



# High temperature rheological properties of crumb rubber modified asphalt binders with various modifiers



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## HIGHLIGHTS

- A 7% ground tire rubber (–40 mesh) incorporated with other modifiers/acid was mixed to produce PG 76 binders.
- Twenty-three binders from three base binders and five polymers or acid were used in this paper.
- Viscosity, fail temperature,  $G^*/\sin \delta$ , phase angle, amplitude and frequency sweep, and creep recovery were evaluated.
- Rheology properties of modified binders are dependent on polymer type and asphalt source.

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## ABSTRACT

This study aimed to analyze the rheological properties of the modified asphalt binders based on the effects of base binder type and other five polymers or acid combined with 7% dosage ground tire rubber (GTR) at the high temperature. The test results included viscosity, fail temperature,  $G^*/\sin \delta$ , phase angle, viscometry, amplitude sweep, frequency sweep, creep and creep recovery, and stress relaxation in this study. The results indicated that two of alternative polymers modified binders had noticeably lower viscosity values compared to SBS modified binders. Additionally, the addition of polyphosphoric acid could remarkably decrease the polymer dosage to produce PG76 binder. Meanwhile, asphalt source played a key role in determining the characteristics of all modified binders. The terminally and laboratory blended binders generally had approaching rheological properties in this study.

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## 1. Introduction

Recently, there has been a growing demand for polymer modified asphalt binders in paving industry for improving the properties of asphalt, as these properties are related to the pavement performance of asphalt mixtures, such as rutting, thermal cracking, moisture damage and etc. [1].

Currently, the most commonly used polymers for asphalt modification are styrene butadiene styrene (SBS), styrene butadiene rubber (SBR), Elvaloy<sup>®</sup>, rubber, ethylene vinyl acetate (EVA), polyethylene, GTR, elastomer, plastomer and others [2]. Among

of above polymers, “SBS is the most used polymer to modify asphalts, followed by reclaimed tire rubber” [3].

SBS block copolymers can be classified as elastomers and obviously increase the elasticity of base asphalt binder [3]. When binders were modified with SBS, the elastomeric of SBS copolymer absorbs the oil fractions from the asphalt and swells up resulting in three phase structure: a continuous asphalt phase with dispersed SBS particles, a continuous polymer phase with dispersed globules of asphalt, or two interlocked continuous phases [2]. It is believed that a critical three-dimensional network of the binder and polymer is better for increasing the resistance to rutting and thermal cracking [4].

SBR latex has been used as an asphalt binder modifier for a long time [5]. SBR modified asphalt binder can improve low

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temperature ductility, viscosity, elastic recovery, and moisture stability [2]. However, SBR modifier has been gradually replaced by SBS duo to its poor high temperature performance.

Elvaloy® is an elastomeric terpolymer and used to increase flexibility, toughness and durability of an asphalt binder. This polymer has been proved to be a good modifier in reducing permanent deformation, thermal cracking and moisture resistance. The addition should be carefully controlled in case of forming an insoluble gel and resulting in the separation [6,7].

Ethylene vinyl acetate (EVA) is a common plastomer used to improve both the workability and rutting resistance of the asphalt binder [8,9]. EVA modified binder through the crystallisation of rigid three-dimensional networks in the binder to improve the deformation resistance [10]. However, low elastic recovery and high glass transition temperature of EVA modified binders restrict its application [11].

Polyethylene (PE) is one of the most popular plastics utilized to improve the Superpave® rutting parameter [ $G^*/\sin \delta$ ] and decrease creep rate of asphalt mixtures at high service temperature [12–14]. Also, it is proved that the addition of PE can significantly improve the fatigue performance of the material at low shear strain levels [15], while resulting in potential storage stability problems [11].

Polyphosphoric acid (PPA) has long been used to increase the performance grade (PG) of the asphalt binder. In recent year, many researchers have shown increasing interests in using PPA as an alternative modifier for cost consideration compared with SBS [16–19]. Typically, the addition of PPA is about 0.5–1.5% by weight of base asphalt binder, increasing a PG grade. Some studies indicate PPA modified asphalt binder combined with other polymer modifiers can obtain a better performance than single PPA modified binder [15,19,20].

GTR, a kind of polymer reclaimed from auto and small truck tires, has been widely used in paving industry worldwide in the last decades. Asphalt mixtures produced with rubberized crumb rubber have been verified to improve the rutting resistance, thermal cracking and durability [21]. The addition of GTR is approximate 15–20%, depending on the base binder source and the performance grade. GTR modified binders increase the properties of  $G^*/\sin \delta$  and affect marginally the  $G^*\sin \delta$  due to the interaction between the rubber and the binder [22,23]. Additionally, some measures had been studied to improve the interaction between GTR and binder [24,25].

