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Optimizing Chemical & Rheological Properties of Rejuvenated Bitumen

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Introduction

Bitumen has long been a material used in the construction of roadways, yet new pavement only consists of 15% of recycled materials due to poor compatibility of aged bitumen and new materials.

Chemical additives such as rejuvenators have been used in an attempt to re-balance the chemical composition and restore the physical properties of aged bitumen back to its virgin state. However, a fundamental understanding of how rejuvenators revitalize bitumen is needed before developing the optimum rejuvenator.

Objectives

- Use Fourier-transform infrared (FTIR) spectroscopy to determine the changes in chemical properties of virgin, aged, and rejuvenated bitumen.
- Employ a linear amplitude sweep (LAS), a procedure using a dynamic shear rheometer (DSR), to investigate rheological properties.
- Relate resulting chemical evolution to changes in macroscopic mechanical properties of the revitalized bitumen.

FTIR Index Data

INDEX / Approximate Wavelength (cm-1)	Carboxylic Acid I_{COOH} 1745	Ether I_{Et} 1156	Carbonyl $I_{C=O}$ 1700	Sulfoxide $I_{S=O}$ 1032	Aliphatic I_B 1377	Aromatic I_{Ar} 1601
VG	-0.00772	0.00650	0.00135	0.00589	0.18629	0.06106
VG 7.5%	0.07572	0.05225	-0.00166	0.00631	0.17887	0.04926
VG 15%	0.12309	0.07404	-0.00408	0.00565	0.17091	0.03995
RTFO	-0.00157	0.01337	0.00241	0.01024	0.18527	0.06205
RTFO 7.5%	0.07039	0.04935	-0.00022	0.00848	0.17826	0.04968
RTFO 15%	0.11658	0.07793	-0.00305	0.00788	0.17167	0.04149
PAV	-0.00398	0.00989	0.00639	0.01689	0.18502	0.06538
PAV 7.5%	0.04455	0.04387	0.00456	0.01584	0.17936	0.05789
PAV 15%	0.08780	0.05971	0.00224	0.01399	0.17399	0.04668
Soybean Oil	0.36656	0.21857	-0.00817	0.00296	0.10430	-0.01074

Table 1: Absorbance of characteristic functional groups in virgin (VG), rolling thin film oven (RTFO) aged, pressure aging vessel (PAV) aged, and rejuvenated bitumen.

