Construction and Building Materials 116 (2016) 403–412

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effect of zycotherm on moisture susceptibility of Warm Mix Asphalt mixtures prepared with different aggregate types and gradations

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HIGHLIGHTS

- Based on XRF test, siliceous aggregates have lower degree of alkalinity.
- Based on FTIR test, zycotherm creates a Si-O-Si hydrophobic layer over the surface.
- Zycotherm significantly increased TSR, RMR, MSR and FER values of siliceous mixtures.
- Aggregate type have greater effect than gradation on water damage of both HMA and WMA.
- Image processing of boiling water test was analogous to the other water susceptibility tests.

ARTICLE INFO

Article history:
Received 25 October 2015
Received in revised form 6 April 2016
Accepted 26 April 2016
Available online 6 May 2016

Keywords:
Water susceptibility
X-Ray Fluorescence (XRF)
Fourier Transformed Infrared spectroscopy (FTIR)
TSR
RMR
MSR
Image processing

ABSTRACT

Asphalt concrete mixtures have various types of distresses, of which, water damage referred as stripping is a major form. This paper is aimed to determine effects of zycotherm- a liquid and nano-organosilane warm mix and anti stripping additive- on water susceptibility of Warm Mix Asphalt mixtures prepared with different aggregate types and gradations. Hence, X-ray Fluorescence (XRF) test was performed on aggregates, Fourier Transformed Infrared spectroscopy (FTIR) test was performed on original and modified binder. Moreover, a total number of 252 asphalt mixtures were fabricated and water damage related test methods such as AASHTO T283 (modified Lottman test), Resilient Modulus Ratio (RMR), Marshall Stability Ratio (MSR), Fracture Energy Ratio (FER) and boiling water were used. The results indicated that although zycotherm significantly improves water susceptibility performance of asphalt mixtures prepared with all aggregate types and gradations, it does not function properly as a WMA additive because an effective additive should improve both the unconditioned and moisture conditioned characteristics of bituminous mixtures to make sure appropriate performance of asphalt pavements in the long run. It was also observed that although gradation of aggregates affects the results of tests related to functional properties of both Hot Mix Asphalt and WMA, types of aggregates seems to have greater impact and it is highly recommended not to use siliceous aggregates without an effective anti-stripping additive because all HMA (control) samples prepared with siliceous materials did not satisfy the least acceptable value to ensure good functioning against stripping of the mixtures.

1. Introduction

From a technical point of view, various solutions have been put forward to reduce energy consumption and diminish release of pollutant gases to protect environment. One such solution is Warm Mix Asphalt which provides a decrease in manufacturing and compaction temperatures by lowering the viscosity of the binder using organic and chemical additives or foaming process [1]. Nevertheless, water susceptibility has been a major concern in WMA mixtures. Water permeates through pavement surface, causing wreck at the interface of aggregate particles and binder which will eventually lead to stripping in pavements [2]. Stripping is recognized through raveling, flushing, localized bleeding, and others. This distress is usually because of either the reduction in the mixing temperature, which unpleasantly affects evaporation of the entrapped moisture in aggregate particles or to the inferior coating of aggregates due to high viscosity of binders [3]. Investigational mechanisms and theories of stripping are still intricate. Most researches ascribe water susceptibility to factors such as bitumen chemical and rheological characteristics, morphology and adsorbed coatings,

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http://dx.doi.org/10.1016/j.conbuildmat.2016.04.143
0950-0618/

Table 1
Properties of base bitumen.

Test	Test temperature (°C)	Standard test	Result	Limits	Unit
Penetration	25	ASTM D5-73	63	60–70	(0.1) mm
Ductility	25	ASTM D113-79	>100	>100	cm
Specific gravity	25	ASTM D70-76	1.03	–	gr/cm^3
Solubility in trichloroethylene	–	ASTM D2042-76	99.2	>99	%
Loss of heating	–	ASTM D1754-78	0.75	0–0.8	%
Flash point (Cleveland)	–	ASTM D92-78	310	>232	°C
Softening point	–	ASTM D36-76	49	49–56	°C
Kinematic viscosity	120	ASTM D2170-85	810	–	mm^2/s
Penetration index (PI)	–	–	−0.915	–	–

