International Association of Chinese Infrastructure Professionals

Investigating fatigue life of asphalt binder based on nonlinear fatigue damage accumulation model

The 11th Annual Workshop:
Low Carbon Technologies and Resilience for Long-Lasting Infrastructure

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Introduction and Objective

➢ **Background**

- Asphalt materials under **variable vehicle loading amplitudes** exhibit obvious **nonlinear fatigue damage accumulation (NLFDA)** characteristics. However, the **traditional Miner's rule fails** to characterize the NLFDA.

➢ **Objective**

- **Develop an NLFDA model** to accurately characterize the NLFDA of asphalt binders, and determine the **optimum loading condition of the fatigue life** for asphalt binder.

Materials and Tests

➢ **Materials and test conditions**

- Materials: SBS modified (SBS) and virgin asphalt binder (VA).
- Equipment: Dynamic shear rheometer (DSR).
- Temperature and frequency: 20℃ and 10Hz, respectively.

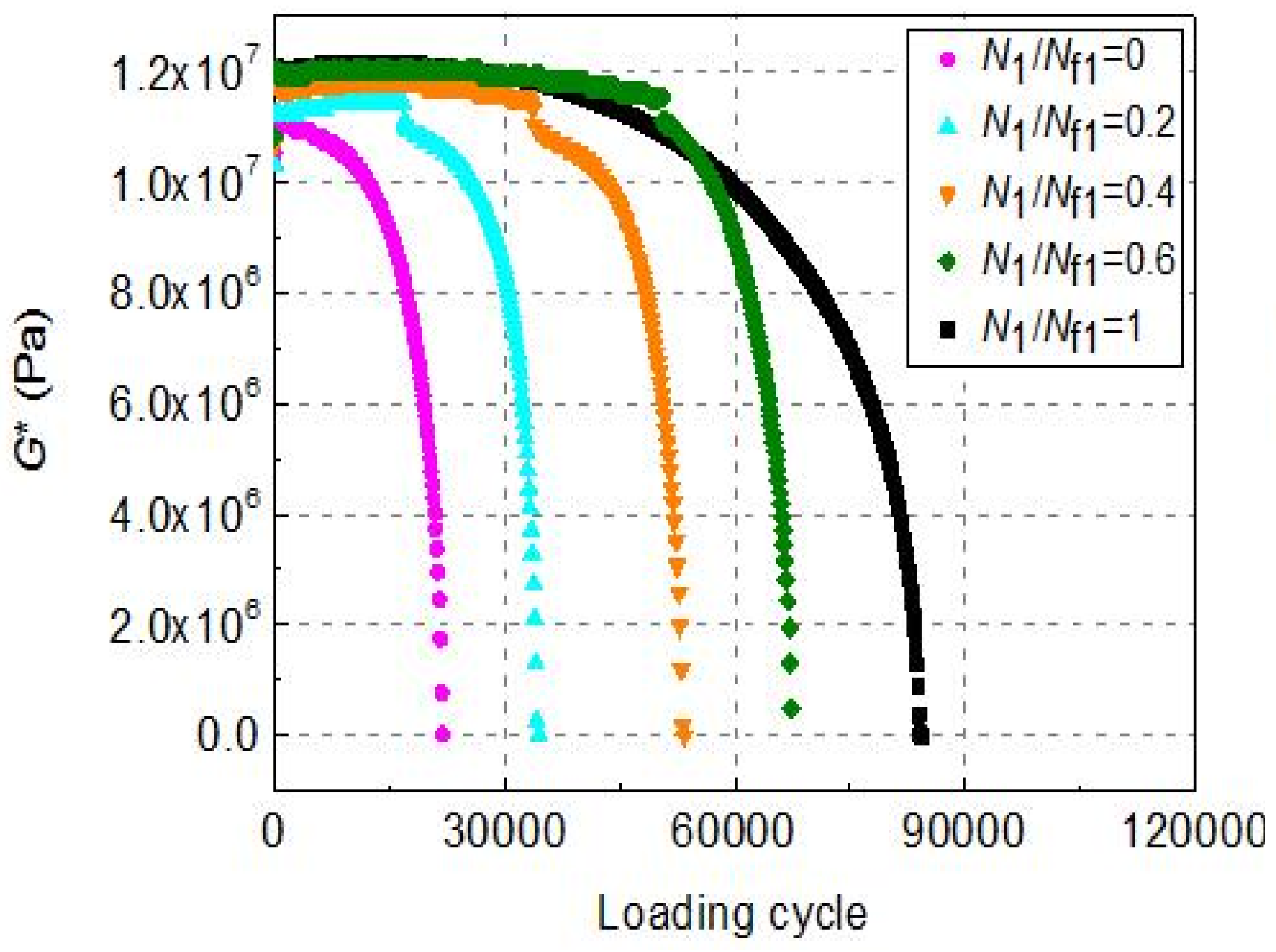

Binder sample DSR

➢ **Constant amplitude fatigue test (CAFT)**

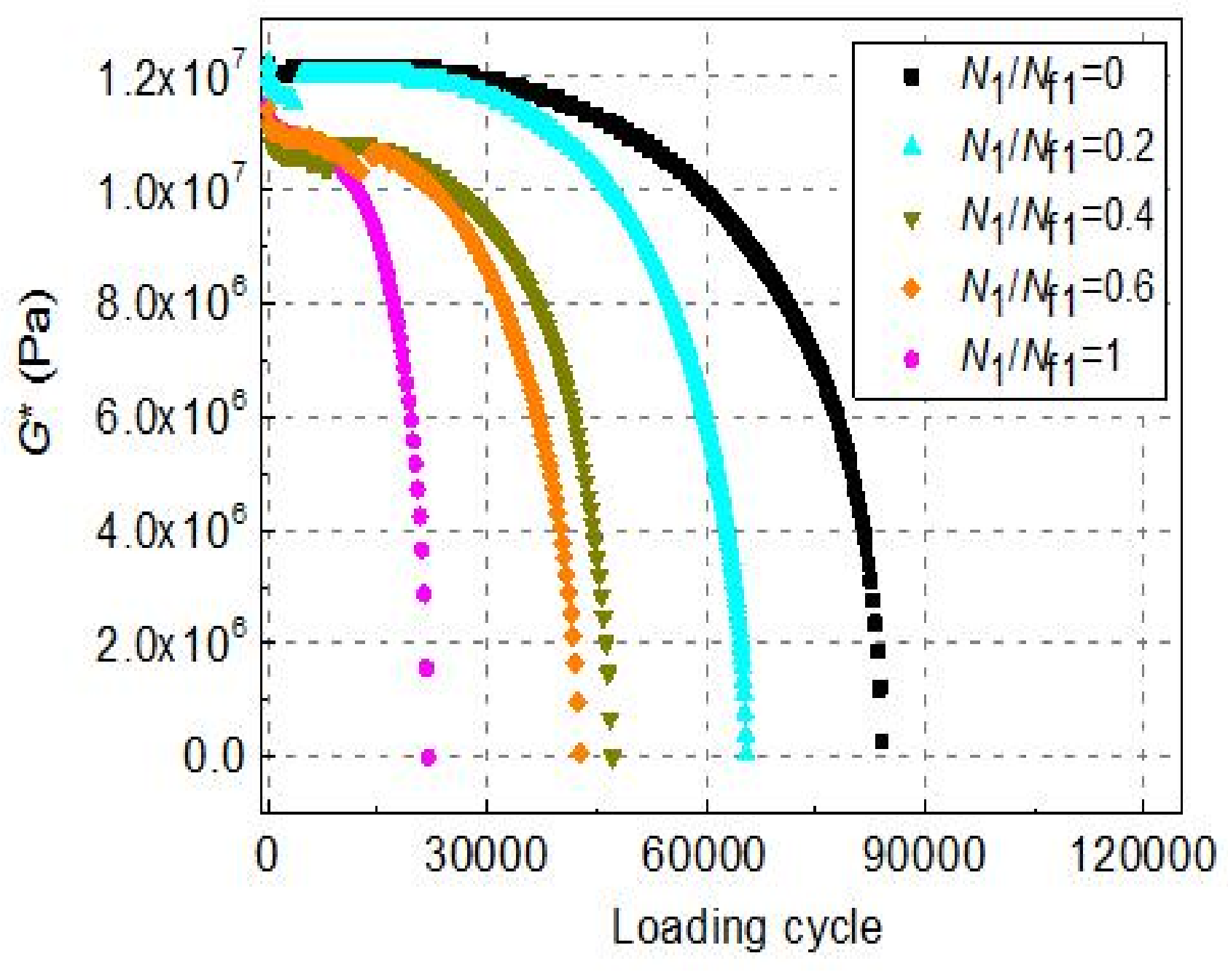
- The high (σ_{high}) and low (σ_{low}) stress levels were applied to the samples, respectively.
- The loading cycle where the shear modulus (***G****) decreases to 0 Pa was defined as the fatigue life (N_f).

