ROAD WORK AHEAD

Designing a Model for Predicting Fatigue Cracking in Asphalt Pavement

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Abstract

The purpose of this research is to use mathematical modeling to replace lab testing of fatigue cracking in asphalt pavement mixtures. To effectively eliminate lab testing, a predictive model of the damage characteristic curve (C vs. S), which indicates the fatigue performance of asphalt pavement mixtures under uniaxial tensile loading, needed to be built using only factors of the asphalt pavement composition with no inclusion of lab tested performance measurements. No such model has yet successfully characterized fatigue cracking, though effective predictive models of transverse cracking have been made using the dynamic modulus. For this research, the generalized regression tools in the JMP Pro 12 software were used to analyze and model a population of 48 asphalt pavement mixtures. Since all factors were all related to mixture composition, not lab tested performance, the model can be considered successful.

Introduction & Rationale

Though cracked pavement seems commonplace, roadway materials development, testing, and construction is a multi-billion dollar per year industry.

An accurate predictive model for fatigue cracking could eliminate up to 90% of corresponding lab testing. This would lower the cost of asphalt paving projects in the field and allow civil engineers to spend more resources developing cost effective solutions for making better, more durable roads.

This research answers the question: ***Can fatigue cracking be predicted using only factors related to the composition of the asphalt pavement mixture with no lab testing of its performance?***

Methods & Materials

A population of 48 asphalt pavement mixtures* was taken from tests that have been conducted at the University of New Hampshire. Ten of these were chosen at random as a representative sample and were used for validation.

**One mixture was identified as an outlier in the analysis of multiple coefficients and was, therefore, excluded from the model.*

The following components of each mixture were analyzed using JMP Pro 12:

- Asphalt binder PG grade high temperature
- Asphalt binder PG grade low temperature
- Nominal Maximum Aggregate Size (NMAS)
- % Asphalt Content
- % Air Void Content
- % Reclaimed Asphalt Pavement
- % Recycled Asphalt Shingle

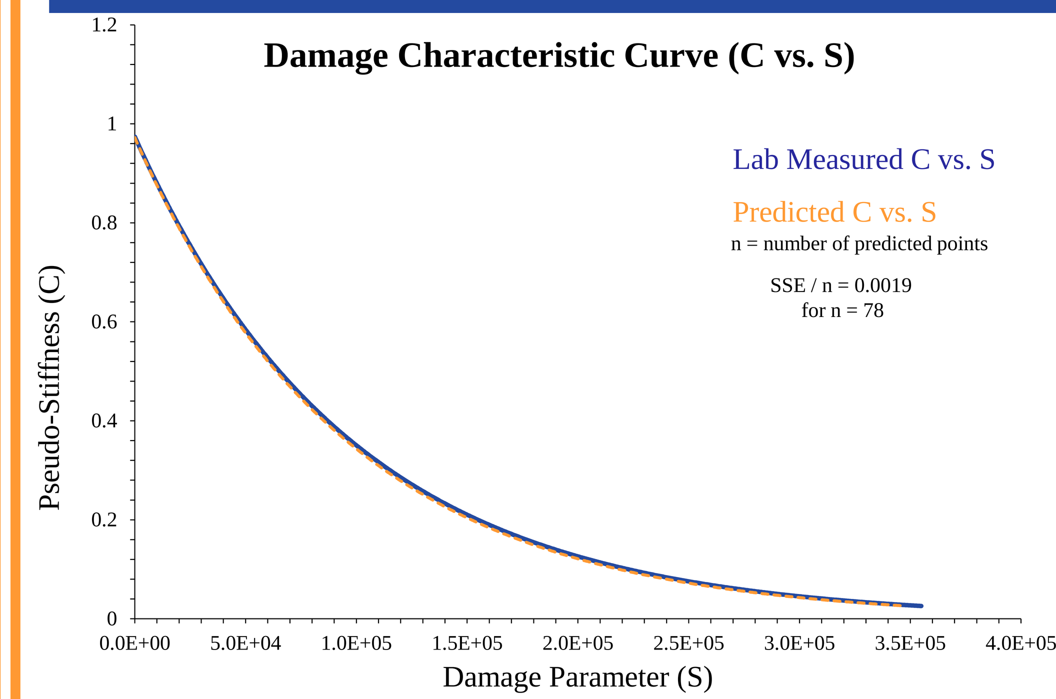
Statistically significant factors were identified using:

R^2 (→1), ChiSquare (<0.0001), p value (<0.05), and RMSE (→0).

