Construction and Building Materials 164 (2018) 326–336

Contents lists available at ScienceDirect

Construction and Building Materials

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

Evaluating the effects of the wet and simple processes for including carbon Nanotube modifier in hot mix asphalt

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HIGHLIGHTS

- Wet-mix method was a successful technique to disperse CNTs in the asphalt binder.
- Modification with CNTs led to higher stiffness and improved rutting resistance.
- CNT-modification improved resistance of HMA specimens against fatigue phenomenon.
- Viscosity of the samples produced by wet-mix method was lower than the maximum range.
- The optimized weight percentage of CNTs in HMA was determined to be 1%.

ARTICLE INFO

Article history:
Received 2 September 2017
Received in revised form 20 December 2017
Accepted 28 December 2017

Keywords:
HMA
CNT
Viscosity
Fatigue life
Rutting

ABSTRACT

Main goal of this study is comparing conventional hot mix asphalt (HMA) with carbon nanotube (CNT) modified-HMA and finding optimized carbon nanotubes content, experimentally. First, two different mixing methods were investigated to find the best one to mix CNTs in asphalt binder as homogeneous as possible. Second, morphology of raw CNTs and CNTs dispersed in asphalt binder was investigated by a scanning electron microscope (SEM). Third, some tests including indirect tensile strength (ITS) test, rotational viscosity (RV) test, resilient modulus test and indirect tensile fatigue (ITF) test were conducted to evaluate properties of modified and unmodified asphalt binders and asphalt mixtures. Regarding SEM test results, it was found that wet-mix method led to more homogeneous mixtures. According to RV test results, the viscosity of CNT-modified asphalt binder produced by wet-mix method is less than the maximum range. It was observed that modification with CNTs led to higher stiffness and consequently improved rutting resistance, particularly when 0.5% to 1% CNT is used. CNT-modification also improved resistance of HMA specimens against fatigue phenomenon, particularly, at low temperatures.

1. Introduction

Increasing Average Annual Daily Truck Traffic (AADTT) and loads' magnitude have caused early rutting of asphalt pavements [1], especially low speed lanes and places that heavy vehicles reduce their speed such as tolling gates. Classification and selection of asphalt binder by Superpave method are other reasons for the increased tendency to use modified asphalt binder. In Superpave methods range of temperature that asphalt binder is supposed to have acceptable function is usually wide, so, modification is a good solution to satisfy it [2]. In the other words, asphalt binder must satisfy the limitations of stiffness at both of high and low temperatures [2,3]. Stiffness of asphalt mixture at high and low temperatures is affected by the physical properties and thermal sensitivity of asphalt binder and these properties will highly affect the final performance of asphalt mixture [4]. Using nanoparticles as an additive in asphalt pavement can play an important role in reducing the construction and maintenance costs, if it improves properties of asphalt mixture. An instance for application of Nanomaterials is using CNT-reinforced HMA with reduced layer thickness compared with conventional HMA [5]. Some weaknesses of unmodified asphalt binder and consequently unmodified asphalt pavement are excessive softness of the asphalt binder at high temperatures [6–8] which results in rutting [9], and higher temperature sensitivity at low temperatures [10] which leads to cracking. Eventually, viscoelastic properties [11,12] of regular asphalt binder will result in plastic deformation of the asphalt pavement under heavy traffic [7]. The purpose of this study is to [13] evaluate carbon nanotube-modified asphalt mixture to understand if it has potential to increase load capacity and improve the performance

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https://doi.org/10.1016/j.conbuildmat.2017.12.237

of the hot mix asphalts or not [14]. In this study, CNTs were used to modify HMA. First, a brief description of wet and simple mix procedures is provided. Second, indirect tensile strength (ITS), rotational viscosity (RV), resilient modulus and indirect tensile fatigue (ITF) tests results were analyzed. Comparison made between results of tests conducted on conventional HMA/asphalt binder and modified ones led to understand the effects of CNT-modification on HMA/asphalt binder.

