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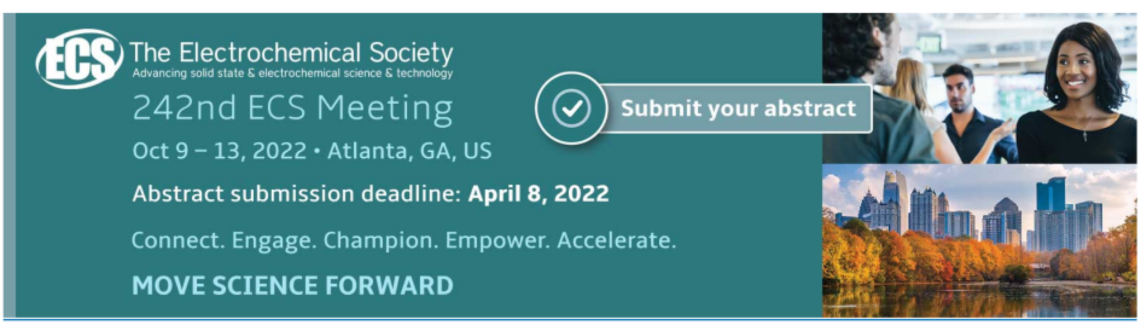

Opportunity applying response surface methodology (RSM) for optimization of performing butonic asphalt mixture using plastic waste modifier: a preliminary study

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Abstract. Non-biodegradable waste plastic made of polyethylene terephthalate (PET) based drinking bottles waste was used as additive in asphalt concrete mixture production. This paper used modified Buton asphalt (MBA) as base binder. The asphalt concrrete mixtures containing 0%, 0.5%, 1.0%, 1.5%, 2.0% and 2.5% of waste PET were prepared with one source of aggregates, filler and stone dust. The effect of waste PET and MBA to asphalt concrete mixture on volumetric properties namely specific gravity, void in mix (VIM), void mineral aggregate (VMA) and void filled bitumen (VFB) is studied. The results of volumetric evaluation indicated that waste PET and MBA could be incorporated in asphalt concrete mixture. After calculating specific gravity, VIM, VMA and VFB, a table was designed as a preliminary study based on Response Surface Methodology (RSM) that can be used as a basis of modelling for continuous improvement of asphalt concrete prepared with waste PET and MBA.

1. Introduction

In Indonesia, large amounts of waste plastics in the landfill accumulate every year generate negative influence on ecology around the landfill area. Waste drink bottles made from PET are one of the plastic wastes that take up a large area in the landfill. Waste PET bottles with other waste plastics would not break down naturally in the landfills. Detrimental effects of waste PET bottles and other waste plastics to the environment can be diminished by producing construction material with waste PET or other waste plastics. The asphalt mixtures fabrication is a way where waste PET bottle is possible to use. Several previous laboratory studies deal with the viability of using waste PET as an additive in asphalt concrete mixtures [1, 2].

Many areas in the southern areas in Buton Island, Indonesia possess immense source of solid bitumen (high hydrocarbon substances). The compounds of Buton rock asphalt (BRA) are approximately 30% bitumen and 70% mineral. Although several products of BRA in granural form have been used in asphalt mixture production but due to the limited information of BRA products those have yet to be tapped for widely usage. In order to develop Buton asphalt products, a lot of effort and research has been done [3, 4, 5]. In recent decades several BRA companies have been succesfully extracted the bitumen from the rock asphalt. Bitumen of BRA has similar properties with the petroleum asphalt therefore it can be blended with petroleum bitumen to produce modified Buton asphalt (MBA). This paper is a part of continuous work to provide sufficient up-to-date information about the application of PET along with MBA to produce asphalt concrete mixture. This study reported the results of the evaluation of asphalt concrete mixture using MAB as the main binding material and waste PET as an additive. Furthermore, volumetric evaluation results are used as a basis for compiling a table as a preliminary study based on Response Surface Methodology (RSM) which was used as a basis of modeling.

2. Materials and methods

2.1. *Waste PET*

Figure 1 shows the waste PET used this study. Waste PET obtained from dringking bottless that were collected from domestic waste in a shredded form. According to the scientific literature the melting point of recycled PET sample is 250°C [1].

Figure 1. Waste PET.

