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Advanced rheological characterization of Reacted and Activated Rubber (RAR) modified asphalt binders

Sampat Kedarisetty [a], Krishna Prapoorna Biligiri [a,*], Jorge B. Sousa [b]

[a] Department of Civil Engineering, Indian Institute of Technology Kharagpur, West Bengal 721 302, India
[b] CONSULPAV International, Milharado – Mafra 2665-305, Portugal

HIGHLIGHTS

- Performed advanced rheological characterization of 10 RAR modified binders at different temperature-frequency combinations.
- Found significant reduction in viscosity-temperature susceptibility and strain responses with RAR modification.
- Noticed augmentation of Performance Grade temperatures due to RAR inclusions in asphalt.
- Established minimal dosage of RAR to improve asphalt binder rheological properties.
- RAR is a promising additive to enhance asphalt binder performance characteristics.

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ABSTRACT

The objective of this research study was to conduct binder characterization of the Reacted and Activated Rubber (RAR) modified asphalts with varying dosages, and compare these materials with two virgin and one commercially available rubber modified (C60) binders. RAR modification raised the upper Performance Grade temperatures to a higher grade than the base binder making these binders well suited to reduce rutting. Non-recoverable creep compliance decreased and recovery increased with increasing RAR contents. RAR modified asphalts were highly resilient in nature since they had substantially lower strains than the virgin and C60 binders attributed to the presence of RAR additive that provided it an enduring viscoelastic characteristic. Overall, it is recommended that at least 15% RAR be used as minimal dosage in designing an asphalt mixture to obtain an effective material with an improved performance than a mixture produced using commercially available asphalts, including the rubber-modified ones.

1. Introduction

Asphalt binder is the key constituent in an asphalt mixture. The properties such as durability, viscoelasticity, and water resistivity make it an indispensible material in civil engineering design and applications, specifically, pavements. Owing to the ever-increasing road traffic and multi-axle loading configurations, unconventional modified binder materials and mixtures have been successfully used to counter a large number of premature failures of pavement structures. Several modifiers such as rubber, polymers, and fibres have been tried as additives to the base virgin asphalt binders in order to enhance the long-term pavement performance characteristics. It is worth noting that rubber modification stands out as one of the most sustainable and reliable strategies to offer resistance to rutting, fatigue cracking, low temperature thermal cracking, moisture susceptibility, and reflective cracking [1–7]. Furthermore, it has also been found that rubber-modified mixtures have been cost effective from life cycle perspective along with alleviating burden on the environment by utilizing the scrap tires in manufacturing the rubber-modified asphalt materials.

Any large-scale use of rubber-modified binders in the industry requires considerable amount of modifications to the existing asphalt plant, its storage capabilities, and working guidelines. An insight into the current research reveals that rubber modification in the binder and mixture has been very effective especially with

* Corresponding author.
E-mail addresses: ksampat164@gmail.com (S. Kedarisetty), kpb@civil.iitkgp.ernet.in (K.P. Biligiri), jmbsousa@aol.com (J.B. Sousa).

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untraditional gradations: gap and open graded aggregate structures [8–12]. The extra space in the gap and open graded gradations provides sufficient room to accommodate the crumb rubber inclusions within the aggregate skeleton. Additionally, rubber-modified binders have been found to be less susceptible to temperature variation, thus indicating their reduced viscosity-temperature susceptibility [10,13,14].

Even though there are issues regarding storage and equipment pertinent to rubber-modified binders, technological advancement has supported the industry in producing rubber-modified asphalts for commercial purposes. Further, these modified binders are prepared by devulcanization of the rubber particles, and processing them under high temperature and pressure to manufacture a smooth and homogeneous product [15]. This product is manufactured under temperatures as high as 200–300 °C with high shearing stresses provided by thousands of rpm under a pressure > 1 atm. The whole process also enables the rubber-modified material to be stored for longer periods of time with no additional handling or mixing processes and perhaps no significant changes in the binder matrix.

It is noteworthy that rubber-modified asphalt materials have depicted superior performance characteristics. However, the wet mixing process commonly used in producing the product at the desired higher temperatures is not fully devoid of storage issues. More so, wet mixing process is accompanied by temporary settlement of rubber particles in the storage tank that necessitates reheating the binder and simultaneous agitation before blending with the aggregate to form the mix. Thus, there is a need to produce an asphalt mix that can be readily used to pave, and which comprises of an enduring material (modifier) fit for storage with minimal changes as well as having better performance characteristics than the conventional asphalt mixtures. In addition, the material must be compatible with the existing plant equipment and working capabilities without altering the sophistication in a significant manner.

