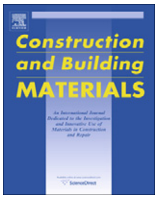
Construction and Building Materials 25 (2011) 859–866

Contents lists available at ScienceDirect

Construction and Building Materials

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



A model for dynamic creep evaluation of SBS modified HMA mixtures

S.F. Kalyoncuoglu *, M. Tigdemir

Suleyman Demirel University, Civil Engineering Department, Isparta, Turkey

ARTICLE INFO

Article history:
Received 6 January 2010
Received in revised form 24 June 2010
Accepted 29 June 2010
Available online 22 July 2010

Keywords:
HMA
SBS
Modified asphalt
Permanent deformation
Dynamic test

ABSTRACT

The specimens, according to the Marshall Stability testing procedure, of hot mix asphalt (HMA) containing bitumen modified with styrene–butadiene–styrene (SBS) have been constructed in the laboratory and tested under dynamic loading for permanent deformation using Suleyman Demirel University Asphalt Tester equipment (SDU-Asphalt Tester). Analysis of data shows that the permanent deformation of the samples may be modeled in terms of the specimen's characteristics in a very satisfactory manner. Benefits of adding styrene–butadiene–styrene (SBS) in variant quantities and in variant types of additive to asphalt cement (AC-60/70) were investigated. Initial research was done to determine the physical properties of asphalt cement and modifiers. Fifteen asphalt binder recipes were prepared with two types of gradation, six different contents of bitumen, four different contents of polymer, three different types of polymer. After that, Marshall samples were prepared by using the modified and unmodified control asphalt binders. The results of investigation indicate that asphalt mixtures modified by any SBS additive gives the best permanent deformation resistance in the tests carried out in this study, so that, this modification increases physical and mechanical properties of asphalt binder. In this study, total deformation of each sample was calculated using a newly developed equation containing variables of mixture characteristics. In addition to these, to develop a model that could fit the creep curve a new logarithmic model derived from first 100 preconditioning loading was developed instead of power law function model for first stage of permanent deformation curves.

1. Introduction

During normal service life the HMA surfacing is exposed to various vehicular and environmental loads, causing gradual deterioration in the condition of the layer. The behavior of the HMA is generally expressed in terms of the number of load repetitions the material is able to carry before the acceptable level of either fatigue cracking, or permanent deformation is transgressed. These acceptable levels are typically defined in terms of both structural and functional properties of the pavement structure and layer. In order to ensure reliable pavement design and maintenance, it is necessary to obtain a sufficient understanding of the behavior of pavement layers and pavement structures under varying vehicular and environmental loads.

Conventional bituminous materials have tended to perform satisfactorily in most highway pavement and airfield runway applications. However, in recent years, increased traffic levels, larger and heavier trucks with new axle designs and high tyre pressures, have seemed to add to severe demands of load and environment on the highway system. This has resulted in the need to enhance the properties of existing asphalt material. Polymer modification offers one solution to overcome the deficiencies of bitumen and thereby improve the performance of asphalt mixtures [1].

Modification of asphalt binders can serve several purposes. It can increase the overall performance of a binder by widening the range between the binder's high- and low-temperature grades, or it can target a specific improvement in a binder's performance in response to a particular severe-service condition, such as a pavement carrying a very high traffic volume or a high percentage of slow-moving, heavy vehicles. Many diverse materials are added to neat asphalt cement as modifiers.

Polyethylene, random and block copolymers of styrene and butadiene, hydrogenated styrene butadiene block copolymers, ethylene vinyl acetate copolymers (EVA), polypropylene, neoprene, and others have all been investigated as modifiers that improve the performance of asphalt binders. The advantages listed in the literature are quite numerous; most polymers are claimed to reduce temperature susceptibility resulting in less cracking at low temperatures and less rutting during summer season [2]. Among these polymers, styrene–butadiene rubber and styrene–butadiene–styrene block copolymer are the most widely used ones [3,4].

Ahmedzade et al. [5] studied the physical properties of AC-10 asphalt cement, TOP and SBS (Kraton D1192) and focused on the engineering and structural properties of TOP- and SBS-modified AC-10, TOP- and SBS-modified AC-10, and AC-10 mixtures.

---

* Corresponding author. Tel.: +90 2462111219.
E-mail address: figen@mmf.sdu.edu.tr (S.F. Kalyoncuoglu).

0950-0618/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2010.06.101

Khodaii and Mehrara [6] studied evaluation of permanent deformation of unmodified and SBS modified asphalt mixtures using dynamic creep test and found some results as: coarse graded asphalt mixtures have more resistance to permanent deformation than dense graded mixtures, which can be due to their lower dependency on mastic properties particularly at high temperatures. Among the three types of mixtures prepared by 4%, 5% and 6% of SBS polymer, the mixtures with 5% SBS had the most improved mechanical behavior. SBS modified asphalt mixtures have considerably lower temperature susceptibility than unmodified mixtures.

2. Background

Rutting is defined as the progressive accumulation of permanent deformation of each layer of the pavement structure under repetitive traffic loading [7]; however, asphalt layer has a remarkable role in its magnitude [8,9].

Permanent deformation in pavements has long been recognized to include two different modes according to Huang and White [10] and Gokhale et al. [11]. The first mode is known as compactive deformation (consolidation of layers) and the second mode is plastic deformation (asphalt shear flow). In the former mode, the deformed surface is lower than the initial pavement surface, and occurs in the wheel path. In the later mode, the deformed surface is higher than the original surface. This mode of deformation, which typically occurs between and outside wheel paths, is attributed to shear flow of asphalt materials under traffic loads, and is often referred to as "heave".

