Development of AI-Based Prediction Models to Evaluate Long-Term Aged Cracking Resistance in Asphalt Mixtures Using SCB Jc Parameter




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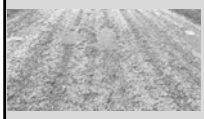
Key Topics

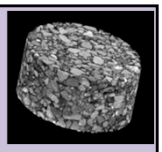
- Background
- Objectives and Scope
- Development Prediction Models
  - Statistical Scaling Factor
  - AI-Based
- Results
- Key Takeaways
- Implementation

Pavement Performance

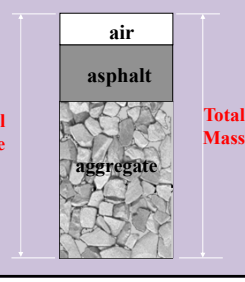
- Ability of a structure to satisfactorily serve traffic and environmental loading over a period of time

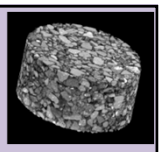

Asphalt Mixture Design



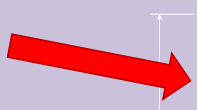
- Volumetrics
  - Voids in the Total Mix, *VTM*
  - Voids in the Mineral Aggregate, *VMA*
  - Voids Filled with Asphalt, *VFA*
- Densification
  - Stages during lab compaction process

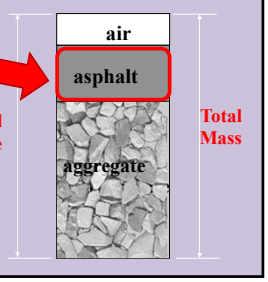



Concerns



- **Optimum asphalt binder content**
  - Quantity
  - NOT QUALITY
  - Aged Binders
    - » Replace virgin binder
    - » RAP and/or RAS



Durable Flexible Pavement

- Permanent deformation
- Fatigue cracking – repeated load
- Low temperature cracking
- Moisture induced damage
- Raveling
- etc …

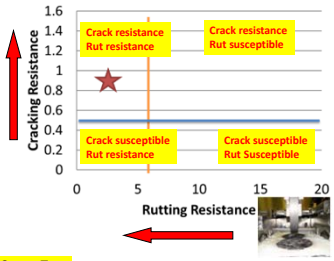

Durable

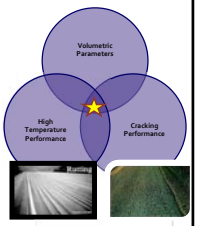
- *… able to exist for a long time without significant deterioration in quality or value.”*

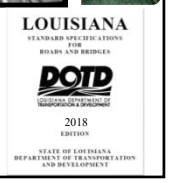
Louisiana's Approach -- Durable Flexible Pavement

Balanced Asphalt Mixture Design

- Volumetric and Performance Mixture Testing
  - Rutting (AASHTO T 324): LWT test (50°C, Wet)
  - Cracking (ASTM 8044): SCB test (25°C)







Asphalt Mixtures Stress Tests

2016 Louisiana DOTD Specifications for Roads and Bridges

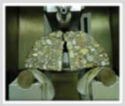
SCB, min, Jc, kJ/m² @ 25° C, **Aged**	All mix design level 1 must meet minimum 0.5 Jc , All mix design level 2 must meet minimum 0.6 Jc.

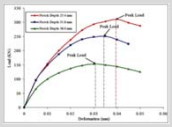
Durable Flexible Pavement

- Permanent deformation
- Fatigue cracking – repeated load
  - Fracture mechanic-based test
    - Semi-Circular Bend (SCB) Test – ASTM D8044
    - Sample preparation
    - Aging (85ºC for 5 days)
    - Testing

Not Practical QC/QA

- Outputs
  Load vs displacement curve
- Compute cracking resistance parameter
  Critical strain energy release rate (J_c)
  Jc ≥ 0.6 kj/m² High volume traffic





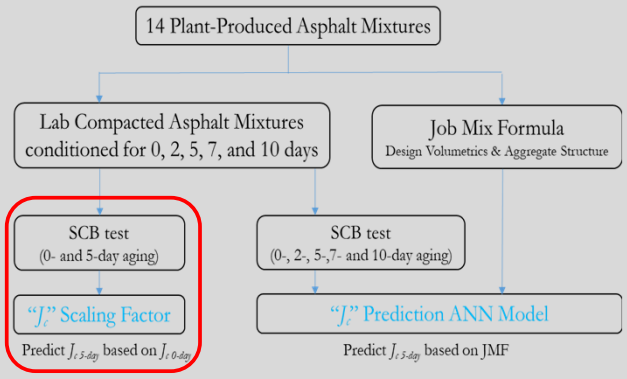
$$J_c = -\left(\frac{1}{b}\right)\frac{du}{da}$$

