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Full Paper

EFFECT OF STYRENE-BUTADIENE ON RHEOLOGICAL PROPERTIES OF ASPHALT EMULSION

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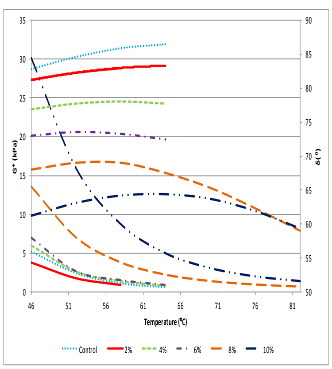
Graphical abstract



Abstract

One of the main issues with cold mix asphalt (CMA) mixtures is having poor abrasion resistance with low cohesion, longer curing time and low elasticity. SBR is used to improve the rheological properties of the asphalt emulsion. This paper evaluates the effect of using different percentages of SBR in unaged slow-setting emulsion (SS-1K) in CMA. These modified emulsions were blended at various percentages, i.e. 2%, 4%, 6%, 8% and 10% of the weight of asphalt emulsion. The investigation focused on the rheological aspect which correlates the properties of unaged modified asphalt emulsion with its performance. Dynamic Shear Rheometer test (DSR) was used to measure the parameters of complex shear modulus, *G** and phase angle, δ of the asphalt samples. Based on the results, it shows that by adding SBR in the asphalt emulsion improve the rutting resistance. From the isochronal curve, the complex modulus, *G** of the modified emulsions was found higher than the unmodified emulsion. The modified emulsions show signs of improvement in binder properties in terms of elastic deformation and viscosity reduction. Therefore, it can be concluded that the SBR could improve the performance of the asphalt emulsion used in CMA.

Keywords: styrene-butadiene rubber, slow setting emulsion, rheology properties, cold mix asphalt

1.0 INTRODUCTION

Styrene-butadiene Rubber (SBR) is one of the most versatile copolymer rubber compounds which consists about 25% of the organic compound styrene and 75% of the chemical butadiene. SBR has a potential to improve the performance of asphalt emulsion especially for the cold mix asphalt (CMA) in terms of abrasion resistance, crack resistance and enhance elastic properties [1,2].

Several types of factors that causing premature failures are such as increased stress on the highway due to heavier loads, higher tire pressures and higher traffic counts [1]. As the network of highway ages, the demand for better quality of road pavement is becoming more important. In order to address these problems, the highway engineer has turned to polymer modification for custom design of pavement materials. Rutting is the predominant damage at high temperature [3].

A previous study has shown that the addition of polymers such as SBR to binder can enhance the thermomechanical resistance, elasticity and adhesivity [4]. The Dynamic Shear Rheometer (DSR) was used in this paper to investigate the rutting resistance of pure slow setting emulsion (SS-1K) and polymer modified emulsion (containing SBR) [3,5].

2.0 MATERIALS AND METHOD

The slow-setting emulsion (SS-1K) supplied by Road Asphalt Sdn. Bhd. was used as a binder for cold mix asphalt which has 57% bitumen content and for the polymer modifier which is SBR was supplied by the Asa Infratech Sdn. Bhd. The proportion of SBR used in this study was in the range of 2% to 10% as recommended by previous researchers [6]. The basic properties of the emulsion are given in Table 1. The SBR was blended with the emulsion using the Shear Laboratory Lab Mixer at the room temperature with 900 RPM for about 10 minutes to achieve the consistency of the polymer modified emulsion (PME). The PME was then subjected to the residue by evaporation to obtain the residue sample for the DSR procedure. The residues were tested using the Dynamic Shear Rheometer to determine the binder rheological properties at a temperature range of 46^{0}C to 82^{0}C. Table 2 shows the designation and detailed constituents of the tested samples.

Table 3 shows all the specifications on the SBR that has been used in this research. It is a cationic styrene butadiene latex specially designed for production of cationic polymeric bitumen emulsion in road industry where it is readily miscible with water and stable in the acidic bitumen emulsion environment.