➢ **Variable amplitude fatigue test (VAFT)**

- The first amplitude (σ_1) with the fatigue life of N_{f1} was applied for N_1 cycles corresponding to the **N_1/N_{f1} equals to 0, 0.2, 0.4, 0.6 and 1**, respectively.
- The second amplitude (σ_2) with the fatigue life of N_{f2} was applied for N_2 cycles.



*G** curves of σ_{low}-σ_{high} mode



*G** curves of σ_{high}-σ_{low} mode

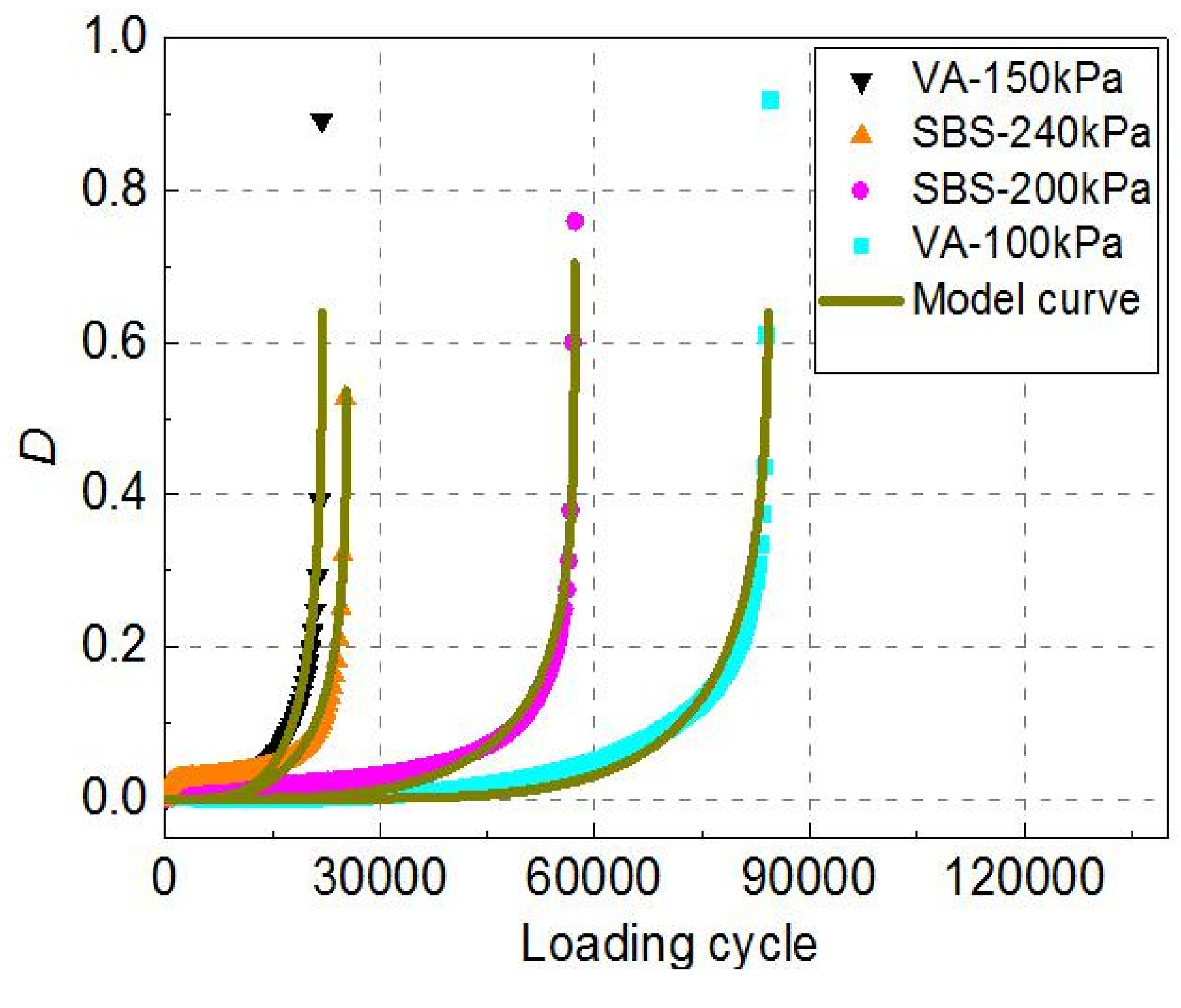
Establishment of NLFDA Model

➢ **Damage variable (*D*)**

- The ratio of the **fatigue crack length** of the *N*th cycle (*c*) to the maximum crack length (c_{max}) is **defined as the damage variable (*D*)**.

$$D = c/c_{\max} = 1-(G^{*A}/G^{*T})^{1/4}$$

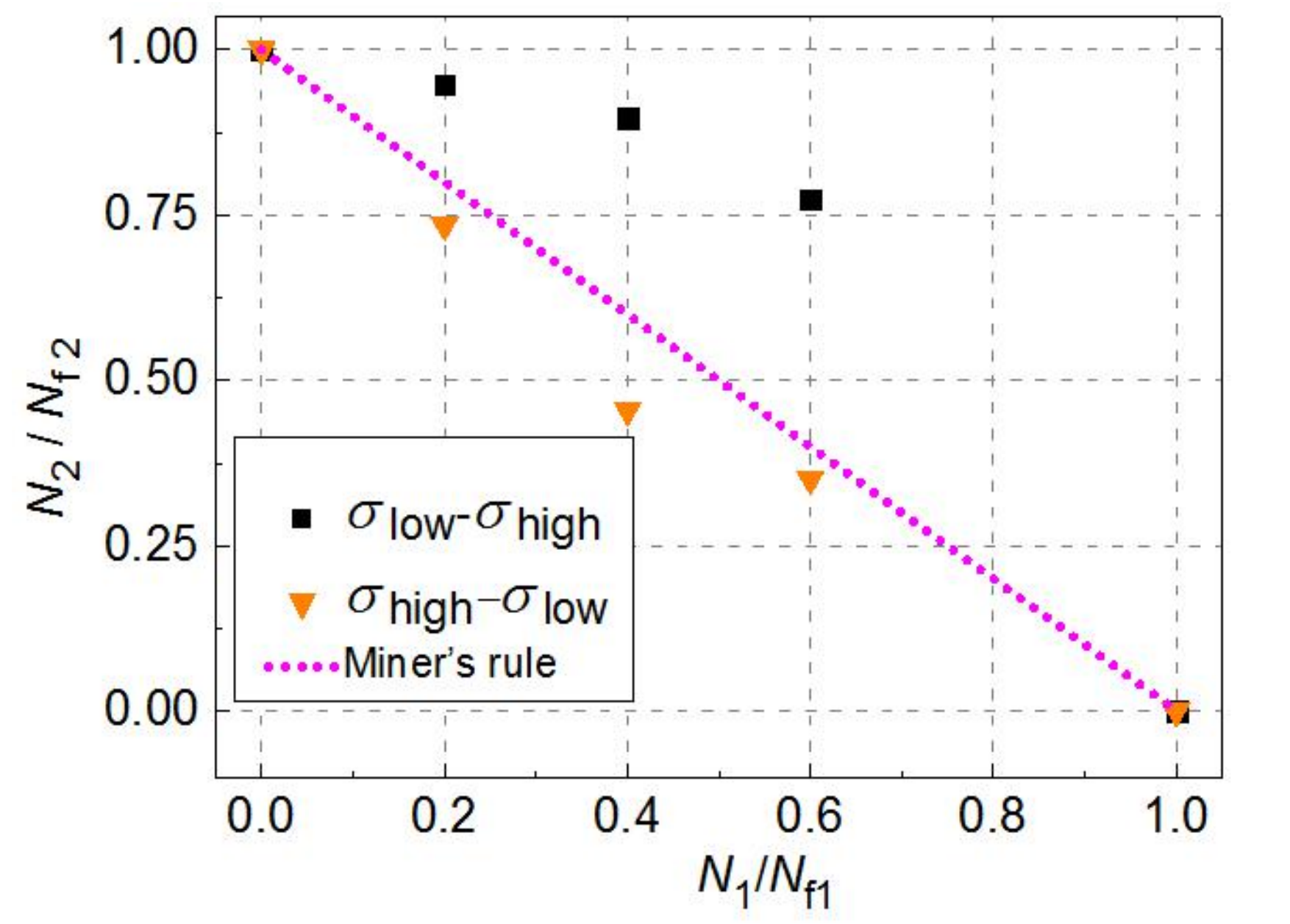
where G^{*A} and G^{*T} are the apparent and true shear modulus, respectively.