Objective

- Develop *practical LTA SCB Jc prediction* models from short-term data available at the design and production phases
  - *Scaling factor*
    - » Forecast SCB Jc at 5 days (Jc 5-day) aging from asphalt plant produced SCB Jc (Jc 0-day)
  - *Machine learning prediction model* to obtain SCB Jc 5-days from parameters available in job mix formulas
    - » Facilitate implementation in QC/QA
    - » User-friendly GUI developed

Elnaml, I., Mohammad, L. N., Cooper, III, S., and Cooper, Jr, S., "Development of Practical Prediction Models to Assess Long-Term Aged Cracking Resistance in Asphalt Mixtures Using the SCB Jc Parameter." Journal of Construction and Building Materials, Vol 491, 2025, pp. 142670: 1-9

Scope



Scope:

- **Materials**
  - **14 field projects**
    - **Asphalt Mixture Types**
      - **SMA**
      - **Dense graded**
    - **NMAS, mm**
      - **9.5, 12.5**
    - **RAP Contents, %**
      - **0 - 26**
    - **Asphalt Binder Type**
      - **PG 67-22 (unmodified) -- 4**
      - **PG 70-22 (SBS modified) -- 4**
      - **PG 70-22 (Latex modified) -- 1**
      - **PG 76-22 (SBS modified) -- 4**
      - **PG 82-22 (Crumb Rubber modified) –1**
    - **Asphalt Binder Source**

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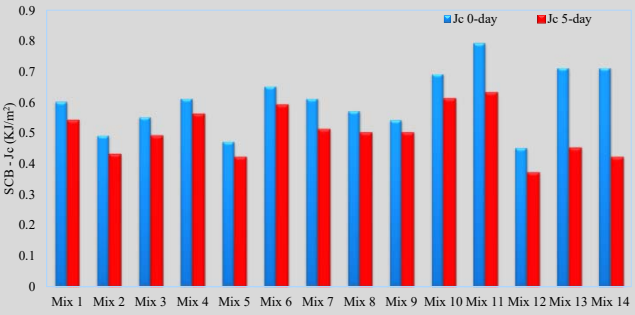
Scope

Mixture Number	RBR	Total %AC	Asphalt Binder PG	Modifier	NMAS, mm	Design Level*	V_a (%)	VMA (%)	VFA (%)	P_{be} (%)	D/B
M1	0.14	5.0	70-22m	SBS	12.5	1	3.5	14.7	76	4.8	0.96
M2	0.00	6.0	82-22rm	CR	12.5	SMA	3.5	16.3	79	5.5	1.31
M3	0.26	4.6	76-22m	SBS	19.0	2	3.5	13.2	73	4.1	1.02
M4	0.00	6.3	76-22m	SBS	12.5	SMA	3.5	17.0	79	5.9	1.29
M5	0.18	5.0	67-22	-	12.5	1	3.7	13.8	74	4.7	1.17
M6	0.16	5.0	76-22m	SBS	12.5	2F	3.5	14.7	76	4.8	0.96
M7	0.15	4.7	67-22	-	12.5	1	3.4	13.9	76	4.5	1.21
M8	0.15	4.7	70-22m	SBS	12.5	1	3.4	13.9	76	4.5	1.21
M9	0.28	4.6	67-22	-	19.0	1	3.6	13.1	72	4.1	1.20
M10	0.20	5.0	67-22	-	12.5	1	3.6	13.9	74	4.5	1.22
M11	0.21	4.7	70-22m	Latex	12.5	1	3.5	14.1	75	4.6	1.17
M12	0.20	5.1	70-22m	SBS	12.5	1F	3.5	13.8	75	4.4	1.18
M13	0.00	6.3	76-22m	SBS	12.5	SMA	3.7	16.5	78	5.6	1.47
M14	0.00	4.2	70-22m	SBS	19.0	1	3.5	12.5	72	3.8	0.92

