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Physico-Mechanical Characterization Of Polyethylene Terephthalate (PET)- Modified Ashalt For Enchanced Flexible Pavements

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Abstract
Cameroon faces a growing waste pollution crisis, with plastic waste posing a major challenge due to its non-biodegradability. Additionally, premature pavement failures remain a persistent issue despite the enforcement of quality-controlled construction practices. To address both challenges, this study investigates the modification of pure bitumen using polyethylene terephthalate (PET) waste and evaluates its impact on asphalt concrete properties. Supermont PET waste bottles were used as the plastic source, while bitumen was supplied by ERES Cameroon. The bitumen was first characterized through standard laboratory tests and then compared with PET-modified bitumen at varying dosages of 0%,3%,6%,9% and 12%, and its effects on consistency and stability were analyzed. The softening point increased from 55.0ºc (0% PET) to 61.0ºc (12% PET), while penetration values decreased from 43.0mm to 36.1mm, indicating enhanced stiffness. Marshall stability decreased at 12% PET. Similarly, flow values increased from 16.3mm to 30.7mm. aging resistance was assessed using the rolling thin film oven (RTFO) test recorded a mass loss reduction from 0.29% to 0.04%, while adhesion tests showed a decrease from 0.9% to 0.3%. overall, the results demonstrate that PET-modified bitumen enhances the physical and mechanical properties of asphalt concrete, with an optimum PET content of 9%. This modification not only improves pavement durability but also contributes to reducing plastic waste pollution.

Keywords: *Bitumen, Polyethylene Terephthalate (PET), Asphalt Modification, Pavement Durability, Plastic Waste Recycling.*

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I. Introduction

The development of an extensive and durable road network is crucial for the economic and social advancement of any nation. Road infrastructure facilitates trade, connectivity, and economic activities, serving as a backbone for national development. However, the rising demand for better roads has placed immense pressure on traditional paving materials such as bitumen, leading to increased costs and environmental concerns. In developing countries like Cameroon, road networks are integral to urbanization and national growth, but their construction and maintenance face significant challenges due to material scarcity and environmental degradation [6].

A critical issue in road construction is the depletion of natural bitumen resources and the escalating cost of petroleum-based products, which are traditionally used in asphalt production. Simultaneously, waste management has become an issue of increasing concern globally, with plastic waste constituting a substantial portion of municipal solid waste. Cameroon alone generates over 600,000 tons of plastic waste annually, of which a significant portion remains unmanaged due to inefficiencies in waste collection and disposal systems [5]. The improper disposal of plastics leads to environmental hazards such as soil and water pollution, and incineration further contributes to air contamination [10].

The use of plastic waste in road construction presents a promising solution to these dual challenges: reducing plastic waste while simultaneously enhancing the properties of asphalt. Research has shown that incorporating polymers, whether natural or synthetic, can significantly improve asphalt performance, particularly in high-traffic areas [9]. Commercial polymers have long been used as asphalt modifiers; however, their high cost limits their widespread application, particularly in low-income economies [2]. As a result, researchers have turned to alternative waste materials such as polyethylene terephthalate (PET), derived from discarded plastic bottles, as a cost-effective and environmentally friendly asphalt modifier [11].

PET is a thermoplastic polymer that exhibits high strength, durability, and resistance to environmental degradation. These properties make it a suitable candidate for improving the mechanical characteristics of asphalt concrete [3]. Studies conducted in various countries, including Australia and Canada, have demonstrated that PET-modified asphalt exhibits enhanced resistance to rutting, moisture damage, and fatigue cracking [8]. Furthermore, the incorporation of PET reduces the demand for virgin bitumen, thereby lowering production costs and promoting sustainability [7].

In Cameroon, where waste management remains a significant challenge, leveraging plastic waste as a road construction material aligns with circular economy principles by transforming waste into a valuable resource. This approach not only addresses the pressing issue of plastic pollution but also enhances the longevity and performance of road infrastructure, making it more resistant to extreme weather conditions and heavy traffic loads. Previous studies have shown that PET-modified asphalt exhibits superior performance characteristics compared to conventional asphalt, with improvements in stability, resistance to deformation, and increased compactness of bituminous mixes [1],[4].

The primary objective of this research is to investigate the feasibility of using PET waste as an additive in asphalt concrete, assessing its impact on mechanical and structural properties. This study will analyze the effects of PET-modified asphalt on parameters such as Marshall stability, water absorption, rutting resistance, and overall durability. By integrating PET waste into asphalt production, this research aims to contribute to sustainable construction practices while mitigating environmental pollution in Cameroon.

Through an extensive experimental analysis, this study seeks to validate the potential of PET waste as a viable solution for enhancing road infrastructure while addressing plastic waste management challenges. The findings will provide valuable insights for policymakers, engineers, and environmentalists, offering a pragmatic approach toward sustainable development in road construction.

II. Materials And Methods Of Experimentation

Materials

Polyethylene Terephthalate (PET) waste bottles from the Supermont brand were collected from Bamenda 3 localities and used as the plastic source. Pure bitumen, supplied by ERES, was heated and transferred to a boiler truck, where its temperature was maintained within the range of 170°C to 180°C before use. The aggregates, including crushed gravel fractions of 10/14 and 6/10, as well as quarry sand (0/6), were sourced from the BUNs quarry. These materials were combined to produce asphalt concrete (bituminous concrete), ensuring a well-graded mixture suitable for road construction applications.

Figure 1: Materials used **(a)** Samples of Different classes of gravel (b) Rubbish dump with Several plastic bottles (Supermont bottles were sorted and used)

Characteristics of materials

The table 1 below gives the composition of various components of the composites.