Predictions were created using generalized regression with normal distribution, then graphed opposite the lab measured values until y = x was achieved.

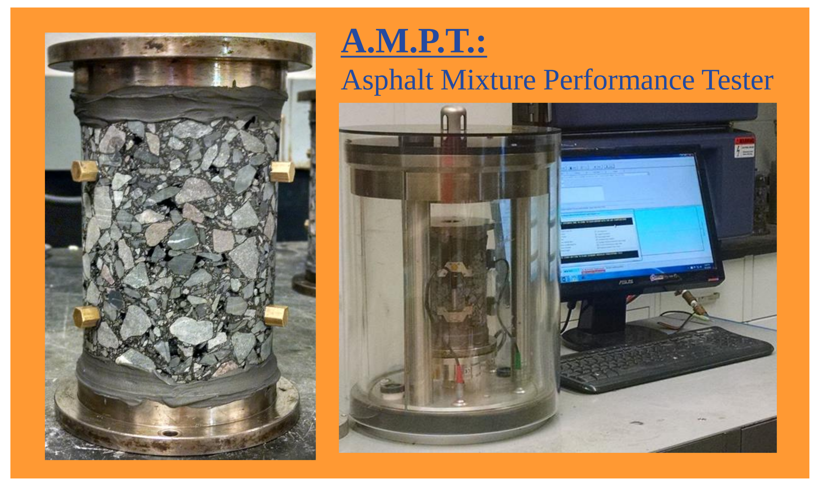
Results

$$C = e^{aS^b}$$

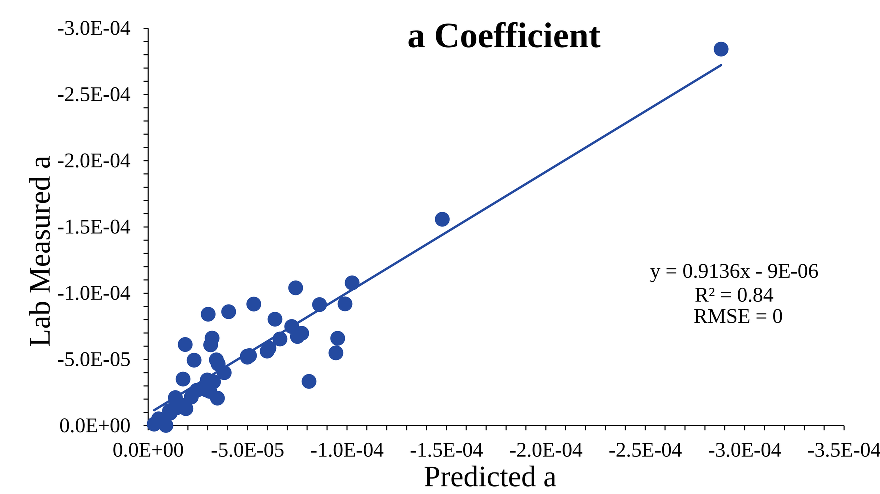


Mix	a	b	S_F	C_F
A	-5.13E-06	1.04E+00	3.55E+05	2.58E-02
	-5.26E-06	1.04E+00	3.47E+05	2.63E-02
B	-2.16E-05	9.32E-01	3.28E+05	3.42E-02
	-2.16E-05	9.32E-01	3.28E+05	3.21E-02
C	-2.68E-05	9.26E-01	1.33E+05	2.50E-01
	-2.95E-05	9.15E-01	1.36E+05	2.35E-01
D	-1.56E-04	7.48E-01	2.10E+05	1.14E-01
	-1.48E-04	7.48E-01	2.56E+05	6.75E-02
E	-9.14E-05	8.25E-01	2.14E+05	1.09E-01
	-8.62E-05	8.36E-01	1.97E+05	1.26E-01
F	-1.34E-05	1.01E+00	1.54E+05	2.02E-01
	-1.42E-05	1.02E+00	1.32E+05	2.47E-01
G	-6.97E-05	8.41E-01	1.75E+05	1.63E-01
	-7.72E-05	8.57E-01	1.42E+05	2.21E-01
H	-8.60E-05	8.10E-01	2.95E+05	4.77E-02
	-4.05E-05	8.75E-01	2.73E+05	5.67E-02
I	-5.29E-05	8.68E-01	9.98E+04	3.51E-01
	-5.10E-05	8.57E-01	1.20E+05	2.78E-01
J	-4.66E-05	8.83E-01	1.64E+05	1.82E-01
	-3.52E-05	9.07E-01	1.57E+05	1.89E-01

