Effects of *Polyethylene Terephthalate* and Crumb Rubber on Selected Properties of Asphaltic Concrete

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ABSTRACT: This study investigated the combined effects of *polyethylene terephthalate* (PET) and crumb rubber (CR) as modifiers on some properties of asphaltic concrete. Asphaltic concrete materials were obtained from a construction site. CR of 9.5 mm size was obtained by sieving, while PET bottles were collected, sorted, washed, dried and shredded by mechanical means. The physical properties of these materials were determined following standard procedure. Bitumen was modified by wet process with PET and characterised. Asphaltic concrete samples with partial replacement of coarse aggregate in the mix with CR were prepared. Samples without modifiers were also prepared as control. These were subjected to Marshall Stability test. The percentage variation for stability and flow between the control and the modified mixes, were 27 % and 0.29 % respectively, while those of the volumetric properties of bulk density, voids filled bitumen (VFB), air voids (VA) and voids in mineral aggregate (VMA) were 0 %, - 0.13 %, 0 % and 0 % respectively. It was concluded that, there was no difference between the flow and volumetric properties of the control and modified mixes.

KEYWORDS: *Polyethylene terephthalate*, crumb rubber, asphaltic concrete, stability, flow, volumetric parameters

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I. INTRODUCTION

Application of modifiers to asphalt mix results in its improved properties compared to conventional mixture (Gawel et al., 2011). Modifiers to asphaltic mix had been identified to increase the stiffness and elasticity of the mixture thus minimising rutting and cracking, improves its fatigue resistance and asphalt-aggregate binding resulting in the reduction of stripping or moisture sensibility. The modifiers also improve its resistance to aging or oxidation as well as abrasion. In short, modifiers improve the overall performance of HMA pavements (National Academy of Sciences, 2019). Crumb rubber in asphaltic concrete mix lowers susceptibility to regular and seasonal temperature fluctuation. It gives higher deformation resistance at high pavement temperatures, improved age resistance properties, higher longevity of mixing fatigue. It has also been reported to give, better adhesion between aggregate and binder, prevention of cracking and reflective cracking, and overall improved performance in extreme climatic and heavy traffic conditions (Hossain, 2006). Bindu and Beena (2010) stabilized stone mastic asphalt with waste plastics and subjected the mixtures to performance tests such as, Marshall Stability, tensile, compressive and tri-axial tests. The study concluded that, flexible pavement with high performance and durability can be obtained with 10% shredded plastic.

Khan and Gundaliya (2012) stated that, the process of modification of bitumen with waste polythene enhances resistance to cracking, pothole formation and rutting by increasing softening point, hardness and reducing stripping due to water, thereby improving the general performance of roads over a long period of time. The waste polythene in the mix, forms coating over aggregates of the mixture which reduces porosity, absorption of moisture and improves binding property.

Akasi and Mohammed (2018), partially replaced coarse aggregate with crumb rubber by weight of total mix. At 2% partial replacement, properties of compacted asphaltic concrete for wearing course were satisfied. Ezemenike and Mohammed (2018), concluded that at 8 % optimum polyethylene terephthalate (PET) content, the Marshall properties of asphaltic concrete mix improved.

The objective of this study is to evaluate the combined effects of polyethylene terephthalate and crumb rubber as modifiers on some properties of asphaltic concrete, in view of the comparative superior stability and volumetric properties of asphaltic concrete modified with PET and crumb rubber respectively.

II. MATERIALS AND METHODS

A. Materials

The bitumen used, a 60/70 penetration type and the polyethylene terephthalate (PET) bottles were procured at Osogbo, Osun State along with the aggregates. The crumb rubber was collected from a dump site at Osu, Osun State.

