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Preparation and characterization on elastomer/plastic compound modified bitumen

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ABSTRACT: Elastomer/plastic compound-modified bitumen was created by adding reactive elastomeric terpolymer (RET) to plastic-modified bitumen, made of either high-density polyethylene (HDPE) or recycled polyethylene (RPE). The rheological properties of the modified bitumen were analyzed. The results indicated that RET elastomer improved high-temperature modulus, temperature insensitivity, anti-rutting properties, elastic recovery, and shear-resistance of both HDPE and RPE-modified bitumen. A high dosage of RET had a negative impact on the cracking resistance of plastic-modified bitumen, thus it is recommended to use 1wt% for optimal results. The increased elasticity in the bitumen was attributed to the creation of a polymer network by RET.

1 INTRODUCTION

Developing sustainable and high-performance asphalt pavement is a primary objective for pavement researchers due to its economic and environmental advantages [1]. However, pure bitumen does not fulfill the temperature performance standards required to maintain the heavy-loading and varied service conditions (due to the synergistic effects of heat, oxygen, moisture, and UV light) [2]. Therefore, researchers have added various organic and inorganic substances to the bitumen matrix, improving its resistance to rutting, cracking, and aging [3].

The reactive ethylene terpolymer (RET) polymers are typically composed of ethylene, glycidylmethacrylate (GMA), and an ester group. RET has similar molecular characteristics to PE-based modifiers, and it possesses a chemical reaction capacity to bitumen components [4]. With high reactivity, RET has served as a compatibilizer for different polymeric blends, including polyethylene, polyolefins, and polyesters [5]. Rheo-chemical findings revealed that the RET elastomer reacts with asphaltenes' carboxylic groups, forming a polymer network structure, which improves the RET-modified bitumen's elasticity and storage stability. Furthermore, the addition of RET was found to improve permanent deformation, thermo-oxidation aging resistance, and provided better cohesion and adhesion performance to crumb rubber [6]. High polarity and chemical cross-linking capability make RET essential to improve compatibility between polymers (SBS and HDPE) and bitumen [7].

In conclusion, achieving an appropriate balance between elastic and plastic performances is crucial for enhancing modified bitumen's high-and-low temperatures comprehensively. The addition of reactive ethylene terpolymer to plastic modified bitumen systems can increase their elasticity and storage stability through chemical reactions and polymer network formation

2 MATERIALS AND METHODS

The study utilized 70-PEN grade fresh bitumen to prepare modified bitumen utilizing elastomer and plastic compounds. The essential characteristics of the virgin bitumen are presented in Table 1. Furthermore, the physical indicators of HDPE, RPE, and RET modifiers are displayed in Table 2.

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Table 1. The physical and chemical properties of SK-70 virgin bitumen.

Properties	Value	Test standard
Penetration (25°C, 0.1mm)	67	ASTM D5
Softening point (°C)	48.4	ASTM D36
Ductility (10°C, cm)	85	ASTM D113
Rotational viscosity (60°C, Pa·s)	210	AASHTO T316
Saturate dosage (S, wt%)	13.3	ASTM D4124
Aromatic dosage (A, wt%)	17.4	
Resin (R, wt%)	39.7	
Asphaltene (As, wt%)	29.6	
Colloidal index	0.75	

Table 2. Basic properties of HDPE, RPE, and RET.

Items	HDPE	RPE	RET
Density (g/cm^3)	0.954	0.922	0.942
Crystallinity (%)	86	-	-
Melt point (°C)	131	105	72
Melt flow index (MFI, g/10min)	7	8	8
Ash (wt%)	-	0.9	-

The study utilized literature review findings [7] and incorporated 5wt% and 7wt% mass concentrations of HDPE and RPE, respectively, in each RET/HDPE and RET/RPE modified bitumen. The review reported that a high dosage of polyethylene had negative effects on storage stability and low-temperature cracking performance. Additionally, RET dosage in compound-modified bitumen was varied from 0 to 3wt% with 1wt% increments. Preparation conditions for various compound-modified binders are presented in Figure 1.

