Effect of Chemical Warm Asphalt Additive on the Rutting Characteristic of Aged Binder Containing Waste Engine Oil

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Abstract. This paper presents a laboratory study on the effect of chemical warm asphalt additive on the rutting characteristic of aged binder containing waste engine oil. The aged binder and waste engine oil were blended with 0%, 1%, 2% and 3% of chemical warm asphalt additive. The samples were tested for rutting characteristics (rutting resistance, $G^\prime\sin \delta$ and creep recovery) using Dynamic Shear Rheometer (DSR). $G^\prime\sin \delta$ was tested at temperature 64°C and creep recovery was tested at temperature 60°C under stress of 50 Pa. The results showed that the chemical warm asphalt additive slightly decreased the rutting resistance of the aged binder containing waste engine oil sample. Meanwhile, the elasticity of asphalt binder was improved with the addition of additive by the reduction of creep compliance. As a conclusion, results of the testing showed that chemical warm asphalt additive could be applied with aged binder and waste engine oil with the satisfactory performance.

1. Introduction

The usage of reclaimed asphalt pavement (RAP) materials were continuously applied due to the significant benefits in term of economic and environmental. In term of economic, the RAP usage derived to cost savings by reducing the new materials. Meanwhile, in term of environmental benefit, the RAP enables to reduce the disposal area required for placing milled material as well as conserves the energy associated with the production and transportation of new materials [1]. These criteria have been defined under green highway elements [2-3]. However, the major concern is the high stiffness of the aged binder in RAP. During the service life, the pavement was exposed to ultraviolet (UV), radiation and oxygen which contributed to the stiff binder. Waste engine oil (WEO) is one of the effective rejuvenator to soften the aged binder [4-5]. The soft binder give a better workability [6]. On the other hand, many researchers have studied the use of warm mix asphalt technology in pavement materials [7–11]. In addition to the role of rejuvenator, warm asphalt additive shows a great potential to improve the workability of aged binder [12-13]. However, after long term in service, the effect of warm mix asphalt was less influenced compared to aged binder to the binder properties [14]. This paper studies the effects of introducing warm asphalt additive to aged binder containing waste engine oil...
oil (WEO). Since the asphalt binder become softer, it was potentially prone to rutting early in service life [15]. Thus, the modified asphalt binder were observed for rutting characteristic.

2. Materials and methods

The base binder used in this study was the 80/100-penetration grade. Meanwhile, the aged binder was obtained from the extraction and recovery of reclaimed asphalt pavement (RAP). Table 1 shows the basic properties of the asphalt binder used in this study. The aged binder was blended with base binder at 50% proportion with 15% waste engine oil (WEO) based on a previous study [16]. Chemical warm asphalt additive is in solid pallet were added to the aforementioned binder at 1%, 2% and 3% respectively. The detailed label and constituens of the samples are shown in Table 2.

| Label | Bitumen | WEO (by weight of bitumen) | Warm asphalt additive (by weight of bitumen) |
|-------|---------|---------------------------|---------------------------------------------|
| A     | Base binder | -                          | -                                           |
| B     | Base binder + aged binder | 15%                        | 0%                                          |
| BC1   | Base binder + aged binder | 15%                        | 1%                                          |
| BC2   | Base binder + aged binder | 15%                        | 2%                                          |
| BC3   | Base binder + aged binder | 15%                        | 3%                                          |

The modified binder (which refer to the sample that contained aged binder, WEO and chemical warm asphalt additive) were blended homogenously at 600 rpm at a temperature around 155 ± 5°C using Silverson-L4RT, a multipurpose high shear mixer. Subsequent the blending process, the rutting characteristics were investigated using dynamic shear rheometer (DSR) with accordance to ASTM D7175 [17]. A 25 mm diameter of circular disk-shaped with 1 mm gap setting for asphalt binder sample was used. There are two parameters used for rutting characteristics: rutting resistance, $G*/\sin \delta$ and creep and recovery. The samples were conditioned in a Rolling Thin Film Oven (RTFO) to simulate the asphalt binder aging during construction of pavement. During this phase, rutting also possible to occur by the consolidation of the pavement layer after construction [18]. The high temperature stiffness of asphalt binder is important to minimize the rutting [18]. The samples for $G*/\sin \delta$ was tested at temperature 64°C and creep recovery at 60°C to represent the service temperature of pavement during high temperature [19]. Meanwhile, creep recovery was run at a stress level of 50 Pa (loading for 1 seconds, recovery for 300 seconds) that represent a high stress level on pavement [20]. According to Xiao et al. [21], the compliance value is typically used to indicate the creep associated with load/stress applied. The loading is applied for a certain time and the strain induced is monitored after the loading is removed. Principally, compliance ($J_{nr}$) function is the ratio of the strain ($\gamma$) to the constant applied load ($\sigma$) with the unit of Pa$^{-1}$.
3. Results and discussions