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B. *Methods*

1) Specimen Preparation

The crumb rubber was cut into different sizes, and sieved to obtain the desired size of 9.5 mm. The polyethylene terephthalate (PET) bottles were sorted, washed, dried and shredded by mechanical means, in sizes between 0.6 and 2.36 mm. The physical properties of the materials were determined by standard procedures (Garber and Hoel, 2015). The optimum binder content of 5.8 % used for the study was determined from the mix design (Garber and Hoel, 2015). This was used as the control mix. The bitumen was modified by wet process (Thom,2014) with the shredded PET at 8 % content by weight of bitumen and characterised. Asphaltic concrete samples were prepared at 2 % by weight of the total mix with partial replacement of coarse aggregate in the mix with crumb rubber. In addition, samples with 8% PET as bitumen modifier and 2% CR as partial replacement of coarse aggregates in mix were prepared separately.

2) Marshal Stability Test

Marshal test was conducted and the values of stability, flow, bulk density, voids filled with bitumen (VFB), air voids (VA), and voids in mineral aggregate (VMA) were determined, for the mixes (ASTM D 1559, 1993).

III. RESULTS AND DISCUSSION

A. *Physical Properties of Bitumen*

Table 1 shows the penetration test, specific gravity test, ductility test, softening point and flash point of the bitumen. The result shows that the bitumen conforms to all asphaltic concrete production specification (FMWH, 2006), and as such, suitable for use for the study.

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B. Physical Properties of Aggregate

Table 2 shows the aggregate flakiness index, crushing and water adsorption values. The values obtained are all within permissible limit by FMWH (2006) specification. Brennan and O' Flaherty (2002) have reported similar findings. The aggregate crushing value, flakiness index and water adsorption factor are 23.8, 15.28 and 0.35 do not exceed the corresponding values of 30, 35 and 0.2-1.5 %, stated in the FMWH (2006), specification.

Table 2: Physical properties of granite aggregate and crumb rubber.

Properties	Aggregate	Crumb rubber	Specification
Specific gravity	2.69	1.15	2.5 -3.0
Aggregate crushing Value (%)	23.8	0	≤ 30
Flakiness index (%)	15.28	19.40	35
Water adsorption (%)	0.35	0.43	0.2-1.5
Los Angeles Abrasion value (%)	29.70	0	-

C. *Aggregate Gradation*

Figure 1 shows the gradation curve for the aggregates. This gradation curve indicates that the combination was well graded and that the aggregate gradation curve obtained for wearing course was within the Federal Ministry of Works and Housing requirement (FMWH, 2006).

D. *Marshall Stability of the Control Mix*

The Marshall test property curves and the mix design properties are as shown on Figure 2 and Table 3 respectively. The Marshall Mix design properties as shown are within the specifications (FMW&H, 2006).

E. *Effects of PET and Crumb Rubber on Marshal Properties of Asphaltic Concrete*

1) *Marshall Stability*

The result in Table 4 shows that the modified asphaltic concrete met the standard specification of Marshall Stability in wearing course range of not less than 3.5 kN (FMWH, 2006). The drop in the stability value of the sample shows the over bearing influence of the CR which has a lower strength value compared to the aggregates. The crumb rubber appears to carry some of the imparted energy, resulting in weaker aggregate structure (Hossain et al., 1996).

Table 3: Marshall mix design properties.

S/N	Properties	Optimum Values	FMW&H Specification
1	Binder Content (%)	5.8	5.0 – 8.0
2	Stability (kN)	16.78	3.5
3	Flow (mm)	3.03	2 – 4
4	Void in total mix (%)	3.7	3 – 5
5	Voids Filled with bitumen (%)	78.2	75 – 82

Table 1: Physical properties of grade 60/70 Bitumen.

PROPERTY	Test Result	specification	Test Method
Penetration test(0.1mm)	63.3	60-70	ASTM D5/D5M
Specific Gravity(g/cm^3)	1.033	1.01-1.06	ASTM D-70
Flash Point(℃)	309	250	ASTM D-93-20
Softening point (℃)	48.3	48-56	ASTM D36/D36M-14
Ductility at 25℃ , 5 cm/min, cm	120	100+	AAHTO 51-9

