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Utilisation of Melted Plastics as Partial Replacement for Binder in Asphalt Production

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Abstract
This study considers using melted waste plastics to partially replace the binder (bitumen) in asphalt production. The use of waste plastics in bituminous mixes enhances its properties, strength and it will serve as remedy to unhealthy plastic disposal. The waste plastic used are poly-ethylene, poly-styrene, poly-propylene. In the research work, the Optimum Binder Content (OBC) of asphalt concrete which was obtained to be 5.5% of bitumen by weight of the overall mix and was replaced as follows; 0%:5.5%, 0.5%:5%, 1%:4.5%, 1.5%:4%, 2%:3.5%, 2.5%:3%, 3%:2.5%, 3.5%:2%, 4%:1.5%, 4.5%:1%, 5%:0.5% (bitumen:plastic). After which Stability test was carried out on the samples. A comparison of the plastic waste replacement and non-replacement asphalt concrete showed that the stability of replacement increased. The maximum stability of plastic waste modified asphalt concrete was recorded at 1%:4.5% (bitumen:plastic) replacement with the stability of 2,054Kg. Therefore, addition of plastic in asphalt proves that it improves the properties of asphalt.

Keywords*: Waste plastic, bitumen, bitumen-plastic mix, optimum binder content.*

1.0 Introduction

In Nigeria and many other countries, the safe disposal of solid waste is of great concern to their environmental protection agencies. The random disposal of worn-out automobile tyres and plastics is considered to be a major cause of damage to our ecosystem that result in alarming health problems for all types of life (Sulyman *et al.*, 2014). These materials pose pollution in the nearby locality for their non-biodegradability and unaesthetic view. This is a known tradition that filler and aggregates etc. are used in asphalt production. These natural materials are getting exhausted in nature and their qualities are depreciating gradually (Prince and Sumit, 2017). Also, plastics have been habitually mixed with our municipal solid wastes and sometimes disposed of in soil; in terms of their chemical characteristics as represented by their chemical bonds, they are very durable and non-biodegradable; they therefore require very effective management worldwide (Sulyman *et al.*, 2014). The advantages of using waste plastics in asphalt production are to reduce the need of bitumen by around 10%, develop a technology which is eco-friendly, improve the fatigue life of roads, improve the strength and better performance of the road and use high percentage of plastic waste (Manju et al, 2017).

This research work is aimed at utilizing melted plastic as partial replacement for binder in the asphalt production. The objectives are to; determine the laboratory properties of bitumen, determine OBC of the bitumen, produce asphalt with coating of plastic material and bituminous material, and finally compare the Stability results of the produced asphalt with the specifications.

Abdul-Rahman and Abdul-Wahab (2012) examined the effects of using waste plastic containing 55-60% PET as replacement for fine aggregates partially on the stiffness and permanent deformation of an asphalt wearing course. They used the PET to replace between 5 and 25% of the aggregate sizes ranging from 1.18 mm to 2.36 mm. The results revealed that the resilient modulus value of unmodified asphalt is greater than recycled PET modified asphalt, while the resistance of permanent deformation of the modified asphalt improves; a 20% replacement gives the best performance.

Ahmadinia *et al.* (2011) stated that one way to reduce the cost of road construction and rendering it more practical was by using inexpensive polymers, i.e., waste polymers. They carried out research to examine the effect on the engineering properties of incorporating waste plastic bottles (polyethylene terephthalate (PET)) in an asphalt mixture using 0%, 2%, 4%, 6%, 8% and 10% PET; they found the appropriate amount of PET to be 6% according to weight of bitumen. The report revealed that the addition of PET has a positive impact on the properties of Stone Mastic Asphalt and could promote the re-use of waste material in industry in an environmentally friendly and economical way.

Appiaha *et al.* (2017) examined the impact of blending waste thermoplastic polymers, namely, High Density Polyethylene (HDPE) and Polypropylene (PP) in conventional AC-20 graded bitumen, also, as a means for the proper management of solid waste, particularly plastics as a solution to the formation of potholes on roads due to excessive traffic and axle weight. In their study, the plastics were shredded and blended with the bitumen 'in-situ' with a shear mixer at a temperature range of 160 °C–170 °C. They found that the properties of the modified bitumen were enhanced. They reported that the viscosity of the unmodified bitumen was improved with the addition of the polymers. Generally, their results revealed that the penetration values decrease as the polymer-bitumen ratio increases, while the softening temperature generally increases as the polymer ratio increases.

