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Comparative Study of the Mechanical Performance of Bitumen Binders and Mixtures Utilizing Crumb Rubber, Tafpack Super, and polypropylene

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Abstract

This research aims to assess and then compare the high-temperature rendering of tafpack super, tire rubber, and Polypropylene. Dynamic shear rheometer experiment out righted to mensuration linear viscoelasticity areas of the modified bitumen at 58-88°C. Additionally, the modified asphalt mixture's rutting depth is measured in millimeters using the wheel tracking test. Finally, the rheological features of the improved asphalt were contrasted together with each other as well as with the perspicuous asphalt. Conclusions manifested that the tire rubber modifier has more excellent characteristics in high temperatures and less rutting depth than poth polypropylene as well tafpack super.

Keywords: Tafpack super; Crumb rubber modifier; Polypropylene; Phase angle; Rutting parameter; Temperature sweep test

Introduction

The pavement characteristics improvement is possible either by bitumen properties amendment or through modified asphalt mixtures improvement. This matter needs numerous experiments to assert this demand. The bitumen mechanical behaviors are highly depending upon ambient temperature due to viscoelasticity property [1]. When temperature increased the viscosity decreased, and the asphalt is becoming resilient [2,3]. Thus, the pavement becomes permanently disfigured, therefore accelerating the rutting in the vehicles' wheel path [4,5]. Besides, the stress induced by loading represents another significant parameter that permanently deforms the asphalt pavement [6,7]. CRM, TPS, and PP have broad applications to get better the pavement rutting performance. Shear resistance characteristics of pure and amended asphalt. This research aims to assess and then compare the high-temperature rendering of tafpack super, tire rubber, and Polypropylene. Dynamic shear rheometer experiment outrighted to mensuration linear viscoelasticity areas of the modified bitumen at 58-88°C. Additionally the modified asphalt mixtures' rutting deepness is measured in millimeters using the wheel tracking test. Finally, the rheological features of the improved asphalt were contrasted together with each other as well as with the perspicuous asphalt. Conclusions manifested that the tire rubber modifier has more excellent characteristics in high temperatures and less rutting depth than Poth polypropylene as well tafpack super. Binders utilizing tafpack super (TPS) [1,8], crumb rubber modifier (CRM), and polypropylene (PP) modified bitumen were discussed. Creep data for these binders were measured by using the dynamic shear rheometer (DSR) test over a wide range of temperatures at (58°C to 88°C) to describe the behaviors of shear creep of modified bitumen binders. Asphalt concrete mixture evaluation to protect it versus the rutting phenomenon of wheel track has turned to the substantial research area in recent years [6,8]. Thus, the wheel tracking experiment was conducted to examine the permanent deformation of bitumen mixtures utilizing the above modifiers for measuring the rutting depth. To characterize the attitude of shear creep of the TPS, CRM, and PP modified asphalt, the shear strain rate and shear creep modulus was used. Wheel tracking test consequences were utilized to compare the influence of the modified asphalt mixtures on the permanent deformation. The shear strain rate and the shear creep modulus of the TPS, CRM, and PP modified asphalt binders are acquired, and compared, together with each other and with base asphalt. Whereas rheology has become a useful tool in the depiction of the asphalt performance on the pavement [3,9], this study also, prepared to compare the complex shear modulus ($G*$) and rutting parameter ($G*/\sin(\delta)$) values of above modifiers with respect to each other and with the base asphalt. Another objective of this study is to prepare and compare the impact of the wheel tracking experiment of the modified asphalt mixtures produced by utilizing the mentioned modifiers. The permanent deformation consequences of all the asphalt modified mixes from the wheel tracking test showed that crumb rubber is the best one than PP and TPS. As these results appear a reasonable endorsement with the findings of the shear strain rates and shear creep modulus over the range of shear stress levels. Crumb rubber modifier (CRM), tafpack super (TPS), and polypropylene (PP) modifiers are the most common modifiers of bitumen binders and mixtures for improving the rheological properties and the permanent deformation performance [10]. Rajesh Kumar and Dr. Mahendran utilized CRM and high-density polyethylene (HDPE) [10,11] they concluded that the CRM asphalt mixtures presented the lower permanent deformation than HDPE and the virgin asphalt mixtures. As well, they summarize that the utilization of CRM asphalt displayed the lower temperature susceptibility in contrast to the base bitumen binder [12]. Wang et al. performed the study on the effectiveness of CRM on the sensitivity of the high-temperature of the surface mixture by evaluating the impacts of the various magnitude of CRM on elevated temperature susceptibility. In this research, two things were measured. Firstly, the rapprochement of the properties of the modified and unmodified asphalt at a broad range of experimentation temperatures and aging situations was conducted. Secondly, a comparison of the rutting resistance of the crumb rubber modified binders and a traditional mixture was achieved. The consequence concluded that all the crumb rubber modifier mixtures have overall participated in the better rendering of both binders and mixtures at high temperatures [6,13].

