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# Stiffness modulus of Polyethylene Terephthalate modified asphalt mixture: A statistical analysis of the laboratory testing results

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ABSTRACT

Stiffness of asphalt mixture is a fundamental design parameter of flexible pavement. According to literature, stiffness value is very susceptible to environmental and loading conditions. In this paper, effects of applied stress and temperature on the stiffness modulus of unmodified and Polyethylene Terephthalate (PET) modified asphalt mixtures were evaluated using Response Surface Methodology (RSM). A quadratic model was successfully fitted to the experimental data. Based on the results achieved in this study, the temperature variation had the highest impact on the mixture's stiffness. Besides, PET content and amount of stress showed to have almost the same effect on the stiffness of mixtures. The optimal amount of PET was found to be 0.41% by weight of aggregate particles to reach the highest stiffness value.



## 1. Introduction

Stiffness of asphalt mixture is a fundamental design parameter of flexible pavement. It was found that there is a correlation between stiffness and other mixture properties such as rutting and fatigue, and thus it can be used as a criterion to evaluate Asphalt Concrete (AC) mixture performance [1]. As it is mentioned by Strategic Highway Research Program (SHRP) the stiffness value of AC mixture is very susceptible to environmental temperature and loading conditions [2].

Stone Mastic Asphalt (SMA) is gap-graded AC mixture which has been developed in Germany in 1916s. SMA consists of more course aggregate particles, mineral filler and asphalt binder. Due to inherited structure of SMA, it provides better permanent deformation (rutting) performance and durability compared to conventional dense-graded mixture [3,4]. Draindown is a common problem in SMA mixture because it contains higher amount of asphalt binder. Hence, to prevent from draindown in SMA mixture stabilizer additives, fibers and polymers are used. Using polymer in SMA mixture is very common. Utilizing polymer in SMA mixture prevents not only from the binder draindown but also it can enhance mixture performance [5,6]. In many cases, using polymers causes higher construction cost due to high cost of polymers. To overcome this disadvantage, many studies investigated using waste polymers in asphalt mixtures [6–8].

One of the important industrial plastic materials is Polyethylene Terephthalate (PET). PET is a semi-crystalline thermo plastic polymer material which is used in beverage and food industries for years. Nowadays, a large amount of waste PET is produced in the world and it is going to cause a serious environmental challenge due to non-biodegradability of PET [9]. 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 find solutions to tackle with this potential environmental hazard and, moreover, to decrease construction cost imposed by application of polymers in asphalt mixture [6,10–12].

Statistical analysis is a precise and popular way to explore and present interactions between parameters affecting one phenomenon. Statistical analysis in pavement engineering has prominent utilization because it helps road engineers and designers 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 and the response came into popularity [13–15].

Aim of this study was examining the AC mixture stiffness at elevated temperatures and stress levels for the unmodified and PET modified mixtures following by finding interactions between these fundamental factors using RSM based on Central Composite Design (CCD).

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## 2. Materials and methods

Asphalt mixtures were fabricated using 80–100 asphalt penetration grade. Granite-rich aggregate particles were used for this investigation. 9% of filler was utilized. The aggregate particle size distribution is shown in Fig. 1. In order to have better understanding about the materials characteristics several tests were performed on asphalt cement and aggregate particles and the results are listed in Table 1.

PET flakes have been used for this study which were obtained from waste PET bottles. For using PET flakes in asphalt mixture, the PET bottles were cut to small parts and by using crushing machine these small parts were crushed. Thereafter, the crushed PET particles were sieved and the particles which were smaller than 2.36 mm in size were used for this investigation.

### *2.1. Mixture fabrication*

In order to fabricate SMA mixture, 1100 g of mixed aggregate and filler were heated inside oven with temperature of 160 °C for 3 h. Asphalt cement was also heated at 130 °C to be suitable for mixing with aggregate particles. All the materials were mixed at the temperature of 160 °C. 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. The loose mixture was compacted using Marshall compactor and 50 blows of compaction efforts were applied on each side of the mixture. It is worth mentioning that all the mixtures were fabricated at their optimum asphalt contents (OAC). The optimum asphalt content for SMA mixtures is usually selected to produce 3–5% air voids [4,5]. In this study, the OAC was selected to produce 4% air voids. The summary of the mix design is reported in Table 2.