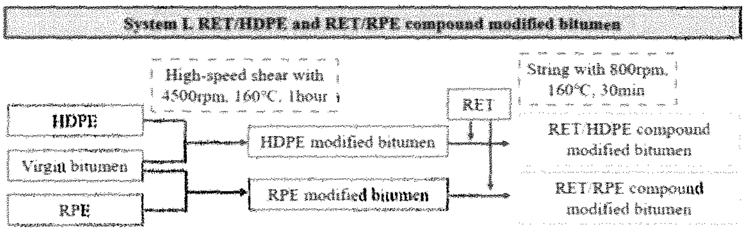

Figure 1. The preparation conditions of various compound-modified bitumen.

3 RESULTS AND DISCUSSION

3.1 *Rutting factor and failure temperature*

The rutting performance of RET/HDPE and RET/RPE compound-modified bitumen was analyzed by measuring the rutting factor (G/sinδ) variations in Figure 2 at different temperatures. A higher G/sinδ value indicates better resistance to rutting at high temperatures. The G/sinδ values of both virgin and modified binders gradually decreased linearly as the temperature increased from 58 to 84°C. This behavior can be explained by the fact that high temperatures reduce intermolecular friction and increase molecular mobility, making asphalt roads more susceptible to rutting in tropical climates.

Table 3 displays the values of parameters a, c, RFT, and correlation coefficient R2 of all bitumen samples. Incorporating HDPE and RPE increased both the G/sinδ and RFT values, suggesting that both HDPE and RPE could enhance the rutting resistance of bitumen. Specifically, the RPE-modified bitumen showed a stronger resistance to rutting than HDPE-modified binder as evidenced by the RFT values of H5 and H7 samples which were 77.11°C and 83.71°C respectively, while the R5 and R7 had the RFT value of 81.07°C and 106.6°C. The observed difference between the two modifiers may be attributed to the additional inorganic filler and aging hardening of the RPE modifier. On the other hand, as the RET dosage rose from 1% to 3%, the RFT value of H5 binder increased by 2.54, 5.15, and 9.29 °C, respectively, indicating that the RET blending played a role in enhancing the rutting resistance of HDPE-modified bitumen. Additionally, the RFT parameter of H7-3 was 6.35°C higher than that of H7, highlighting the potential of RET to improve the rutting performance of bitumen.

Table 3. The rutting failure temperature of RET/HDPE and RET/RPE modified bitumen.

Samples	a	c	RFT/°C	Samples	a	c	RFT/°C
SK-70	-0.047	3.24	69.60	SK-70	-0.047	3.24	69.60
H5	-0.052	4.03	77.11	R5	-0.048	3.89	81.07
H5-1	-0.051	4.03	79.65	R5-1	-0.048	3.78	78.43
H5-2	-0.050	4.09	82.26	R5-2	-0.048	3.94	81.62
H5-3	-0.049	4.20	86.40	R5-3	-0.045	3.88	85.44
H7	-0.051	4.27	83.71	R7	-0.030	4.31	106.6
H7-3	-0.046	4.14	90.06	R7-3	-0.047	3.16	90.97

The effect of Reactive Epoxy Terpolymer (RET) on the rutting properties of RPE-modified bitumen varies depending on the dosage of RPE used. While the RFT value of R5 decreases by 2.64°C when RPE is used as a modifier, it rises by 0.55 and 4.37°C upon the addition of 1%, 2%, and 3% RET, respectively. However, the RFT value of R7-3 is significantly lower by 15.63°C than R7, which suggests that the use of RET deteriorated the rutting resistance of RPE-modified bitumen containing a high RPE composition of 7 wt%. This can be attributed to RPE's distinct chemical structure, which requires a minimum amount of RET to enable a complete chemical reaction. In conclusion, while the incorporation of RET improves the anti-rutting performance of RPE-modified bitumen, exceeding the optimal RPE dosage point results in the degradation of high-temperature performance.

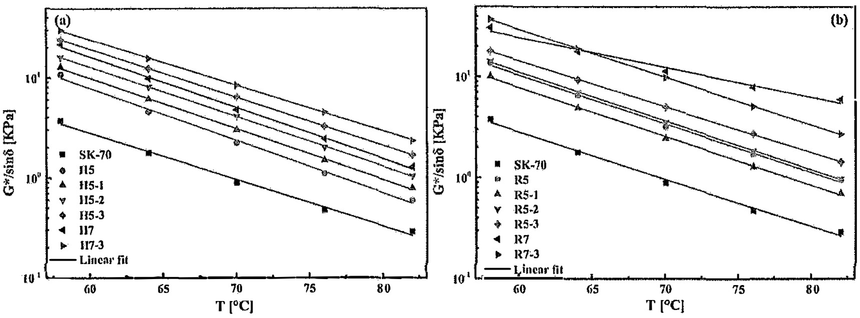

Figure 2. Rutting factor of RET/HDPE and RET/RPE modified bitumen.