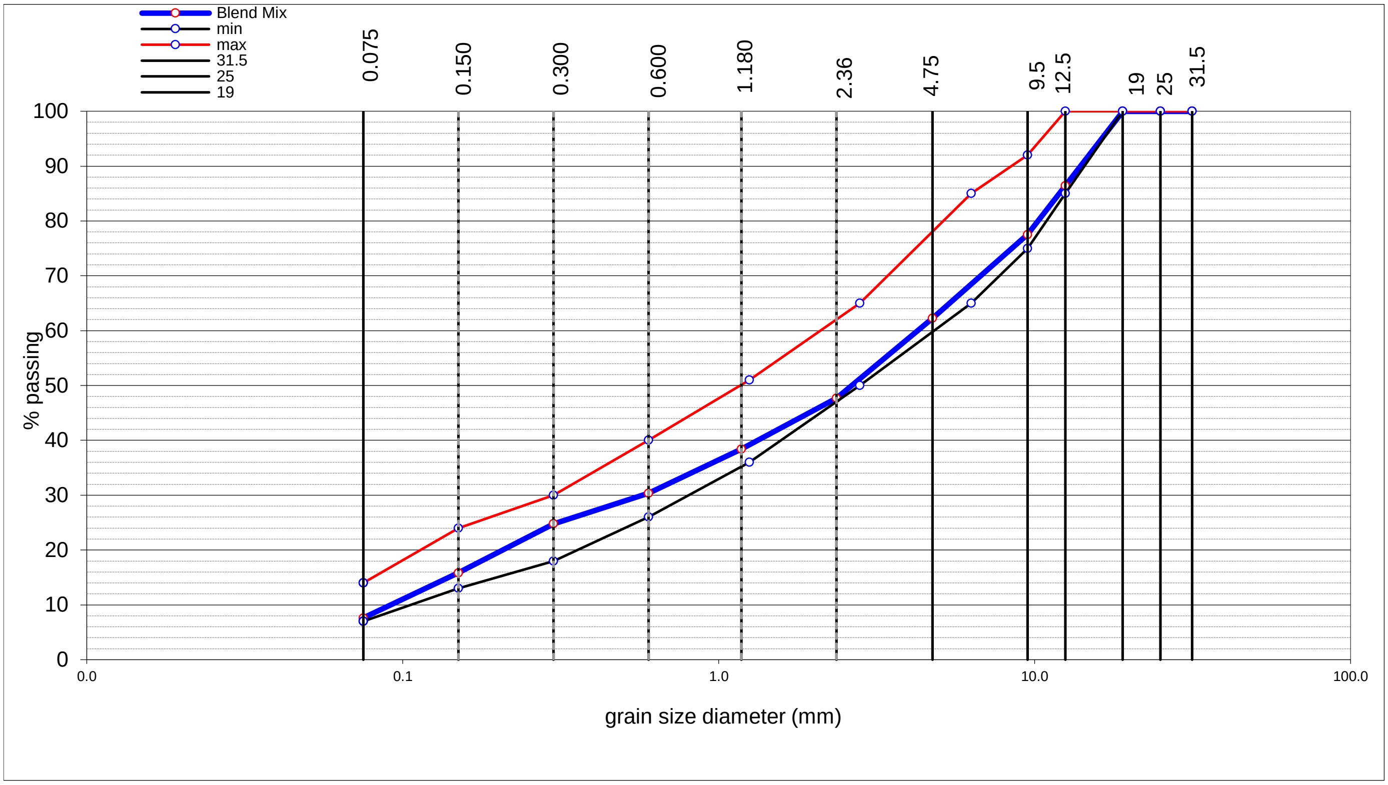


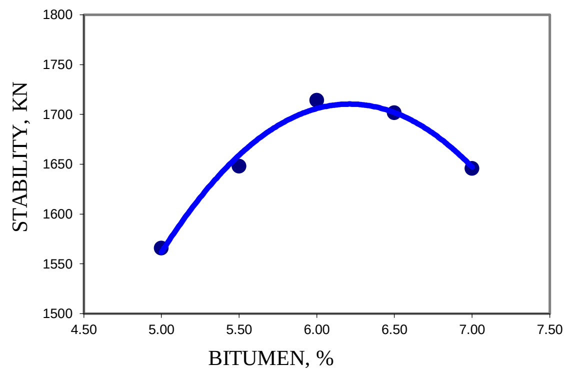
Figure 1: Aggregate grading curve.

