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Evaluation of mixture characteristics of warm mix asphalt involving natural and synthetic zeolite additives

Ali Topal [a], Burak Sengoz [a,*], Baha Vural Kok [b], Mehmet Yilmaz [b], Peyman Aghazadeh Dokandari [c], Julide Oner [c], Derya Kaya [c]

[a] Dokuz Eylul University, Faculty of Engineering, Department of Civil Engineering, 35160 Buca, Izmir, Turkey
[b] Firat University, Faculty of Engineering, Department of Civil Engineering, 23119 Elazıg, Turkey
[c] Dokuz Eylul University, Graduate School of Natural and Applied Sciences, 35160 Buca, Izmir, Turkey

HIGHLIGHTS

- The utilization of zeolites decreases the optimum bitumen content.
- Zeolites improve the repetitive loading strength of bituminous mixtures.
- Zeolites improves permanent deformation ability and increases rigidity.
- Natural zeolite is an acceptable alternative to commercial synthetic zeolite.

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ABSTRACT

Concerning global warming and economical issues, many recent studies try to introduce innovative technologies applying lower temperatures with higher performance characteristics as alternative solutions for hot mix asphalt (HMA) applications. These new technologies generally named as warm mix asphalt (WMA) technologies implementing various techniques to reduce application temperatures in order to diminish harmful environmental effects of HMA applications and minimize construction costs. An effective technique to perform this task is to provide a foaming effect in mixing phase to increase workability by use of water containing additives such as zeolites.

This paper investigates the feasibility of utilizing WMA containing natural zeolite additive in comparison with a commercial kind of synthetic zeolite. Marshall stability, indirect tensile stiffness moduli and fatigue behavior of WMA containing natural and synthetic zeolites have been analyzed and compared with HMA.

1. Introduction

Most of the field pavement practices around the world consist of conventional hot mix asphalt (HMA). For the last decade, implementing of warm mix asphalt (WMA) technologies has gained popularity in Europe and in some other countries as well as in the USA. The goal of WMA technologies is to obtain required strength and durability which is equivalent to or even better than HMA pavements [1].

The use of WMA technologies offer many benefits to asphalt industries. Many studies have common sight about the various advantages of the utilization of WMA technologies. These advantages are all originated from the major feature of WMA additives which is reducing the viscosity of the bitumen [2]. This reduction results in increasing workability and ease of use, ecological benefits due to less emissions and reduction in costs due to less energy use. In terms of workability, the reduced viscosity helps the aggregates to be coated more easily [3,4]. When discussing about environmental benefits, there are serious worries about the greenhouse gases emissions in HMA pavement applications. Due to lower application temperatures of WMA mixes, the emission of carbon dioxide (CO_2) and other so called greenhouse gases are lowered in comparison with HMA mixes [5]. Besides, the evaporation of less heavy components of bitumen occurs less than conventional applications. This causes less odors in asphalt plants, therefore provides more pleasant working conditions. Builders comments also indicate that the fumes are rather less in WMA production in comparison with HMA production [6]. The fuel consumption

* Corresponding author. Tel.: +90 232 301 7072; fax: +90 232 301 7253.
E-mail address: burak.sengoz@deu.edu.tr (B. Sengoz).

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of WMA technologies is rather less than conventional HMA mixtures. Energy consumption for WMA production has been reported as 60–80% of HMA production [4]. Some studies have also reported the range of 20–35% of savings in burner fuel with use of WMA technologies [5].

In asphalt industry, a common way of achieving lower application temperatures in order to produce WMA is the utilization of WMA additives. All of the current WMA additives facilitate lowering of production temperature by either lowering the viscosity and/or expanding the volume of the bitumen at a given temperature [7,8].

Nowadays, there are many WMA additives available on the market. One of these additives is categorized as synthetic zeolite. Zeolites due to their honeycomb microstructure can preserve water within their micropores and release it above the boiling point of water when heated. [5]. Hence, zeolites have been detected as suitable additives by asphalt industries in order to expand the volume of bitumen by foaming effect.

Synthetic zeolite has been hydro-thermally crystallized. It contains about 18–21% water of crystallization which is released by increasing temperature above 85 °C. The expansion of water causes foaming of asphalt bitumen [9,10].

Natural zeolites are microporous, hydrated aluminosilicate minerals commonly used as commercial adsorbents [11]. Clinoptilolite is one of the most common natural zeolite comprising a microporous arrangement of silica and alumina tetrahedral which has large amount of pore space, high resistance to extreme temperatures and chemically neutral basic structure [11].

This study investigates the feasibility of utilizing WMA mixtures containing natural zeolite additive in comparison with a commercial kind of synthetic zeolite. Marshall stability, Indirect Tensile Stiffness Moduli (ITSM) and fatigue behavior of WMA specimens containing natural and synthetic zeolites have been analyzed and compared with HMA specimens.

2. Experimental

2.1. Materials

The base bitumen with a 50/70 penetration grade was obtained from Aliaga/Izmir Oil Terminal of the Turkish Petroleum Refinery Corporation. In order to characterize the properties of the base bitumen, conventional test methods such as: penetration test (ASTM D5-06), softening point test (ASTM D36-95), thin film oven test (TFOT) (ASTM D1754-97), penetration and softening point after TFOT, etc. were performed [12–14]. These tests were conducted in conformity with the relevant test methods that are presented in Table 1.