Various experimental tests such as static creep, dynamic creep, wheel tracking and indirect tensile tests are used to evaluate permanent deformation potential of asphalt mixtures. Among the mentioned methods of assessing permanent deformation potential of asphalt mixtures, dynamic creep test is thought to be one of the best methods. This test was developed by Monismith et al. [12] in 1970, based on the concepts of axial compression test. NCHRP conducted a comprehensive research study to develop a simple mechanical test to supplement the Superpave volumetric method of mixtures design. Research of Kaloush and Witczak [13] also indicates that Superpave volumetric method alone cannot guarantee the proper functioning of the asphalt layer according to field experiments.

NCHRP reported, that among the five laboratory tests investigated, dynamic creep test had very good correlation with measured rut depth and a high capability to estimate rutting potential of asphalt layers [13]. On grounds of the results of the research, dynamic creep test was chosen as an appropriate laboratory method to evaluate the permanent deformation susceptibility of modified and unmodified asphalt mixtures.

The study by Young et al. [14] deals with a strength property, which is showing high correlation with rutting resistance of asphalt mixtures. The test procedure was developed by applying a load to the compacted asphalt samples and calculating the strength by using the deformation of the mixture at the failure point. To evaluate the validity of this test, various mixtures were prepared with two aggregates and seven binders using four loading head types at the loading speed of 50.8 mm/min at 60 °C. Maximum load and deformation were recorded for each test and deformation strength, S_D, was calculated using a newly developed equation.

The flow number has been widely used to determine the rutting distress as well as permanent deformation characteristics since the mid 1970s [15,16]. Brown and Snaith [17] performed experiments to investigate the response of an asphalt mixture due to a repeated load. The failure of the asphalt mixture was defined as the cycle number when a marked deformation occurred. Brown and Cooper [18] indicated that the penetration grade of asphalt slightly affected the development of permanent shear strain in the F_N test. Additionally, the gradation of the mixture affected the shear strain significantly and higher shear strain was found under fewer load cycles for gap-graded mixtures.

The development of a SPT has been the focus of considerable research efforts in the past several years. In fact, some aspects of the tests have been available for decades, such as the dynamic modulus ($|E^*|$) and flow number (F_N) tests of asphalt mixtures. These tests were found to have a good correlation with field performance [19–21]. When comparing $|E^*|$ with F_N, Zhou and Scullion [22] indicated that F_N can be better for differentiating the performance and quality of asphalt mixtures [22,23]. Faheem et al. [24] showed that F_N is an important mixture property and has a strong correlation to the Traffic Force Index (TFI), which represents densification loading by the traffic during its service life [24]. More recently, a study conducted by Witczak [25] demonstrated that a good correlation exists between the F_N and field rutting performance. Goh and You [26] studied a simple stepwise method to determine and evaluate the initiation of tertiatry flow for asphalt mixtures.

Dynamic creep test has various outcomes that can be used as a measure of evaluation of permanent deformation potential. Airey [27], for instance, used ultimate strain and mean strain rate for this purpose, and according to him, of the two mentioned parameters the latter is more reliable to measure the rutting performance of the asphalt mixture than the former because mean strain, unlike ultimate strain, is independent of the initial strain experienced during the dynamic creep test.

Kaloush et al. [28] used another outcome of dynamic creep test namely flow number (FN) as a comparison measure. This parameter is obtained from creep curve (a plot of cumulative plastic strain versus number of load cycles). The creep curve is generally divided into three stages as indicated in the literature [28].

Since the mid 1970s, several permanent deformation methods and approaches have been proposed. The rutting models including Power-law model [16], VESYS model, Ohio State model, Superpave Model, and AASHTO Model 2002 were developed [15,22]. Many data smoothening techniques were also employed to describe the permanent deformation curve [29,30]. Some of these included the polynomial fitting model, moving average periods (MAPs), and the regression technique.

Zhou et al. [31] believe that (FN) cannot be an appropriate criterion for evaluating the mixtures permanent deformation potential, so they proposed a three-stage model (one model for each stage of the creep curve) with a simple algorithm for estimating the initial point of each stage. West et al. have also developed a three-stage model [32], but their model cannot estimate the boundary points of curve stages. Khodaii and Mehrara [6] have used the Zhou Model for evaluation of permanent deformation of unmodified and SBS modified asphalt mixtures using dynamic creep test.

To determine the permanent deformation, characteristics of paving materials is employed a repeated dynamic load test for several thousand repetitions and record the cumulative permanent deformation as a function of the number of cycles (repetitions) over the test period. This approach was employed by Monismith et al. [33] in the mid 1970's using uniaxial compression tests. Several research studies conducted by Witczak et al. [34] used a temperature of 100 F or 130 F, and at 10, 20, or 30 psi unconfined deviator stress level. A haversine pulse load of 0.1 s and 0.9 s dwell (rest time) is applied for the test duration of approximately 3 h. This approach results in approximately 10,000 cycles applied to the specimen. Brown and Cooper used a range of various levels of confining pressure for the repeated load test [35]. A stress level of 14.4 psi (100 kPa) was subsequently adopted as the standard for their tests. The test was conducted at 104 F (40 °C).