Table 1 Basic properties of slow-setting emulsion (SS-1K)

Properties	Units	SS-1K
Saybolt Furol Viscosity @ 25^{0}C	Second	Minimum: 20 Maximum: 100
Settlement 5 days (maximum)	% different	5
Sieve Test (maximum)	%	0.1
Particle Charge Test	-	Positive
Residue from Distillation	% mass	57
pH Value (maximum)	-	6.7

Table 2 Basic properties of styrene-butadiene rubber

SBR Specification	
Appearance	Off white liquid
Total solids content	62.0 ± 1.0%
Specific gravity	0.95
pH value	5.0 ± 0.5
Viscosity	1000 ± 500 cps (Brookfield RVT, spindle 3 speed 10 rpm)
Boiling point	100°C (water)
Recommended dosage	3% (up to 25% for specialized application)

Table 3 Designation and constituents of binder

Designation	Constituents
Binder A	SS-1K (control)
Binder B	SS-1K + 2% SBR
Binder C	SS-1K + 4% SBR
Binder D	SS-1K + 6% SBR
Binder E	SS-1K + 8% SBR
Binder F	SS-1K + 10% SBR

Figure 1 Thermo Scientific Haake Rheo Stress 1 Dynamic Shear Rheometer

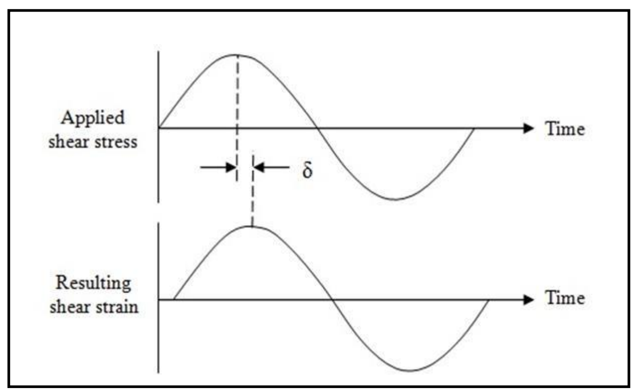


Figure 2 Typical DSR curves [5]

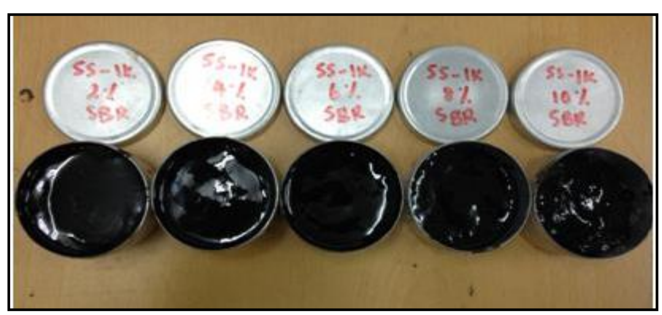


Figure 3 Samples of polymer modified emulsion (SBR)

3.0 RESULTS AND DISCUSSION

3.1 Effect On Isochronal Curve

The Dynamic Shear Rheometer measures asphalt's complex shear modulus, G* and phase angle, δ at various temperatures. Using rheological master curves is quite difficult in order to determine changes in properties related to pavement performance [7]. However, the isochronal curves can be used to examine the corresponding relationship between the complex shear modulus and phase angle. This curve represents the variation of G* and δ with temperature at a selected frequency.

Figure 4 shows the corresponding relationship of G* and δ control and modified polymer emulsion at the oscillation speed of frequency 10 rad/s (approximately 1.592 Hz). SBR appears to increase the stiffness of the polymer modified emulsion. Binder F (SS-1K + 10% SBR) produced higher stiffness than Binder A (control sample). Another researcher [8] said that with the addition of polymers to the neat bitumen can increase the mechanical properties of the mixture because the polymer may dissolve into the maltenic medium. This proved that polymer modified emulsion shows a viscoelastic behavior, increases the viscosity and complex modulus [9], particularly at high service temperatures. However, the performance of the polymer modified emulsion all depends on the polymer nature and mixing process where less promising results are usually obtained with a lab-scale mixer.

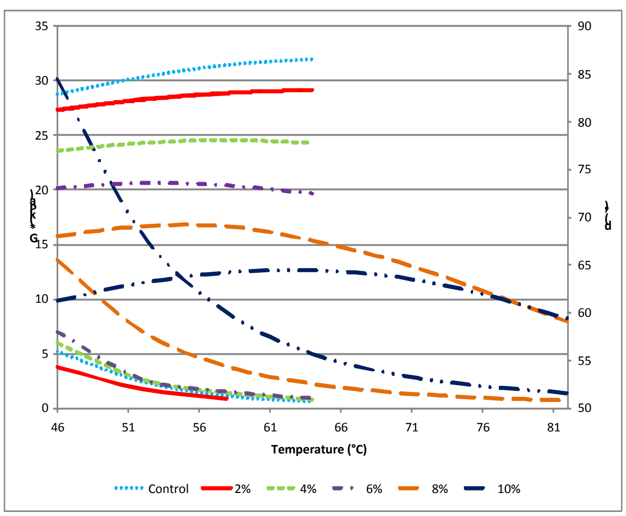


Figure 4 Complex shear modulus as function of temperature

3.2 Effect on rutting Resistance

There are two rheological parameters that can be developed from DSR tests which are G*/sin δ (rutting factor) and G*.sin δ (fatigue resistance). However, this study discusses only on the property subjected to rutting factor. According to Superpave performance classifications, G*/sin δ is used to refer the rutting deformation criterion and the rutting criteria must be at least 1.0 kPa for unaged binder.