2) Marshall flow

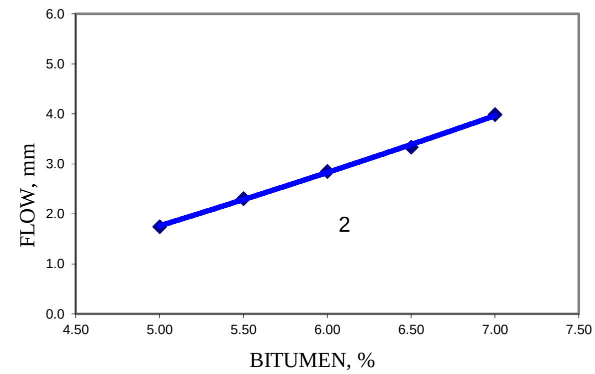
The result in Table 4 shows that the modified specimen meets the standard specification for Marshall Flow in wearing course range of 2mm – 4mm ((FMWH, 2006). The slight decrease in the flow value may be due to reduction in viscosity of the bitumen as a result of the PET and may also be attributable to the fact that crumb rubber has high elastic property which enabled it to experience broad deformation from which almost complete, instantaneous recovery is achieved when load is removed (Beaty, 1992).

Table 4: Tests results.

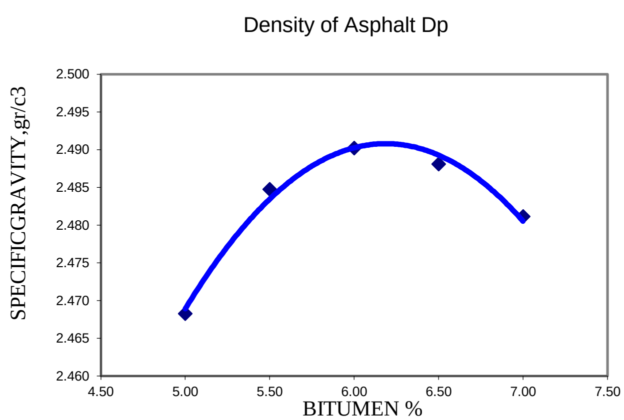
Bitumen Content	No. of Samples	Stability (kN)	Flow (mm)	Bulk Specific Gravity (G_{mm})	Theoretical Specific Gravity (G_{mm})	Air Void VA (%)	Void in Mineral Aggregate VMA (%)	Void Filled with Bitumen VFB (%)
	1	8.94	3.21	2.311	2.419	4.5	23.1	81.0
0								
	2	10.97	3.43	2.295	2.419	5.1	23.7	78.0
	3	10.63	3.55	2.306	2.419	4.7	23.3	80.0
	Average	10.18	3.40	2.304	2.419	4.7	23.4	79.7
	1	7.74	3.44	2.308	2.419	4.6	23.2	80.0
2% CR and 8% PET	2	8.09	3.41	2.312	2.419	4.4	23.1	81.0
	3	6.47	3.32	2.293	2.419	5.2	23.7	78.0
8% PET	Average	7.43	3.39	2.305	2.419	4.7	23.4	79.8
	1	9.41	3.21	2.316	2.419	4.3	23.0	81.0
	2	5.42	3.01	2.311	2.419	4.4	23.1	81.0
	3	10.48	3.36	2.313	2.419	4.4	23.1	81.0
2% CR	Average	8.44	3.19	2.313	2.419	4.4	23.1	81.1
	1	8.29	3.26	2.313	2.419	4.4	23.1	81.0
	2	7.36	2.92	2.299	2.419	5.0	23.5	79.0
	3	7.57	3.18	2.315	2.419	4.3	23.0	81.0
	Average	7.74	3.12	2.309	2.419	4.5	23.3	80.4



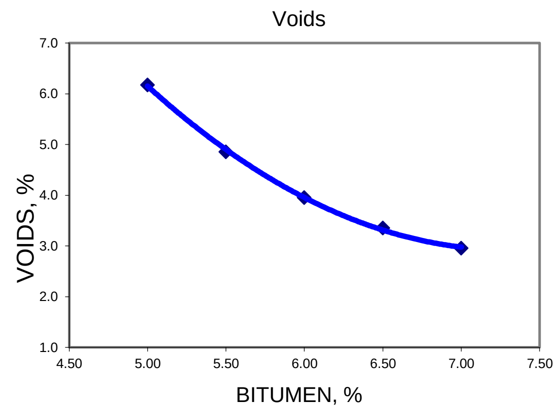
(a) Stability against Bitumen content.



