Construction and Building Materials 181 (2018) 455–464

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Investigations on behavioral characteristics of asphalt binder with crumb rubber modification: Rheological and thermo-chemical approach

Veena Venudharan [a], Krishna Prapoorna Biligiri [b,*], Narayan Chandra Das [a]

[a] Indian Institute of Technology, Kharagpur, India
[b] Indian Institute of Technology, Tirupati, India

HIGHLIGHTS

- Performed thermo-chemical analyses of asphalt binders covering 5000 data points.
- Assessed AR binders with varying crumb rubber gradations and dosages.
- CR inclusions augmented AR binders' thermal stability corroborated by TGA.
- Increased intensity of sulfoxide in AR confirmed binders' enhanced performance.
- Framed guidelines to choose outstanding AR binder based on parametric relationships.

ARTICLE INFO

Article history:
Received 22 November 2017
Received in revised form 2 June 2018
Accepted 9 June 2018

Keywords:
Crumb rubber
Asphalt-rubber
Rheology
Thermogravimetric analysis
Fourier transform infrared spectroscopy

ABSTRACT

The objective was to investigate the rheological and thermo-chemical behavior of asphalt-rubber (AR) binders and to evaluate the effect of various parameters on AR binder performance. The effort encompassed binder consistency, rheological, thermogravimetric, and Fourier transform infrared spectroscopy analyses of twelve different asphalts. It was found that CR inclusions not only improved the physical characteristics but also influenced the chemical and thermal properties of asphalt binder. Furthermore, it was inferred that employing higher CR dosages and fine CR gradations in asphalt binder will aid in producing an outstanding AR binder capable of performing well under extreme traffic and environmental conditions.

1. Introduction

Rapid urbanization and increased transportation needs across the globe demand better roadway pavements with improved performance and minimal maintenance. Many approaches have been investigated and explored by researchers to improve the performance of pavements to withstand different types of distress caused due to increased traffic and extraneous environmental conditions. Out of the various globally employed methods, modification of asphalt binders has achieved positive significance over the last few decades due to its ability in augmenting the binders' performance leading to rut- and cracking-resistant pavement systems. Amongst the additives used to modify virgin (base) asphalt binder, shredded crumb rubber (CR) from truck/car tires has been popular due to its many advantages, including: (a) resistance to fatigue cracking, rutting, and reflective cracking in asphalt overlays, (b) reduction in maintenance costs, (c) increased pavement life, and (d) efficient use of scrap tires that help keep the environment green [1]. The disadvantages of CR as binder additive are mainly construction related: (1) settlement of CR during transportation, and (2) sticking of CR onto the mixing unit due to uneven temperature control.

In the past, several researchers have worked on understanding the various aspects of CR modification of asphalt binders such as: (1) binder blending parameters and related importance for asphalt-rubber (AR) binder characteristics [2–5]; (2) binder performance in resisting pavement distress, namely, rutting, fatigue, and thermal cracking [6–11]; and (3) aging and other in-service related performance of AR binders [12–14]. These investigations on AR binders have shown that a mixture of CR and base binder generally results in a homogeneous blend with superior performance compared to conventional virgin binders with respect to pavement distress. Many studies [15–17] have indicated the importance of CR

* Corresponding author.
E-mail addresses: bkp@iittp.ac.in (K.P. Biligiri), ncdas@rtc.iitkgp.ernet.in (N.C. Das).

https://doi.org/10.1016/j.conbuildmat.2018.06.087
0950-0618/

modification, leading to improvement in the asphalt mix performance. However, no standard practice to blend and use a superior performing AR binder has yet completely evolved. Although ASTM D6114-09 [18] specifies that a minimum of 15% CR content by weight of AR binder be used, there is limited research that strongly supports the specified dosage having a significant influence on AR binder performance. Not only that, several USA State highway agencies and/or Departments of Transportation (DOTs) also propose varying CR gradations for AR blending purposes as well as using different dosages of CR in the manufacturing process. Thus, there are also very limited studies [13,19] available in the literature that provide clear insight into the contribution of CR gradation and size to AR binder performance.

