Case Studies in Construction Materials 8 (2018) 447–454

Contents lists available at ScienceDirect

Case Studies in Construction Materials

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

Case study

Effect of nanosilica particles on polypropylene polymer modified asphalt mixture performance

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ARTICLE INFO

Keywords:
Polypropylene
Fatigue cracking
Stiffness modulus
Modified asphalt
Draindown

ABSTRACT

The current study was conducted to investigate the effect of nanosilica particles on the performance characteristics of polymer modified asphalt binders. In this study, control 80/100 binder were modified with polypropylene polymer and nanosilica particles at concentration of 0%–4%. Both nanosilica particles and polypropylene polymer were added by weight of total bitumen content. The asphalt performance tests flexural four point beam fatigue test, indirect tensile strength, indirect tensile stiffness modulus and draindown tests are conducted to evaluate the effect of nanosilica particles. The results of the study shows that nanosilica particles improves the fatigue properties of polypropylene polymer modified binder. This indicates that nanosilica particles have significant effect on improving the performance properties of polymer modified binders. Also, the result reveals that thermoplastic polymer polypropylene with nanosilica particles when used as bitumen modifiers improve the performance and durability of asphalt mixtures.

1. Introduction

Pavement lifetime is one of the most important issues to be addressed for the economy and other reasons. Asphalt pavement distresses reduce the lifetime of pavement, and to sustain the lifespan of pavement, there is need to address this issue. Most common pavement mode of distresses is rutting damage which is commonly happened in the form of permanent deformation and fatigue cracking damage which generally initiated due to the successive accumulation of tensile strain induced by repeated load application on the pavement [1,2]. Another factor that affects the durability of asphalt pavements is moisture damage [3,4]. The cohesive and adhesive bonding between binder and aggregates in asphalt mixture determines the performance of hot mixed asphalts (HMA) pavements [5].

Fatigue cracking is a distress which seriously decreases the life service of asphaltic pavements, cracking in asphalt pavement occurs over an extended period of time due to the effect of two main factors identified as temperature and loading. In most cases, cracking due to repeated load application begins at the bottom of asphalt pavement layers and propagates upward, while cracking due to usually happen from surface layers of asphalt pavement and moved downward to bottom layers [6]. The repetitive load applications decrease asphalt pavement resistance due to continuos degradation of materials which eventually resulted in the formation of micro cracks and total failure of the pavement [7,8].

The common method of improving the performance of asphaltic pavements is through modification [9,10]. Previous studies have

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https://doi.org/10.1016/j.cscm.2018.03.011
Received 21 March 2018; Accepted 28 March 2018
Available online 04 April 2018
2214-5095/

shown that application of various types of polymers enhances the life of asphalt pavements. Polymers enhance the adhesion between aggregates and bitumen in the mixture [11]. However, the major concerns of using polymers modified bitumen are its instability due to the formation of two distinct phases of asphalt binder and polymer after modification, poor adhesion, and oxidation [9,12,13]. The instability of polymer modified bitumen encourages researchers to explore new materials for improving the performance of polymer modified bitumen.

Recently, nano material additives have extensively gained a great attention by pavement researchers for the preparation of durable asphaltic mixtures with high performance due to their excellent beneficial properties such as large surface area, excellent dispersion ability, strong absorption, excellent stability as well as high chemical purity [14–16]. Currently, applications of nano-material's in conjunction with polymers was found to be significant in enhancing bituminous binder properties due to excellent properties small particle size of nano materials which makes them easily blend and more compatible with bitumen [17,18]. Composite nanomaterial/polymer modification is generally more cost-effective as they reduce both the quantity of polymers and nanomaterials and at the same time increasing compatibility of polymers with bitumen [19]. Common nanomaterials applied in bitumen modification are carbon nanotubes, titanium dioxide, nano-clay (organic montmorillonite), nano calcium trioxocarbonate, nano silicon oxide and nano zinc oxide [20]. Among the nanomaterials, nanosilica is generally applied in the preparation of polymeric nanocomposite blends due to the high reaction between silica material and asphalt binder which resulted in higher dispersion ability of nano silica and polymers within the bitumen blend compared to other nanomaterials [21,22].

Currently, most of the existing studies on nanomaterials asphalt modification only focus on the application of virgin elastomeric polymers such as styrene-butadiene-styrene (SBS) copolymer and evaloy which are expensive and difficult to find [13,23–25]. However, the result was not encouraging as it increases the cost of modification, also most of the studies on nanomaterial and nanocomposite polymer asphalt modification found high optimum content of 4–8% [26–29]. by weight of bitumen, however, nanomaterials are still expensive, and therefore considering the cost of nanomaterials, the high content used in asphalt modification needs to also be studied.

In order to address these issues, the current research investigates the application of low cost plastomeric polymer (polypropylene) which can be obtained from daily waste with the addition of nanosilica at lower contents (1%–4%). The main objective of this study is to investigate the effect of nanosilica particles on performance properties of polypropylene polymer modified binder. Application of low cost plastomeric polymers with nano particles especially low temperature effects (fatigue) have not been reported. Therefore, the current investigation could contribute to understanding the performance characteristics of composite modified asphalt mixtures for improving the design of asphalt mixtures with high performance.

2. Materials and experimentation methods

2.1. Materials

Bitumen binder grade 80/100 penetration having properties shown in Table 1 were used to prepare the modified binder blends. Thermoplastic polypropylene polymers with nanosilica particles were used to modify the bitumen for the preparation of nanocomposite modified binders. The properties of nanosilica particles used in this study are presented in Table 2

Coarse and fine aggregates are both used to prepare asphalt mixture samples, the coarse aggregate used is crushed granite having a maximum nominal size of 19 mm. For obtaining appropriate aggregates interlocking, a dense gradation plot shown in Fig. 1 was used for the asphalt mixture preparation.

2.2. Experimentation methods

2.2.1. Preparation of polypropylene/nanosilica composite binder

Nanosilica/polypropylene composite modified binders were prepared through addition of 5% polypropylene polymer together with varying concentration (1%–4%) of nanosilica particles by weight of base bitumen binder. Polypropylene polymer was first dissolve on to 500 g weight of base binder (80/100 Pen) prior to the addition of nanosilica particles addition. When polypropylene dissolves completely on the base binder, nanosilica particles were then slowly added to the polypropylene modified binder and sheared using high shear mixer at high shearing rate. Shearing rate of 4000 rpm was utilized for the mixing. Throughout the mixing time, temperature was maintained at 150 ± 10 °C.

The control mix were prepared with only 5% polypropylene polymer by weight of base bitumen without nanosilica particles, while the polymer nano composite mixes were prepared with 5% polypropylene and 1%–4% nanosilica particles.

Table 1
Properties of base bitumen.

Property	Value	Unit
Penetration (25 °C, 5 s, 0.1 mm, 100 g)	84	dmm
Softening point temperature	42	°C
Ductility at 25 °C, 5 cm/min	> 150	cm
Viscosity at 135 °C	0.64	Pa s
Mass loss	0.06	%