Construction and Building Materials 54 (2014) 320–325

Contents lists available at ScienceDirect

Construction and Building Materials

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

Preparation process to affect stability in waste polyethylene-modified bitumen

Changqing Fang *, Pei Liu, Ruien Yu, Xiaolong Liu

College of Printing and Packing Engineering, Xi'an University of Technology, Xi'an 710048, Shaanxi, PR China

HIGHLIGHTS

- Modified bitumens are prepared under conditions of different process parameters.
- 3750 rpm, 150 °C and 1.5 h are the optimal processes parameters.
- The thermal stability of modified bitumens are enhanced to some extend.
- The cost for bitumen modification could be reduced with waste packaging polymer.

ARTICLE INFO

Article history:
Received 9 October 2013
Received in revised form 11 December 2013
Accepted 17 December 2013
Available online 19 January 2014

Keywords:
Modified bitumen
Processes parameters
Storage stability
Thermal stability

ABSTRACT

An analysis of waste polyethylene (WPE) modified bitumens prepared using a variety of approaches is described in this study. The WPE was obtained from commercially-available packaging bags. It has recently been shown that addition of WPE to bitumen enhances the high temperature stability of the modified bitumen. In this paper, WPE-modified bitumens were prepared using a high-speed shear mixer employing different processing parameters. High temperature storage stability tests and morphological analysis showed that a shear rate of 3750 rpm, at 150 °C and shear time of 1.5 h to be the optimal processing parameters of storage stability. In addition, differential scanning calorimetry (DSC) and thermal gravimetric analysis (TGA) were used to analyze the thermal stability of the WPE-modified bitumen. We found that the thermal stability of the modified bitumen surpassed that of the base bitumen, but was generally independent of the preparation parameters.

1. Introduction

Bitumen is a flammable mixture of complex hydrocarbons and other substances, such as oxygen, sulfur, and nitrogen Bitumen can take several physical forms found as liquid, semi-solid or solid products [1–4]. Commercially, bitumen is employed for waterproofing, resisting moisture and corrosion protection as an organic gelling material. Bitumen has been used in road construction for over a century and plays a very significant role in all aspects of the properties of a road bed such as adhesion, temperature susceptibility, friction, aging resistance and durability [5,6]. Due to the growing levels of traffic load on roads and changeable weather conditions, research to improve the properties bitumen has become increasingly important.

To this end, one approach combine different fillers such as rubbers, resins, polymers or other admixtures into bitumen to achieve improved performance, e.g., lower temperature sensitivity, lower equivalent brittle point and higher softening point. As with other composite materials, the improvement of the modified bitumen is highly dependent on the compatibility between the filler and the base bitumen [7,8]. This compatibility depends on a number of factors such as polarity, particle size and morphology of the fillers, as well as the interfacial stability in the bitumen matrix. Recently, preparation temperature and modification procedures were also found to be important in improving the performance of modified bitumen [9,10].

Giuliani et al. [11] prepared a ethylene vinyl acetate (EVA) modified bitumen by shearing the bitumen and polymer for 45 min at 180 °C with a shear speed of 4000 rpm. The samples were then degassed under the condition of 60 rpm for 5 min. Naskar et al. [12] studied the thermal stability of modified bitumen. Waste plastic-modified bitumen samples of varying compositions were prepared using a shearing speed of 3500 rpm, a shearing temperature of 180 °C and a shearing time of 45 min. Polacco et al. [13,14] posited that the polymer in the modified bitumens is swelled by absorbing the light components in bitumen, which affects the changes in the properties of the bitumen. At a set temperature, the polymer particles' physical properties in bitumen would also affect the compatibility, and finally influence the modification effect of the bitumen. Other researchers [15–18] have prepared polymer/nano-material co-modified bitumen as a means of modifying the base material.

* Corresponding author. Tel.: +86 29 82312038; fax: +86 29 83212512.
E-mail address: fcqxaut@163.com (C. Fang).

0950-0618/$ - see front matter
http://dx.doi.org/10.1016/j.conbuildmat.2013.12.071

But use of these materials requires very different preparations conditions than using polymers alone. Some of these process conditions prevent the opportunity for appropriate polymer swelling in the bitumen.

The method for preparing various polymer-modified bitumens using a shear mixer as wells as their properties, the compatibility of the filler and bitumen are key to improvement in bitumen performance. Therefore, finding the optimal shear rate, the modification temperature and the mixing time is essential to ensuring optimum polymer/bitumen compatibility. In most parts of the world, packaging constitutes as much as one third of the nonindustrial waste stream and the recycling rate is still very low. In this sense, the use of waste packaging plastics for replacing virgin polymers as a modifier is a worthy concept, which may result in greater cost savings. However, previous research has been largely reticent concerning the effect of the preparation process on the stability of polymer-modified bitumen. In this paper, we selected commercial WPE as a modifier and prepared WPE-modified bitumen using different shearing parameters. Following this, the effect of the preparation procedures on the modified bitumen storage and thermal stability were investigated using DSC and TGA.