Development Prediction Models – Scaling Factor

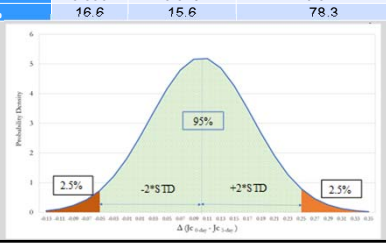


Development Prediction Models – Scaling Factor

Descriptive statistics

	$J_{c\ 0\text{-day}}$	$J_{c\ 5\text{-day}}$	Δ ($J_{c\ 0\text{-day}}$ - $J_{c\ 5\text{-day}}$)
Maximum	0.79	0.63	0.29
Minimum	0.45	0.37	0.04
Average	0.603	0.501	0.101
STD	0.096	0.075	0.077
COV, %	16.6	15.6	78.3

Normal Distribution for Δ values



Development Prediction Models – Scaling Factor

Scaling Factor

	Dataset Scaling Factor ($J_{c\ 5\text{-day}}$ / $J_{c\ 0\text{-day}}$) N=14	Recommended Scaling Factor ($J_{c\ 5\text{-day}}$ / $J_{c\ 0\text{-day}}$) N=12	95% Confidence Band of Recommended Scaling Factor
Maximum	0.93	0.93	
Minimum	0.59	0.80	95% CI = Average ± 1.96*STD
Average	0.84	0.87	95% CI = 0.87 ± 1.96*0.04
STD	0.10	0.04	**95% CI = [0.79 – 0.94]**
COV, %	12.3	4.5	

N= number of mixtures; CI = confidence interval

$$J_{c\,5-day} = J_{c\,0-day} * SF$$

Where:

$J_{c\ 5\text{-day}}$: Predicted SCB J_c value at 5 days at 85°C, kJ/m²

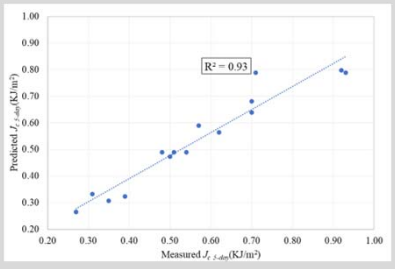
$J_{c\ 0\text{-day}}$: Measured SCB J_c value, at 0 days, kJ/m²

SF: Scaling factor range [79% – 94%], with an average of **87%.**

Development Prediction Models – Scaling Factor Results

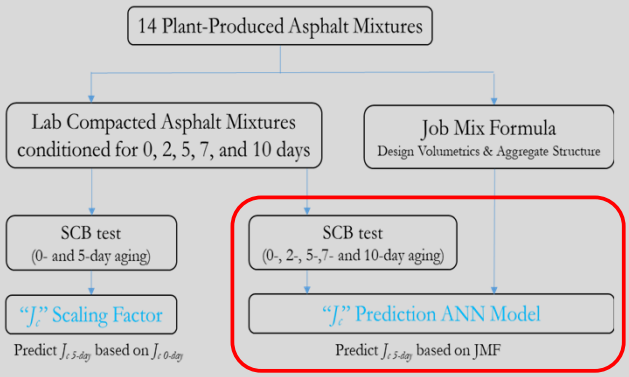
$$J_{c\,5-day} = J_{c\,0-day} * SF$$

Scaling Factor Validation (15 new mixtures)



Comparison of measured $J_{c\ 5\text{-day}}$ and predicted $J_{c\ 5\text{-day}}$ using the Scaling Factor developed

Scope



Development Prediction Models -- ANN

- 40 asphalt mixtures at different aging levels
  - –0-, 2-, 5-, 7-, and 10-day
- Diverse set of asphalt mixture component materials
  - – unmodified, polymer modified, various recycled binder ratios (RBR)
  - – different gradations
- 104 data points were used to select significant parameters in predicting SCB Jc
  - –LL & PL specimens

Development Prediction Models -- ANN

- Artificial neural network (ANN) model
  - – 12 variables were considered
  - – readily available
    - » Volumetric properties of asphalt mixture
    - » aging level
    - » asphalt binder modification level.
  - – **Mixture Volumetric Properties** --10
    - » %AC (asphalt content)
    - » %RAP and %RAS
    - » P_{be} (effective asphalt binder)
    - » P200 (%passing no. 200 sieve)
    - » P4 (%passing no.4 sieve)
    - » VMA (void in mineral aggregate)
    - » VFA (void filled with asphalt)
    - » SA (surface area, m²)
    - » FT (film thickness, μm)
    - » DB (dust to binder ratio)