Figure 5 shows the result of rutting resistance for control samples and polymer modified emulsion obtained from DSR test. The test is conducted starting at temperature of 46^{0}C and continued to the next temperature until the value of rutting not met the Strategic Highway Research Program (SHRP) specification. From Figure 5, Binder F which was blended with 10% SBR exhibited the highest rutting resistance. It is shown that with the polymer modification, the complex modulus will increase and the phase angle of bitumen will decrease [10, 15-18]. Among the five modified emulsion used, Binder B showed the lowest benefit from polymer modification. The rutting resistance for Binder B is much lower than the Binder A which is control sample.

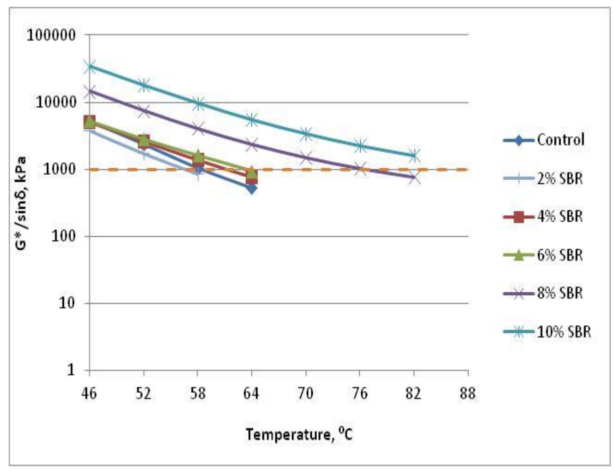


Figure 5 Phase angle as function of temperature

3.3 Failure Temperature

Another indicator for rutting evaluation is the failure temperature. Any binder that has the highest failure temperature values shows that the binder is less susceptible to permanent deformation at high temperature [11, 14, 19-21].

Table 4 shows the failure temperature of the binders. Binder F showed the highest failure temperature meanwhile Binder B has the lowest failure temperature. Similar to rutting resistance results where the binder that has higher rutting resistance will also have the highest failure temperature than the others. However, binder B which was blended with 2% SBR has the lowest performance if compared to the control samples. This is due to the degree of modification with respect to the binder rheology varied with temperature and frequency, and was dependent on the bitumen grade and the polymer concentration and structure where this can be proved by adding more percentage of SBR, the performance of modified binder is significantly improved [12, 13].

Table 4 Failure temperature of binder

Binder type	Failure temperature (^{0}C)
	G*/sinδ = 1.0 kPa (unaged)
Binder A	69.91
Binder B	57.98
Binder C	63.89
Binder D	63.69
Binder E	81.72
Binder F	81.77

4.0 CONCLUSION

A general investigation of the effect of the SBR behavior of slow setting emulsion using a Dynamic Shear Rheometer is reported in this paper.

Based on the result, it can be concluded that modified emulsion with SBR can perform well compared to the basic emulsion. Residue from emulsion SS-1K blended with 10% of SBR produced a higher value of stiffness and failure temperature performance. However, further studies need to be done in order to finalize the optimum value of polymer that need to be blended with the binder. This is due to the concern that it tends to become brittle, which could lead to cracking the problem. Mixing process also plays an important role because it can affect the engineering properties of bituminous binders. Chemical compatibility and processing conditions are crucial to obtain suitable properties. A high energy mixing process is needed to stabilize and disperse a polymer modified emulsion where it may lead to changes in the rheological response of such materials as a consequence of bituminous components oxidation, yielding an increase in the linear viscoelastic functions and steady-state viscosity.

For more comprehensive test result, data from conventional binder tests such as penetration, softening point, penetration index and ductility need to be collected. These binders are recommended for further investigation under the short term and long term aging condition in order to evaluate the age hardening occurring during mixing (ASTM D-1754 and ASTM D-2872). Furthermore, there are many factors that can influence the performance result of the polymer modified emulsion.

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