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Effect of nano silica and pretreated rubber on the properties of terminal blend crumb rubber modified asphalt

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HIGHLIGHTS

- Nano silica enhanced high temperature property of terminal blend binder.
- NaClO solution pre treated crumb rubber improved binder property and compatibility.
- The proposed modified binder matched to SBS polymer modified binder (I-C).
- Treated rubber and nano modified binder held greater subzero creep compliance.
- Nano silica interacted physically rather than chemically in modification.

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ABSTRACT

This research aimed to evaluate the physical and rheological properties of crumb rubber (CR) and nano silica modified asphalt. The wet process terminal blend (TB) CR-nano binders were prepared and characterized through a set of physical property tests and fluorescence microscopy, scanning electron microscopy as well as Fourier transform infrared spectroscopy techniques. Results indicate incorporation of nano silica into TB enhanced high temperature binder property but slightly reduced its low temperature ductility. However, by pre treating CR with sodium hypochlorite solution, the binder property and compatibility could be improved which was comparable to polymer modified bitumen. Additionally, nano-TB asphalt demonstrated enhanced dynamic modulus and decreased phase angle compared to TB, indicating its deformation resistance was increased. The bending beam rheometer test reveals rubber pre treating could increase the low temperature creep compliance of nano-TB binder. The microscopic images verified nano silica and CR grains were well dispersed in matrix asphalt, and several peaks disappeared whereas no silicon-related absorption was found in the spectrum of nano-TB binder, indicating the change in functional groups was probably caused by blending condition and nano silica barely interacted chemically with base bitumen or crumb rubber.

1. Introduction

Due to good high temperature performance, excellent resistance to fatigue or thermal dehiscence as well as its echo-friendly characteristics e.g. digesting vast end-of-life tires, absorbing traffic noise etc., incorporation of crumb rubber (CR) from waste tires in road asphalt mixture has been a central issue since 1930s [1–3]. Commonly adopted processes to produce CR modified asphalt mixture include the wet process and dry process. In the dry process, CR is not used as binder modifier but as partial substitution for fine aggregate. However in terms of wet process, the CR powder which acts as a binder modifier is first blended with hot base asphalt as per strict technical procedure and then swelled in the matrix to prepare modified asphalt with aforementioned merits. The finished binder property depends a great deal upon processing variables such as CR fineness and content, mixing temperature as well as blending technique. Generally, the wet process could produce two totally different modified asphalts, known as asphalt rubber (AR, also called wet-process-high-viscosity) and terminal blend (TB, also named wet-process-no-agitation) [4,5].

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Using coarser and more rubber (minus 30 mesh, greater than 15 wt % of virgin asphalt), AR binders have been documented well-proven resistance to rutting and reflective cracking. However, some limitations were found closely related to the exorbitant high viscosity of AR, causing issues such as difficulty to handle when paving, incapability of storing over long periods and necessity for contractors to modify mixing equipment [6–8]. In lieu of this, a good alternative is the TB binder that overcomes the viscosity issue by using less and finer CR and by introducing high temperature shearing in the modification. With the TB technology, full desulfurization and depolymerization of the CR (plus 30 mesh) take place in hot matrix due to high shear process, thus reducing binder viscosity significantly. What's more, due to high curing process full digestion of rubber in the matrix asphalt greatly improves the compatibility between rubber and matrix asphalt. Therefore TB demonstrated better storage stability than wet process AR [3,6,8]. Researchers found the TB binder holds many advantages such as low viscosity, good workability and applicability to dense graded mixture [6–8]. However, although been acknowledged as a potential competitor against traditional polymer modified asphalt, TB still needs to be further improved and verified by pilot projects [7–9] in that a number of researchers argued that over degradation of CR might impair the binder elasticity and high temperature performance [1,3,10]. Besides, although high-degree digestion of rubber improves its thermal storage stability, TB binder still has some separation problems due to partial undissolved rubber particles [6,7].