Louisiana Department of Transportation and Development
JMF SUPERPAVE ASPHALTIC CONCRETE MIXTURES

Development Prediction Models -- ANN

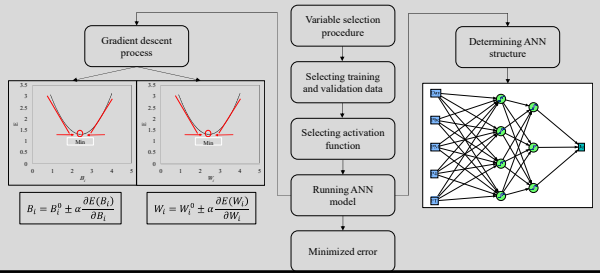
- Artificial neural network (ANN) model
  - – 12 variables were considered
  - – readily available
    - » Volumetric properties of asphalt mixture
    - » aging level
    - » asphalt binder modification level.
  - – **Asphalt Binder Properties**
    - » asphalt binder modification level
      - 0 = PG 67-22; 1 = PG 70-22; 2 = PG 76-22
  - – **Aging Level**
    - » Days
      - 0-, 2-, 5-, 7-, and 10-days
- Stepwise Regression Analysis
  - – building a model by successively adding or removing independent variables
    - » based on F-statistics of estimated coefficients
  - – significant variables to predict the SCB

Development Prediction Models -- ANN

	Step	Parameter	Action	F-value	R^2	No. of parameters in model
✓	1	Surface Area	Entered	0.0000	0.3210	2
✓	2	Aging Days	Entered	0.0000	0.5086	3
✓	3	Polymer modification level	Entered	0.0000	0.6105	4
✓	4	%Passing from sieve #4	Entered	0.0000	0.6769	5
✓	5	Effective Asphalt Binder	Entered	0.0149	0.6961	6
	6	Surface Area	Removed	0.7551	0.6958	5
✓	7	Film Thickness	Entered	0.0226	0.7118	6
	8	Surface Area	Entered	0.0187	0.7280	7
	9	Recycled Asphalt Shingle	Entered	0.0772	0.7369	8
	10	All	Removed	.	0.0000	1
	11	Surface Area	Entered	0.0000	0.3210	2
	12	Aging Days	Entered	0.0000	0.5086	3
	13	Polymer modification level	Entered	0.0000	0.6105	4
	14	%Passing from sieve #4	Entered	0.0000	0.6769	5
	15	Effective Asphalt Binder	Entered	0.0149	0.6961	6
	16	Surface Area	Removed	0.7551	0.6958	5
	17	Film Thickness	Entered	0.0226	0.7118	6
	18	Surface Area	Entered	0.0187	0.7280	7

Development Prediction Models -- ANN

- Model Development
  - » R-studio software – Training 70% and Validation 30%
  - » Sample size should be more than 10*parameters studied (6) = 60 < 104 used ✓



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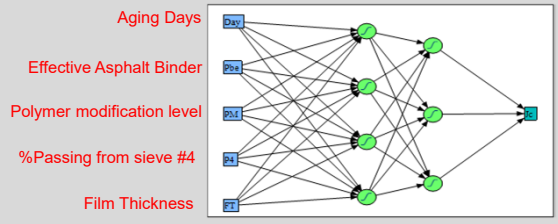

Structure of ANN Model for Predicting SCB J_c

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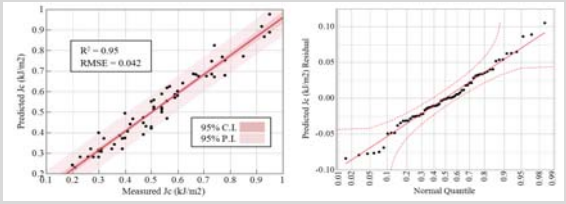
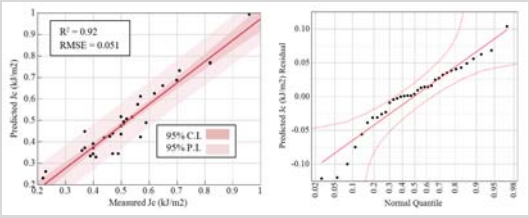


Training Result (a) Predicted versus Measured SCB Jc, (b) Residual Normal Quantile Plot

Development Prediction Models -- ANN

- Model Validation
  - R-studio software – Training 70% and Validation 30%



Validation Result (a) Predicted versus Measured SCB Jc, (b) Residual Normal Quantile Plot