Materials and Methods

Materials

Inclusive research was conducted on utilizing additives in asphalt

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binders and in the manufacturing of asphalt mixtures to enhance their capabilities against dynamic loads. The depressed impedance of pavement against dynamic loads and their short life of serves are the most considerable existing problems in the scope of preservation and maintenance of roads. Aggregates, asphalt, crumb rubber, tafpack super, and polypropylene were used. The aggregate used in the current research was the crushed basalt stone that consists of the mixture of the coarse and fine aggregate as well as mineral fillers. Figure 1 clarified the aggregation curve of the used aggregate.

Asphalt binders Asphalt is a combination hodgepodge of high-molecular-weight hydrocarbon molecules [14]. Thirteen kinds of asphalt, i.e., base asphalt, 2%, 3%, 3.5%, and 4% TPS, 2%, 3%, 3.5%, and 4% PP, 2%, 3%, 3.5%, and 4% CRM modifiers were used. Virgin bitumen utilized was asphalt 60/70 penetration grade. The asphalt and bitumen modifiers (i.e., TPS, PP, and CRM) come from Jiangsu Yi Nuo Road and Bridge Engineering and Testing material Co., Ltd., Jiangsu Province/China. Base asphalt 60/70 was utilized to prepare all modified bitumen binders by adding their percentages and using a constant mixing temperature at 180°C by utilizing elevated shear emulsify instrument. To procure the identical between base asphalt and each modifier, the TPS, PP, and CRM were inserted tardily into the pre-heated fresh bitumen and blending them 4h. Physical features of utilized base asphalt are illustrated in Table 1.

Crumb rubber modifier: The crumb rubber modifier is the expression commonly second-hand recycled rubber from the vehicles and trucks junk tires [12,15]. The size of used CRM is passing the sieve No. 100 mesh (holes per inch). Figure 2 shows the crumb rubber used in the present study. The CRM wet process was used in the current study.

Tafpack super: Tafpack super (TPS) is containing thermoplastic elastomers as a significant component extremely tough to disband in asphalt. Nevertheless, at mixing the polymer with a cohesive resin, a plasticizer is possible to dissolve into pure bitumen while to amended it to high- viscosity and good quality [1]. The used tafpack super explained in Figure 3.

Polypropylene: Different percentages of the polypropylene contents were utilized in this study. Polypropylene (PP) was introduced to bitumen at the temperature of 180-185°C and mixed for 4 hours using high shear propeller mixture. Afterward, modified asphalt was added to the preheated aggregates — Figure 4 clarified polypropylene used in current research.

Methods

DSR specimens preparation: The DSR experiment includes the determination of the complex shear modulus, and rutting parameter ($G^*/\sin(\delta)$), as well as phase angle (δ) of the modified asphalt within several situations. Dynamic shear rheometer apparatus with the parallel plate geometry 25 mm diameter utilized for identifying the rheological features of the asphalt. A test was being conducted at a temperature of 58-88°C in 25 mm plate with a gap of 1 mm in fatigue-controlled style. The amount of 0.6 g specimen was a sandwiched amidst two plates together with the diameter of a 25 mm. DSR experiment setup and the sample sandwiched between the two plates has been clarified in Figure 5.

Results and Laboratory work

Temperature sweep test

DSR test is performed by measuring the bitumen's rutting parameter ($G^*/\sin(d)$) value at elevated temperatures to determine an asphalt binder's resistance to permanent deformation.

Crumb rubber modifier-modified asphalt binders have a higher resistance to the permanent deformations than their PP and TPS counterparts. Figures 6 and 7 illustrated that complex modulus and rutting parameter of adhesives show a more significant difference in high temperature and increase with an increase of CRM content. But in the case of TPS, and PP modifiers complex modulus and rutting parameter are improved with an increase in TPS, and PP contents at percentages of 3% and 3.5% respectively then decreased. Hence, the modifier dosage has a great importance on a high-temperature property and rutting-resisting property of the modified asphalt. Thus, asphalt rheological characteristics have significantly improved by adding 4% CRM 3.5%, PP, and 3% TPS modifiers. Concretely high-temperature property of 4% CR modified asphalt is better than a feature of 3% TPS-, and 3.5% PP- modified asphalt binder and the property of 3.5% PP-modified bitumen binder is also better than a property of 3% TPS modified bitumen binder.