2. Experimental

2.1. Materials

Base bitumen is the primary material for the production of modified bitumen. The physical and chemical properties of the base bitumen determine the degree of difficulty in the modified bitumen's production process, product quality technology and production costs [19]. In this study we chose the 90A# bitumen as the base bitumen which was obtained from Xi'an Petroleum & Chemical Corporation.

The WPE used in this paper was recycled milk bags, which were cleaned and dried prior to being cut into particles using an extruder. Waste milk bags and the resultant WPE particles are shown in Fig. 1.

2.2. Preparation of modified bitumen

To begin with, 500 g of the base bitumen was placed in the iron container and heated to 190 °C. This material was then sheared using a FLUKO FM300 high shear emulsifier (Shanghai, China). The shear mixer's speed was maintained at 3750 rpm, as 20 g of the WPE particles was added into the base bitumen over 5 min, with continuous shearing of the mixture. The temperature was maintained at 190 °C during this process and the mixture was sheared for 30 min, the preparation of sample 1 was completed. Using this general procedure, we proceeded to prepare three additional samples. Samples 2–4 were obtained at the shearing temperature of 190 °C, using shearing times of 1, 1.5 and 2 h, respectively. Samples 5–8 were obtained at the shearing temperature of 170 °C and a shear time of 0.5, 1, 1.5 and 2 h and 9–12 samples were obtained at the shearing temperature of 150 °C with a shear time of 0.5, 1, 1.5 and 2 h. In each preparation process, modified bitumen samples were all swelled for 10 min after each half hour of shearing.

2.3. Characterization

2.3.1. High temperature storage stability test

After mixing, aliquots of the modified bitumen samples were transferred to a glass tube. The tube was sealed and stored vertically in an oven at 163 °C for 48 h, after which the glass tube was cooled to room temperature and cut horizontally into three equal sections. Samples were taken from the top and bottom sections of each tube were used to evaluate the storage stability of the WPE-modified bitumen by measuring their softening points.

2.3.2. Microstructure observations

Fluorescence microscopy was used to observe the morphology and relative dispersion of the polymer in the bitumen. The instrument used for the test was a Nikon 80i fluorescence microscope (Nikon Corporation, Japan).

2.3.3. Thermal analysis measurements

Differential scanning calorimetry (DSC) was used to measure the endothermic heat release thermograms of the bitumen and WPE-modified bitumens. A DSC 823e (Switzerland Mettler-Toledo) was used for these tests using an argon atmosphere to blanket the samples, the heating rate was 10 °C/min, the temperature range was from −50 to 230 °C. In addition, each sample was examined using a TGA/DSC 1 (Mettler-Toledo, Switzerland) to determine the thermal stability of the modified bitumens. The conditions for these analyses were: air atmosphere at a scan rate of 15 °C/min ranging from 100 to 550 °C.

3. Results

3.1. Storage stability

The results for high temperature storage stability tests of samples 1–12 are shown in Table 1. As can be seen, when the shearing temperature is 150 °C, the materials' phase segregation changed with the duration of shearing time. Phase segregation was low at the shorter shear times, and then increased with prolonged shearing, but was minimal at 1.5 h shearing the experimental mixtures at 170 °C, resulted in phase segregation with no significant trend with respect to time reaching a minimum after 1.5 h, and a maximum after 1 h. When the mixtures were sheared at 190 °C, the phase segregation level initially increased and then decreased with increasing shear time. From 12 sets of data it can be seen that shearing the mixture at 150 °C yields an optimum WPE dispersion in the mixture after 1.5 h of shearing. Fluorescence micrographs of modified bitumens prepared at a shearing temperature of 150 °C are shown in Fig. 2. Here it can be seen that with the increase of shearing time the polymer is cut to increasingly finer pieces from the original brawnier long strips into smaller ones, and finally into a fine shape that eventually becomes filamentous. The lengths of the polymer strips range from 300 μm to 1 mm after 0.5 h of shearing and the length of the polymer is decreased substantially to 200 μm when the shearing time was 1.5 h. The polymer distribution in the bitumen gradually becomes more uniform with increasing shearing time achieving the best dispersion after 1.5 h of shearing. When the shearing time reached 2 h, polymer agglomeration occurs. Fig. 3 is the fluorescence micrographs of modified bitumen sheared after 1.5 h at various temperatures. With the increase in shearing temperature, the uniform dispersion of the polymer in the bitumen decreased. In addition, it is clear that the length of the polymer strips is longer at 170 °C causing the polymer to agglomerate. This effect appears to become accentuated at 190 °C.

Fig. 1. Waste milk bags and WPE particles.