Construction and Building Materials 71 (2014) 283–288

Contents lists available at ScienceDirect

Construction and Building Materials

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

Performance evaluation of nano-modified asphalt concrete

Sebnem Sargin Karahancer [a,*], Melek Kiristi [b,2], Serdal Terzi [a,1], Mehmet Saltan [a,1], Aysegul Uygun Oksuz [b,2], Lutfi Oksuz [c,3]

[a] Civil Engineering Department & Faculty of Engineering, Suleyman Demirel University, 32100 Central-ISPARTA, Turkey
[b] Chemistry Department, Faculty of Arts & Sciences, Suleyman Demirel University, 32100 Central-ISPARTA, Turkey
[c] Physics Department, Faculty of Arts & Sciences, Suleyman Demirel University, 32100 Central-ISPARTA, Turkey

HIGHLIGHTS

- Limestone mineral filler was modified by plasma processing.
- Stability of asphalt mixtures increased after plasma modification.
- Moisture susceptibility reduced after plasma modification.
- MMA plasma modified samples showed better performance, relatively.

ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 14 August 2014
Accepted 24 August 2014
Available online 18 September 2014

Keywords:
Plasma modifications
Hot mix asphalt
Nano materials
Marshall Stability
Indirect Tensile Strength

ABSTRACT

Plasma modification method was used in order to increase the performance of the hot mix asphalt. Surface of mineral filler was modified by using three different components: methylmethacrylate (MMA), hexamethyldisiloxane (HMDSO) and silicon tetrachloride ($SiCl_4$). Plasma modified mineral fillers with hot mix asphalts were evaluated by Marshall Stability (MS) and Indirect Tensile (IDT) Strength tests, comparatively. According to the results, plasma modified samples showed higher stabilities and better properties. Especially, tensile strength of MMA plasma modified sample exhibit increase of 30%. Eco-friendly plasma modification technique provided homogenous, single step and fast processing for the modification of the asphalt materials.

1. Introduction

Modified asphalt binders have been widely studied in the field of road construction. For this aim, innovative materials are promising to improve the performance of the asphalt binders and asphalt mixtures. Up to now, styrene–butadiene–styrene (SBS), styrene–butadiene-rubber (SBR) and ethylene glycidyl acrylate (EGA) were mostly used in the asphalt modification effort [1]. These additives in the base asphalt binder improved both anti-aging performance of asphalt mixtures and reduced the moisture damage potential in the low-temperature. In addition to that carbon fiber and crumb rubber were used as the asphalt binder and mixture, recently. For instance, nano sized of SiO_2 and SBS were used together for the asphalt modification and reported its better physical and mechanical properties after treatment [2].

Moreover, methylmethacrylate (MMA) was used as an asphalt additive with aluminium trihydrate. Regarding to performance of modified asphalt mixtures, it was found that both additives considerably reduce moisture susceptibility and formation of ruts [3].

In the current study, plasma modification methods are introduced for hot mix asphalt (HMA) to increase the performance of asphalt mixtures. Plasma is known as a fourth state of the material and has variety of advantages as an eco-friendly surface coatings technology [4,5]. Plasma nanocoating is a solvent-free (dry), non-toxic, single-step process that provides thickness control ranging from tens of angstrom to micrometers [6]. All types of surface can be coated homogenously through plasma methods with desired liquid and/or gaseous chemical without damaged the targeted structures [7]. Generally, in plasma processing vapor of a material is exposed to an electrical field so that ionization and excitation are generated [8]. The chemical material or gaseous is

* Corresponding author. Tel.: +90 246 211 1226; fax: +90 246 237 12 83.
E-mail addresses: sebnemsargin@sdu.edu.tr (S.S. Karahancer), melekkiristi@gmail.com (M. Kiristi), serdalterzi@sdu.edu.tr (S. Terzi), mehmetsaltan@sdu.edu.tr (M. Saltan), ayseguloksuz@sdu.edu.tr (A.U. Oksuz), lutfioksuz@sdu.edu.tr (L. Oksuz).
[1] Tel.: +90 246 211 1226; fax: +90 246 237 12 83.
[2] Tel.: +90 246 211 38 01; fax: +90 246 237 11 06.
[3] Tel.: +90 246 211 40 38; fax: +90 246 237 11 06.

http://dx.doi.org/10.1016/j.conbuildmat.2014.08.072
0950-0618/

fragmented into reactive species (positive and negative ions, atoms, neutrals, metastables and free radicals) of plasma in order to modify targeted structures [9]. In this study, mineral filler was modified by plasma coatings with MMA, HMDSO and $SiCl_4$, and examined comparatively. Performance, stability, flow values and specific gravity parameters of plasma-modified asphalt mixtures were evaluated with Marshall Stability (MS) and Indirect Tensile (IDT) Strength tests. In addition, structural and chemical characteristics of the materials were clarified by Scanning Electron Microscopy (SEM) and Fourier Transform Infrared (FTIR) spectroscopy. To the best of our knowledge, plasma modified asphalt mixtures have not been reported yet. Hence, the study and results will be the basis of the future related works.

2. Objectives and scope

The objective of the study is to obtain road construction material with the highest performance by using plasma-modified asphalt mixtures. Two types of plasma techniques were used as a new approach to coat homogenously of the surface of the limestone. These plasma techniques are radio frequency (RF: 13.56 MHz) and microwave (MW: 2.45 GHz). Plasma phase was created in the plasma reactor by using three different materials: MMA, HMDSO and $SiCl_4$, separately. During plasma processing ionized and excited vapor of these materials were coated around the limestone particles in the reactor. These plasma coated materials served like a bridge around at limestone particles. Therefore, improved properties of the limestone were achieved after plasma modification. Structural analyses were examined by FTIR and SEM studies. Besides, MS and IDT strength tests were conducted to assess the performance of plasma-modified asphalt mixtures. Standard aggregate gradation and 60–70 pen. asphalt binder were used for producing all asphalt mixture samples.