Complex shear modulus

The values of G^* has been tested at 58 to 88°C and explained in Figure 6. The tests consequences show a significant decrease in G^* with the temperature increase. The percentage increase of G^* concerning base asphalt shown in Figure 8. This point out to the degree of changes in the bitumen structure and composition and may be attribute to the fact that the viscosity of the all components was a very low to allowing the elastic network of the modifier to impact in the mechanical characteristics of the modified bitumen [3,16].

Comparison of modifiers effect in phase angle

The measurements of phase angle (δ) regard as the more sensitive to the chemical structures. Referring to Figure 8 the results explained that; there was a reduction in phase angles, compared to base asphalt. But this decline has been observed clearly in CR-modifier where phase angle is in the less value. At 4% CRM, the elastic response was more significant. Also, there was a considerable reduction in TPS phase angle at 3%, mainly after 70°C. Thus, the elastic response was improved. The results exhibited decreases in phase angle were observed after adding the bitumen modifiers to the base asphalt in the temperature range of 58°C to 88°C.

Wheel tracking test

The groups of samples were manufactured with the dimensions of 300 × 300 × 50 mm utilizing a roller compactor. WTT conducted to the samples manufactured utilized the diversified modifiers such as CRM, TPS and PP. Tests were conducted at a temperature of 60°C to evaluate rutting resistance. The rolling wheel with a standard load of 0.7 MPa has been passed over the samples at a constant speed of 42 load cycles per minute for 60 minutes. Figures 9a and 9b illustrated the wheel tracking experiment setup and sample respectively. The wheel tracking experiment is also utilized to evaluate the moisture susceptibility of the hot mix asphalt related to the aggregate structure, the asphalt binder stiffness, or the adherent ligament between the aggregate and bitumen binder [17] (Figure 10).

Rut depth

It can be observed in Figure 11, that the rut depth values in the crumb rubber modified asphalt are far lower than that of TPS and PP modifiers. Also, these rut depth values are far lower than that of unmodified asphalt mixtures which range from 4.402 mm to 5.361 mm — considering the dynamic stability values (DS) of these three modified bitumen mixtures, which are represents the number of the cycles needed to produce 1 mm of the rut depth in the interval of the testing time ranging from 45 minutes to 60 minutes. Figure 12 illustrated the dynamic stability and

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the modifier content curves. To make the comparison between the used modifiers, the ideal percentage to improve the rutting resisting property of each bitumen modifier was used. The results are calculated and compared as follows (cycle/mm): 4% TPS (2441.86) <4% PP (4172.185) <4% CRM (4200). It is seen that the dynamic stability increased with the increase of the modifier percentage. In comparison between modified asphalt mixtures using TPS, PP, and CRM modifiers, the dynamic stability of specimen with CRM is higher than that of the specimen using PP and TPS modified mixtures which mean that the CR modifier has a lower rut depth followed by PP and TPS modifiers. The effect of CRM modification on rutting resistance is thus more significant than

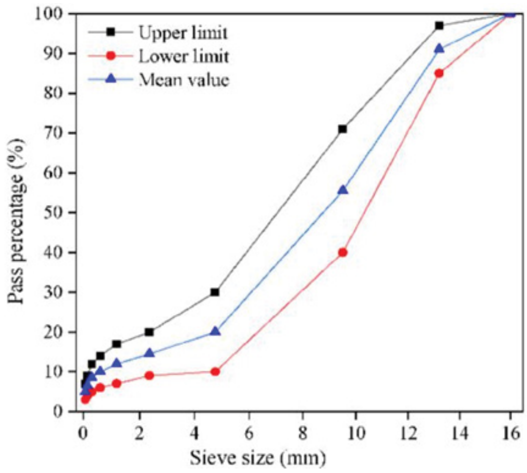

Figure 1: Gradation curve of the utilized aggregate.

Figure 2: Crumb rubber modifier used in this study.

Figure 3: Tafpack super used in current study.

Figure 4: Polypropylene utilized in this study.

Figure 5: DSR experimental setup and sample sandwiched between two plates.