Awaeed *et al.* (2012) examined the usage of polyethylene terephthalate (PET) to enhance the properties of asphalt concrete. They used five different proportions (2, 4, 6, 8 and 10%) as additives of the OBC of 5% according to the weight of the aggregates. They heated the bitumen in an oven, and the PET was blended into small sizes using a shredding machine before being mixed with the bitumen. They were left in the oven for 45 minutes at 150 °C. The aggregates and filler of each specimen were heated to 160-170 °C. They reported that the bulk density increased as the amount of PET increased. Also, the stability of the modified asphalt was greater than that of the unmodified asphalt, with the maximum stability value recorded at an 8% PET content.

Gawande *et al.* (2012) observed that the amount of plastic waste in India was greater due to increases in the population, urbanization, development activities, and changes in life styles, which led to widespread littering. Therefore, they decided to review the literature on the effective utilization of waste, which was becoming a serious problem due to its non-biodegradability. They concluded that the use of recycled plastic waste in pavement asphalt would represent a valuable outlet for the safe disposal of such materials and that it would help in substantially improving the Marshall stability, strength, fatigue life, and other preferred properties of an asphalt mixture, thereby resulting in an improved pavement performance with marginal savings in the use of bitumen.

Moghaddam *et al.* (2013) investigated the impact of plastic in road pavements. They evaluated the stability properties as well as the specific gravity of a bituminous mixture containing different fractions of plastic. Results indicated that the stability and flow values of an asphalt mixture increased after the addition of shredded waste plastic bottles to an asphalt mixture.

Generally, the literature review expressed that different forms of plastic have been used to modify asphalt mixtures and have been found to improve some of its properties. This study investigates the use of the following plastics; polyethylene, polypropylene, polystyrene and polyvinyl chloride which were blended and melted together for partial replacement of bitumen, also, the stability and flow properties of the asphalt concrete used in Nigeria. It is aimed at encouraging road construction and management agencies to adopt the use of plastic waste in asphalt to reduce the concerns of waste management authorities about ensuring the safe disposal of such waste.

2.0 Materials and Method

2.1 Materials

The materials used in the study are 19 mm, 12.5 mm, and 9.5 mm single-sized aggregates, quarry dust and river sand, bitumen (60/70 penetration grade), and plastic waste. The plastic waste consists of poly-ethylene, poly-styrene, poly-propylene polyethylene, and polyvinyl chloride

2.2 Methods

The aggregates used for the research were exposed to a mechanical sieve analysis to evaluate the particle size distribution. The coarse aggregate was subjected to aggregate impact and crushing test, while the bitumen was subjected to a penetration test. The composition of the asphalt concrete mix was in accordance to the Federal Government of Nigeria's Specifications for Road and Bridges (FGN, 1997). The asphalt mixture was prepared using 9% of 19mm aggregate size, 21% of 12.5mm aggregate, 18% of 9.5mm aggregate size, 37% of stone dust, and 15% of river sand with 4%, 4.5%, 5.0%, 5.5% and 6% bitumen content according to the weight of the aggregates. The samples were put through to the stability test to determine the (OBC). The OBC was determined using the Asphalt Institute Procedure, i.e., the average of the bitumen contents that correspond to maximum stability, maximum density, and air voids. Once the OBC was determined, the modified asphalt concrete samples were prepared by replacing the OBC with 0% : 5.5%, 0.5% : 5%, 1% : 4.5%, 1.5% : 4%, 2% : 3.5%, 2.5% : 3%, 3% : 2.5%, 3.5% : 2%, 4% : 1.5%, 4.5% : 1%, 5% : 0.5% (bitumen : plastic) according to the weight of the bitumen. The plastic-modified asphalt concrete samples were exposed to the Marshall test to examine the outcome of the modifier.

2.3 Test Procedures

2.3.1 Sieve analysis

The aggregate gradations were assessed in accordance with BS EN 933-1:2012 (BSI, 2012).