3.2 *Recovery percentage and non-recoverable creep compliance*

Figure 3 displays the R% (percentage recovery) and Jnr (non-recoverable creep compliance) curves of bitumen binders at 60°C and 3.2 kPa. The R% and Jnr values of fresh bitumen exhibit the minimum and maximum values due to its dominant viscous characteristic. Compared to virgin bitumen, the R% parameter increases from 0.13% to 2.02%, 10.14%, 11.01%, and 45.47% for H5, H7, R5, and R7 modified with HDPE and RPE, respectively. Meanwhile, the corresponding Jnr values decrease from 3.47 to 1.38, 0.40, 0.66, and 0.13 (kPa-1), respectively. Overall, both HDPE and RPE improve the elastic properties and reduce the potential for permanent deformation of bitumen.

Furthermore, the incorporation of RET elastomer has a significant impact on the R% and Jnr parameters of HDPE- and RPE-modified bitumen. Specifically, H5-1, H5-2, and H5-3 compound-modified bitumen show an increase in R% by 5.17%, 17.19%, and 30.26%, respectively, when compared to the H5 sample. Meanwhile, the R% value of H7-3 is 37.62% higher than H7. Despite the increase in R% parameter, the influence degree of RET on the Jnr value is significantly less pronounced than R%. Additionally, the incorporation of RET elastomer can enhance the elastic recovery capacity of HDPE-modified bitumen containing 5% and 7% HDPE content.

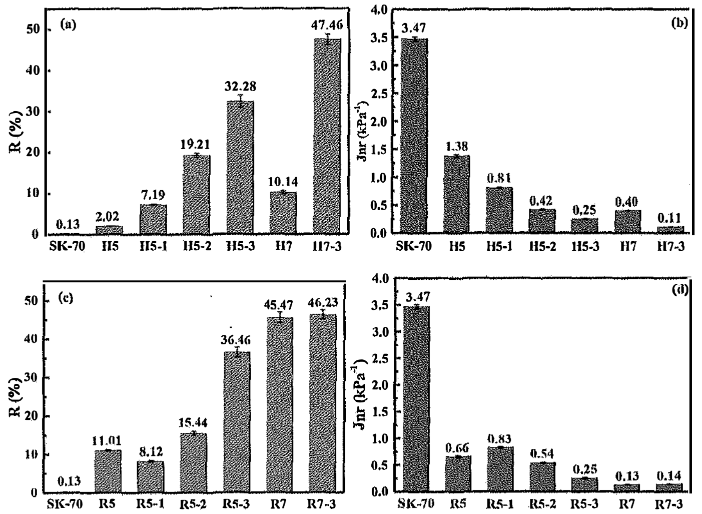

Figure 3. The R% and Jnr of RET/HDPE and RET/RPE modified bitumen.

The R% values of R5-1, R5-2, and R5-3 were found to be 2.89% lower, 4.43%, and 25.45% higher than that of R5 binder, respectively. In contrast, R7-3 showed only a 0.76% increment relative to R7. RET had a more significant effect on the R% and Jnr values of HDPE-modified binder than that of RPE-modified bitumen. Overall, RET elastomer was effective in strengthening the elastic properties and deformation resistance of both HDPE and RPE-modified bitumen, particularly in H5, H7, and R5 modified binders. An optimum RET dosage of 3wt% was recommended to enhance the elastic properties and high-temperature deformation resistance of HDPE (5% and 7%) and RPE (5%) modified binders.

3.3 *Low-temperature cracking resistance*

Figure 4 displays the Bending Beam Rheometer (BBR) results for HDPE-based modified bitumen, both before and after aging. The results show that all fresh bitumen samples meet the specification requirement of 300MPa and 0.3 for the S and m-values, respectively, at -12°C. However, at -18°C, these values exceed the specified limits. Moreover, incorporating 5wt% and 7wt% HDPE into the bitumen results in increased stiffness and decreased m-value, indicating that the HDPE modifier negatively affects the bitumen's low-temperature cracking resistance.

