



Effect of crumb rubber degradation on components distribution and rheological properties of Terminal Blend rubberized asphalt binder



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HIGHLIGHTS

- Components distribution of Terminal Blend rubberized asphalt binder is presented.
- The apparent asphaltenes is well linked with various rheological parameters.
- Increase of medium size molecules affects rheological properties of asphalt binder.
- There is peak dissolved polymers in the degradation process.

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ABSTRACT

The degradation of crumb rubber modifier (CRM) was confirmed to affect the rheological properties in the production Terminal Blend (TB) rubberized asphalt binder. However, the quantitative analysis on the components distribution of TB rubberized asphalt binder and correlations to rheological properties were not investigated yet. The present study was to investigate the effect of CRM degradation on components distribution and rheological properties of TB rubberized asphalt binders produced under various curing temperatures and times. The solubility test and the Gel Permeation Chromatography (GPC) test were performed to obtain the distribution of insoluble components, dissolved polymers, apparent asphaltenes and maltenes. Brookfield viscometer and Dynamic Shear Rheometer (DSR) were used to investigate the viscosity properties, rutting resistance and rheological behaviour at wide frequencies. The results indicated that interaction time played a similar role as interaction temperature did in promoting the dissolution of CRM whereas the breaking of backbone of the main chain of rubber was more dependent on interaction temperature. With the gradual degradation of CRM, the workability and storage stability were improved with the sacrifice of rutting resistance. In addition, the enhance effects of CRM on $|G^*|$ values at both lower and higher frequencies and phase angle values at lower frequencies gradually weakened. The evolution of $\log |G^*|$ lower asymptote and crossover modulus indicated TB rubberized asphalt binders became softer with the degradation of CRM. The well link between apparent asphaltenes and various rheological parameters indicated that it was the transform of CRM from insoluble components and dissolved polymers to medium size molecules that affected the rheological properties of TB rubberized asphalt binder.

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1. Introduction

The recycling use of waste tire rubber to enhance the pavement performance is a common practice in pavement construction and

rehabilitation. There are mainly three technical routes in the incorporation of crumb rubber modifier (CRM) into asphalt pavement, namely dry process, wet process and Terminal Blend (TB). In the dry process, CRM is used as a substitute of 1–3% of total aggregates in the asphalt mix and there is limited interaction between CRM and asphalt during blending in the mix plant [1]. Traditional wet-process technique, such as Asphalt Rubber (AR), produced at 180–190 °C, has been used for a long history and it can significantly improve engineering performance compared to conven-

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tional paving grade bitumen. However, the construction of AR pavements is more challenging as temperature requirements are more critical and the storage stability of AR also raises concern [2].

In recent years, TB rubberized asphalt technology arose in America has shown its potential in greatly improving storage stability of rubber/asphalt composite. The difference between traditional wet process technique and TB rubberized asphalt technique is that the producing temperature of TB rubberized asphalt is from 220 to 260 °C for thermal method without shearing [3,4]. Meanwhile the interaction time of TB rubberized asphalt is much longer than that of in wet-process technique. In this way, the crumb rubber is fully digested into the asphalt and storage stability problem of Asphalt Rubber is solved [3]. Although the high temperature rheological properties of TB rubberized asphalt are not as good as Asphalt Rubber, with the addition of other modifiers, it still has considerable performance in pavement practice [5]. TB rubberized asphalt binder is produced at the refinery (or terminal) like any other polymer modified asphalt and could be used in both dense and open graded asphalt mixtures, which broadens the scope use of rubberized asphalt and reduces the possibility of segregation [6–8]. Full scale projects and heavy vehicle simulator testing in California indicated that fatigue performance of TB rubberized asphalt binder was better than that of asphalt rubber and base binder [6]. The FHWA's Accelerated Loading Facility (ALF) testing results indicated that Texas TB rubberized asphalt binder offered better rutting resistance than Arizona wet process asphalt rubber although the latter provided better fatigue performance [9]. It was reported that the production of TB rubberized asphalt binder can be achieved through digestion of crumb rubber into asphalt matrix using heat and shear, meanwhile polymers might be added to the degraded rubber/asphalt composite to meet the performance grade criteria [10].