2. Literature review

According to the study performed on fresh asphalt binder by Khattak et al. [15], which used both wet and dry methods for mixing carbon nanofibers, it was found that rutting and fatigue resistance of HMA increases by CNF modification. On the other hand, it was concluded that such improvements depends on the method used to disperse the nanoparticles (wet or dry method) [2]. Tatsuo Shirakawa et al. [16] used asphalt emulsion as solvent to disperse carbon nanotubes. They showed that nanotubes in anionic and non-ionic emulsions are better dispersed compared with cationic emulsions. In this study Carbon Nanotube-modified asphalt binder showed higher degrees of penetration and better absorption of short waves, in comparison with carbon powder modified asphalt binder. Ezio Santagata et al. [17] used simple mix method to disperse CNTs in asphalt binder and showed that asphalt binder modification with high percentages of CNTs (more than 0.5% of asphalt binder's weight) leads to improvement in rheological properties of the asphalt binder. This improvement in properties would reduce the rutting at high temperatures and thermal cracking at low temperatures [2]. Xiaoming et al. [18] analyzed effects of graphite and CNT additives on mechanical properties of asphalt mixture, separately and together. They realized that adding just CNTs would increase the marshal strength and would reduce the strength against rutting, but using CNTs and graphite simultaneously would improve both of these properties. Amirkhanian et al. [19,20] suggested using of higher weight percentages (more than 1% of asphalt binder's weight) of nanotubes would increase the strength of the HMA against plastic deformation at high temperatures. Faramarzi et al. [21] used two different methods of mixing CNT (0.1, 0.5 and 1%) in asphalt binder and performed different tests to investigate morphology and properties of virgin and modified-asphalt binder. As results, mixing procedures were found successful to mix CNT into the asphalt binder homogeneously. Also viscosity and shear modulus of asphalt binder were increased due to CNT-modification and that increase was more considerable at higher percentages. Finally, Arabani e al. [22] showed that applying CNT-modified asphalt binder in HMA can improve resistance of mixture against fatigue and rutting which are considered as the most important pavement distresses besides thermal cracking.

3. Laboratory procedure

3.1. Materials

Rheological properties of virgin asphalt binder were evaluated before CNT-modification to have a basis to understand effects of CNT on asphalt binder properties. Evaluated properties are shown in Table 1; studied asphalt binder was produced by the Tehran Refinery and categorized as PG 64-22 asphalt binder.

CNTs were produced by chemical vapor deposition (CVD) and purchased from Notrino Company. Properties of used CNTs are enlisted in Table 2.

In this study, the aggregates are graded according to continuous type V scale of the AASHTO standard [23], enlisted in Table 3.

3.2. Preparation of CNT-Modified asphalt binder

Carbon nanotubes were mixed in asphalt binder by two different methods, wet and simple [15]. Asphalt binders made by both mixing methods were analyzed by rotational viscosity (RV) test, indirect tensile strength test (ITST) and resilient modulus test. In addition, indirect tensile fatigue test (ITFT) was conducted on CNT-modified HMA by wet process. In the simple process, the asphalt binder and CNT mixture were blended applying a high shear mixer operating at a speed of 1550 rpm for 40 min so that the nanotubes would be homogeneously dispersed through the asphalt binder. During the mixing procedure, the temperature was kept constant at 160 °C using an oil bath set on a heater. In wet mixing, there are three steps of sonication, each for 8 min with 25-min breaks in between, and mixing the solution with over 3000 rpm shear. In this case, 70% of the particles are smaller than 3 μm. The sonication was done with 240 Watts of power and 90% pulse. Kerosene used to disperse CNTs weighted 290 g. In the end, the carbon nanotubes dispersed in kerosene were mixed with an optimized amount of asphalt binder in 160 °C with low shear mixing. The mixing procedure was continued until almost only 2 percent of kerosene was left in the final asphalt binder. As shown in Fig. 1 after 165 min of mixing, 2% of the kerosene was left. The weight percentages of carbon nanotubes in modified HMAs were 0%, 0.5%, 1%, and 2%. To evaluate effects of mixing processes on properties of asphalt binder, a sample was made by exposing to wet and simple mixing without addition of CNTs. This sample is called 0% (control mixture) CNT-modified asphalt binder.

3.3. Laboratory tests

3.3.1. Scanning electron microscopy (SEM)

Morphology images of CNT-modified asphalt binder mixed by wet and simple methods were prepared, using a SEM. These

Table 1
The properties of the asphalt binder used in this study.

Properties	PG grade	Purity grade	Flash point	Softening point	Penetration Grade at 25°c	Ductility at 25°c	Viscosity at 135°c	Density
Unit	–	(%)	(°C)	(°C)	(mm/10)	(cm)	(mPa.s)	–
Value	64–22	99	262	54	67	104	349	1.03

Table 2
The properties of the carbon nanotubes (CNTs).

Characteristic	Outer diameter (nm)	Inner diameter (nm)	Average length (μm)	Special surface area (m^2/gr)	Special weight (gcc^{-1})	True density (gr/cm^3(	Electric conductivity ($Wm^{-1}k^{-1}$)	Purity (%)
Value	10–20	1–10	10–30	>200	0.8–1.8	1.74	3000	>90