2.3.2 Aggregate impact and crushing test

The aggregate Impact and Crushing test were determined in accordance with BS: 812 (Part 112) – 1990 and BS: 812 (Part 110) – 1990 respectively.

2.3.3 Bitumen penetration test

The penetration test is a measure of the consistency of the bitumen expressed as the distance in tenths of a millimeter (decimilimeter) that a standard needle is allowed to penetrate vertically into a sample of the bitumen, under a specified load and loading time, at a fixed temperature of 25^{o}C (Airey, 1997). The penetration test was carried out in accordance with BS EN 1426:2015 (BSI, 2015).

2.3.4 Marshal stability test

The samples for the Marshall test were prepared by blending the aggregates as explained in paragraph 2.2. Then, 1200g of the blended aggregates were measured along with 5.5% bitumen according to the weight of the aggregates. The aggregates were heated to a temperature of 160°C before being mixed with the bitumen. A crater was formed in the aggregate, and the 60/70 bitumen heated to 160°C was added. The aggregates and the bitumen were thoroughly mixed until all the aggregates were properly coated. Filter paper was placed in the bottom of a thoroughly cleaned mould and heated to 160°C; the mixture placed in the mould was spread with a heated spatula around it. The collar was removed, and the surface of the mix was smoothed with a trowel to a slightly rounded shape. The temperature of mixture after the compaction was maintained at 140°C. The collar was replaced, and the mould assembly was placed on the compaction plinth in the mould holder; 75 blows were released to the top of the specimen. The baseplate and the collar were removed; the sample was then inverted and the mould reassembled. The inverted face was also given 75 blows. Then, the base plate was removed, and the specimen was removed from the mould using a sample extruder and an appropriate jack and frame arrangement. The specimen was set on a level surface and left it to cool to room temperature. This process was repeated for the production of the samples with 4.5%, 5.0%, 5.5%, and 6.0% bitumen according to the weight of the aggregates. The modified asphalt concrete samples were produced using the same process, but with the OBC replaced as follows 0% : 5.5%, 0.5% : 5%, 1% : 4.5%, 1.5% : 4%, 2% : 3.5%, 2.5% : 3%, 3% : 2.5%, 3.5% : 2%, 4% : 1.5%, 4.5% : 1%, 5% : 0.5% (bitumen : plastic) according to the weight of the bitumen.

3.0 Results and Discussion

3.1 Impact Value Test

Table 1: Result of Impact Value Test of Aggregates

Weight	Trial I (g)	Trial II (g)
Weight of mould	2700	2700
Weight of sample + mould	3130	3240
Weight of sample	530	540
Weight of sample retained	430	450
Weight of sample passing	100	90

After determining the mean of the two trials, the aggregate impact value was determined to be 17.77% The value conforms to the requirement as per BS: 812 (Part 112) - 1990. Aggregates to be used for wearing course, the impact value should not exceed 30%. For bituminous macadam, the maximum permissible value is 35%. For water bound macadam base courses the maximum permissible value is 40%.

3.2 Crushing Value Test

Table 2: Crushing Value Test of Aggregates

Weight	Trial I (g)	Trial II (g)
Weight of Mould	13210	13210
Weight of Sample + Mould	16120	16240
Weight of Sample	2910	3030
Weight of Sample retained	2470	2520
Weight of Sample passing	440	510

By determining the mean of the two trials, the aggregate crushing value was determined to be 15.98%. The value conforms to the requirement as per BS: 812 (Part 110) – 1990. A value less than 10% signifies an exceptionally strong aggregate while above 35% is normally regarded as weak aggregates.

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Table 3: Bitumen Penetration Test Results

Parameters	Trial ID			Average	Specification
	A (mm)	B (mm)	C (mm)	Results (mm)	
Penetration @ 25 ^{o}C	59	61	64	61	60-70

The result obtained in Table 3 was compared with BS EN 1426:2015. The specification includes five penetration grades ranging from hard asphalt graded at "40-50" to soft asphalt cement graded at "200-300". But 60-70 was obtained from the result in Table 3, which implies that the bitumen is in the range of hard asphalt grade.