### *2.2. Indirect tensile stiffness modulus test*

Indirect tensile stiffness modulus (ITSM) test gives the relationship between stress and strain of asphalt mixture and used to evaluate the stiffness of asphalt mixture at specific environmental conditions. ITSM test was performed in accordance with AASHTO TP31. ITSM test can be performed by using Universal Testing Machine (UTM) which is one of the important testing equipment in pavement laboratory. UTM is a computer controlled system which operates automatically. During the test, compressive haversine waveform loads were applied across the thickness of specimen, and by utilizing Linear Variable Differential Transducers (LVDTs) which were installed along diametrical section of specimen displacement of asphalt mixture was measured. Horizontal tensile stress and stiffness modulus of asphalt mixtures was calculated using the following equations [10,16]:

$$\sigma_x(\max) = \frac{2 \times P}{\pi \times d \times t} \tag{1}$$

$$S_m = \frac{P \times (v + 0.27)}{H \times t} \tag{2}$$

where $\sigma_x(\max)$ is the maximum horizontal tensile stress in middle of specimen (kPa); $S_m$ is the stiffness modulus (MPa); $P$, applied vertical peak load (N); $H$, amplitude of horizontal deformation (mm); $t$, average thickness of specimen (mm); $d$, average diameter of specimen (mm) and $v$, Poisson's ratio.

In order to characterize effects of applied stress and temperatures on the mixture's stiffness, ITSM test was conducted at stress levels of 200, 300 and 400 kPa for each percentage of PET which are the stress amounts mostly used at pavement laboratories. Additionally, testing temperatures of 10 °C, 25 °C and 40 °C were designated which can be referred to relatively low, medium and high environmental temperatures respectively.

### *2.3. Method of analysis*

One factor at a time (OFAT) methodology is a conventional approach to optimize multifactor experiments. OFAT includes a changeable single factor for a specific experiments design while other factors are kept constant. OFAT is unable to provide appropriate output because the effect of interactions amongst all involved factors in the designs is not examined truly, and it is not capable of reaching the true optimum value [17,18]. Hence, RSM methodology was introduced for parameter optimization in a way that number of experiments and interaction among the parameters are reduced to minimal value [19–21]. Consequently, the Design Expert 8.0.5 was designated for this study to generate statistical analysis, experimental designs, and to calculate the sorbent adaption conditions.

For this study, a developed quadratic model and $a = 0.5$ were utilized using RSM method for design and data analyzing. In this investigation, the effects of three independent numerical variables

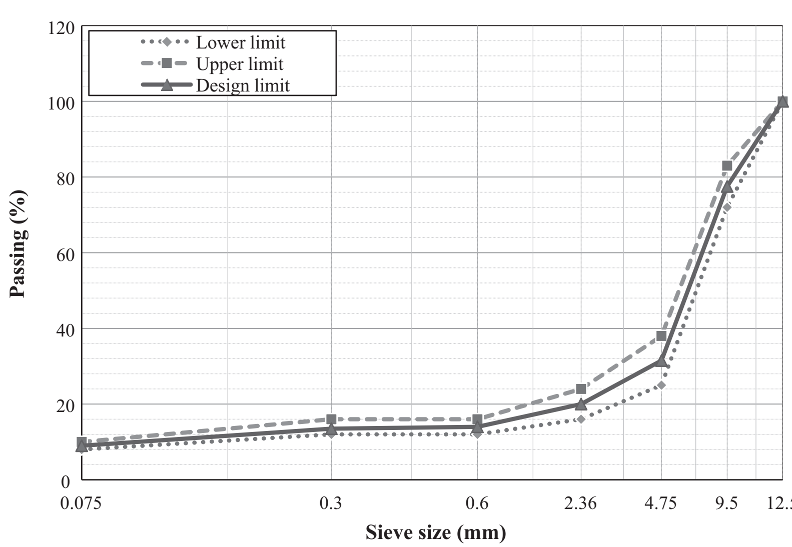


**Fig. 1.** Aggregate particle size distribution for stone mastic asphalt.