International Association of Chinese Infrastructure Professionals

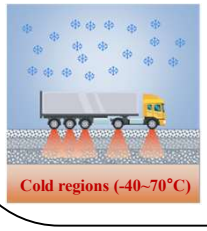
Carboxylated styrene-butadiene latex (XSB) in asphalt modification towards cleaner production and enhanced performance of pavement in cold regions

THE 13th IACIP Annual Workshop: *Adaptive Infrastructure under Climate Change*

Jiaqiu Xu, Harbin Institute of Technology & The Hong Kong Polytechnic University, jiaqiu.xu@connect.polyu.hk
Dawei Wang, Harbin Institute of Technology, wang@isac.rwth-aachen.de
Zhen Leng, The Hong Kong Polytechnic University, zhen.leng@polyu.edu.hk

INTRODUCTION

- In cold regions, the actual service temperature of pavements can range from minus 40°C to 70°C, and the temperature span exceeds 100°C.
- Polymer-modified asphalt (PMA) is currently the most widely used in cold regions, especially SBS and SBR-modified asphalts.
- However, the construction temperature of SBS-modified asphalt pavement is as high as 175~190°C, which will lead to high energy consumption, high volatile organic compounds (VOCs) and Greenhouse gas (GHG) emissions.
- The transportation industry is exactly one of the largest contributors to global carbon emissions.
- In September 2020, the Chinese government proposed the "dual-carbon" goal.
- SBR has relatively limited improvement in the high-temperature and anti-aging performance of asphalt.
- Under the background of "dual-carbon," it is imperative to find a modifier with low construction temperature, low energy consumption, fewer VOCs and GHG emissions, and excellent mechanical properties.
- The carboxyl groups were introduced to the butadiene end of SBR to generate carboxylated styrene-butadiene latex (XSB) for asphalt modification towards cleaner production and enhanced performance.



- **High energy consumption**
- **High VOCs emissions**
- **High GHG emission**

- **Limited rutting performance**
- **Poor anti-aging property**

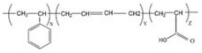
- **Liquid modification**
- **Cleaner production**
- **Enhanced performances**

OBJECTIVES

- To evaluate the mechanical performances of XSB-modified asphalt.
- To reveal the modification mechanism of XSB in asphalt using chemical and microscopic tests.
- To characterize the pavement performances of XSB-modified asphalt mixture, and the requirements of Chinese specifications are compared.

METHODOLOGY

- Raw materials
  - Base asphalt: JB70# and ZH70#
  - Modifier: XSB (3%, 4%, and 6%)



Molecular structure of XSB

Properties of XSB

Properties	Values
Solid content	51%
Density	1.04g*cm^{-3}
T_g	-24°C
Particle size	0.1~10μm
pH value	7.5
Thermal decomposition	370°C

- Preparation of XSB-modified asphalt
  - Stirring temperature: 145°C
  - Stirring rate: 800 RPM
  - Stirring time: 0.5 hour

Mixing of modified asphalt

- Preparation of XSB-modified asphalt mixture
  - Mixture gradation: AC-13
  - Mixing temperature: 160°C
  - Addition sequence: aggregates → asphalt → XSB → filler

Mixing of modified mixture

- Macro test methods of asphalt binders

Viscosity

Segregation

DSR

BBR

- Micro test methods of asphalt binders

FTIR

GPC

SEM

AFM

- Asphalt mixture test methods

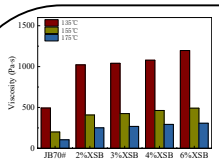
Wheel tracking test

Four-point bending fatigue test

Low-temperature bending test

Immersion Marshall test

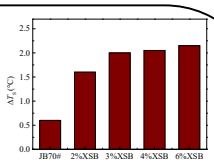
MECHANICAL PERFORMANCES OF XSB-MODIFIED ASPHALT



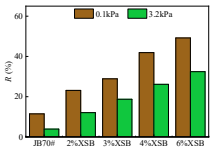
Viscosity

- The addition of XSB observably improved the viscosity of asphalt, and higher contents of XSB modifiers resulted in a higher viscosity of XSB-modified asphalt.

- The use of XSB adversely affects the storage stability of base asphalt, but the ΔT_S of all XSB-modified asphalt is less than the required value (2.5°C) in Chinese specifications.

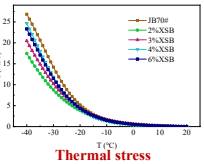


Storage stability

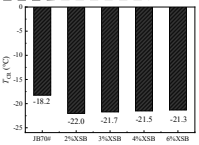


R ***J_{nr}***

- The introduction of XSB significantly enhances the rutting resistance of base asphalt, and the enhancement effect becomes more obvious when the content of XSB increases.