A mix of basalt and limestone aggregates provided from Dere Madencilik Inc. (Quarry located in Belkahve–İzmir/Turkey) was used in this study. In order to find out the properties of basalt and limestone aggregate, sieve analysis (ASTM C136), specific gravity (ASTM C127-07, ASTM C128-12), Los Angeles abrasion resistance test (ASTM C131-06), sodium sulfate soundness test (ASTM C88-05), fine aggregate angularity test (ASTM C1252-06) and flat and elongated particle tests (ASTM D4791-10) were conducted on basalt and limestone aggregates [15–21]. Physical properties of each kind are given in Table 2.

Based on the associated test results, a mix gradation of basalt and limestone was intentionally chosen to provide desired performance in conformity with Turkish specifications concerning the Type 1 wearing course. Basalt plays the role of strengthening constituent as coarse aggregate while limestone participates in the fine aggregate framework. The gradation is given in Table 3.

A kind of synthetic zeolite additive is manufactured in North America by PQ Corporation. Austerman et al. [9] and PQ Corporation [10] have reported that the maximum rate of this synthetic additive in base bitumen varies between 4% and 6% by weight of bitumen. The synthetic zeolite additive concentration in the base bitumen was chosen as 5% based on a past research made by PQ Corporation [10].

Natural zeolite WMA additive which is used in this study has been supplied from a Turkish local company in powder form. The complex formula of this natural zeolite is $(Na_3K_3)(Al_6Si_{30}O_{72})\cdot 27H_2O$. It forms as white to reddish tabular monoclinic tectosilicate crystals with a Mohs hardness of 3.5–4.0 and a specific gravity of 2.1–2.2. The content of natural zeolite in this study has been chosen as 5% by weight of bitumen in order to compare its fundamental characteristics with synthetic zeolite. The properties of natural zeolite are presented in Table 4.

2.2. Test methods

2.2.1. Conventional bitumen tests

The base samples and the bitumen samples containing synthetic zeolite and natural zeolite additives were subjected to the following conventional bitumen tests; penetration (ASTM D5-06), ring and ball softening point (ASTM D36-95), thin film oven test (TFOT) (ASTM D 1754M-09), penetration and softening point after TFOT and storage stability test (EN 13399 (2010)) [12–14]. In addition, the temperature susceptibility of the bitumen samples has been calculated in terms of penetration index (PI) using the results obtained from penetration and softening point tests [22].

The effect of viscosity on asphalt bitumen's workability is very important in selecting proper mixing and compacting temperatures. Brookfield Viscometer was employed to inspect the mixing and compaction temperatures in according to ASTM D4402-12 [23,24]. The test was performed at 135 °C and 165 °C. The temperatures corresponding to bitumen viscosities 170 ± 20 m Pa s and 280 ± 30 m Pa s were chosen as mixing and compaction temperatures respectively.

2.2.2. Mechanical properties

The effect of synthetic zeolite and natural zeolite additives on the mechanical properties of WMA has been determined by Marshall method (ASTM D3549) in terms of stability, flow and air void content as well as by indirect tensile stiffness modulus test (BS DD 213) and indirect tensile fatigue test (BS DD ABF) [25–28].

The tests were conducted on WMA samples at recommended contents and on HMA as control samples. Asphalt concrete specimens were prepared with a compaction effort of 75 blows simulating heavy traffic loading conditions.

The ITSM test is a non-destructive test that is used to evaluate the relative quality of materials and study the effect of temperature and loading rate. The ITSM S_m in MPa is defined as below [27];

$$S_m = F(R + 0.27)/LH \quad (1)$$

where F is the peak value of the applied vertical load (repeated load, N), H is the mean amplitude of the horizontal deformation (mm) obtained from five applications of the load pulse, L is the mean thickness of the test specimen (mm), and R is the Poisson's ratio (assumed as 0.35). The test was performed by way of a universal testing machine (UTM) in deformation-controlled mode. The magnitude of the applied force was adjusted by the system during the first five conditioning pulses such that the specified target peak transient diametral deformation was obtained. An appropriate value was chosen to ensure that sufficiently high signal amplitudes were obtained from the transducers which would produce consistent and accurate results. Accordingly, this value was selected as 5 μm for this test. The rise time, which is measured from the origination of load pulse and denotes the duration of the applied load rising from zero to the maximum value, was set at 124 ms. The load pulse application was adjusted to 3.0 s. ITSM tests were conducted at three different temperatures (20 °C, 25 °C and 30 °C).

The indirect tensile fatigue test is one of the constant stress test that characterizes the fatigue behavior of the mixture [29]. In this study, the fatigue test was performed in a controlled stress mode based on BS DD ABF standard [28]. The UTM was also used for this purpose. The loading frame was housed in an environmental chamber to control temperature during the test. The desired load level, load rate and load duration were controlled by a computer. The deformation of the specimen was monitored through linear variable-differential transducers (LVDTs). The LVDTs

Table 1
Properties of the base bitumen.

Test	Specification	Results	Specification limits
Penetration (25 °C; 0.1 mm)	ASTM D5	55	50–70
Softening point (°C)	ASTM D36	49.1	46–54
Viscosity at (135 °C)-Pa s	ASTM D4402	0.413	–
Thin film oven test (TFOT) (163 °C; 5 h)	ASTM D1754		
Change of mass (%)		0.04	0.5 (max)
Retained penetration after TFOT (%)	ASTM D5	25	–
Softening point diff. after TFOT (°C)	ASTM D36	5	7 (max)
Specific gravity	ASTM D70	1.030	–
Flash point (°C)	ASTM D92	+260	230 (min)