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Interaction between crumb rubber modifier (CRM) and asphalt binder in dry process

Junan Shen [a,b,*], Bo Li [c], Zhaoxing Xie [d]

[a] Suzhou University of Science and Technology, Suzhou, China
[b] Georgia Southern University, Statesboro, GA, USA
[c] Lanzhou Jiaotong University, China
[d] Auburn University, Auburn, AL, USA

HIGHLIGHTS

- Interaction between CRM and asphalt binder in dry process was investigated.
- Gel Permeation Chromatography (GPC) and Fourier transform infrared spectroscopy (FTIR) were used.
- The existence of interaction between CRM and asphalt binder in dry process.
- Storage time were important parameters to influence the interaction.

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ABSTRACT

The objective of this study is mainly to investigate the interaction between CRM and asphalt binder in asphalt mixtures added with CRM in dry process during the time period after mixing and before paving, including the storage in silo. High pressure-gel permeation chromatographic (HP-GPC) and Fourier transform infrared spectroscopy (FTIR) tests were used on extracted binders from the asphalt mixtures stored in the oven at four time phases of 0, 30, 60, 90 min at the temperature of 160 °C. The results showed that (1) the percentage of the large molecular size (LMS) from GPC test increased as the storage time of the mixtures in dry process increased, and could reach that from wet process; (2) the ratio of bonding at C=O, an aging index from FTIR, had a sharp increase from storage time 0–30 min, and kept less change for further storage; (3) increase in LMS as storage time increase could be mainly caused by the interaction of CRM with the asphalt, not by aging.

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1. Introduction

Crumb rubber modifier (CRM) produced from scrap tires has been successfully utilized as an additive in Hot Mix Asphalt (HMA) with the goal of improving the hot temperature sensitivity and the durability of the asphalt pavement in addition to protecting the environment and saving resources (e.g., landfill space) [1–4]. Because of these advantages, there is an increasing interest in utilizing rubberized binders in HMA pavements in some states in the Unites States and other countries [5].

CRM can be incorporated into asphalt paving mixes using two different methods, which are referred to as a wet process and a dry process. The wet process has the advantage that modified binder properties can be better controlled through its mixing equipment to blend bitumen and rubber [6–11]. It is a main production method to use CRM for asphalt binders. However, the dry process has potential to consume larger quantities of recycled crumb rubber compared to the wet process resulting in greater environmental benefits. In addition, the production of CRM asphalt mixture in dry process is logistically easier than the wet process and, therefore, the dry process would be potentially available to a larger market [12]. Up to now, the dry process is still a far less popular method. In dry process, crumb rubber is assumed to be a substitute for a small portion of the fine aggregate (usually 1–3 percent by weight of the total aggregate in the mix). The rubber particle are blended with the aggregates prior to the addition of the asphalt cement. Research into the dry process has been limited.

* Corresponding author at: Suzhou University of Science and Technology, Suzhou, China.

E-mail addresses: jshen@georgiasouthern.edu (J. Shen), libolzjtu@hotmail.com (B. Li), zxie0011@gmail.com (Z. Xie).

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The reaction between bitumen and crumb rubber in the traditional dry process is negligible due to the following reasons: larger CRM particle size, higher CRM content, and no reaction additives [13,14]. Georgia DOT has been paving CRM mix using a modified dry process since 2007: smaller size (30 or 40 mesh) and lower content of CRM (about 10% mass of asphalt binder), and a cross-link agent [transpolyoctenamer (TOR) polymer] in the rubberized mixture [15–19]. It is unknown whether the rubber-asphalt interaction could happen in the rubberized asphalt mix produced by Georgia modified dry process.

Recent researches on rubber-asphalt interaction demonstrated that during the mixing period as well as during the transportation and laydown of the mixtures, CRM particles swollen and the rate and amount of asphalt absorption by rubber particles were fairly high, resulting in a stiffer and more elastic residual. The interaction also changed the shape and rigidity of the rubber particle [20]. Due to the presence of the CRM, the rubber modified binders could not be evaluated as well as neat binders by standard Superpave binder test procedures. Several potential problems were reported during dynamic shear rheometer (DSR) testing including stiffness-related problems, plate slip, and equipment limits [8]. New method to characterize rubber asphalt binder and recycled aged rubber asphalt binder is necessary.