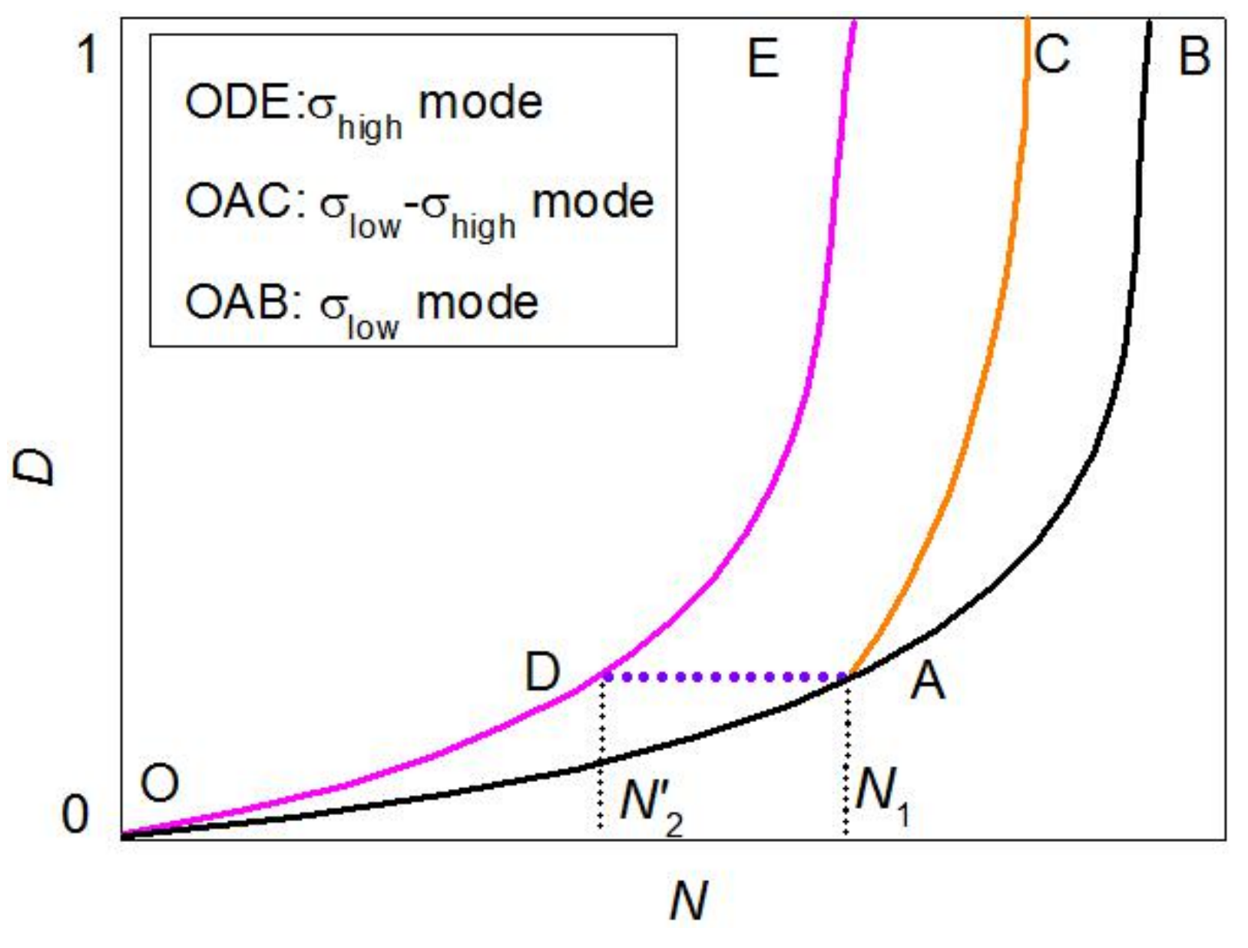
D curves

➢ **Loading sequence effect on NLFDA**

- The **N_2/N_{f2}** of σ_{low}-σ_{high} and σ_{high}- σ_{low} modes are **different**, which indicates that the **NLFDA is affected by loading sequence.**



N_2/N_{f2} of different modes



Damage accumulation path

➢ **Loading interaction effect on NLFDA**

- According to the **equivalence of fatigue damage**, the damage caused by σ_1 for N_1 cycles should be equal to that caused by σ_2 for N'_2 cycles.
- However, the path **AC is not parallel to DE**, which indicates the **NLFDA is affected by loading interaction**.

➢ **NLFDA Model Establishment**

- The **loading sequence factor (*ω*)** is defined as **(σ_1/σ_2)$^\lambda$**. The **loading interaction factor (*γ*)** is defined as **(1-*α* ₂)/(1-*α* ₁)**.
- According to the **damage equivalence criterion**, the NLFDA model is established based on the Chabaoche fatigue damage model.

$$D_1 = 1-[1-(N_1/N_{f1})^{1/(1-\alpha_1)}]^{1/(1+\beta)} = 1-[1-(N'_2/N_{f2})^{\omega/(1-\alpha_2)}]^{1/(1+\beta)}$$