3.1. Complex Modulus and Phase Angle

Complex modulus, $G^*$ and phase angle, $\delta$ is a basic property measured by the DSR. Complex modulus represents the stiffness and phase angle represent the elasticity of asphalt binder. Basically, a high value of $G^*$ is favourable because it indicated a higher resistance to deformation. Meanwhile, a lower $\delta$ is desirable because it reflects more elastic component to deformation [22]. Figure 1 shows the complex modulus and phase angle value for asphalt binder. The sample of base binder which abbreviated as A, has been used as a reference. This is to show the effect of the modification. As can be seen, the complex modulus ($G^*$) of modified binder is higher than binder A. Meanwhile, the phase angle ($\delta$) of modified binder is lower than binder A. As previously discussed, these results corresponds to greater rutting resistance by the modified binder. In the modified binder, the addition of chemical warm mix additive reduced the stiffness as asphalt binder by a slight reduction of $G^*$. However, the additives were found enhanced the elastic behaviour of the binder B from 73.81$^\circ$ to 69.35$^\circ$, 70.14$^\circ$ and 70.73$^\circ$ respectively.

![Complex Modulus and Phase Angle](image)

Figure 1. Results of asphalt binder for (a) complex modulus (b) phase angle.

3.2. Rutting Resistance

$G^*/\sin \delta$ is the indicator of rutting resistance. Figure 2 shows the rutting resistance values of base binder and the modified binder. It can be seen that the modified binder showed higher $G^*/\sin \delta$ value compared to the base binder, A. The increased of $G^*/\sin \delta$ of the modified binder can be explained the addition of aged binder and WEO. The addition of chemical warm asphalt additive was observed not to compromise the aged binder and WEO. The addition of 1% warm asphalt additive to the asphalt binder displayed the increasing rutting resistance with value 10.09 kPa. In the different container, 2% of chemical warm asphalt additive was blended with binder composition of BC, the $G^*/\sin \delta$ decreased to 8.46 kPa and at 3% to 6.12 kPa. A similar finding has been observed in other studies [23]. A possible explanation for this reduction is the warm asphalt additive was blended at a temperature around 155°C ± 5°C which quickly dispersed the chemical warm mix additive in the asphalt binder as the melting point of chemical warm asphalt additive is 110°C [24]. The additive then uniformly blended with waste engine oil and thus, produced a slightly soft asphalt binder regardless the aged binder content.
3.3 Creep and Recovery

During creep phase, the stress was applied for a certain time and the resultant strain was monitored. Then, the stress was removed and the recovery strain was continuously monitored. Figure 3 shows the monitored strain during creep and recovery phase under stress of 50 Pa with total time 300 seconds at temperature 60°C. The binder A exhibited the higher strain during the creep phase. Meanwhile, the modified binder showed the overlapped strain. During the recovery phase, some of the binders showed increase strain. Since the actual resultant strain depends on the applied stress, creep compliance J_{nr} usually used as a deformation indicator in creep test rather than strain [25]. The lower value of creep compliance implies higher rutting resistance [20][26]. The creep compliance of the asphalt binder is presented in Table 3. From the data, as expected, the binder A showed the highest J_{nr} value while the binder BC2 exhibits the lowest J_{nr} value. In specific, warm asphalt additive improved the deformation resistance of the aged binder containing WEO (sample B). The J_{nr} value was decreased from 7.29E-04 Pa$^{-1}$ to 6.44E-04 Pa$^{-1}$, 5.96E-04 Pa$^{-1}$ and 6.65E-04 Pa$^{-1}$ respectively with the addition 1%, 2% and 3% chemical warm mix additive. These results demonstrate that the modified binder showed the better elastic response under the applied stress and thus improved the rutting resistance. This improvement could be explained by the lower phase angle reported in section 3.1. Lower phase angle reflects to a more recoverable component of total deformation [27].
Figure 3. Strain value during creep and recovery test

Table 3. Results of creep and recovery test

| Binder | Creep Compliance, \( J_{nr} \) (Pa\(^{-1}\)) |
|--------|------------------------------------------|
| A      | 7.88E-04                                 |
| B      | 7.29E-04                                 |
| BC1    | 6.44E-04                                 |
| BC2    | 5.96E-04                                 |
| BC3    | 6.65E-04                                 |

4. Conclusions

In this study, the effects of chemical warm asphalt additive on the rutting characteristic of aged binder containing waste engine oil were evaluated. It was found that the addition of additive, slightly decreased the rutting resistance of asphalt binder. Meanwhile, in creep recovery test, the addition of warm asphalt additive has improved the creep recovery of the aged binder containing waste engine oil. As a conclusion, results of the testing showed that warm asphalt additive could be applied with aged binder and waste engine oil. Although the rutting resistance slightly decreased with the addition of chemical warm asphalt additive, the blending binder still has sufficient stiffness and elasticity to resist the rutting.

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