Engineering Failure Analysis 58 (2015) 238–248

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Analysis of fatigue properties of unmodified and polyethylene terephthalate modified asphalt mixtures using response surface methodology

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A R T I C L E I N F O

Article history:
Received 18 May 2015
Received in revised form 10 August 2015
Accepted 10 September 2015
Available online 12 September 2015

Keywords:
Asphalt mixture
Waste PET
Environmental temperature
Response surface methodology

A B S T R A C T

Fatigue is a major distress mode of flexible pavements that generally occurs in the form of irregular (alligator) cracking in the wheel paths. This paper evaluates the effects of applied stress and temperature on the fatigue lives of polyethylene terephthalate (PET) modified asphalt mixtures using response surface methodology (RSM). As it is shown in this study a quadratic model is successfully fitted to the experimental data. Fatigue lives of mixtures are influenced by changes in selected parameters. In addition, the effect of temperature variation is more drastic on the fatigue lives than the effects of stress level and modifier content.

1. Introduction

Road pavement is subjected to external loads including mechanical loading induced by heavy traffic and thermal loading induced by thermal changes. The applied loads, along with environmental conditions result in pavement deterioration which, in some cases, happens even before its expected service life. Pavement damage is usually occurred in the form of permanent deformation (surface rutting), fatigue failure and low temperature cracking. Fatigue failure is a common mode of distress of pavement structures which is caused by successive tensile strain induced by repeated traffic loadings [1]. This form of distress mostly appears as cracking damage which initially occurs at the bottom of asphalt layer where the tensile stresses are maximum. Then these cracks spread to the surface of asphalt mixture. Previous studies showed the fatigue life of asphalt mixture has correlation with the mode and amount of applied loads as well as environmental temperature [2,3].

Stone mastic asphalt (SMA) is gap-graded asphalt mixture which has been developed in Germany in 1960s [4]. It has a high percentage (60 to 80%) of coarse aggregate, greater than 5 mm in size, high binder content (5.5 to 7% by weight), high percentage of mineral filler (7 to 11%), and added fibers (1%) [5]. Due to inherited structure of SMA, it can provide better permanent deformation (rutting) performance and durability compared to conventional dense-graded mixture [6,7] but it becomes controversial in case of fatigue property. However some studies showed that SMA mixture had lower fatigue life [8,9], others concluded that it had better fatigue properties compared to the conventional mixture [10,11]. In SMA mixture in order to prevent draindown (due to high asphalt content) and improve mixture performance stabilizer additives, fibers and polymers are used. In this case, using polymer in asphalt

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http://dx.doi.org/10.1016/j.engfailanal.2015.09.005
1350-6307/

mixture is very common [12–15]. Tapkın has utilized polypropylene fibers as reinforcement in asphalt mixture and it was realized that the mixture fabricated by polypropylene fibers had better performance in comparison with control mixture [16].

In many cases, using polymers causes higher construction cost due to high polymer cost. In order to overcome this problem, many studies have used waste polymers in asphalt mixtures [13,17–20]. One of the important industrial plastic materials is polyethylene terephthalate (PET). PET is a semi-crystalline thermoplastic polymer material which has been used in beverage and food industries for years. Currently, a large amount of waste PET is being produced worldwide and it is going to cause a serious environmental challenge due to its non-biodegradability [21]. Hence, some studies have been previously performed to evaluate the effects of using post-consumer PET as secondary materials in road pavement in order to tackle this potential environmental hazard and, moreover, to decrease construction cost imposed by application of polymers in asphalt mixture [2,13,22,23].

Mathematical modeling is useful for real-world application as it is robust in terms of its ability to deal with many constraints and objectives [24,25]. In addition, using statistical analysis in pavement engineering is increasing among engineers and designers because it helps to have better perspective about the pavement performance parameters. In this case, factorial design of experiments (DOE) which through the use of techniques such as response surface methodology (RSM) simultaneously consider several factors at different levels, and give a suitable model for the relationship between the various factors [26–30].

The aim of this study is examining the fatigue property of SMA mixtures at elevated temperatures and stress levels for the unmodified and PET modified mixtures followed by finding interactions between these fundamental factors using RSM based on central composite design (CCD).

2. Materials and methods

SMA mixtures were fabricated using 80/100 penetration grade asphalt cement. Granite-rich aggregate particles were used for this investigation. Nine percent of filler was utilized. The aggregate particle size distribution is shown in Fig. 1. As it is shown in this figure, the SMA mixture contains coarser aggregate particle (68.5% of particles are greater than 4.75 mm) which provides better stone on stone contact. In order to have better understanding of the materials' characteristics several tests were performed on asphalt cement and aggregate particles and the results are listed in Table 1. As can be seen in Table 1, materials' properties are satisfactorily passed the requirements.

PET flakes which have been used for this study were obtained from waste PET bottles. For using PET flakes in asphalt mixture, the PET bottles were cut to small parts and crushed using a crushing machine. Thereafter, the crushed PET particles were sieved and particles smaller than 2.36 mm in size were used for this research. Table 2 depicts physical and mechanical properties of PET.

2.1. Mixture fabrication

In order to fabricate SMA mixtures, 1100 g of mixed aggregate and filler were heated inside oven at temperature of 160 °C for 3 h. Asphalt cement was also heated at 130 °C to be suitable for mixing with aggregate particles. Mixing temperature of 160 °C was determined using plot of binder viscosity against temperature (viscosity at mixing temperature must be 0.17 ± 0.02 Pa s). PET particles with different percentages (0%, 0.5% and 1% by weight of aggregate particles) were added directly to the mixture as the method of dry process. It is worth mentioning that in previous research it was believed that due to the high melting point of PET wet process (adding modifier to the asphalt cement) cannot be appropriate because it might hinder the mixing [17]. The loose mixture was compacted using Marshall compactor and 50 blows of compaction effort were applied on each side of the mixture. It should be mentioned that all the mixtures were fabricated at their optimum asphalt contents using Marshall mix design method [22,31,32] and the results are presented in Table 3.

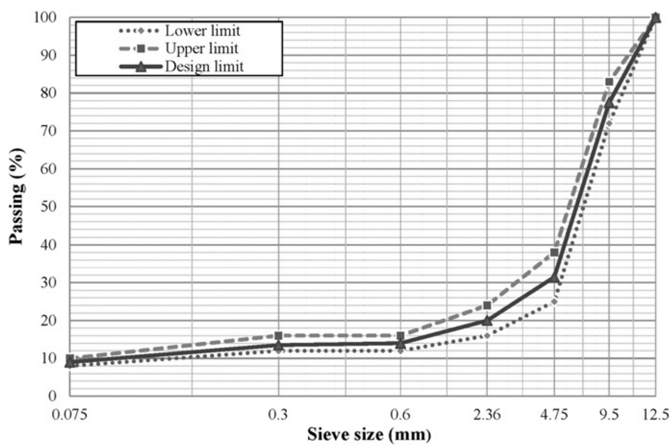

Fig. 1. Aggregate particle size distribution for stone mastic asphalt.