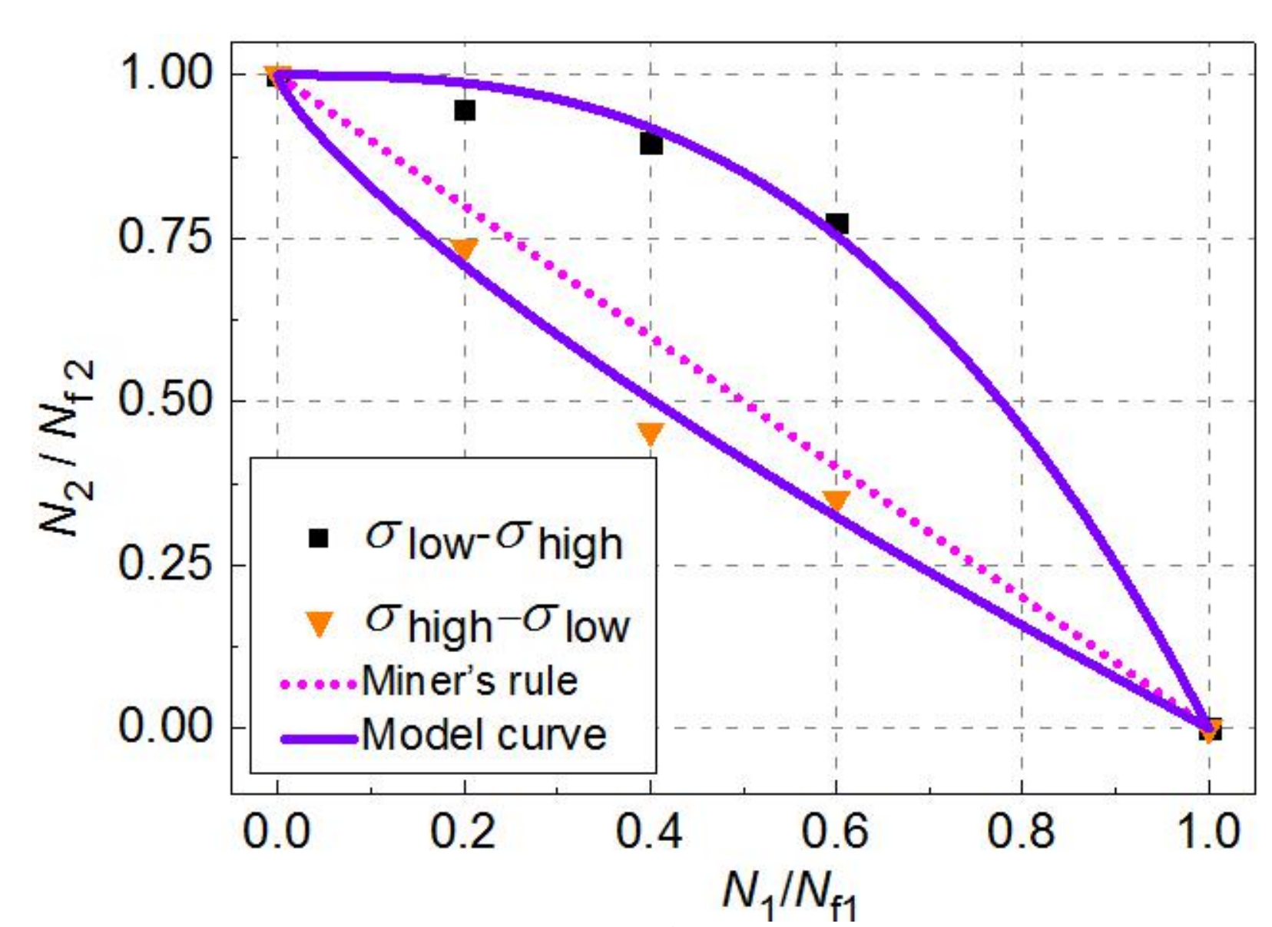
$$\Rightarrow N_2/N_{f2} = 1\text{-}(N_1/N_{f1})^{(1-\alpha_2)/(1-\alpha_1)}$$

where *α* is the model parameter which depends on temperature and stress amplitude, and *β* is the model parameter which depends on temperature.