Previous studies [9–11] conducted by the authors attempted to explain the effect of CR dosage, base binder, and CR gradation on AR binder rutting performance based on selected conventional consistency and rheological tests. But, it was actually necessary to understand the physio-chemical alterations happening to the asphalt binder with the addition of CR particles in a specific manner. Not many studies [20,21] have accounted for the interaction mechanism of different components within the AR binder, which perhaps could explain the enhanced behavioral characteristics of the material. Also, it is deemed important to understand the chemical changes occurring in the asphalt binders due to CR inclusion. With this background, there is an absolute need to comprehensively understand the basic traits of AR binders with respect to rheological and thermo-chemical properties pertinent to CR dosage and gradation parameters. The effect of CR inclusions and their associated properties on the behavioral characteristics of AR binders is of utmost importance, chiefly to arrive at a design accounting for the most cost-effective combination of CR and asphalt binder blend. An AR amalgamate created in this way should behave as an outstanding AR binder with enhanced strength properties and superior elastic characteristics.

Thus, the main objective of this research was to investigate the rheological and thermo-chemical behavior of AR binders and to evaluate the effect of various CR parameters on the AR binder performance characteristics. The study also aimed at determining the most suitable CR gradation and dosage for the production of superior performing AR binders. The effort encompassed advanced binder rheological evaluation and thermo-chemical analysis of twelve different asphalts. The scope of the work included:

- Preparation of laboratory blended CR modified binders with different CR dosages and CR gradations
- Evaluation of the binders' conventional consistency tests in order to estimate the AR binders' basic performance characteristics
- Assessment of the rheological characteristics of AR binders using temperature-frequency oscillation
- Analysis of the thermal behavior of the AR binders using Thermogravimetric analysis (TGA) and comparison with the base binder and CR particles
- Establishment of chemical characteristics of the AR binders using Fourier Transform Infrared Spectroscopy (FTIR).

It is envisioned that the thermo-chemical analyses and rheological tests detailed in this study will help understand the influence of various binder parameters such as the CR size, gradation, and dosage on the improvement of mechanical performance of AR binders. Furthermore, this study will aid in the selection of the most suitable AR binder combination to counter the various pavement distress types, thus leading to a long-lasting pavement with minimum maintenance.

2. Materials and experimental program

2.1. Materials

A total of twelve asphalt binders, including, one virgin viscosity graded VG40 (viscosity at 60 °C–4000 P), and twelve laboratory prepared AR binders were used. A blender-stirrer combination was used to produce the laboratory blended AR binders with VG40 as the base binder and three CR dosages (10, 20, and 30%) by weight of the virgin asphalt binder. The properties of the base binder are provided elsewhere [9]. A total of nine CR gradations specified by many USA State DOTs and presented in Venudharan *et al.* [1] were used as shown in Table 1.

The nine CR gradations included three gradations specified by Texas DOT, three gradations of Florida DOT, two gradations of Arizona DOT, and one gradation of California DOT (commonly known as Caltrans). The CR used in the study was obtained from shredded truck tires with a specific gravity of 1.012. The CR passed the 2.36 mm sieve and the CR gradations were adopted based on the recommendations of the DOTs. CR was added to the base binder, which was maintained at 170–180 °C, and then blended for 90 min at 2000 rpm to achieve a homogeneous CR modified binder matrix in accordance with the study conducted by Venudharan and Biligiri [5]. The designations of all the twelve AR binders are given in Table 2. In order to understand the effect of CR dosage, the CR gradation designated as ADOT-B was chosen since it is a well-graded mid-range gradation. It was envisaged that a well-graded CR gradation would aid in a better understanding of the effect of digestion time without having an interaction with the influence of CR size combinations. Further, CR dosage was fixed at 20% for the CR gradation study based on a former study conducted by the authors [9].

For ease of understanding, the nine CR gradations were divided into three groups: (a) coarse (AR-coarse), (b) fine (AR-fine), and (c) well-graded (AR-well) as explained in Venudharan and Biligiri [11]. The AR binders included in AR-coarse were V4AA and V4Cal,

Table 1
Gradations of crumb rubber.

Sieve Size (mm)	Caltrans	Texas DOT	Texas DOT	Texas DOT	Arizona DOT	Arizona DOT	Florida DOT	Florida DOT	Florida DOT
% Passing	Scrap tire	Grade A	Grade B	Grade C	Type A	Type B	Type A	Type B	Type C
2.36	100	100			100				
2	98–100	95–100	100		95–100	100			
1.18	45–75		70–100	100	0–10	65–100			100
0.6	2–20		25–60	90–100		20–100		100	70–100
0.425				45–100					
0.3	0–6	0–10				0–45	100	40–60	20–40
0.15	0–2						50–80		
0.075	0		0–5			0–5	–	–	–