In a recent development, a new material called Reacted and Activated Rubber (hereafter referred to as RAR) was designed as a rubber modifier that can be added directly to the pugmill at the end of the batching process in a mixing plant and generate high quality rubber-modified asphalt mixes [16]. Preliminary investigations have found that the addition of RAR particles with the virgin asphalt resulted in a significant improvement in the performance of asphalt mixtures in terms of rutting, fatigue cracking, and moisture damage compared to the conventional ones [16,17]. Further, field test sections constructed using RAR modified asphalt mixtures have performed successfully with no major repair since the initial construction [18].

Several studies [19–22] have indicated that binder characterization a priori mixture preparation acts as a precursor towards asphalt mixture design, analysis, and construction and possesses strong correlation towards mixture performance. Furthermore, binder rheological characterization tests are used in estimating the mixing and compaction temperatures for the corresponding asphalt mixtures [23]. In this direction, there is a need to try different dosages of RAR material with the virgin binder to arrive at an optimal dosage of the RAR material that can be blended to form a mixture. In addition, there is a definitive need to develop models pertinent to viscous and elastic properties of RAR modified materials to understand their resilient and outperforming characteristics in respect of pavement durability aspects. Contemporaneously, the RAR modified binders must be compared to the commercially available rubber-modified binders in order to comprehensively assess the contribution of rubber inclusions as an additive in asphalt mixture performance.

The main objective of this study was to conduct binder characterization of the RAR modified asphalts with varying dosages, and compare the rheological performance of these materials with two base virgin binders and a commercially available crumb rubber modified bitumen (CRMB). A total of thirteen asphalt binders were available for analyses, including: 10 RAR modified, two virgin, and one CRMB. Further, the viscoelastic characteristics of the different binders were investigated using the advanced Dynamic Shear Rheometer (DSR) and Multiple Stress Creep and Recovery (MSCR) tests in order to understand the time-dependent viscoelastic responses. The scope of the work included (Fig. 1):

- Conduct fundamental binder consistency tests on thirteen asphalts and establish ASTM A-VTS relationships: Penetration, softening point, and rotational viscosity tests (Section 4.1)

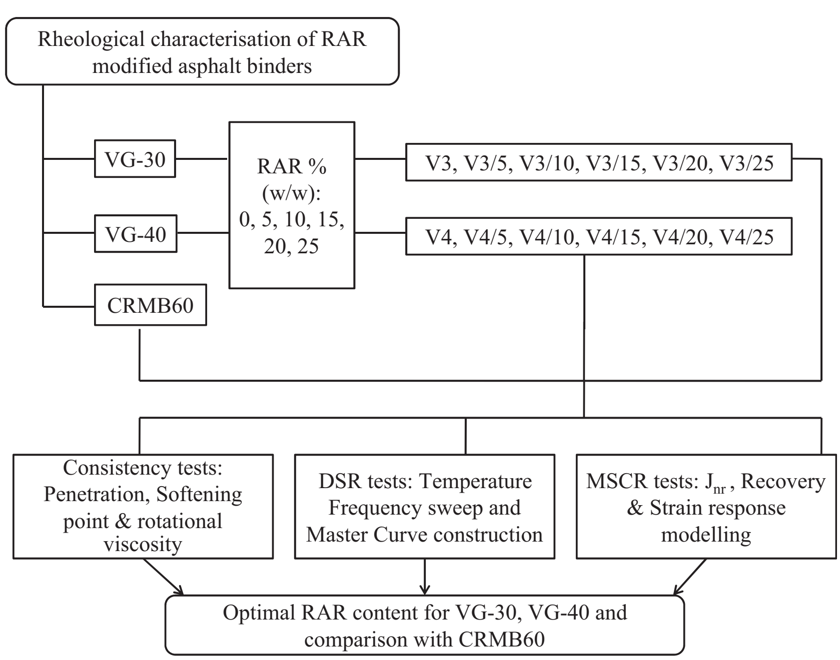

Fig. 1. Research outline.