2.2. *Aggregates*

Coarse and fine aggregates were obtained by crushing river stone procured from the Jeneberang Quarry, Southesat Suawesi, Indonesia. The crushed stone was sieved into various fractions after washing and drying. Aggregate grading that satisfied the requirement of the Indonesian National Standard Revised 3 2010 specifications was selected. The aggregate grading selected is presented in table 1. The properties of the aggregates, such as crushing value, impact value, abrasion value, water absorption value, and combined (EI + FI) index) were determined, and the test results are presented in table 2.

The properties of the selected aggregates were within the requirements as specified by the Indonesian National Standard Revised 3 2010. The gradation of the aggregate meets the range of gradation limits specified by Indonesian National Standard Revised 3 2010 [6] for dense mixtures of the wearing course (asphalt concrete wearing course).

Table 1. Aggregate gradations of asphalt concrete mixtures selected for AC-WC mixture.

Sieve size		Specified limits: Percent passing (%)	Specified limits: Adopted (%)
19.0 (mm)		100	100
13.2 (mm)		90 – 100	96
9.50 (mm)		77 – 90	86.93
4.75 (mm)	No. 4	53 – 69	63.90
2.36 (mm)	No. 8	33 – 53	43.56
1.18 (mm)	No. 16	21 – 40	28.62
0.60 (mm)	No. 30	14 – 30	20.76
0.30 (mm)	No. 50	9 – 22	15.60
0.15 (mm)	No. 100	6 – 15	10.79
0.075 (mm)	No. 200	4 – 9	8.43

Table 2. Properties of aggregates used for the present study.

Properties tested	Test results	Indonesian National Standard Revised 3 2010 spesification
Crushing value	33.2%	45% max
Aggregate impact value	28.1%	30% max
Los Angeles abrasion value	24.36%	40% max
Water absorption value	2.07%	3% max
Spesific gravity	2.68	2.5 – 3.0
Combined (EI + FI) index)	20.10%	25% max

The o.b.c for the control mix was calculated at 5.0% which agrees with previous investigations [9], whilst the o.b.c for the Plastiphalt mix was determined at 6.0%. Tables 5 and 6 show the Asphalt Institute Mix Design Criteria for satisfactory paving mixes and the results obtained in this investigation exceed all design requirements.

2.3. Rheological properties of MBA

Table 3 shows the rheological properties of MBA.

Table 3. Testing methods for rheological properties of BMA.

Properties	Value	Unit
Penetration at 25°C	78.6	0.1 mm
Softening Point	52.0	°C
Ductility	114	cm
Flash Point	280	°C
Density	1.12	
Loss on Heating TFOT	0.30	% wt
Penetration after loss on heating	86.00	0.1 mm

2.4. Sample preparations
In order to fabricate the samples, the stages to be followed are as follows:

- Before adding aggregates, stone dust and filler to the mixture, it was heated to 200°C for a period of approximately 30 minutes.
- The bitumen contents used in the mixture was varied between 5% and 7% (5%, 5.5%, 6%, 6.5% and 7%) by the weight of aggregate. The selected bitumen was heated to 150°C for about 1 h prior to blending with the aggregate.
- The combination of aggregate, bitumen and filler was mixed at a temperature of 160 ± 5°C for around 5 min.
- Before adding waste PET to the mixture, it was heated to 185°C for a period of approximately 30 minutes.
- PET was introduced into the combination and blended with it for about 2 min. The percentage of the added PET varied between 0% and 2.5% (0%, 0.5%, 1%, 1.5%, 2% and 2.5%) by weight of bitumen.
- The Marshall Compactor was used for the compaction stage of the process with 75 blows applied to the top and bottom side of the mixture at 145°C.

3. Results and discussion

3.1. Bulk specific gravity
As Fig. 2 illustrates an increase in the waste PET content resulted the bulk specific gravity to increase for each binder contents, regardless of the waste PET and MBA content, the bulk specific gravity of the mixture without waste PET was slightly lower than that of the mixture containing waste PET. The bulk specific gravity value in case of mixtures without PET is due to the lower elasticity of the PET in comparison with the mineral aggregates that influence the compaction result of mixture with waste PET, may slightly reduce the bulk specific gravity.