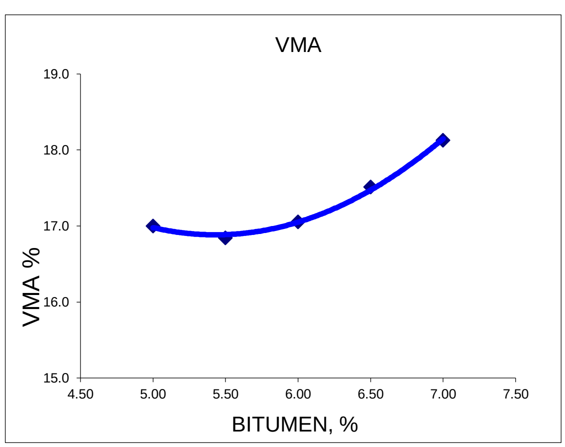
(b) Flow against Bitumen content.



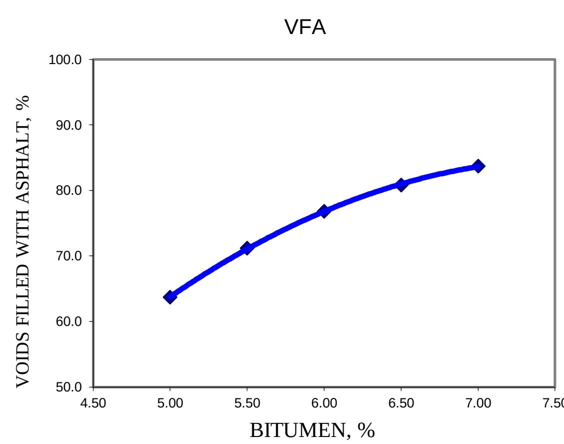
(c) Bulk specific gravity against Bitumen content.



(d) Air void against Bitumen content.



(e) Void in mineral aggregate (VMA).



(f) Void filled with Bitumen (VFB).

Figure 2: Marshall test property curves.

3) Bulk density

Table 4 shows that there is no significant change in the bulk density of the modified specimen when compared with the control mix. This may be due to the moderating effect of PET in the mix. PET has a higher density value compared with bitumen (Al-Haydari and Al-Haidari, 2020) and crumb rubber.

4) Air void (AV)

Table 4 shows that the specimen with the modifiers meets the standard specification for air void for wearing course. This value however does not differ from the value of the control mix. This result indicates that the mix is comparable to the conventional asphalt mix.

5) Voids in mineral aggregate (VMA)

The result in Table 4 shows that the value of the VMA of modified samples meets the standard specification of void in mineral aggregate. It is however noted that result is not different from that of the control mix.

6) Voids filled with bitumen (VFB)

The result in Table 4 shows that the specimens met the standard specification of void filled with bitumen in wearing course range (FMWH, 2006). Furthermore, the result showed a slight increase in the VFB value of the modified mix, when compared with the control mix. This is however not significant. The results of the asphaltic concrete properties modified with PET and CR in Table 4 confirmed the comparative superior stability and volumetric properties of asphaltic concrete modified with PET and crumb rubber respectively. This is in line with studies by Ezemenike and Mohammed (2017) and Akasi and Mohammed (2018).

IV. CONCLUSION

The effect of the combination of PET and CR on some properties of asphaltic concrete was investigated in this study. The results showed that the combination satisfied the specifications for asphaltic concrete mix. The study concluded that there is no significant difference in the flow and volumetric properties (bulk density, AV, VMA and VFB) of the modified asphaltic concrete and the conventional one, even when the, the stability values (which are still within specification) are slightly lower.

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