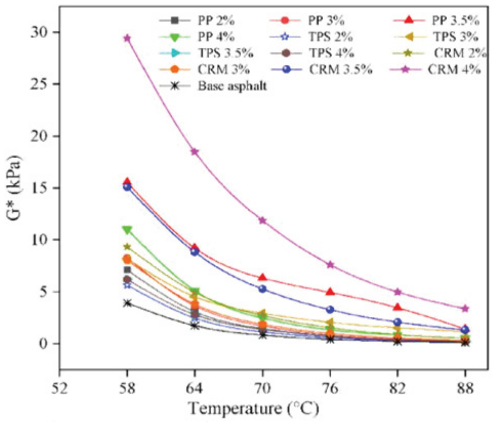

Figure 6: Complex sheer modulus-temperature curves.

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that of modification using PP and TPS. According to the rut depth in Figure 11, the results reported that the rate of rutting (RR) for CR-modified asphalt had a lower amount of rutting in comparison with TPS and PP modified asphalt mixtures. Moreover, it was observed that the crumb rubber modified asphalt mixtures get the more resistance to the permanent deformation followed by polypropylene and tafpack super modifiers. Thus, TPS and PP have less strength versus permanent deformation. It is of interest to know that the crumb rubber modified asphalt mixtures had the best conclusion in the wheel tracking test and the best permanent deformation behavior. As the consequences, the utilization of crumb rubber improved rutting resistance of mixtures considerably better than TPS and PP.

Due to some technical restrains in incinerators, its efficiency on producing electricity from solid waste is 20% [14,15]. So, we can get

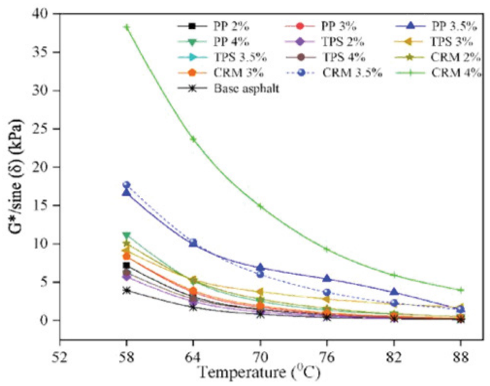

Figure 7: Rutting parameter – temperature curves.

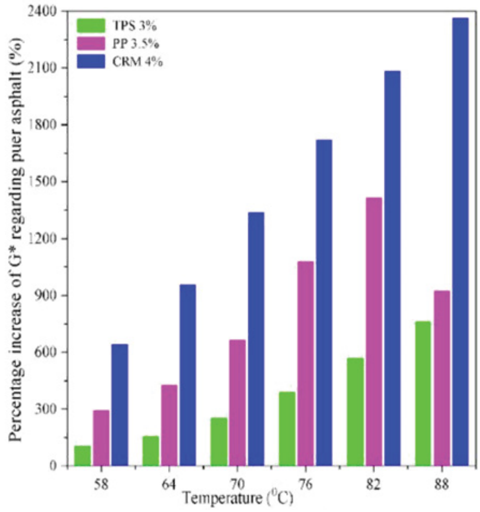

Figure 8: Percentage increase of G with respect to base asphalt.

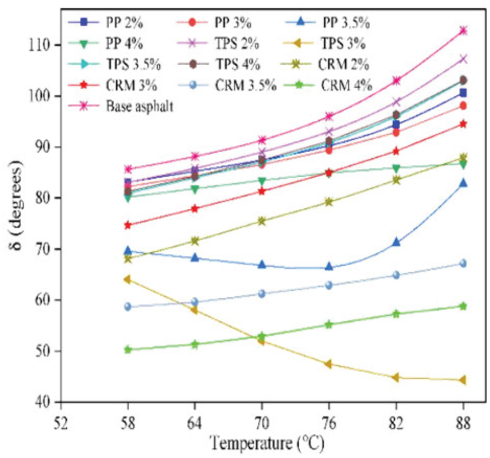

Figure 9: Effect on modification on phase angle at varying temperatures.

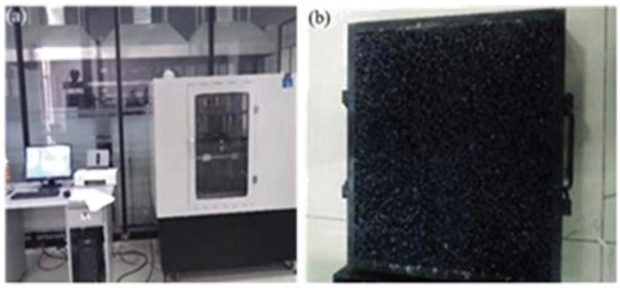

Figure 10: Depicts the schematic view of wheel track test. (a) WTT apparatus, (b) WTT sample.

