Experimental investigation of PP masks/PP-g-MAH/SBR polymer blends on the storage stability and low-temperature properties of modified bitumen

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ABSTRACT: Owing to the pandemic of COVID-19, tons of disposable masks have derived severe plastic disposal issues these years. One typical reuse avenue is recycling waste polypropylene (WPP) masks in large-scale asphalt pavement construction. Yet only a limited amount of research has been conducted to alleviate the phase segregation issues and the severe cracking distress that WPP brings to asphalt. This study explored the feasibility of using styrene-butadiene rubber (SBR) and maleic anhydride grafted PP (PP-g-MAH) in repurposing WPP in bitumen. The study aims to investigate its modification mechanisms and solve the bad performance that plastic bring to modified bitumen. The results indicate that adding SBR and PP-g-MAH can help PP distribute homogeneously in asphalt binder. Meanwhile, the low temperature anti-cracking performance is enhanced. This recycling method can reduce the quantity of indiscriminate disposal WPP masks and improve the properties of asphalt pavement.

1 INSTRUCTION

Management of waste plastics has been a global environmental challenge. According to PEMRG (2021) report, global plastics production in 2020 reached around 367 million tons. The disposed waste plastics not only occupy precious land space but may also lead to various environmental problems (Saliu et al., 2021). This situation has worsened due to the ongoing COVID-19 pandemic, dramatically increasing the use of masks (Patrício Silva et al., 2021). To address the environmental challenges posed by waste polypropylene (WPP), one typical reuse avenue is recycling waste masks in large-scale civil projects (Wang et al., 2022).

Referring to the literature, WPP can increase several high-temperature properties (Nekhoroshev et al., 2017), permanent deformation resistance (Qadir, 2014), and moisture anti-stripping properties of asphalt pavements (Goli and Sadeghi, 2022). However, only a limited number of studies have been conducted on its potentially detrimental effects on low-temperature anti-cracking resistance, which can result in severe cracking distress, structural failure and even pavement disintegration if not treated. (Jackson and Vinson, 1996; Liu et al., 2018; Lv et al., 2020; Zahoor et al., 2021). On the other hand, WPP modified bitumen blends are not thermodynamically stable, which may have a direct relationship with the resulting unpredictable properties of modified bitumen (Nizamuddin et al., 2021). Thus, the poor compatibility between WPP and asphalt binder is another primary technical concern, which has not been sufficiently studied and has usually been ignored by previous studies (Wu & Montalvo, 2021). Hence, owing to the extraordinary impact of styrene-butadiene rubber (SBR) on the low-temperature performance of bitumen (Becker et al., 2001) and the function of a compatibility agent, maleic anhydride grafted PP (PP-g-MAH), in improving the compatibility of PP (Wu et al., 2020), they were selected as compound functional modifiers to recycling waste PP into durable asphalt pavement. The interaction mechanism among PP, SBR and PP-g-MAH was also discussed in this study. Overall, it is expected to provide a novel and practical approach to recycling WPP that would otherwise end up in landfills and improve the performance of asphalt pavements.

2 MATERIALS AND RESEARCH METHODS

The WPP masks employed in this study are defective products from local factories. They were removed the mental bar and cotton thread (2 wt. %by neat bitumen) and cut into small pieces and then blended with Pen 60/70 bitumen at 165 ºC by a mechanical mixer for 10 mins, followed by a high shearing mixing at 4000 rpm for 1.5 hrs. To enhance the performance of WPP modified bitumen (WPPMB), PP-g-MAH (2.5wt. %by PP) and SBR (1&3wt. %by neat bitumen) were selected to incorporate into bitumen before high shear mixing. To simplify, 2%PP2.5%PP-g-MAH3%SBR modified bitumen was named 2PP2.5PGM3SBRMB. The density of raw materials and basic properties of bitumen are listed in Table 1 and Table 2.

Table 1. Density properties of raw materials.

Materials	Density* g/cm^3 at 25°C
PP-g-MAH	0.88
PP mask	0.12
Virgin bitumen (VB)	1.02
SBR	1.09

* Density was measured by the automatic density measuring instrument BYES MH-300A.