The S and m-values of RET/HDPE modified bitumen are dependent on the dosage of the RET elastomer. At a temperature of -12°C, the addition of 1% RET elastomer leads to a 9.8% and 1.6% decrease in the S-value for fresh and aged H5 samples, respectively. The corresponding m-value shows an increase of 3.5% and 6.2%, respectively. However, at higher RET dosages (2% and 3%), the S and m-values behave differently, with the S-value increasing and m-value decreasing for the RET/HDPE modified binder. This trend is observed due to the high tendency of low-temperature cracking for the H5-3 and H7-3 binders. Therefore, for optimized low-temperature properties of the RET/HDPE modified bitumen, the optimum RET dosage is recommended to be 1 wt%.

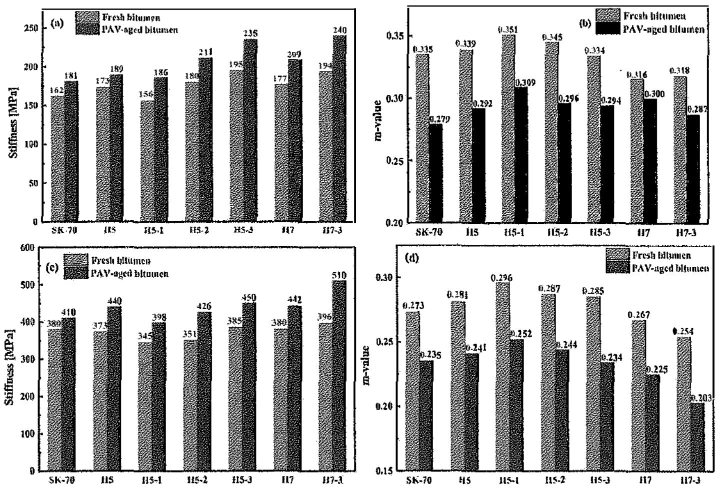

Figure 4. The S and m-value of RET/HDPE modified bitumen at -12°C and -18°C.

4 CONCLUSIONS

In this study, we aimed to enhance the elasticity of bitumen modified with recycled polyethylene through the inclusion of RET elastomer. While the incorporation of RET improved the elastic properties of HDPE- and RPE-modified bitumen, a softening effect was observed in RPE-modified binder with high RPE content. Adding RET significantly improved the anti-rutting, elastic recovery, and deformation resistance of HDPE- and RPE-modified bitumen, with notable shear resistance augmentation, particularly for HDPE-modified bitumen. At a moderate RET content (1%), a significant improvement in the low-temperature cracking resistance of plastic-modified bitumen was observed. Considering the low-temperature properties of compound-modified binders, we recommended an optimum RET content of 1wt%. Furthermore, blending the elastomer was found to significantly improve the storage stability and compatibility between bitumen and HDPE and RPE plastics.

REFERENCES

1. Ali, B., Soudani, K., Haddadi, S. Effect of waste plastic and crumb rubber on the thermal oxidative aging of modified bitumen. Road Materials and Pavement Design. 2022, 23(1), 222–233
2. Behnood, A., Gharehveran, M.M. Morphology, rheology, and physical properties of polymer-modified asphalt binders. European Polymer Journal. 2019, 112, 766–791.
3. Camargo, I., Dhia, T., Loulizi, A., Hofko, B., Mirwald, J. Anti-aging additives: proposed evaluation process based on literature review. Road Materials and Pavement Design. 2021, 22(1), S134–S153.
4. Cuadri, A.A., Roman, C., Garcia-Morales, M., Guisado, F., Moreno, E., Partal, P. Formulation and processing of recycled-low-density-polyethylene-modified bitumen emulsions for reduced-temperature asphalt technologies. Chemical Engineering Science. 2016, 156, 197–205.
5. Das, P.K., Tasdemir, Y., Birgisson, B. Evaluation of fracture and moisture damage performance of wax modified asphalt mixtures. Road Materials and Pavement Design. 2012, 13(1), 142–155.
6. Domingos, M., Faxina, A., Bernucci, L. Modelling and permanent deformation analysis of low-density polyethylene (PE)-modified bitumens and asphalts. Road Materials and Pavement Design. 2021, 22(8), 1860–1880.
7. Duarte, G.M., Faxina, A.L. Asphalt concrete mixtures modified with polymeric waste by the wet and dry processes: A literature review. Construction and Building Materials. 2021, 312, 125408.