Development Prediction Models -- ANN

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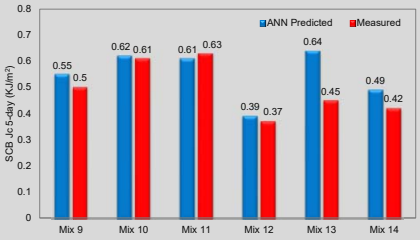

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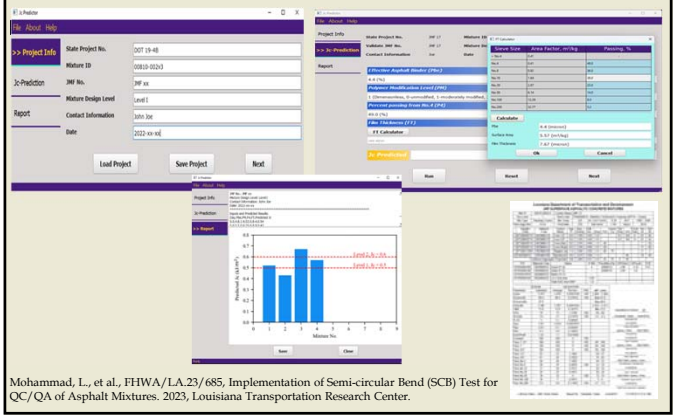
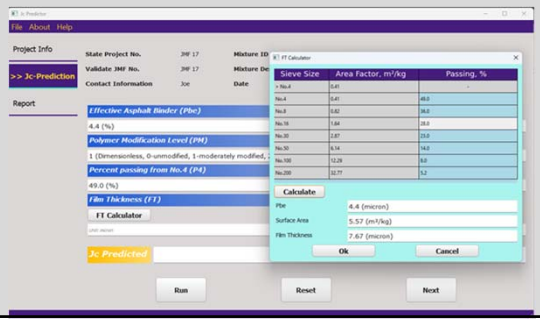
SCB Jc Prediction - ANN Model



Mohammad, L., et al., FHWA/LA.23/685, Implementation of Semi-circular Bend (SCB) Test for QC/QA of Asphalt Mixtures. 2023, Louisiana Transportation Research Center.

Results of Prediction Models

- 2. Results of ANN Prediction Model
  - 2.4. User Interface



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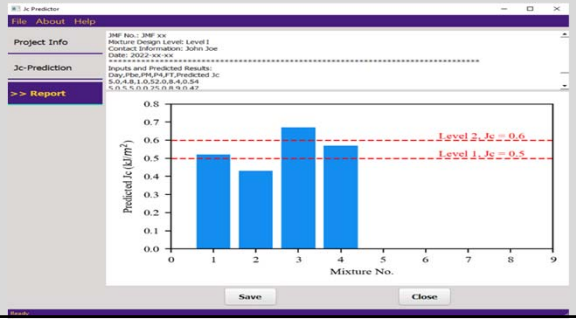
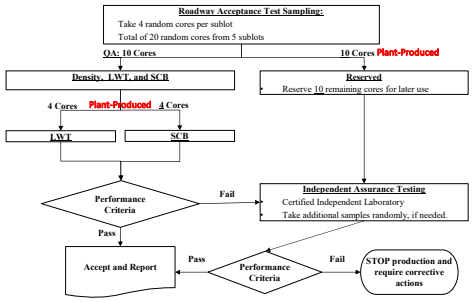


Key Takeaways

- SCB Jc parameter was effective in capturing the effect of progressive aging
- Scaling factor [87%] was developed to forecast SCB Jc 5-day at 85°C aging from SCB Jc 0-day aging (i.e., plant-produced mixtures).
  - $R^2 = 0.93$
- ANN prediction model for SCB Jc 5-day value based on data available in the JMF.
  - $R^2 = 0.92$
- A user-friendly interface was developed for evaluation and implementation in the Louisiana DOTD's asphalt mixture QA programs.

Proposed Implementation

- Acceptance Testing Plan



Mohammad, L.N., et. al., "Development Of Performance Based Specifications For Louisiana Asphalt Mixtures." Report No. FHWA/LA.14/558. Baton Rouge, LA. 2016

Proposed Implementation

- Pilot Specification for 2026
  - Link interface to production QC data submitted through LaPAVE (DOTD Mix Design and Production Database)
  - Monitor real time variation in model output.