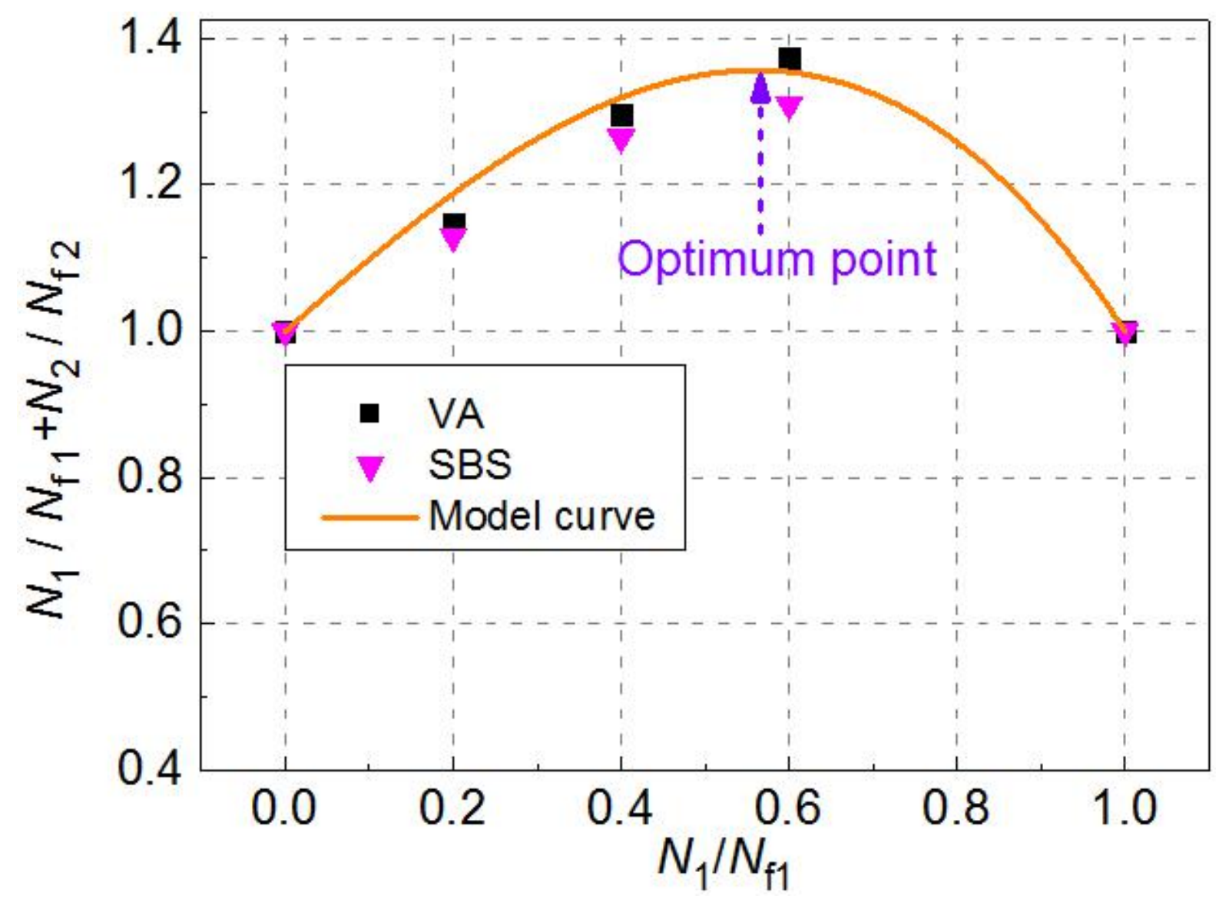
Optimum Loading Condition of Fatigue Life

- The acumulative life ratio (**$N_1/N_{f1}+N_2/N_{f2}$**) of **σ_{low}-σ_{high} mode** is **greater than 1**. The σ_{low}-σ_{high} mode **can extend fatigue life**. The **cumulative life ratio (R_c) model** can be established.
- The **optimum N_1/N_{f1} of σ_{low}-σ_{high} model** of **the fatigue life** of VA and SBS can be determined, which equals to 0.53.

$$R_c = 1\text{-}(N_1/N_{f1})^{\gamma\omega} + N_1/N_{f1} \Rightarrow N_1/N_{f1} = (\gamma\omega)^{(1-\gamma\omega)^{-1}}$$



Matching results of the NLFDA model



Optimum loading condition

Findings and Conclusions

- The **NLFDA of asphalt binder is affected by loading sequence and interaction** effects.
- The established **NLFDA model** can **accurately characterize the NLFDA** of asphalt binder.
- The established NLFDA model can be applied to **determine the optimum loading condition** which maximizes the **fatigue life** of asphalt binder.

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