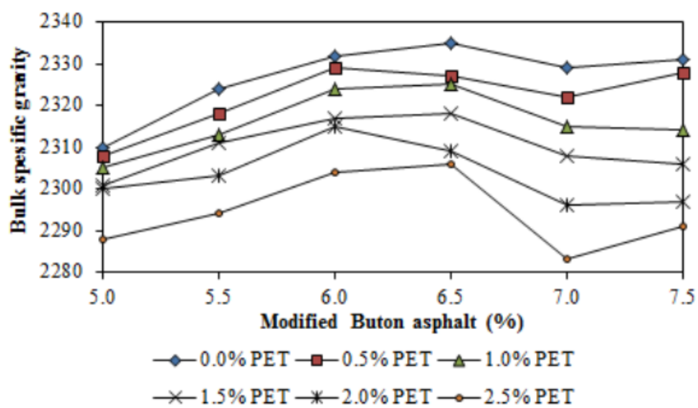

Figure 2. Bulk specific gravity value versus PET content for each modified Buton asphalt (MBA) content.

3.2. Air void (VIM)
When designing asphalt mixtures, it is necessary to obtain the right amount of VIM because the amount of VIM or excessive air causes easy cracking due to inadequate asphalt covering the aggregate, while rutting and bleeding easily occur when VIM is very low. Based on the figure3 and table 4, several VIM is available in the right amount so that it can prevent cracking, rutting and bleeding. [7, 8, 9, 10].

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As fig. 3 shows, increasing the waste PET content in the mixture results in more air voids in the mixture. Based on figure 3 and table 4, mixtures met the VIM requirements (3 - 5%) were mixed with the MBA content 5.5% and the PET waste content 0.5 - 2.0%, the MBA content 6.0% and the waste PET content 0.0 - 2.5% and the MBA content 6.5% and PET waste content of 0.0 - 0.5%.

Table 4. Air void value which fulfills the requirements.

MBA content (%)	Waste PET (%)					
	0.0	0.5	1.0	1.5	2.0	2.5
5.0	9.03	2.84	2.79	2.58	2.47	2.35
5.5	6.86	3.42	3.39	3.27	3.04	2.83
6.0	3.95	4.00	4.64	4.76	4.81	4.93
6.5	3.27	4.59	5.46	5.49	5.65	5.74
7.0	1.54	5.17	5.75	5.82	5.89	5.96
7.5	0.92	5.17	6.14	6.17	6.23	6.74

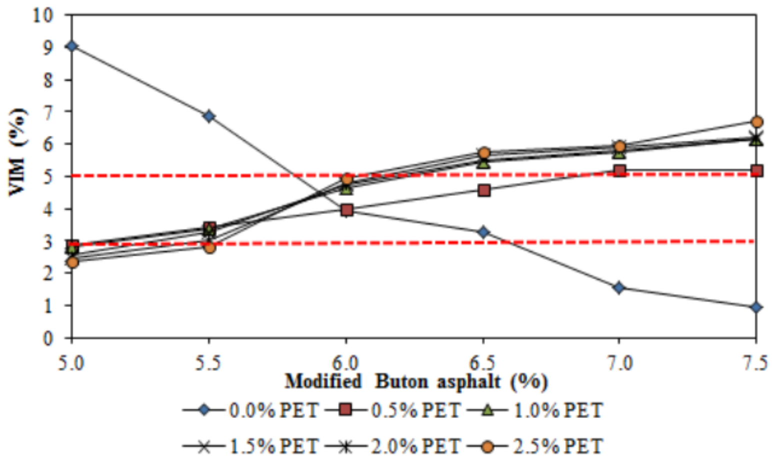

Figure 3. Air void value versus PET content for each modified Buton asphalt (MBA) content.

3.3. Voids in mineral aggregate (VMA)

Space for the binding film on aggregate particles is provided by voids in mineral aggregates (VMA). With the availability of sufficient film thickness on aggregate particles, adequate mixture durability can be achieved. Minimum VMA requirements are recommended so that the mixture has the required durability [10]. Figure 4 shows the value of VMA versus PET for the percentage range of the binding content. VIM values were all located within the specification range, which may provide adequate durability for mixture.