chemistry and energy of the aggregate surface, pH at the interface, traffic, construction operations; and presence and nature of ASA[1]s [4]. It is also important to see how aggregate type and gradation can affect the fundamental properties of bituminous mixtures in terms of moisture susceptibility because bituminous mixtures are composed of nearly 80% by volume or 95% by weight, coarse and fine aggregates. Adherence and cohesion between asphalt mixture particles must be strong enough to resist stripping in the presence of water. Chemical features of coarse and fine aggregates related to their nature, significantly contributes in this adhesion. Furthermore, compatibility with ASA that is probably incorporated in the binder is another main parameter which, unquestionably, has a significant influence on performance of asphalt mixtures against moisture damage. Therefore, the surface chemistry of the aggregate particles plays an important role in performance of both HMA and WMA. It was also firmly established in SHRP studies that mineralogy and chemical composition of aggregate are of primary importance in stripping [5]. DiVito and Morris [6] evaluated the performance of aggregates treated with silane to aggregates treated with commercial amine-based ASAs against moisture damage and their investigations revealed that silane treated materials have better resistance than the other one does. In recent years, some researches have been carried out focusing on the use of nano- organosilane as ASA in HMA mixtures; however, the effects of these additives on moisture susceptibility of WMA are still contemplative. In a laboratory study conducted by Nejad et al. [7] it was shown that addition of Zycosoil (a silane-based ASA) in hot mix asphalt containing lime stone and granite aggregates will increase tensile strength ratio (TSR) as compared to the control mixtures. The special area of aggregates which is related to its gradation, seems to be another important factor affecting water sensitivity [8–10] proposed that gradation of the materials is maybe the most significant feature affecting nearly all the main properties of asphalt mixtures including resistance to water damage. Yet, the basic causes of stripping is still speculative, and the question is still persistent. Rapidly changing technology accompanied by the necessity for long-lasting and long-serving pavements challenges the investigation fraternity. This paper highlights the laboratory investigation which was made as a contribution to this task.

2. Scopes and objectives

The main objective of this research is to investigate the role of a liquid warm-mix and anti-striping additive named zycotherm on moisture susceptibility of asphalt mixtures prepared with different aggregate types and gradations in terms of laboratory tests. Test methods related with the evaluation of water damage such as AASHTO T283, FER, MSR, RMR and boiling water test have been utilized. To better investigate and analyze the parameters which affects the stripping of the mixtures, FTIR was performed on binders and XRF was applied on aggregates. It was also hypothesized that the failure of the specimens because of water damage is just a function of adhesive and cohesive bonds created between binder and aggregates.

3. Laboratory experimental program and procedure for testing materials

3.1. Asphalt binder and additive

For preparation of both HMA and WMA mixtures, a 60/70 penetration grade asphalt binder was used. The properties of base bitumen are shown in Table 1. To prepare WMA mixtures, zycotherm was utilized, which is a silane-based technology and seems to be more efficient unlike common chemical WMA additives that are based on amines, because it creates a molecular level hydrophobic zone which is water-repellent. Organofunctional silanes couple an organic and inorganic phase through covalent bonding. This bonding is very renitent against moisture conditions as inorganic part of the couple, hydrogen bond with the hydroxylated agent on surface of the stones while the organic part is condensed in the procedure of hydrolysis in the presence of water and transformed into hydrophobic siloxanes in the bitumen. When temperature increases, hydrogen bond collapses which will result in the production of H_2O and a covalently bonded metallosiloxane and, therefore, cross-linked siloxane (Si-O-Si) film structure over the surface. This hydrophobic layer is shown in Fig. 1. The properties of zycotherm is illustrated in Table 2.

3.2. Aggregate types and gradations

In this research study, two types of aggregates including siliceous and calcareous and two aggregate gradations according to local code were used. All of selected aggregate types and gradations are the most popular ones for designers and contractors in Iran. Aggregates are composed of various minerals and each has a certain chemical composition. Most aggregates have both alkaline and acidic characterizations. Hence, degree of alkalinity could be stated as the ratio of alkaline components (mainly Fe_2O_3, MgO, Na_2O, K_2O, CaO, Al_2O_3) to acid ones (SiO_2, CO_2). Siliceous aggregates have high amounts of quartz (SiO_4) and upon exposure to water, have weak adhesion with bitumen because of hydrogen bonds. Calcareous aggregates have high amounts of calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) which have strong electrostatic adhesion with bitumen even in presence of water. Both aggregates were analyzed with XRF (X-ray fluorescence) to specify their chemical properties and the results are presented in Table 3. The corresponding required aggregate gradation properties are presented in Table 4 and related aggregate grading of asphalt mixtures is illustrated in Fig. 2. As can be seen, the structure of gradation No.

[1] Anti Stripping Additive.