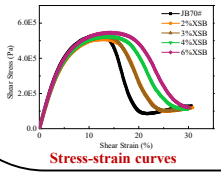


Thermal stress

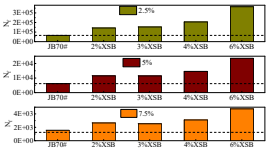


T_{CR}

- XSB reduces the thermal stress and T_{CR} of base asphalt, which indicates that the addition of XSB effectively enhances the low-temperature failure performance of asphalt.



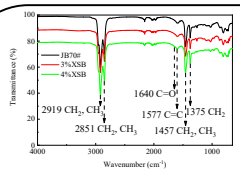
Stress-strain curves



Fatigue life

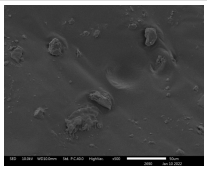
- The use of XSB dramatically enhances the fatigue performance of the asphalt. For instance, 2%XSB, 3%XSB, 4%XSB, and 6%XSB prolong the Nf of base asphalt by 119%, 135%, 215%, and 458%, respectively at the strain level of 2.5%.

MODIFICATION MECHANISM OF XSB IN ASPHALT



FTIR

- The modification of XSB is mainly a physical blending process without any chemical reaction.

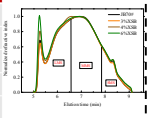


SEM

- The surface of XSB particles is full of tiny folds and voids and has a large specific surface area, which can effectively absorb small molecular components and light components in asphalt and plays a good role in reinforcing the mechanical properties of asphalt.

GPC test results

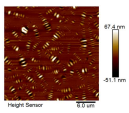
Indexes	JB70#	3%XSB	4%XSB	6%XSB
M_n	836	854	901	918
M_w	1951	1944	2090	2240
LMS (%)	39.653	39.714	40.674	41.827
MMS (%)	46.099	46.201	44.537	43.571
SMS (%)	14.248	14.085	14.789	14.602



- XSB enlarges the molecular weight and components of the LMS of base asphalt, which indicates an improvement in rutting performance.

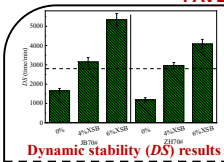
AFM test results

Indexes	JB70#	3%XSB	4%XSB	6%XSB
R_q	12.1	10.7	10.4	11.1
R_a	6.79	6.00	5.58	6.18
Area (μm)	57.15	66.78	67.32	65.43
Ratio (%)	6.35	7.42	7.48	7.27



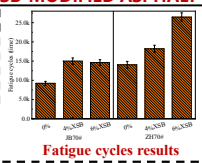
- The addition of XSB reduces the roughness of asphalt and improves the area and proportion of bee-like structures.

PAVEMENT PERFORMANCES OF XSB-MODIFIED ASPHALT MIXTURE



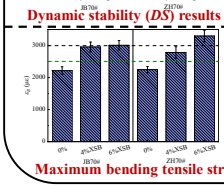
Dynamic stability (*DS*) results

- XSB dramatically enhances the rutting performance of base asphalt mixtures. The *DS* of all XSB-modified asphalt mixtures is higher than the required value (2800 time/min) in Chinese specifications.



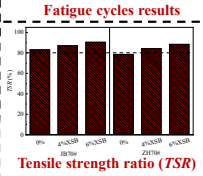
Fatigue cycles results

- XSB significantly enhances the fatigue property of base asphalt mixtures, which is manifested in the improvement of the fatigue cycles.



Maximum bending tensile strain ε_B

- XSB dramatically enhances the low-temperature performance of base asphalt mixtures. But only 6%XSB can meet the requirements (3000με) of the coldest region in China.



Tensile strength ratio (*TSR*)

- XSB markedly improves the moisture resistance of base asphalt mixtures. The *TSR* of all XSB-modified asphalt mixtures is higher than the required value (80%) in Chinese specifications.

CONCLUSIONS

- The introduction of XSB can dramatically enhance the mechanical properties of asphalt, including rutting, fatigue, low-temperature cracking, and viscosity performances, and higher contents of XSB lead to a more significant enhancing effect. Although the introduction of XSB has a negative impact on the storage stability of asphalt, the effect is small and fully meets the requirements of Chinese specifications.
- On the premise of reducing the production temperature of the mixture by 20~30°C, the use of XSB can comprehensively enhance the pavement performances of asphalt mixtures, including rutting, low-temperature cracking, fatigue, and moisture resistance, and the performances of modified asphalt mixtures can meet the most stringent specification requirements in China when the content of XSB is 6%.
- The enhancing effect of XSB on asphalt can be attributed to the fact that the surface of XSB particles is full of tiny folds and voids that absorb light components and aggravate the aggregation of polar components in asphalt, which is manifested by an increase in the number of "bee-like structures," and a decrease in the microscopic roughness of modified asphalt.