The model above was derived using following predicted coefficients:

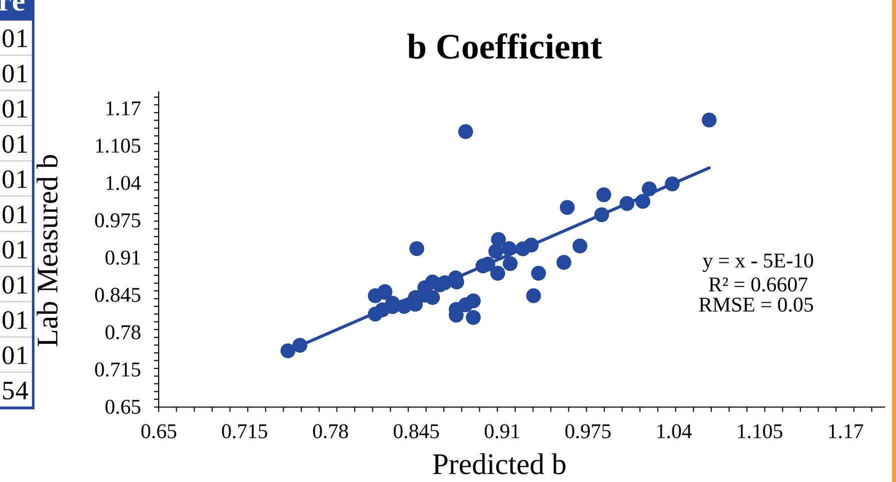


A.M.P.T.:
Asphalt Mixture Performance Tester



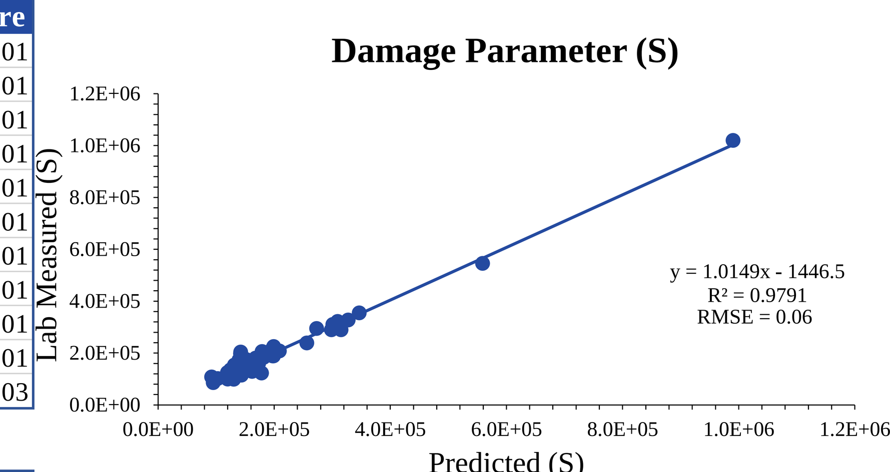
b Coefficient Effect Tests

Source	ChiSquare	Source	ChiSquare
Binder Low Temp*%Va	<0.0001	%RAS*Binder High Temp.	<0.0001
%RAP	<0.0001	%Va*%RAP	<0.0001
NMAS*%RAS	<0.0001	NMAS	<0.0001
Binder High Temp.*NMAS	<0.0001	%RAP*Binder Low Temp.	<0.0001
NMAS*%RAP	<0.0001	%Va*%RAS	<0.0001
Binder High Temp.	<0.0001	%RAP*Binder High Temp.	<0.0001
Binder High Temp.*%Va	<0.0001	%Va*%Va	<0.0001
%AC	<0.0001	%Va	<0.0001
%AC*Binder High Temp.	<0.0001	Binder Low Temp.	<0.0001
Binder Low Temp.*NMAS	<0.0001	%RAS	<0.0001
%RAP*%AC	<0.0001	%AC*NMAS	0.0254