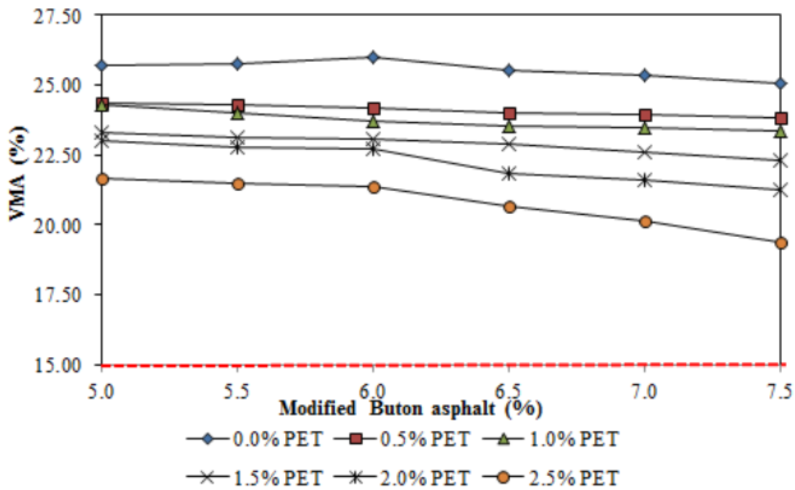

Figure 4. Void in mineral aggregate (VMA) versus PET content for each modified Buton asphalt (MBA) content.

3.4. *Void Filled Bitumen (VFB)*

An unstable interface adhesion is generated from a very low VFB due to insufficient asphalt binder penetrating into voids of aggregate particles that may create interfacial failure between asphalt film and aggregate surface. A minimum VFB should be provided to induce adequate interface adhesion [10]. The VFB value versus PET for a percentage range of binder contents is illustrated in fig. 5. As the figure displays, all VFB values, were all located within the specification range, which may provide adequate interface adhesion.

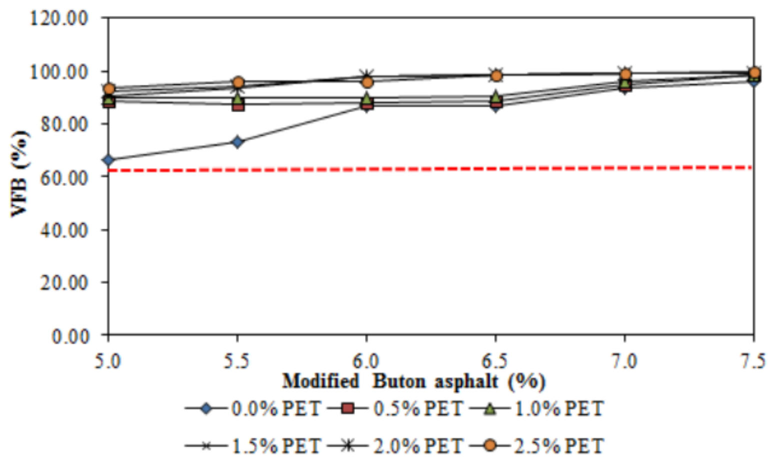

Figure 5. Void in filled bitumen (VFB) versus PET content for each modified Buton asphalt (MBA) content.

3.5. *Preliminary Study of Response Surface Methodology (RSM)*

Based on the results obtained from Section 3.1 to 3.4, then it can be arranged Table 5 which is a preliminary design of the RSM to obtain the Marshall Quetiont (MQ), Void in Mix (VIM) and density models for continuous improvement of asphalt concrete prepared with waste PET and MBA.

Tabel 5. Response surface methodology.

Run	Factor 1 A: MBA content (%)	Factor 2 B: Waste PET content (%)	Factor 3 C: Mixing time (minute)	Response 1 MQ (kN/mm)	Response 2 VIM (%)	Response 3 Density (g/cm^3)
1	4 (0)	3 (0)	25 (0)			
2	6 (+1)	3 (0)	30 (+1)			
3	4 (0)	4 (+1)	30 (+1)			
4	4 (0)	3 (0)	25 (0)			
5	4 (0)	2 (-1)	30 (+1)			
6	4 (0)	3 (0)	25 (0)			
7	4 (0)	4(+1)	20 (-1)			
8	6 (+1)	4 (+1)	25 (0)			
9	2 (-1)	3 (0)	30 (+1)	RMS	RMS	RMS
10	6 (+1)	3 (0)	20 (-1)			
11	2 (-1)	3 (0)	20 (-1)			
12	6 (+1)	2 (-1)	25 (0)			
13	4 (0)	3 (0)	25 (0)			
14	4 (0)	3 (0)	25 (0)			
15	2 (-1)	2 (-1)	25 (0)			
16	2 (-1)	4(+1)	25 (0)			
17	4 (0)	2 (-1)	20 (-1)			

4. Concluding Remarks

Waste PET can be used together with the MBA to produce AC-WC and subsequently based on volumetric results (bulk specific gravity, VIM, VMA and VFB) can be arranged table to be used as RSM-based preliminary which will be used as a model for continuous improvement of asphalt concrete prepared with waste PET and MBA.

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