Where $I_{C=O} = A_{1700cm^{-1}} / \sum A$

$\sum A = Total\ Peak\ Areas$

FTIR Analysis

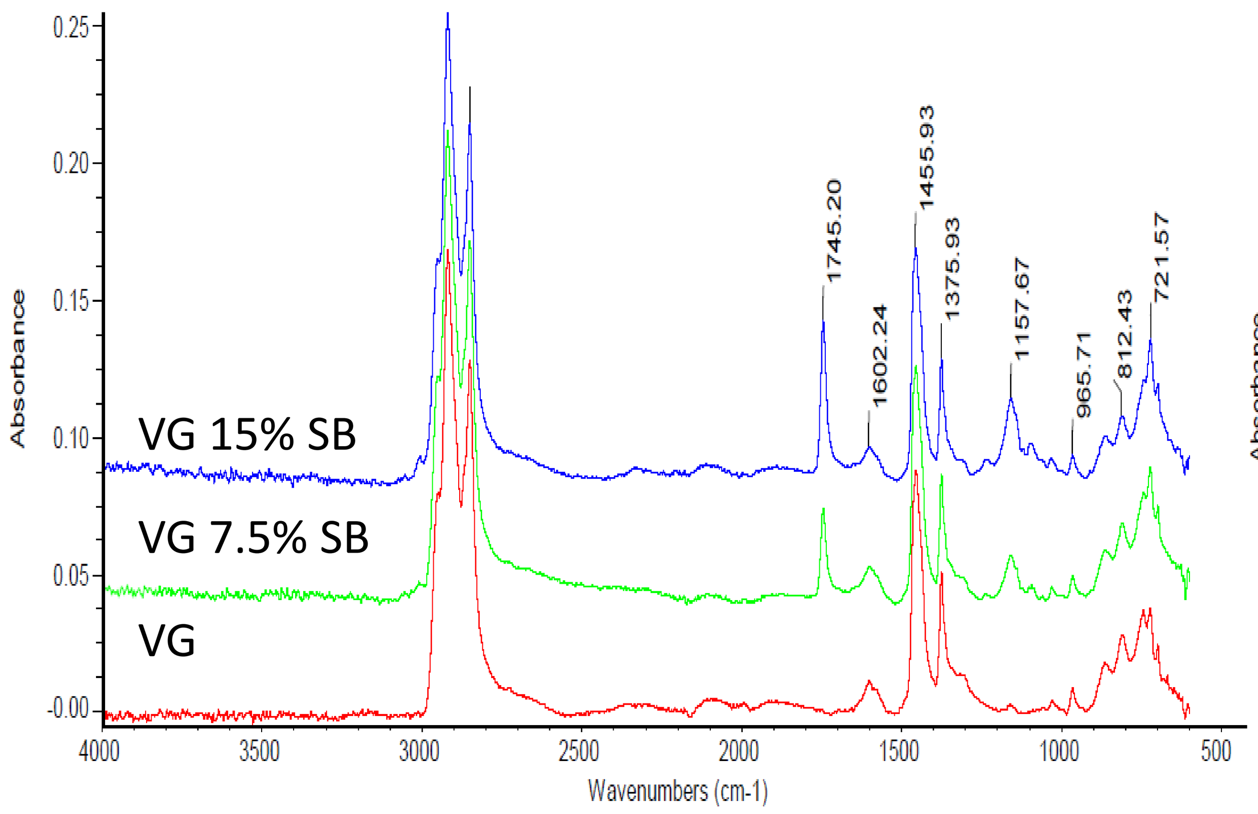


Fig 1: FTIR spectra of VG, VG 7.5% SB, and VG 15% SB bitumen samples.

