The effect of crumb rubber on the physical and rheological properties of modified binder

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Abstract. Bitumen is widely used in highway pavement construction. The highway intensity of traffic causes overloading and subsequently contributes to pavement distress i.e. rutting, cracking and disintegration. Hence, to minimize the pavement distress and enhance its durability, conventional bitumen properties need to be improved. An effort has been made by modifying the conventional bitumen with crumb rubber. The physical and rheological properties of crumb rubber modified binder (CRMB) were study by conducting fundamental physical test (including penetration, softening point, ductility, and storage stability) and Dynamic Shear Rheometer (DSR) test. Results indicated that, penetration decreased, and softening point increased, for unaged and short term aged samples, respectively. Temperature susceptibility of CRMB also improved as PI value increased. Moreover, rheology testing exhibited an improvement of $G^*$/sin $\delta$ value and increased bitumen’s performance grade (PG) by one level. These properties enhancement indicates greater resistance to rutting.

1. Introduction

Asphalt pavement provides the necessary stiffness and strength to increased driving comfort and flexible maintenance and repair action [1]. Over the years, many studies have been conducted to improve the conventional bitumen for better performance and prolonged pavement life that benefits road authorities and road user by ensuring a comfortable ride and lower maintenance cost in the long run. A major concern of Malaysia highway industry is the excessive of permanent deformation while pavement is still in service. Premature failures resulting to the frequent repetition of heavy axle load and worsen with the presence of excessive moisture in pavement, particularly in wet climate. Hence, in order to reduce the pavement premature failure and improve its performance, addition of polymers is a very effective way [2-4]. However, since polymers are rather expensive, using waste polymer to act as alternative may help to improve the pavement performance as well as to solve the waste disposal problem [5-7].

Widely used waste in modifying bitumen is crumb rubber, which is scrapped from waste tires. Crumb rubber can be incorporated into base bitumen using two different methods, which are dry and wet
process [8]. Dry process consists in the production of asphalt mixture with the addition of small ground rubber quantity from discarded tyres as a substitute for a part of the mineral aggregate. Meanwhile, wet process involves modification of bitumen with rubber to produce a new binder which captures beneficial engineering properties of both base material [9]. During the process, rubber and bitumen are allowed to blend together for a designate period of 45 to 60 minutes to promote an interaction between rubber and bitumen [10,11]. The blending temperature normally used is between 176 to 204°C [10]. Zanetti et al. [11] suggested that rubber is thoroughly mixed with bitumen at temperature of 175 to 225°C and subsequently kept in agitation at temperature of 150 to 215°C.

An effective modified binder should be able to increase rutting resistance at high temperature without making it too viscous during mixing or too brittle at low temperature. Sufficient content of rubber is crucial to ensure its compatibility with base bitumen to avoid phase separation during storage, transportation, application, and service [5].

This paper presents is intended to study the effect of crumb rubber on physical and rheological bitumen properties incorporating wet process.

2. Material and method
A conventional bitumen Penetration Grade (PEN) 80/100 was used in this study as virgin bitumen. Meanwhile, fine crumb rubber (40 mesh) was used as modifier to produce crumb rubber modified binder (CRMB). The preparation of CRMB involved the addition of different percentages of crumb rubber namely 2, 4, 6 and 8% by weight of bitumen. Prior to blending process, 500g of base bitumen was heated at 170 ± 5°C. The required amount of crumb rubber was then added and mixed with hot bitumen using high shear mixer at 1200 rpm for approximately 60 minutes. Subsequently, the CRMB was exposed to high temperature (163°C) in Rolling Thin Oven Film (RTFO) to prepare a short term aged binder.

3. Result and discussion
3.1. Physical testing
The fundamental physical tests such as softening point, penetration, ductility, penetration index (PI) and storage stability conducted on both conventional and modified bitumen were presented in Table 1. As can be seen from the table, penetration and ductility were decreasing and softening point was increasing with the increasing crumb rubber content. The result also showed an increment of PI to positive value with the increasing of crumb rubber content. Greater PI indicates the binder less susceptibility to temperature.

