Construction and Building Materials 131 (2017) 278–290

Contents lists available at ScienceDirect

Construction and Building Materials

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

Comparative assessment of the mechanical properties of asphalt layers under the traffic and environmental conditions

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HIGHLIGHTS

- Experimental investigation of the mechanical properties of the asphalt layers with neat and SBS-modified bitumen.
- Finite element analysis of stress on asphalt layers.
- Numerical approach for horizontal and vertical deformation of asphalt layers.
- Regression analysis of Von Mises stresses and deformations.

ARTICLE INFO

Article history:
Received 5 July 2016
Received in revised form 1 October 2016
Accepted 12 November 2016

Keywords:
SBS polymer
Asphalt
FEM
HMA
Regression analysis
Performance test

ABSTRACT

It is necessary that the asphalt concrete coating, which is prepared with Hot Mix Asphalt (HMA), shows the expected performance along their service lives and sustain their endurance against traffic and climate conditions. It is also necessary to use additives in order to ensure long service lives because the raw material is scarcely available. Polymers have been widely used in HMA as additives in recent years. The use of Styrene Butadiene Styrene (SBS) polymer materials in HMA mixtures come to the front line among the additives. In this study, the behaviors of the super structure of the roads, which were prepared with pure and SBS-modified additive HMA mixtures, in various traffic and climate conditions and in a sample road platform within one year in various periods were examined in order to understand the mechanical properties of HMA. In the scope of the study, empirical and numerical studies have been considered. The physical and mechanical properties of the layers (coating, base and sub-base) that constituted the super structure of the road have been examined in an empirical manner by considering the field and laboratory works.

The deformation and stress distributions of the super structures of the roads in various time periods have been compared using the finite element method (FEM) in numerical analyses. As a conclusion, it has been determined that the use of SBS-polymer additive influences the endurance and performance properties of the roads in a positive way.

1. Introduction

In order for asphalt concrete coating to show the expected performance throughout their service life cycles, their mechanical properties and behaviors must be examined well. In recent years, the increase in the population and -parallel to this- the increase in the traffic have made it compulsory to use additives in order to ensure that Hot Mixtures Asphalt (HMA) serve better for longer durations under the influence of the traffic and the environment. Especially the limited raw materials and the intense use of highways lead to the variety in the use of additives. Polymers, fibers and fibrous materials are used in order to increase performance properties, decrease maintenance works to minimum level, and for longer service life cycles of roads. In recent years, Styrene Butadiene Styrene (SBS) polymers have been used widely in order to increase the performance properties in areas where continental climate dominates and where there is heavy traffic. The numerical analyses as well as the empirical ones have to be made to determine the physical and mechanical properties of the asphalt concrete coating by using SBS additives. This is necessary to support the empirical studies conducted so far. Numerical analyses provide us great advantages by making use of the parameters obtained from empirical studies in determining the stress and deformation

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http://dx.doi.org/10.1016/j.conbuildmat.2016.11.049

properties, corrosion, binder, basis and infra-basis layers, which constitute the super structure of the roads, and in realizing future estimations. Among the other numerical approaches, the FEM is preferred frequently because it allows making various changes in forming the numeric models of physical problems and because it ensures sensitive measurements. FEM Program, which is used in numerical analyses, is a numerical solution method developed for the analyses of problems that are expressed with differential equations. In the program, a continuous medium is divided into finite (limited) numbers of elements, the equations are written for one element, and integrated to obtain the whole system equation. As a conclusion, the complex differential equations that are considered for a continuous medium are converted into matrix format and reduced into a linear equation set [1,2].

In this study, the all models representing geometrical, physical and mechanical properties of superstructure road were analyzed using ANSYS 14.0 finite element program. The software enables many benefits in terms of time and labor efficiency.

2. Literature work

The use of polymer in asphalt combinations started in 1980s, and tested in many countries in the world. According to Hamit et al., when the HMAs that are prepared with grinded and non-grinded SBS polymer modified are compared, better results are obtained in the grinded ones; and according to the laboratory test results, there are increases in the endurance to stress, decreases in the density, and slight increase in air gap and aggregate volume [3].

In order to increase the performances of binders, to protect them for longer durations, and increase their service life cycles, various additives that are called modifiers have been used throughout history. Further, in order to increase the endurance of bitumen and HMAs against traffic load and temperature, generally additives based on polymer are added to the bitumen. Among these additives, SBS Block Copolymers are used more commonly. It has been determined in many previous studies that SBS increases the endurance against cracks at low temperatures, wheel traces in high temperatures and fatigue [4–8].