Table 2. Basic properties of the bitumen involved in this study.

Samples	Ductility (10°C, cm)	Brookfield viscosity (135°C, mPa·s)
VB	142.0	446
2PPMB	99.2	612
2PP2.5PPGMAHMB	81.6	603
2PP2.5PPGMAH1SBRMB	133.6	665
2PP2.5PPGMAH3SBRMB	154.1	761
Standard	ASTM D113	AASHTO T316

In this study, the feasibility of reusing WPP in asphalt pavement has been explored and evaluated in the wet method. The conventional storage stability test, Dynamic Shear Rheometer (DSR) test and Fluorescence Microscopy (FM) were carried out to evaluate the segregation resistance of WPPMB containing various percentages of PP-g-MAH and SBR. Storage stability tests were conducted based on the Softening point difference (SPD) according to ASTM D6930. As for the DSR test, the SHRP specification defines the following separation index based on the complex shear modulus tests to evaluate the storage stability of bitumen:

$$I_s = log\left(\frac{|G|_b^*}{|G|_t^*}\right) \tag{1}$$

where $|G|_b^*$ and $|G|_t^*$ = the complex shear modulus at 25°C at a frequency of 10 rad/s of the bottom and top parts after storage, respectively. Then, 3-D reconstruction images of FM morphology at an objective of 10× magnification was generated and provided an immediate impression of the PP distribution in the top and bottom sections of the storage tube. Finally, the low-temperature performance of test binders was evaluated in ductility tests at 10 ºC (ASTM D113).

3 RESULTS AND DISCUSSION

3.1 *Storage stability of PP modified bitumen incorporating PP-g-MAH and SBR*

3.1.1 *SPD*

Figure 1 illustrates the effects of various additives on the storage stability of the binders containing 2% WPP masks. Overall, the SPD values of the binders with 2% WPP were significantly higher than VB, indicating that WPP in bitumen can cause a worse storage problem because the nonpolar PP is unstable and vulnerable to separation from the polar bitumen. However, PP-g-MAH is a compatibility agent that helps to reduce storage issues in WPPMB by acting as a bridge between PP and asphalt binder. This agent contains a nonpolar group that has an excellent affinity to PP and a hydrophobic group that can interact with the polar group of asphalt bitumen. Thus, the improved compatibility between PP and bitumen leads to a lower SPD value, as observed in 2PP2.5PGMMB. Surprisingly, the composite SBR and PP-g-MAH were found to have more significant effects on decreasing the SPD values of WPPMB. This is probably because, on the one hand, SBR's higher density makes it tend to sediment in bitumen, which inhibits the upwards trends of PP in the storage tube. On the other hand, the increased viscosity of plastic modified bitumen with SBR slows down the movements of free polymers inside.

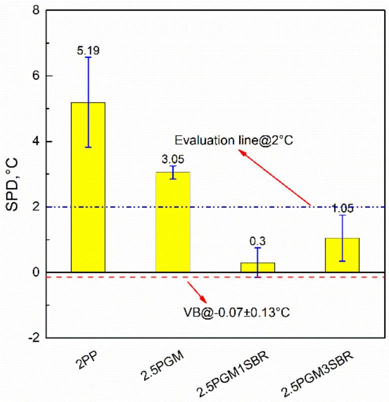

Figure 1. SPD of the bitumen containing WPP masks.

3.1.2 *Separation index (Is)*

Figure 2 present $|G|_b^*$, $|G|_t^*$ and I_s of test binders. A lower separation index indicates better storage stability. It can be observed that although the surprisingly higher I_s was observed in 2PP2.5PGMMB, it decreased when 1% SBR was introduced into bitumen. Such better storage performance resulted from reduced differences in the complex modulus of bitumen's top and bottom parts. It is also worth mentioning that when more SBR were dosed into PPMB, the $|G|_b^*$ dominated over $|G|_t^*$, indicating a higher polymer content at the bottom, and I_s became positive.