3. Materials and methods

3.1. Aggregates and gradation

Aggregates used in the study were supplied from asphalt construction site of municipal of Isparta. The nominal maximum aggregate size is 9.5 mm, and the wearing course design method was used for the mixtures. "Standard Test Methods for aggregate water absorption, saturated surface gravity and specific gravity" was used to determine water absorption of the aggregate samples. In addition, "Standard test method for aggregate abrasion loss (Los Angeles)" test was examined to evaluate the abrasion resistance of the aggregate samples. Aggregate properties were given in Table 1. Aggregate grading curves for asphalt mixtures were selected in convenience with Turkish Highway Construction Specifications (Fig. 1).

3.2. Bitumen

Variety of standard tests were examined in order to determine properties of bitumen. For instance, ASTM D5 [13] "Standard Test Method for penetration of bitumen materials", ASTM D70 [14] "Standard Test Method for density of semi-flexible bitumen materials (pycnometer method)", ASTM D36 [15] "Standard Test Method for softening point of bitumen (ring and ball apparatus)", ASTM D92 [16] "Standard Test Method for combustion and flash point with Cleveland open cup test apparatus", ASTM D113 [17] "Standard Test Method for ductility of bitumen materials" were used and assessed respectively. Test results were summarized in Table 2.

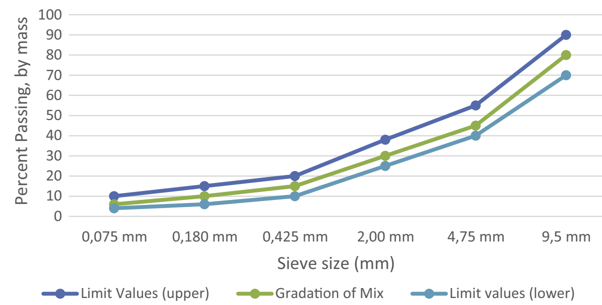

Fig. 1. Gradation limits of the aggregates used in the study.

3.3. Plasma modification of mineral filler

Surface modification of limestone mineral fillers was carried out in a Pyrex glass tube with RF and MW generators (Fig. 2). During the modification the Pyrex glass tube was evacuated down to a pressure of 2.6 Pa. Three modification agents were used separately (MMA, HMDSO and $SiCl_4$) and their vapors were flown into the tube without a precursor or any other auxiliary. FTIR (Perkin Elmer BX system, Beaconsfield, Buckinghamshire, HP91QA, England) and SEM (Philips XL-30S FEG) analyses were examined in order to investigate the effect of plasma processing onto asphalt mixtures.

The beginning of the study, RF plasma of HMDSO was used for the limestone coating and resulted in low value according to the MS test. Therefore, MW plasma was preferred for the all modifications because of its dense plasma phase. Duration of plasma modification process was increased from 30 to 60 min to investigate time effect onto modified samples.

3.4. Marshall stability test

In the study, 2%, 2.5%, 3%, 3.5%, 4%, 4.5%, 5% (by the weight of 1245 g) asphalt binders were examined in the asphalt mixture samples (totally twenty-one samples) to determine the optimum bitumen content and the optimum one was 5 wt%. First, plasma modified samples for 30 min (MMA–MW, HMDSO–MW and HMDSO–RF) and unmodified sample were selected. Then, each three fraction of them (totally twelve samples) were tested. After evaluation of first part, MW plasma modified samples for 1 h were used in order to investigate the effect of plasma processing time. In this time, HMDSO species were eliminated because of their low stabilities. MS test was examined with each three fraction of MMA–MW, $SiCl_4$–MW and unmodified sample (totally nine samples) as a second part of the study. All experimental studies summarized in Fig. 3.

3.5. Indirect Tensile (IDT) Strength test

One commonly used parameter to evaluate asphalt mixtures is tensile strength which can be used to quantify the effects of moisture and to determine the fracture resistance of an asphalt mixture. Typically, the tensile strength can be accurately determined from an IDT strength test carried out in accordance with AASHTO TP9-02 [18].

The IDT strength test is a simple test that proposes to use currently available equipment in most laboratories, being MS machine and a water bath set at 45 °C.

Loading configuration develops a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametral plane, which ultimately causes the specimen to fail by splitting along the vertical diameter. Ensuring the test was carried out in a consistent manner, a testing procedure of the IDT Strength test was prepared [19].

In this study prior to the testing, the pats were measured according to the procedure and were placed in the water bath for a period of conditioning of 30–40 min at a temperature of 45 °C. The test temperature of 45 °C was selected as it represented the strength of asphalt at the high temperature range but below the softening point of standard bitumen. Thus the working of the binder with the aggregate

Table 1
Properties of limestone aggregate used in the tests.

Sieve diameter	Properties	Standard	Limestone aggregate
4.75–0.075 mm	Specific gravity (g/cm^3)	ASTM C 127-88 [10]	2.660
	Saturated specific gravity		2.652
	Water absorption (%)		0.130
25–4.75 mm	Specific gravity (g/cm^3)	ASTM C 128-88 [11]	2.329
	Saturated specific gravity		2.428
	Water absorption (%)		2.800
	Abrasion loss (%) (Los Angeles)	ASTM C 131 [12]	20.38