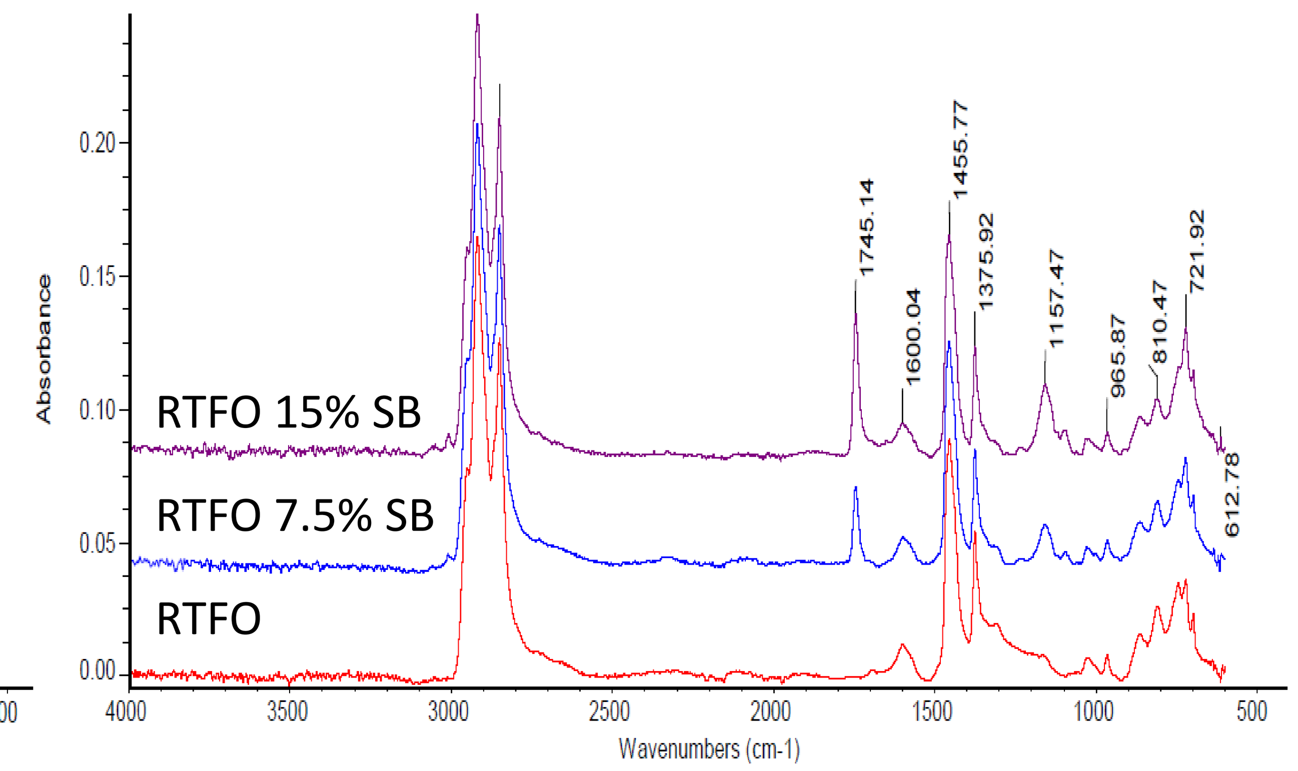


Fig 2: FTIR spectra of RTFO, RTFO 7.5% SB, and RTFO 15% SB bitumen samples.

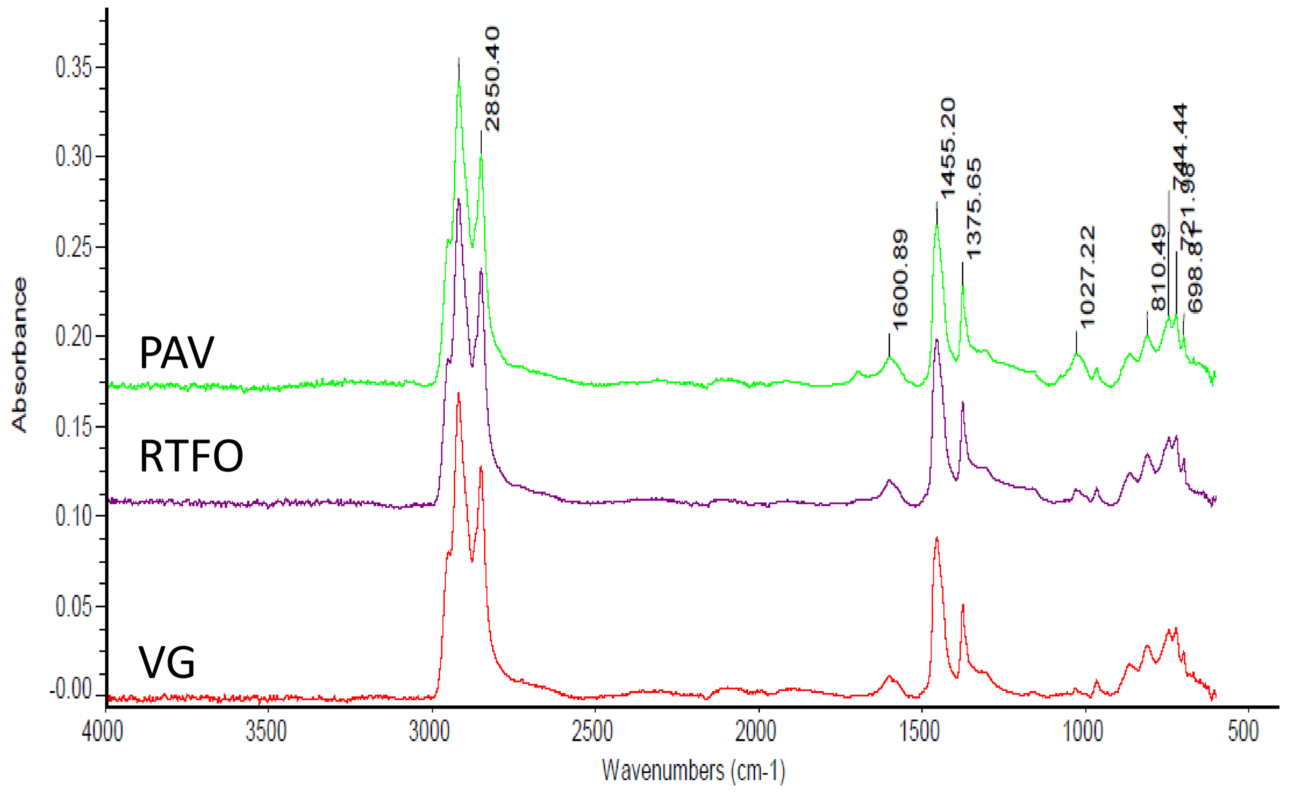


Fig 3: FTIR spectra of unmodified VG, RTFO, and PAV bitumen samples.