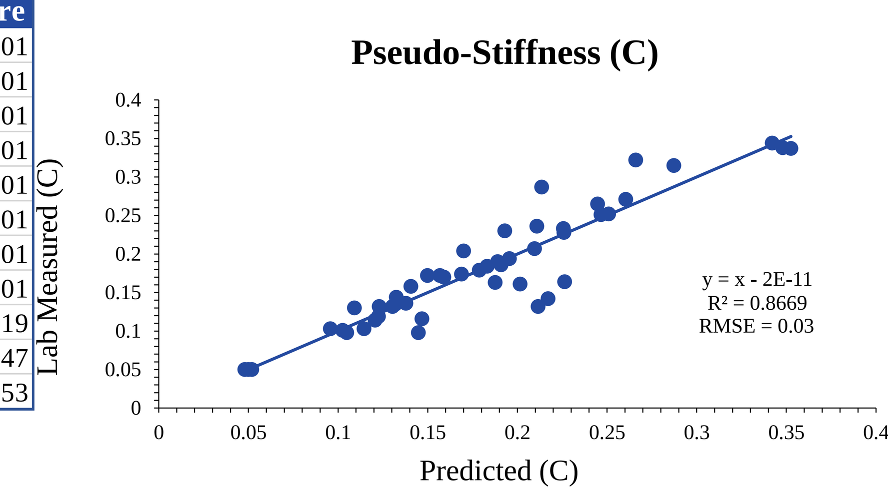
Damage Parameter (S) Effect Tests

Source	ChiSquare	Source	ChiSquare
%AC*b	<0.0001	%RAP*Binder High Temp.	<0.0001
NMAS*%RAS	<0.0001	b*b	<0.0001
%AC	<0.0001	%RAP*Binder Low Temp.	<0.0001
NMAS*%Va	<0.0001	%AC*%RAP	<0.0001
Binder High Temp.	<0.0001	Binder Low Temp.	<0.0001
%RAS	<0.0001	%RAP	<0.0001
%RAP*b	<0.0001	a*%Va	<0.0001
NMAS*%RAP	<0.0001	NMAS	<0.0001
Binder High Temp.*%AC	<0.0001	b	<0.0001
%RAP*a	<0.0001	a*%Va	<0.0001
NMAS*Binder Low Temp.	<0.0001	%Va*%RAP	0.0003



Pseudo-Stiffness (C) Effect Tests

Source	ChiSquare	Source	ChiSquare
%AC*Binder Low Temp.	<0.0001	%Va	<0.0001
Binder Low Temp.	<0.0001	a*%RAP	<0.0001
%Va*b	<0.0001	%RAS	<0.0001
%Va*%RAP	<0.0001	a*b	<0.0001
a*NMAS	<0.0001	a*%RAS	<0.0001
%Va*NMAS	<0.0001	Binder Low Temp.*%RAP	<0.0001
b*%RAP	<0.0001	%RAP	<0.0001
Binder Low Temp.*a	<0.0001	NMAS	<0.0001
%AC*NMAS	<0.0001	Binder High Temp.	0.0019
%VA*Binder High Temp.	<0.0001	%AC	0.0047
Binder Low Temp.*b	<0.0001	a	0.0053



Discussion

The factors that occurred most frequently, having the most interactions with other factors are:

- % Reclaimed Asphalt Pavement
- Nominal Maximum Aggregate Size (NMAS)
- % Air Void Content
- Asphalt binder PG grade high temperature
- % Asphalt Content
- Asphalt binder PG grade low temperature
- % Recycled Asphalt Shingle

In any regression analysis model satisfying the requirement for statistical significance and where y=x for the lab measured vs. the predicted value, it can be assumed that the model has high accuracy.

Predictive C and S were fitted using only the test failure point (S_F, C_F) from the lab testing for each mixture. The overall shape of the damage characteristic curve is also important, characterizing the performance of the pavement for its entire loading life. This model successfully predicted the entire curve.

Conclusion

The success of this limited model suggests that further investigation and development would be worthwhile. A larger, more varied population would likely create greater accuracy.

This preliminary research demonstrates that it is possible to use asphalt pavement composition factors to predict fatigue cracking, effectively replacing lab testing. Q.E.D.

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