According to current literature [7], various measures could be taken to improve TB high temperature performance, for instance, increasing rubber content, using high natural rubber content CR, feeding with chemicals as well as composite modification with a second modifier. Nowadays, composite modification using polymers, acids, rock asphalt as well as nano materials was introduced into TB technology and researchers have obtained useful conclusions. For example, Jan and Greene et al. adopted styrene butadiene styrene (SBS) to reinforce TB and witnessed improvement in both high and low temperature performance based on a series of lab experiments and field project [11,12]. Attia also produced high-performance terminal blend binders in which 2% SBS was added to enhance the binder performance [13]. In addition to SBS, other polymers or acid were also applied in the composite modification of wet process TB binder, such as poly ethylene, propylene-maleic anhydride, Elvaloy and poly phosphoric acid [14,15]. In 2016, Huang prepared rock asphalt and CR modified binder and conducted a series of tests. Eventually he proved that incorporation of rock asphalt into TB could enhance the binder softening point and further increase the dynamic stability of the mixture while keeping the low temperature binder grade almost unchanged [16]. In recent years, nanotechnology has been applied into the transportation industry, among which one important usage is binder modification. Up to now, numerous experts have conducted investigations into nano modification of base asphalt using nano montmorillonite, nano silica and nano calcium carbonate to improve comprehensive binder properties [17–19]. However, in terms of nano modification to TB, only few limited work has been reported. For instance, Liu W. used layered double hydroxide (LDH) nano material to modify TB and found the binder anti-rutting property was improved since LDHs broke the original colloid balance between rubber and binder and contributed to the gelatinization of the system [20]. Xiao concluded that using organic montmorillonite, the TB binder exhibited improved high temperature performance as well as thermal stability [21]. However, research on the nano-modification of TB using other nano materials needs to be further conducted.

Actually, measures that could improve the high temperature performance of TB might have a negative impact on its storage stability. In terms of improving the thermal storage stability of CR asphalt binder, many studies could be found in the literature. In these studies, chemicals that generated free radicals in the blend, furfural extract oil, conjugated diene polymer, poly phosphoric acid, hydrosilylation catalysts, fluid catalytic cracking slurry and sulfur-based cross linking agents were reported to be effective in alleviating the phase separation tendency in TB [22–25]. Other than the chemical method, lowering storage temperature and pretreating crumb rubber using sodium hypochlorite, hydrogen peroxide and furfural extract oil could also improve the compatibility between rubber and asphalt [13,26,27].

In this view, the current research aims to enhance the high temperature performance of wet process terminal blend binder by using nano silica modification. A series of property tests were conducted to show the effect of nano silica on the physical and rheological properties of TB binder. Additionally, one group of nano-TB binder with sodium hypochlorite solution pretreated CR was also included in the experimental program to show its effect on binder storage stability. Moreover, the binder micro morphology and functional groups were also characterized using the microscopic imaging and infrared spectroscopy techniques.

2. Experimental

2.1. Materials

This section presents the basic information of raw materials for preparing crumb rubber and nano silica modified asphalt. The 60/80 penetration grade (PG64-22) paving binder was selected as the matrix and the crumb rubber in this research was manufactured in Shandong Province China, which was produced from vulcanized tire rubber using ambient grinding process. Its basic technical indicators were tested as shown in Table 1.

Since particle size and gradation of rubber powder have significant impact on the performance of CR modified asphalt [3], great attention was paid to the selection of CR modifier in this research. According to California department of transportation (CALTRANS) experience, crumb rubber finer than 30 mesh is thought to be suitable to prepare wet process terminal blend binder [3,4]. Consequently the CR powder with a granule fineness ranging from 40 to 100 mesh (as depicted in Fig. 1 and Table 2) was adopted in this research and the gradation of the rubber was obtained with reference to the screening experiment of mineral filler.

The nano silica selected to prepare rubber and nano modified binder is light grey powder with primary particle size 80 nm (shown in Fig. 2), a specific surface area of 20–45 m^2/g, the iron sesquioxide content less than 1% and the ignition loss no more than 8%.

This research adopted nano silica to reinforce traditional wet process no agitation or terminal blend binder. Since two modifiers were incorporated in the binder, the modification processing is hence more complex than traditional TB technology. This section describes the laboratory preparation method of CR and nano silica jointly modified asphalt.

The indoor preparation of CR and nano silica collectively modified asphalt adopted melt blending method under high temperature and intensive shearing to ensure full devulcanisation of the rubber and even dispersion of nano particles in the matrix. However, to alleviate the ageing issues of the binder and to eliminate smoke and particulates emissions [29], the heating temperature was suggested not to surpass 200 °C. The main steps are given below.

(1) Heating the base binder up to 170–190 °C and adding with certain amount of CR powder (depends upon the CR content) while stirring manually for 20–30 min;