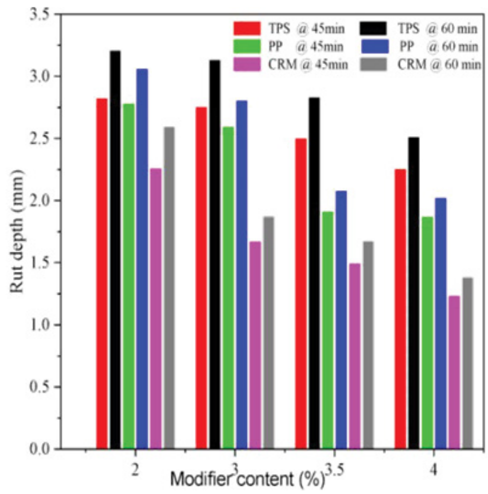

Figure 11: Rut depths of modified mixtures.

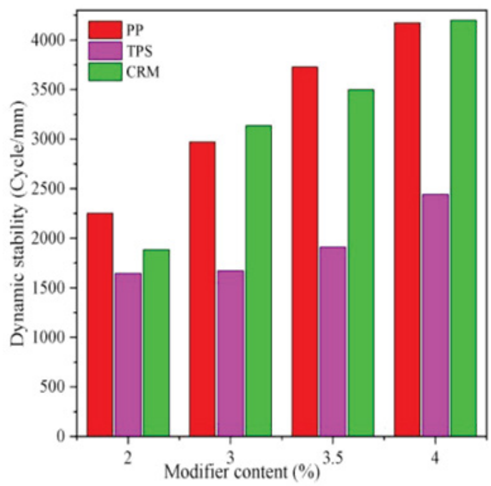

Figure 12: DS of bitumen modified mixtures.

Test	Method	Quantity	Specification limits
Penetration at (25°C, 100 g, 5 s), 0.1 mm	ASTM D5	64	60–70
Ductility (25°C, 5 cm/min), (cm)	ASTM D113	150	Min 100
Kinematic viscosity at 135°C (Pa. s)	ASTM D2170	0.422	-
Softening point (Ring & Ball method) (°C)	ASTM D36	49	Min 46.0
Flash point (°C)	ASTM D92	317	-
Fire point (°C)	ASTM D92	331	-
Specific gravity at 25°C (g/cm^3)	ASTM D70	1.043	-
Loss on heat (%)	ASTM D-6	0.04	-
Dynamic viscosity at 60°C (Pa.s)	ASTM D2171	0.411	-

Table 1: Physical properties of base asphalt used in current study.

2546.18 Kwh electricity from food waste and 882.52 Kwh electricity from paper products. In total, we can easily get 3428.70 Kwh of electricity if we can properly utilize the generated waste of this area.

Discussion and Conclusion

Crumb rubber modifier (CRM), tafpack super (TPS), and polypropylene (PP) have a function of improving the asphalt binders and mixtures by mixing them with aggregates and asphalt homogenously. According to the current study consequences, the following conclusions can be obtained:

1. The results explained that there was a reduction in phase angles of the all modified binders, but the considerable reduction is seen in CR-modified binders where the phase angle is in the lower value; the elastic response is more significant, particularly at 4% CRM. The obtained results may be employed to the development of a stiff flexible mixture that is suitable for high temperature service pavement.
2. The obtained values of the rut depth are less in the CRM mixtures than PP and TPS asphalt modified mixtures.
3. Consequences noted that the improvement of all the high-temperature property, of CRM modified bitumen, is the best than those of TPS and PP modified bituminous binders.
4. The best improvement of the mechanical properties and performance of the CRM, PP, and TPS modified binders was observed at concentrations 4, 3.5, and 3 wt% respectively, and CRM is the better one.
5. CR-modified binders and mixtures showed better high-temperature performance followed by the PP- and TPS modifier. Furthermore, the crumb rubber modifier, polypropylene, and tafpack super modifiers can improve the high-temperature rutting-resisting property of the bitumen binders and mixtures. Likewise, the crumb rubber modified asphalt mixtures had the better consequence in the wheel tracking test and best permanent deformation behavior.

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