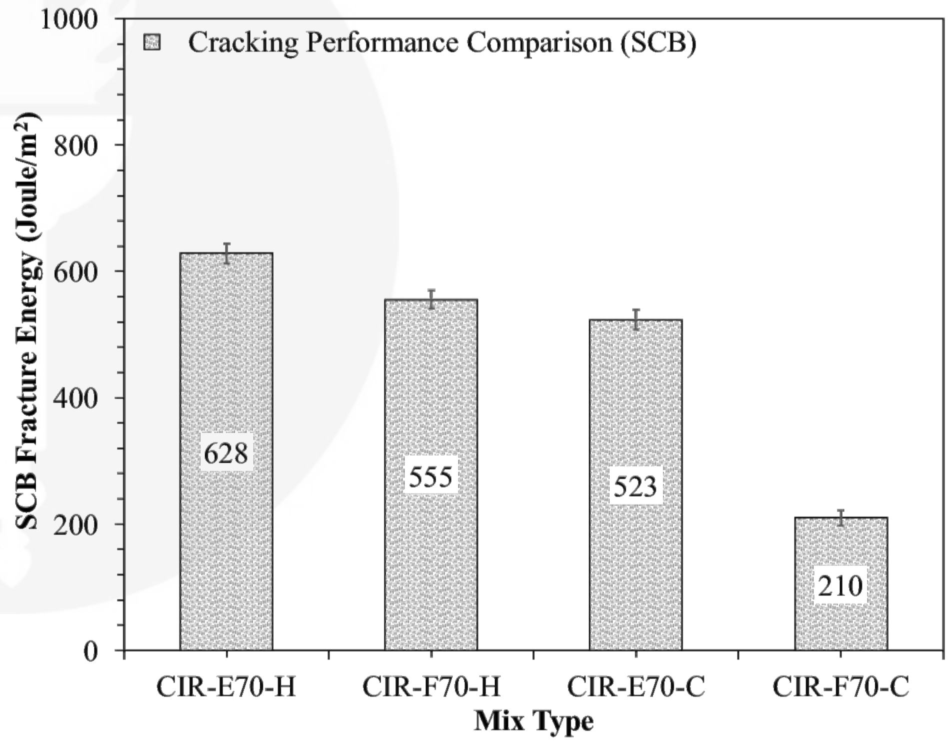


DCM

Impact of Curing Temperature

- At 70 Gyrations





ITS Cracking

SCB Cracking

Performance Comparison

- The binding agent type, curing process, and compaction level affect the rutting and cracking performances of CIR BMD mixes.
- With regard to <u>cracking</u>:
  - Samples submitted to hot curing presented higher FE, ITS, and |E*| values for all mixes.
  - Samples compacted with 70 gyrations presented higher FE, ITS, and |E*| values than those compacted with 30 gyrations.

Performance Comparison

- With regard to <u>cracking</u>:
  - Samples submitted to hot curing presented higher FE and ITS values for all mixes.
  - Samples compacted with 70 gyrations presented higher FE and ITS values than those compacted with 30 gyrations.

Performance Comparison

- With regard to rutting:
  - When submitted to the same curing process, emulsion and foamed asphalt CIR BMD samples presented similar responses to rutting.
  - At same compaction level, rut depth of hot cured CIR samples is higher than that of cold cured samples.
  - Samples compacted with 70 gyrations presented lower rut depth values than those compacted with 30 gyrations.

Preliminary Conclusion

Preliminary Conclusion

- BMD design approach showed success in designing CIR mixes.
- Regression analysis showed that CIR binder content is a good predictor for APA rut depth, ITS, and SCB FE.
- CIR binder content had little to no impact on CIR stiffness. Therefore, DCM was excluded.

Preliminary Conclusion

- The compaction level and curing process of emulsion and foamed asphalt CIR mixtures had significant impact on rut depth, ITS, and SCB FE.
- Given the same gyration level, CIR mixes prepared with foamed or emulsion have similar ability to resist rutting.

Preliminary Conclusion

- Emulsion and foamed asphalt CIR samples showed similar ITS responses at optimum binder contents.
- At optimum binder contents, SCB-FE of foamed asphalt CIR mixes was higher than that of emulsion CIR mixes.

Preliminary Conclusion

- When cured at 140^{o}F, foamed asphalt CIR mixes present higher cracking resistance than emulsion CIR mixes. However, emulsion CIR samples present a better cracking resistance when cured at 50^{o}F.

Rowan University

CENTER FOR RESEARCH & EDUCATION IN ADVANCED TRANSPORTATION ENGINEERING SYSTEMS

ERDC

Engineer Research and Development Center

Questions?

Ayman Ali, Ph.D.
Manager,
Center for Research and Education in Advanced Transportation Engineering Systems (CREATEs)
Phone: 908.283.0467
Email: alia@rowan.edu
Website: www.rowan.edu/creates