3.3 Marshal Stability Test Result

In marshal stability test, the deformation of specimen of bituminous mixture is measured when the same load is applied. This test procedure is used in designing and evaluating bituminous paving mixes. The marshal stability of mix is explained as a maximum load carried by a compacted specimen (Brown and Murphy, 1994). The following results of Marshal Stability test are

Table 4: Marshal Stability Results for Optimum Binder Content

Sample	Percentage Composition (%)	Stability (kg)	Stability Correction	Corrected Stability (kg)	Flow (mm)
A_1	4.0	576	0.81	1166	2.21
A_2	4.5	858	0.78	1673	2.25
A_3	5.0	827	0.78	1613	2.50
A_4	5.5	964	0.78	1880	3.07
A_5	6.0	842	0.78	1642	3.80

Table 5: Unit weight, Void in Mineral Aggregate and Corrected Stability

Sample	Percentage Composition (%)	Unit Weight (g/cm^3)	Void in Mineral aggregate (%)	Corrected Stability (Kg)
A_1	4.0	2.48	26.26	1166
A_2	4.5	2.46	25.92	1673
A_3	5.0	2.44	25.82	1613
A_4	5.5	2.42	26.34	1880
A_5	6.0	2.41	27.09	1642

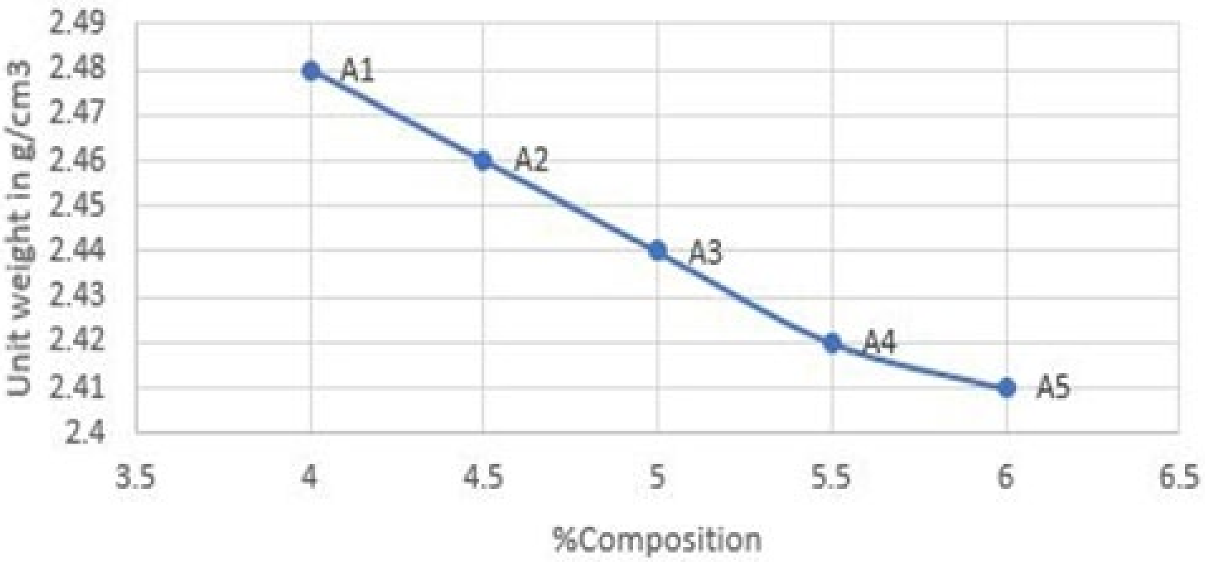

Figure 1: Unit Weight (g/cm^3) against % bitumen by weight of mix

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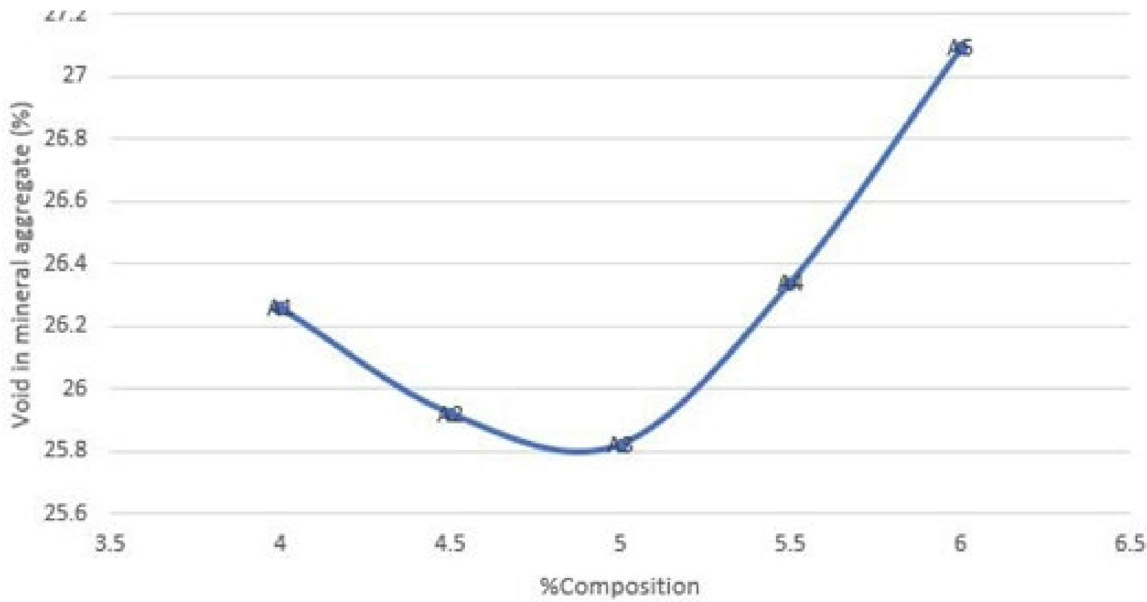

Figure 2: Void in Mineral Aggregate (%) against % bitumen by weight of mix

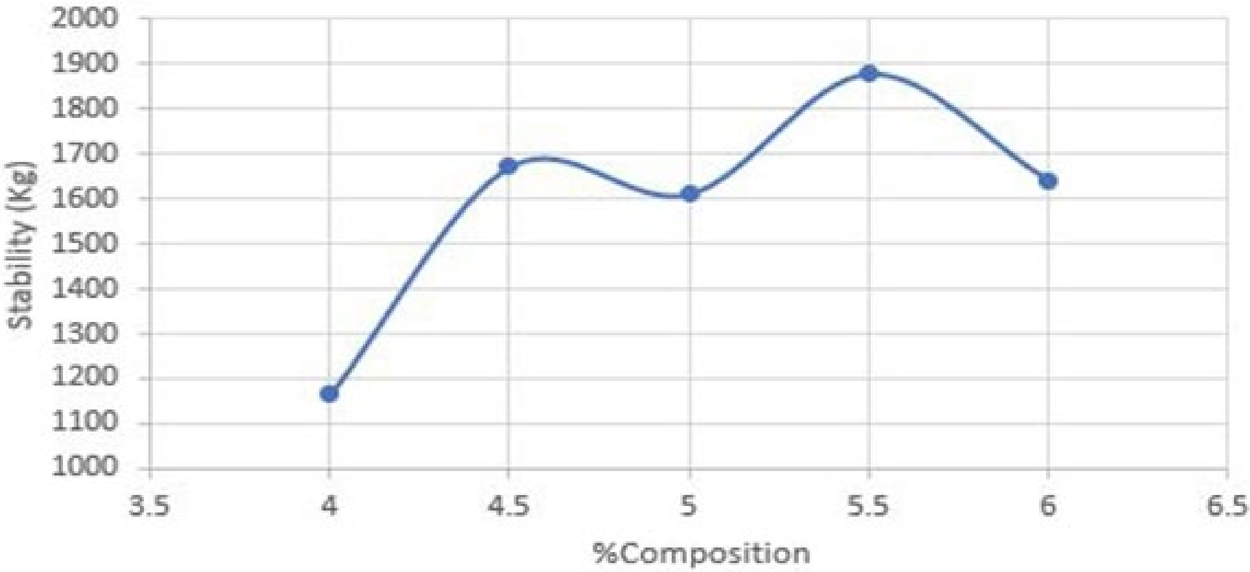

Figure 3: Corrected Stability (Kg) against % bitumen by weight of mix

The OBC was obtained as the average binder content for maximum density, maximum percent air voids in the total mix and Maximum stability. The Optimum Binder Content is determined from Figures 1, 2 and 3 above to be 5.5%