An ideal modifier will increase binder resistance to multiple types of distresses [2]. Undoubtedly, SBS is the best choice of modifying asphalt binders for pavement construction. However, enormous market demand and high price of SBS limit its application in paving industry. Reclaimed crumb rubber is relatively cheaper than SBS, but sacrificing ductility. A single modifier is often difficult to solve all the problems. Thus, it is a reasonable try to modify asphalt binder with two or more modifiers, which may obtain multiple performance improvements due to multiple interaction.

The objective of this study is to evaluate the high temperature rheological properties of five alternative polymer or acid modified binders combined with a low concentration GTR, which is 7% by the weight of base binder compared to conventional amount of

10–15% for the application in southeast area of USA, and explore their possible application in asphalt industries. Three base asphalt binders, and five polymers or acid are utilized to produce the modified binders. Also, three terminally blended binders with SBS, one terminally blended binder with GTR, and one laboratory blended binder with GTR are selected as control binders. In this study, the rheological properties of these multiple modified binders, such as viscosity, fail temperature,  $G^*/\sin \delta$ , phase angle, viscometry, amplitude sweep, frequency sweep, creep and creep recovery, and stress relaxation are investigated.

## 2. Materials and experimental procedures

### 2.1. Materials

Three base asphalt binders, which were from southeast area of USA. Two of asphalt binders are PG 64-22 from different sources referred to base binders A and B, commonly used by various state departments of transportation (DOTs). And another one is PG 64-16 referred to base binder C. The basic rheological properties of three base binders are investigated as shown in Table 1. It can be noted that binder A generally has a lower viscosity, fail temperature, and  $G^*/\sin \delta$  at unaged states compared to binder B. Also, binder C has the above values between binders A and B at unaged state.

Five modifiers used in this study were Oxidized Polyethylene, Propylene–Maleic Anhydride, Polyphosphoric acid, Elvaloy®, and SBS are referred to as P1–P5, respectively. Meanwhile, minus 40 mesh crumb rubber produced with ambient process is used as a base modifier for each modified binder referred to as GTR. The main physical and chemical properties of these materials are shown in Table 2. Polymers 1 and 2 are used for producing PG 76-22/PG76-16 binders with a concentration of 1–1.5% (by weight of base binder) plus 7% GTR (by weight of base binder), referred to AP1, BP1, CP1 and AP2, BP2, CP2. Polymer 3, PPA, is utilized for improving the high temperature performance with 0.3–0.5% (by weight of base binder) integrated with 7% GTR (by weight of base binder) to produce the PG 76-22/PG 76-16 binders (denoted as AP3, BP3 and CP3). Approximately 1.4–1.6% (by weight of base binder) of EVA and 7% GTR (by weight of base binder) were blended with base binders A–C to produce PG 76-22/PG 76-16 binders (denoted as AP4, BP4 and CP4). Similarly, 1.5–1.6% (by weight of base binder) Polymer 5, SBS, and 7% GTR (by weight of base binder) were used to produce the modified binders AP5, BP5 and CP5. 10% GTR blended with base binder B produces the PG 76-22 binder as a control laboratory blended binder LB.

The blending temperature used in this study was 177 °C for all modified binders. Firstly, the 7% GTR was blended with the base binders for 30 min, subsequently, the polymer was added to blend for another 30 min. However, when added with PPA or Elvaloy®, additional blending time should increase to 2 h for homogenization based on the recommendation from suppliers. Three terminally blended modified asphalt products (all are PG 76-22 modified with SBS and referred to AP0, BP0, and CP0 respectively), one terminally blended rubber modified binder (PG 76-22 referred to TB), and one laboratory blended rubber modified binder (PG 76-22 referred to LB) were selected as control binders. The produced materials were designated as shown in Table 3.

## 3. Experimental procedure

Rotational viscosity, SHRP performance grade, viscometer, amplitude sweep, frequency sweep, creep/creep recovery, stress relaxation tests were performed to characterize rubber-polymer/acid modified asphalt binders according to Superpave binder specifications. The viscosity was measured using a Brookfield Rotational Viscometer at 135 °C, 150 °C and 165 °C per AASHTO T316. Approximately 10.5 g modified binders were utilized to obtain

**Table 1**  
Rheology of base binders A–C.

Binder type	Source	Aging states						
		Unaged			PAV			
		Viscosity @ 135 °C (cP)	Fail temp. (°C)	$G^*/\sin \delta$ @ 64 °C (kPa)	$G^*/\sin \delta$ @ 64 °C (kPa)	$G^*\sin \delta$ @ 64 °C (kPa)	Stiffness @ –12 °C (kPa)	m-value @ –12 °C
PG 64-22	A	450	65.6	1.19	2.87	3229	257	0.312
PG 64-22	B	587	69.5	1.93	4.94	1429	103	0.376
PG 64-16	C	533	67.8	1.59	–	–	–	–

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