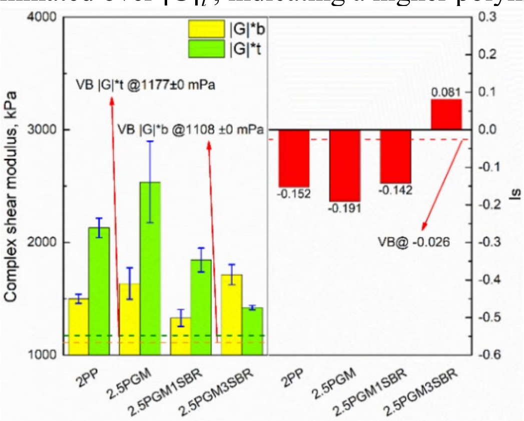

Figure 2. $|G|_b^*$, $|G|_t^*$ and separation index of test binders.

3.1.3 *FM*

Figure 3 shows the 3D FM images of typical binders. As despised, the yellow components were PP particles inside the bitumen. The PP distribution in FM was consistent with the G* value in Figure 2. Thus, the unexpectedly higher $|G|_t^*$ of 2PP2.5PGMMB can be explained by the agglomerated yellow particles shown in FM images. It was apparent that the PP-rich proportions and bitumen-rich parts were interchanged as more SBR dosed into bitumen. This impressive result was the same as obtained I_s value from negative to positive, indicating an optimum value of SBR content to improve the storage stability properties of WPPMB. Above all, almost no PP can be observed in compound SBR and PP-g-MAH modified bitumen, which performed the best in the microscopic test.

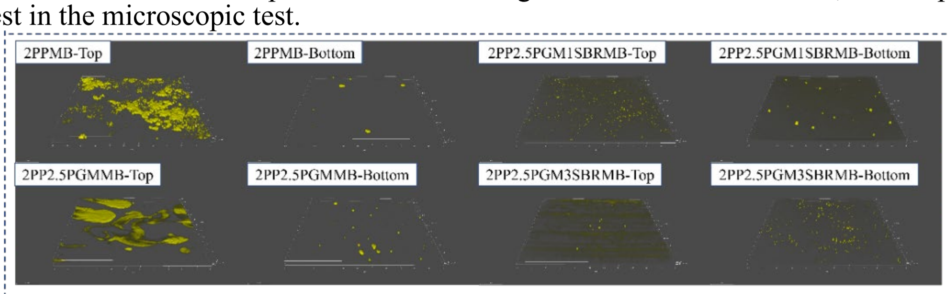

Figure 3. 3D FM images of modified asphalt after storage.

3.2 *Low-temperature properties of PP modified bitumen incorporating PP-g-MAH and SBR*

Table 2 describes the low-temperature ductility results. The ductility of WPPMB was observed to drop dramatically compared with that of VB. Clearly, the ductility of PP-g-MAH modified bitumen was even worse than that of PPMB. These results manifested that PP and PP-g-MAH had detrimental influences on the low-temperature anti-cracking resistance of hot mix asphalt (HMA). It was worth noting that the binders incorporating 1% and 3%SBR were found to increase the low-temperature ductility, further demonstrating the necessity of adding the SBR into the PP modified asphalt to improve its low-temperature performance.

4 FINDINGS AND CONCLUSIONS

This study explored the feasibility of applying SBR and PP-g-MAH into WPP modified asphalt to solve its poor storage issue and terrible low-temperature problems. The major findings are summarized below:

- The SPD result implies that WPP in bitumen can cause a terrible storage problem. However, the poor compatibility between PP and bitumen can be minimized by using the compatibility agent PP-g-MAH as well as SBR's high density and its contributions to the viscosity.
- The separation index and FM images indicate there could be an optimum SBR content to minimize the phase differences between the top and bottom parts of WPPMB. And the composite PP-g-MAH/SBR performed the best in the storage stability of waste masks modified bitumen.
- The ductility test results point out that SBR can significantly enhance the low-temperature anti-cracking resistance of WPPMB, while PP and PP-g-MAH have detrimental influences on the low-temperature performance of bitumen.

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