High pressure-gel permeation chromatography (HP-GPC) can separate an asphalt binder into fractions of various molecular sizes, thus establishing a profile of molecular size distribution (MSD) plotted with detector responses on an ordinate and elution times on an abscissa. The application of this technique to asphalt binders was systematically reviewed by the SHRP research group [21,22]. The GPC could be used for evaluating the changing of molecular size caused by any interaction of the CRM and asphalt binder.

The main objective of the study is to exam the interaction of CRM and asphalt in the mixtures with CRM added in dry process during the period of time between mixing and paving. GPC and FTIR were used to test the extracted binders from the mixtures stored at different times of 0, 30, 60 and 90 min. Two mixture gradations of PEM and SMA were used. In addition, extracted binders from rubberized PEM and SMA in wet process without storage was tested for a control.

2. Materials and test procedures

2.1. Materials

CRM in wet process was produced by mixing -30 mesh CRM at 10% of the weight of asphalt binder with a base binder of PG 67–22 at 170 °C and 700 RMP for 45 min in the laboratory. The dry process binder used the same CRM and base binder of PG 67-22, which were introduced into aggregates together with a cross-link agent-TOR polymer at 4.5% of the weight of the CRM.

Crushed granite aggregate was utilized in all mixtures. Hydrated lime at 1.0% by the weight of the total aggregate was used for anti-stripping purpose which was recommended by GDOT. In addition, cellulose fiber at 0.35% by the weight of the total mixture was added to protect excessive drain-down.

Gradations of 12.5-mm Porous European Mix (PEM) and Stone Matrix Asphalt (SMA) showed in Fig. 1 were designed in accordance with Georgia mix design procedure (Section 828), and optimum asphalt contents (OAC) of PEM and SMA mixtures were designed according to the specifications of GDT114 and GDT 123, respectively. Both PEM and SMA gradations met the control tolerances and design criteria of Section 828 of the Standard Specifications. Table 1 presents OAC of SMA and PEM mixtures.

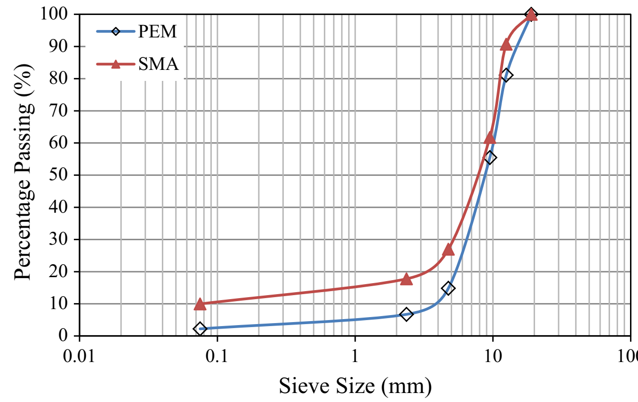

Fig. 1. Aggregate Gradations of PEM.

Table 1
OAC of PEM and SMA.

Mix Type		OAC (%)
PEM	Dry Process	6.0
	Wet process	6.5
SMA	Dry Process	6.3
	Wet process	6.9

2.2. Test procedures

The CRM was introduced into the mixer at the same time with the aggregate and asphalt binder, then were mixed at 165 °C together to produce rubberized PEM and SMA in dry process. After mixing, loose mixtures were placed on a shallow tray and aged in an oven (Fig. 2) for four storage times of 0, 30, 60, and 90 min in this study before the aged binders were recovered using Abson method. The storage temperature was set at 160 °C. The storage times were selected to consider a typical length of 1–2 h for asphalt paving from mixing to finishing paving, and simply divided into the same intervals.

For the wet process, it is assumed that rubber-asphalt has fully-reacted before rubberized mix production since crumb rubber has been blended with binder at 175–200 °C for 45–60 min. Rubberized PEM and SMA in wet were produced and there is no any storage before the recovery of aged binders.

Extraction of the aged asphalt from the stored PEM and SMA mixtures was conducted based on the ASTM D2172 procedure. The binders were recovered from the solution of trichloroethylene and asphalt (Fig. 3). Three replicates for each mixes were extracted

Fig. 2. Loose mixture storage in the oven.