3.4 Marshal Stability after the Replacement

Marshal stability results for the replacement is given as follows:

Table 6: Stability of the replacement

Sample	Stability (kg)	Correlation Ratio	Corrected Stability (kg)	Flow (mm)
A_1	890	0.76	1792.5	3.10
A_2	835	0.76	1681.7	2.90
A_3	900	0.76	1812.6	3.30
A_4	860	0.76	1732.0	3.00
A_5	870	0.78	1798.3	3.01
A_6	815	0.78	1684.6	2.80
A_7	810	0.81	1738.7	2.60
A_8	917	0.78	1895.4	3.40
A_9	925	0.81	1985.5	3.42

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Sample	Stability (kg)	Correlation Ratio	Corrected Stability (kg)	Flow (mm)
A_{10}	1020	0.76	2054.3	3.63
A_{11}	650	0.83	1429.7	2.10
A_{12}	635	0.78	1312.6	2.30

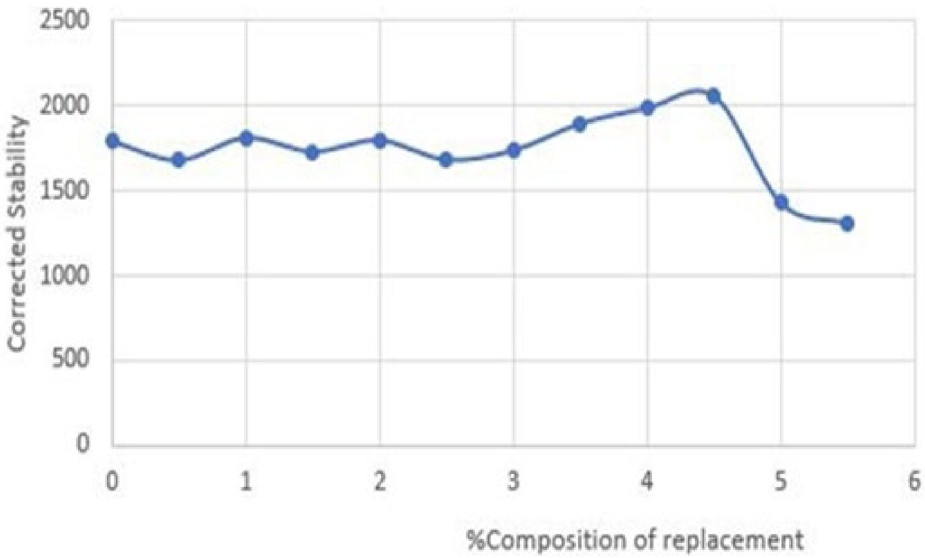

Figure 4: Variations in stability of bitumen with increase in percentage of plastic

From Figure 4, it is obtained that the point at which the maximum stability occurs is at percentage composition of 4.5% and the corrected stability value is 2054.3 kg (20.15 kN)

The graph of corrected stability versus the percentage composition of plastic replacement used in the production of the asphalt concrete is shown in Figure 4. It shows that introducing plastics into the asphalt concrete increases its stability. This agrees with the study of Kotresh *et al.* (2016). The increase in stability could be ascribed to the addition of the mixture of the plastic and bitumen. Nevertheless, the stability values of the plastic-modified asphalt concrete samples were all greater than 3.5 kN, which is the least value specified in the General Specifications for Roads and Bridges (FGN, 1997). This implies the plastic-modified asphalt concrete can be used for the construction of pavements.

4.0 Conclusion

The study investigates the utilization of waste plastics as partial replacement for bitumen in asphalt concrete. The study was necessitated because of the high volume of this waste being generated daily, which makes it imperative that it should be safely disposed of. It was found that the introduction of plastic causes an increase in the stability of the asphalt concrete and it reduces flow. This implies that adding plastic as partial replacement for binder could improve the resistance of permanent deformation of asphalt, while there is concern about the reduction in fatigue resistance. Generally, the study finds that plastic can partially replace binder in the production of asphalt. However, further tests such as the indirect tensile stiffness modulus, indirect tensile fatigue test or four-point bending test, repeated load axial test, etc., will be required to ascertain the properties of the waste PET-modified asphalt concrete.

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