Meanwhile, the potential CRMB to segregation during storage was measured by storage stability test. The difference of softening point between top and bottom section less than 2.2°C can be considered as stable. As can be seen, increasing of crumb rubber content affected the storage stability result as the difference between top and bottom value increased. It was also found that, better stability can be seen in binder contains less than 4% of crumb rubber. Moreover, crumb rubber addition more than 4% could lead to binder instability. Consequently, rubber particles may separate gradually and assemble at the top during storage.

| Table 1. Physical properties of CRMB |
|--------------------------------------|
| Testing                           | Control | 2-CRMB | 4-CRMB | 6-CRMB | 8-CRMB |
| Softening Point (°C)               | 48.3    | 51.9   | 54.0   | 57.2   | 59.2   |
| Penetration (d-mm)                 | 81.9    | 70.7   | 68.1   | 62.2   | 56.3   |
| Penetration Index (PI)             | -0.40   | 0.12   | 0.54   | 1.00   | 1.16   |
| Ductility (cm)                     | 142.4   | 32.4   | 28.3   | 26.4   | 24.5   |
| Δ Softening point (°C)             | 1.0     | 1.9    | 1.6    | 8.0    | 14.4   |
3.2. High temperature performance grade
The effective high temperature performance grade (PG) for a given binder determined at $G^*/\sin \delta$ value greater than 1.0 kPa (unaged) and 2.2 kPa (short term aged). Table 2 showed the high service temperature as well as failure temperature obtained for control and CRMB. Results revealed that the increasing content of crumb rubber in bitumen resulting in higher service temperature compared to control binder. As expected, control binder recorded high temperature performance at PG 64 as failure temperature obtained were 65.6 and 64.6°C for unaged and short term aged condition, respectively. Likewise, modifying conventional bitumen with 2 and 4% crumb rubber produced a modified binder with PG 64. Meanwhile, adding crumb rubber at 6% and more, successfully improved the performance grade from PG 64 to PG 70. The upgrading of PG indicated by failure temperature recorded above 70°C for 6 and 8% at both unaged and short term aged conditions.

| Binder type | Failure temperature (°C) | Performance Grade (PG) |
|-------------|--------------------------|------------------------|
|             | Unaged (G*/sin $\delta$ > 1.0 kPa) | Short term aged (G*/sin $\delta$ > 2.2 kPa) | |
| Control     | 65.6                      | 64.5                   | PG 64 |
| 2-CRMB      | 67.7                      | 64.0                   | PG 64 |
| 4-CRMB      | 68.9                      | 66.5                   | PG 64 |
| 6-CRMB      | 71.5                      | 71.9                   | PG 70 |
| 8-CRMB      | 73.7                      | 74.6                   | PG 70 |

3.3. Rutting resistance
Effect of crumb rubber content on rutting resistance ($G^*/\sin \delta$) at 70°C was depicted in Figure 1. As can be seen, the addition of crumb rubber positively affected the binder’s rutting resistance. Generally, $G^*/\sin \delta$ value improved with the increasing of crumb rubber content. 8% crumb rubber has the higher $G^*/\sin \delta$ value among all modified binder for unaged and short term aged conditions. In comparing to control binder, results recorded $G^*/\sin \delta$ value for unaged and short term aged binder increased by 60 and 69%, respectively, with the presence of crumb rubber up to 8%. It is believed that the improvement of $G^*/\sin \delta$ value is due to the interaction between bitumen and rubber particles during wet process causing rubber particles to swell. The swelling of rubber particles resulting in binder hardening and enhances its stiffness.
4. Conclusion

Based on the result, associating crumb rubber enhances the physical properties of conventional bitumen. The improvement of penetration and softening point, as well as PI indicates that bitumen response to temperature is improved. This improvement is supported by Dynamic Shear Rheometer (DSR) result, which shown an upgrading high service temperature performance grade by one level (from PG 64 to PG 70). It is also found that $G*/\sin \delta$ value increases with the presence of crumb rubber. However, storage stability result reveals that, adding crumb rubber more than 4% causing binder instability during storage. Taken together, modifying conventional bitumen with appropriate content of crumb rubber does produce a modified binder that has high potential in improving rutting resistance and has high stability during storage, hence, could reduce asphalt pavement permanent deformation.

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