Qadi et al. investigated the influences of various additives and modifiers on asphalt concrete coating. The additives and modifiers used in the study have been selected among Liquid Anti Strip (LAS), Polyphosphoric Acid (PPA) and hydrated lime. It was observed that the use of Liquid Anti Stripe and hydrated lime decreased the moisture sensitivity in asphalt mixtures [9].

Karakas et al. conducted empirical and numerical studies and examined the use of SBS additive in HMA mixtures for one year. In numerical analysis stage, they used FEM analyses in Abaqus CAE software, and obtained Von Mises stresses. It was reported that when SBS is used in HMA mixtures, the rigidity and endurance of the mixtures against permanent deformation and fatigue cracks increased in a one year period; however, this situation caused brittle fractures in the materials. In addition, the use of SBS additive in Bitumen Hot Mixtures has given better results in terms of endurance characteristics when compared with pure mixtures. It has been also observed that numerical studies support empirical ones [10,11].

Zhang and Liu examined the influence of the Recycled Asphalt Pavements (RAP) and Renewable Additive Materials on performance indicators. Their results revealed that adding recycled SBS-modified asphalt pavements to asphalt mixtures resulted in better moisture sensitivity, better wheel resistance, dynamic module, low temperature, anti-cracking performance and better fatigue strength [12].

According to Cong et al., perfect diffusion may be decreased with potential wheel trace damage. For this reason, renewable additives must provide long-term stability as well as better diffusion to repair and decay. Previous studies showed that proper physical properties and coating performance with renewable SBS-modified asphalt binders was obtained with recycled SBS-modified asphalt, new SBS-modified asphalt binders, and renewable additives [13].

Chen et al. investigated the morphology and engineering characteristics of modified asphalt binders using SBS-triblock copolymer as modified asphalt binder with the help of Transmission Electron Microscope (TEM). Major increases were observed in the complex module that defined the wheel track resistance in the binders because of the mesh formation between the polymer and asphalt in optimum SBS content [14].

Hadidy et al. tested the use of Starch (ST) and Styrene-Butadiene-Styrene (SBS) in Stone-Mastic Asphalt (SMA) mixtures. They performed modified and non-modified bitumen and performance tests. In the analyses of the test results, it was observed that the moisture damage and temperature sensitivity decreased by adding ST and SBS to asphalt mixtures. In addition to this, by using finite element simulation, safe super-structure design criteria of the modified and non-modified SMA mixtures based on anisotropic elasticity analysis were obtained [15].

Golzara et al. conducted a study and recommended models to predict the physical-mechanical characteristics of the modified bitumen by using the data obtained from empirical studies in which the use of polymer materials developed the characteristics of the bitumen by using a software performing numerical solutions [16].

Styrene Butadiene Styrene Copolymers (SBSC) are classified as thermoplastic elastomers because of their elastic and thermoplastic characteristics, and are used as modifiers for the bitumen because of their important characteristics contributing to the mechanical characteristics of the asphalt [17–19].

Xia et al. arranged a study that 30% styrene content in SBS-modified asphalts ensured optimum viscoelastic function and high viscosity. They also observed less sensitivity to temperature changes and improved viscoelastic characteristics. In addition, it was observed that as the styrene content increased, the sensitivity of the cutting strength for asphalts became less; because, the deformation and movement ability of the aggregates that are bigger and that have high endurance together with polystyrene is more difficult [20].

Liang, Xin et al. performed the influences of the Crumb Rubber (CR)/SBS modifiers on the rheological characteristics and stability. As a conclusion, they reported that the CR/SBS modified the mechanical properties of the asphalts. Crumb Rubber (CR) provides economic benefits in terms of the use of raw SBS [21].

Luo, Xu and Zhao conducted a study and investigated the use of polymer modified asphalt binders, which had been used for 20 years, in asphalt concrete coating. They examined mainly the use of waste modified asphalt mixtures. They also examined the use of renewable waste SBS-modified asphalt binders together with SBS asphalt binders and renewable additives. According to the results, good physical characteristics and coating performance were observed with the use of renewable SBS-modified asphalt binders, recycled SBS-modified asphalt, raw SBS-modified asphalt and renewable additives. They reported these results when the rate of the recycled asphalt to pure asphalt was 35–65%; and when the rate of the renewable additives was between 5% and 10% [22].

Shirini and Imaninasab carried out that, on the one hand, the CR and SBS decreased the PA permeability; and on the other hand, they improved the wheel track resistance at a significant level. In addition, it was also reported that, although there were improvements in resilient module at first, there were negative influences on skid resistance and moisture sensitivity resistance with the addition of more CR [23].