Various studies confirmed that degradation of CRM binders can affect rheological properties of asphalt binder significantly [11–13]. Meanwhile, molecular weight distribution and molecular structure present remarkable changes from chemical perspective [12,14]. It would be better to understand the degradation mechanism through qualitative or quantitative analysis of molecular weight distribution and molecular structure of asphalt binder in combination with rheological investigations. However, the current research on molecular weight distribution of CRM binders could not fully characterize the rubber/asphalt composite as some dissolvable rubber components were removed by syringe filter before Gel Permeation Chromatography (GPC) test [15]. The combined use of solubility test and GPC test with the aim of quantifying the components distribution of TB rubberized asphalt binder is proposed in this study. On one hand, the components distribution results could

be used to investigate the degradation behaviour of CRM in the production of TB rubberized asphalt binder. On the other hand, the components distribution could explain the rheological behaviour of TB rubberized asphalt binder.

The objective of this study is to investigate the effect of CRM degradation on components distribution and rheological properties of TB rubberized asphalt binders produced under various interaction temperatures and times. The solubility test and the GPC test were performed to obtain the distribution of insoluble components, dissolved polymers, apparent asphaltenes and maltenes. Attempts were made to correlate each component in TB rubberized asphalt binder with rheological parameters. The terminology, apparent asphaltenes was defined as the amount of depolymerized material [12] and true asphaltenes with molecular weights between 3000 and 19,000 Daltons [16].

2. Materials and methods

2.1. Materials and preparation of TB rubberized asphalt binder

The base binder used in this study was graded as PG 64-22. One ambient processed minus 30 mesh crumb rubber from truck tire, containing 54% natural rubber and synthesis rubber was used to prepare TB rubberized binders. Based on the typical production conditions reported by Abdelrahman and Carpenter [11], Billiter et al. [12], Zanzotto and Kennepohl [13] and Flanigan [17], 20% crumb rubber by weight of asphalt binder were mixed with base binder at four temperatures of 220 °C, 240 °C, 260 °C and 280 °C for 2, 4, 6 and 8 h to produce TB rubberized asphalt binder. The blending speed was 400 rpm. As storage stability is very important for engineering use, the separation test were performed for each sample through keeping an aluminium tube containing 50 ± 0.5 g binder at 163 °C for 48 h according to ASTM D7173 [18]. The top and bottom parts of the tube were collected for softening point test (ASTM D36 [19]) and the softening point difference between the top and bottom is used as an index to evaluate the storage stability. In China, if the difference is less than 2.5 °C, the binder is considered to have good storage stability [20]. The storage stability test results are presented in Table 1. On the whole, increasing interaction temperature and extending curing time will help to improve the storage stability. The main reason is that the degradation process would cause the size reduction of CRM and viscosity increase of liquid phase of CRM binder. Based on Stoke's law, the sedimentation velocity of CRM particle would be reduced and storage stability would be improved [21].

The methodologies applied in this study can be simply summarized in Fig. 1. The detailed experimental methods can be found in the following sections.

2.2. Solubility test and Gel Permeation Chromatography (GPC) test

Each binder sample, weighed from 20 mg to 25 mg, was dissolved with tetrahydrofuran (THF) in a 10 mL volumetric flask for 24 h before solubility test and GPC test. The solution was then filtered through a weighted 0.45 µm PTFE filter and was collected in a 0.5 mL centrifugal tube for GPC test. The remaining solution in the volumetric flask was accordingly filtrated through the weighted filter. After this, about 5 mL clean THF was filtrated through the filter until the filtrated solution was

Table 1
Storage stability test results.

Blending Temperature	Softening Point °C	Blending Time			
		2 h	4 h	6 h	8 h
220 °C	Up	67.3	58.3	69.6	58.9
	Bottom	68	61.9	68.2	55.7
	Difference	−0.7	−3.6	1.4	3.2
240 °C	Up	53.4	47.4	54.7	51.3
	Bottom	57.6	50.3	54.2	49.2
	Difference	−4.2	−2.9	0.5	2.1
260 °C	Up	49.1	48.2	44.8	47.3
	Bottom	52.3	49.9	46.8	48.2
	Difference	−3.2	−1.7	−2	−0.9
280 °C	Up	49.1	48.5	46.1	47.5
	Bottom	50.8	49	45.5	46.8
	Difference	−1.7	−0.5	0.6	0.7

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