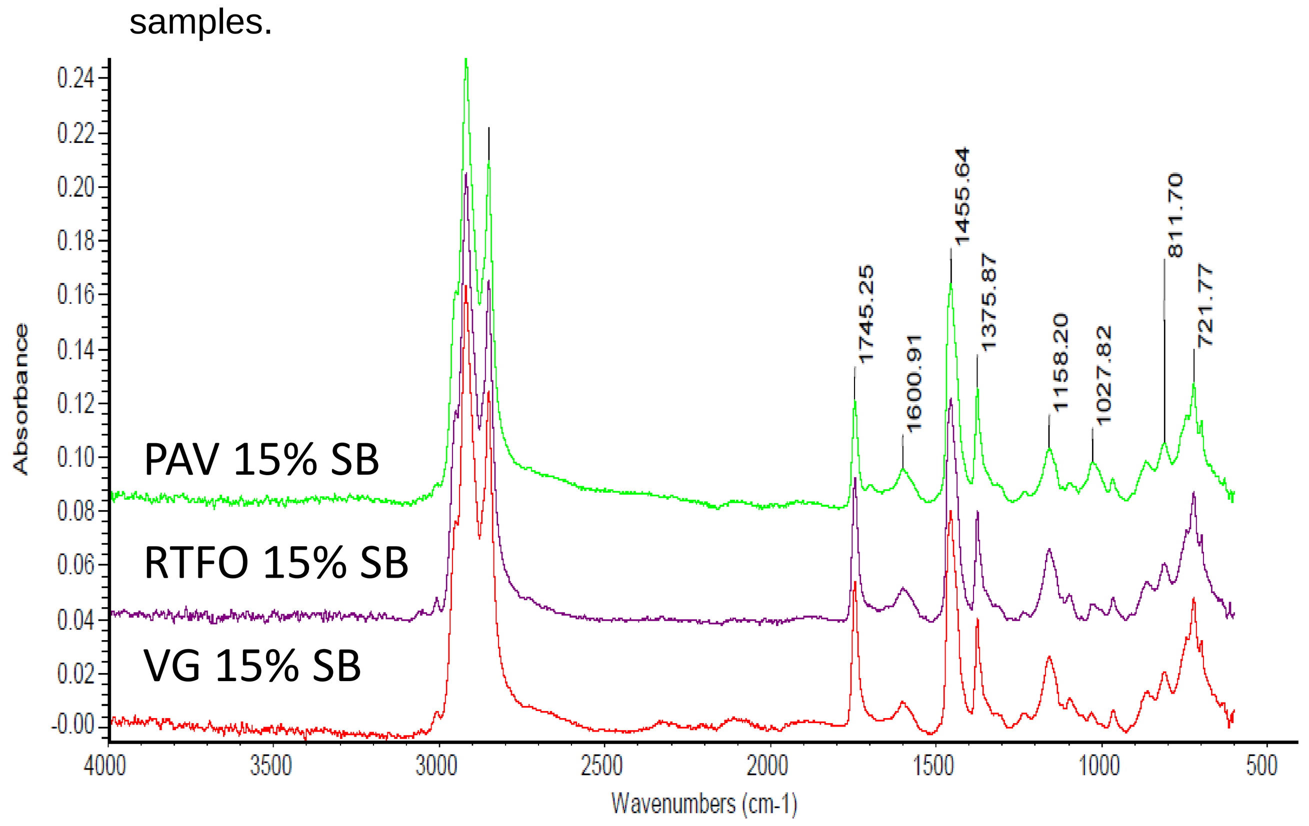


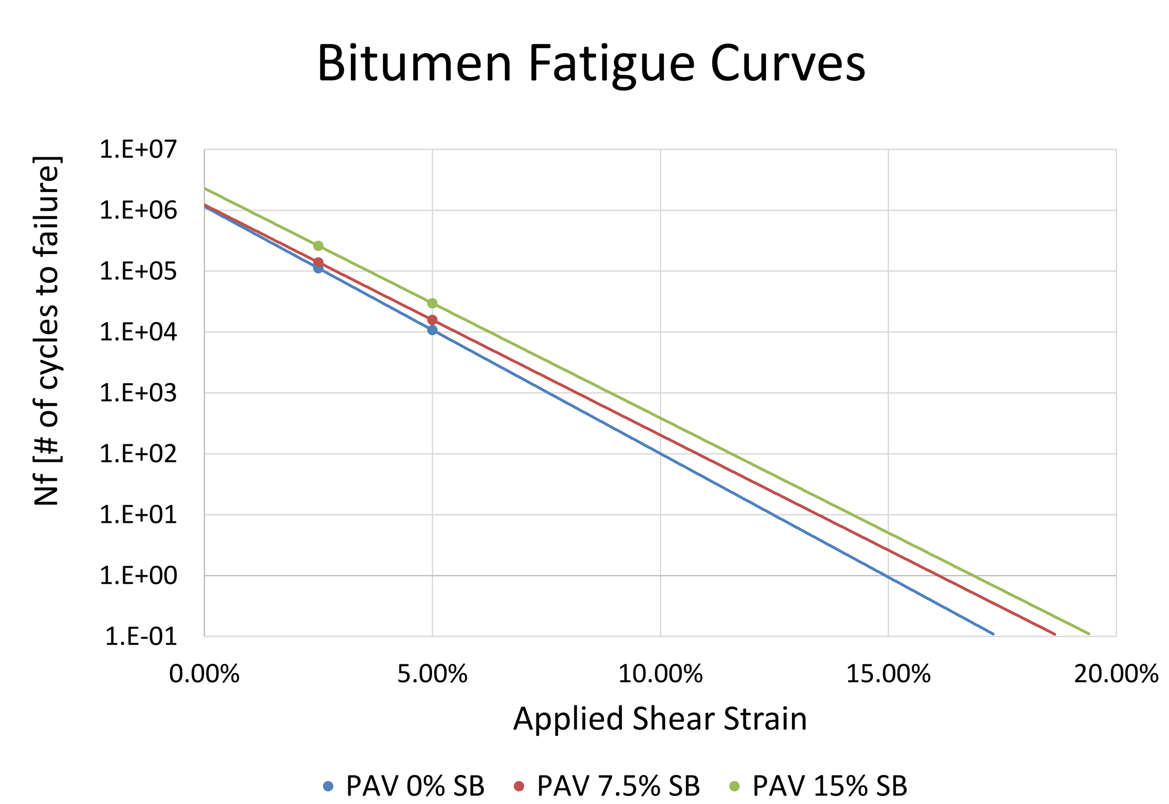
Fig 4: FTIR spectra of VG 15% SB, RTFO 15% SB, and PAV 15% SB bitumen samples.

LAS Analysis

A frequency sweep test followed by a strain sweep test with linear increasing amplitude were used to calculate important binder parameters, A and B, used to determine fatigue performance (N_f).

$$A = \frac{f(D_f)^k}{k(\pi C_1 C_2)^\alpha} \qquad B = -2\alpha \qquad N_f = A(\gamma_{max})^B$$

LAS Data of PAV Samples	PAV 0%	PAV 7.5%	PAV 15%
A	2443248	2471710	4586733
B	-3.37037	-3.14031	-3.13159
Nf (2.5%)	111,369	139,105	260,207
Nf (5.0%)	10,769	15,777	29,690



Conclusions

FTIR analysis of I_{COOH} and I_{Et} confirms that soybean oil has been introduced to bitumen in the rejuvenation process. I_{Et} indicates soybean oil may have already been partially oxidized.

$I_{C=O}$ and $I_{S=O}$ decrease in RTFO and PAV samples suggesting the aging process in the aged bitumen has been reversed from rejuvenation with soybean oil. I_B and I_{Ar} also decrease due to rejuvenation, indicating chain scission and aromatization that occurs during aging has been reversed.

LAS analysis of PAV samples manifests fatigue resistances (N_f) of bitumen samples increases at every applied shear strain as a result of increasing concentration of rejuvenator.

The relation of FTIR and LAS results indicates rejuvenation of aged bitumen with soybean oil reverses the aging process at a molecular level and as a result, increases the fatigue life of the bitumen.

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