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Optimization of asphalt and modifier contents for polyethylene terephthalate modified asphalt mixtures using response surface methodology

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ABSTRACT

Optimization of polymer and asphalt content in polymer modified asphalt mixture is the aim of road engineers and designers. The purpose of this study is to characterize Stone Mastic Asphalt (SMA) mixture's properties containing waste polyethylene terephthalate (PET) which is a type of polymer material. Response Surface Methodology (RSM) was designated as a new method to measure mixture properties at different PET content and asphalt binder value. To fabricate the mixture fresh 80/100 penetration grade asphalt binder with different percentages (5–7% by weight of aggregate particles) was utilized. Different amounts of PET were used from 0% to 1% by weight of aggregate particles. Marshall Stability and Flow test was performed on the mixtures. Specific gravity and volumetric properties of mixtures were obtained. RSM was used to analyze Marshall and volumetric properties of unmodified and PET modified asphalt mixtures. Models were produced to fit the experimental results. As shown in this study suggested models were successfully fitted to the experimental results. Based on the results achieved amounts of 5.88% of asphalt content and 0.18% of PET were found to be the optimal values.

1. Introduction

Stone Mastic Asphalt (SMA) is a gap-graded mix that has a high percentage (60–80%) of coarse aggregate, greater than 5 mm in size, high binder content (5.5–7% by weight), high percentage of mineral filler (7–11%), and added fibers (1%) [1]. SMA mixtures are more durable and rut resistant compared to conventional Hot Mix Asphalt (HMA) [2–5]. The higher amount of coarse aggregate provides stone-on-stone contact among aggregate particles while higher asphalt content results in more durability [6]. Furthermore, SMA mixture has higher resistance to plastic deformation and has good properties at lower temperature [4,7]. Fibers (cellulose or mineral) and mineral filler (Portland cement, hydrated lime and rock dust passing sieve 75 μm in a high amount) are commonly used in SMA mixtures to prevent drain-down due to usage of higher asphalt content in the mixtures [8]. Also, utilization of asphalt with modified characteristics (e.g. offering higher viscosity) can be another way to prevent drain-down in SMA mixtures [6]. The use of SMA in the pavement structure is also very advantageous when the structural design is done using a mechanistic pavement design method [9].

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Improving asphalt mixture properties is the aim of engineers and experts to increase service life of asphalt pavement. Using additives such as various types of fibers and polymers is a common way to improve asphalt mixture characteristics [10,11]. Polymer fibers were also used in asphalt mixture. Tapkin 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 [12]. Another study showed that polypropylene fiber – reinforced mixture had better resistance under repeated creep testing. In addition, initial and final creep stiffness had been increased by 49.27% and 44.98%, respectively which have contributed to 31% reduction in strain value [13,14].

Among additives, waste materials as secondary materials have the advantages of being cost effective and environmentally friendly. Waste glass, steel slag, tyres and plastics are examples of waste materials used in asphalt pavements [15–17]. Asphalt shingle modifier was found to be an appropriate waste additive for asphalt mixtures [18,19]. Waste plastic (polymer) also has prominent utilization in asphalt mixture. There are seven common types of recycled polymer namely: LDPE, MDPE, HDPE (low, medium and high density polyethylene), PP (polypropylene), PVC (polyvinyl chloride), PET (polyethylene terephthalate) and ABC (acrylonitrile butadiene styrene) [20]. Among these additives, LDPE and HDPE have been subjected to more studies compared to other waste polymer materials [15,21–23]. In recent years the use of waste PET in asphalt mixture has become popular [24–27] since it is one of the main packaging materials, and a large amount of waste PET is being produced worldwide. In other words, the usage of natural resources and environmental pollution could be reduced by using waste PET as an alternative in road construction projects.

The main objectives of this study are to characterize Marshall characteristic and volumetric properties of SMA mixtures modified by waste PET, with different percentages. Consequently, the optimum amounts of asphalt and PET were calculated.

2. Objective and test procedure

The main objective of this study is utilizing Response Surface Methodology (RSM) as a new method to evaluate Marshall and volumetric properties of PET modified asphalt mixtures. The effects of PET and asphalt variations on Marshall and volumetric properties of SMA mixtures are investigated through the RSM. In addition, the performance of RSM which is a well-recognized method in finding optimum condition is evaluated for finding optimum asphalt and PET contents. To achieve these aims the following steps are designated:

(1) Conducting the Marshall Stability and Flow test for the mixture constructed with different PET percentages and asphalt contents.
(2) Obtaining the bulk specific gravity, void in mix and void in mineral aggregate.
(3) Applying the Composite Central Design (CCD) methodology based on the Analysis of Variance (Anova).
(4) Developing models for all responses according to CCD.
(5) Finding optimum amount of PET as well as asphalt binder based on the Marshall mix design criterion via RSM method.

3. Materials and methods

3.1. Aggregate

The Granite-rich aggregate used in this study was prepared from Kajang Rock Quarry in Malaysia. Aggregate gradation for SMA mixture has been chosen as shown in Table 1. Moreover, due to the importance of aggregate quality in SMA mixture, several tests have been conducted on aggregate particles.

Large amount of filler (8–10%) is used in SMA mixture, and as a result, SMA mixture has different performance in comparison with conventional HMA mixtures [28]. In this investigation 9% filler material was used.

3.2. Asphalt cement

SMA mixtures have been prepared with fresh 80/100 penetration grade asphalt cement. No stabilizing additives were added to asphalt cement. Table 2 illustrates the properties of used material. In order to minimize complications, the asphalt and aggregate sources were kept the same during the study.

3.3. Polyethylene terephthalate (PET)

Polyethylene terephthalate (PET) is one of the major types of plastics that can be found in the Municipal Solid Waste (MSW) [29]. PET is a semi-crystalline thermoplastic polymer, and is considered as polyester material with low friction surface [30]. PET is identified as a clear, safe, light, transparent, reliable, chemical resistant, easily moldable and economical material. Thus, it is most often used to make containers for food and beverages [31]. Table 3 depicts properties of PET material.

In this study, waste PET was obtained from PET bottles. After collection, PET bottles were washed and cut into small parts, which were then further crushed using a crushing machine. The crushed PET particles were then passed through a 2.36 mm sieve. The particle size

Table 1
SMA gradation limit used in this study.

Sieve size (mm)	Used gradation (%)	Gradation limit (%)
12.5	100	100
9.5	77.5	72–83
4.75	31.5	25–38
2.36	20	16–24
0.6	14	12–16
0.3	13.5	12–15
0.075 (Filler)	9	8–10