Properties	Present study	Fokwa et al. 2019 [18]	
Softening point (°c)	170	170	
Penetration point(mm)	43.0	88	
Softening point of pure bitumen (mm)	55.0	45	

Percentage of the gravel 10/14 (%)	25	32	
Coarse sand 6/10 (%)	20	15	
Sand 0/6 (%)	55	53	
% mass loss (RTFOT)/NF EN 12607-1	0.29	Not reported	
Adhesion (%loss)	0.9	Not reported	

Processing waste PET

After collection, the bottles were rinsed in a water bath and then dried to eliminate any soil particles and to eliminate any none PET elements. They were then shredded and heated in a pot for several hours until they became completely liquid.

Sample preparation

Pure bitumen used in this study was supplied by ERES, while the graded gravel aggregates (0/6mm, 6/10 mm, and 10/14mm) were sourced from BUNS quarry, located at mile 10, Akom. Waste polyethylene terephthalate (PET) was cleaned, dried, and shredded into manageable flakes before being heated to a temperature of approximately 100ºC, ensuring adequate softening without decomposition, in accordance with the procedures outlined by [22]. The pure bitumen was simultaneously heated to a temperature range of 170oc to 180oc, consistent with typical mixing temperatures for bituminous binders [23]. Once both materials reached the desired temperatures, the softened PET was gradually blended with the molten bitumen to ensure a uniform mixture. Subsequently, the preheated graded aggregates were added to the modified binder and thoroughly mixed to prepare asphalt specimens. These samples were then molded for Marshall stability and other mechanical properties evaluations, following ASTM D6927-15 Standard.[24]

Physical and mechanical properties

PET Modified Bitumen Properties

i) Softening Point of PET-Modified Bitumen (ASTM D 36-95)

The softening point of pet-modified bitumen was determined following the ASTM D36-95 ring-and-ball method, adhering to the protocol used by previous researchers [12–14]. The test was conducted within a temperature range of 30°C to 157°C, using distilled water (30–80°C), USP glycerin (above 80–157°C), or ethylene glycol (30–110°C) as the immersion medium. The bitumen was heated until it flowed freely, then poured into brass rings and allowed to cool for one hour, after which excess material was trimmed. The rings were placed in a water bath for 30 minutes, with the temperature monitored. The test apparatus, including steel balls and an ASTM-compliant thermometer, was assembled, and the bath was heated at 5°C/min. The softening point was recorded as the mean temperature at which both balls fell 25 mm, providing a consistent measure of bitumen's thermal behavior.[20]

Figure 2: Softening Point test apparatus

ii) Penetration Test Of PET-Modified Bitumen

The penetration test on PET-Modified bitumen was conducted following NF EN 1426 [20]. The bitumen was heated to 90°C and stirring to ensure uniformity. It was then poured into a container and allowed to cool at room temperature for one hour before being placed in a water bath for 30 minutes, with the bath temperature recorded during the final 5 minutes. The container was positioned beneath the penetrometer's needle, and the needle was lowered to just touch the bitumen. After recording the initial reading, the needle was allowed to penetrate the sample for 5 seconds, and the final reading was taken. The container was returned to the water bath for 5 minutes, and two additional readings were taken at different spots on the sample.

iii) Rolling Thin Film Oven Test RTFO

RTFOT is a method used to simulate the short-term ageing behavior of bituminous binders in hot mix asphalt, as outlined in EN 12607-1. To begin, a sample of asphalt binder is heated until fluid and stirred to ensure homogeneity while removing air bubbles. For mass change determination, two RTFO bottles are labeled and weighed empty. Then, 35 g (1.23 oz) of asphalt binder is poured into each bottle, which is placed on its side on a cooling rack without twisting. The bottles are allowed to cool for 60 to 180 minutes. After cooling, the bottles are re-weighed, and the weights are recorded. The bottles are then placed in the RTFO oven carousel, where they are rotated at 15 RPM for 85 minutes at 325°F (163°C), with airflow maintained at 244 in³/min (4000 ml/min). After the test, the bottles are cooled for 60 to 180 minutes, weighed again, and their residue discarded. The mass change is calculated as a percentage of the initial mass using the formula:

Variation in mass (%) = $\frac{A-B}{A} \times 100$ (1)

Where:

A = initial sample weight

B = final sample weight

Typical mass loss ranges from 0.05 to 0.5 percent.

iv) Marshall Stability Test

The test measures the stability and flow of a cylindrical bituminous pavement specimen using the Marshall machine as outlined by NF P98-251-2 standard [19]. The objective is to determine the stability and flow to predict the performance of the Marshall Mix design method and find the optimum binder content for the aggregate mix and traffic intensity. The procedure involves batching and heating the bituminous constituents (gravel, sand, fillers, and bitumen) at 150°C, followed by mixing them in a specific order. The mixture is then heated at 200°C for 40 minutes. Plastic sheets are placed in the mould, and the mixture is compacted using the Marshall compaction machine with 50 strokes per side. The molded specimen's mass and average height are measured, and it is then placed in a 60°C water bath for 30 minutes. After cooling, the mass is re-weighed, and the specimen is ready for testing on the Marshall machine

III. Results And Discussion

Grain size analysis

The grain size distribution curves of all tested samples align closely with the reference envelopes specified by the French standard (NF P 18-560). This conformity indicates that the aggregates meet the gradation requirements necessary for optimal compaction and mechanical performance in pavement applications. The consistency with the standard curves also suggests a well-graded mix, which is essential for ensuring adequate interlocking, reduced void content, and improved load- bearing capacity. [25-26]

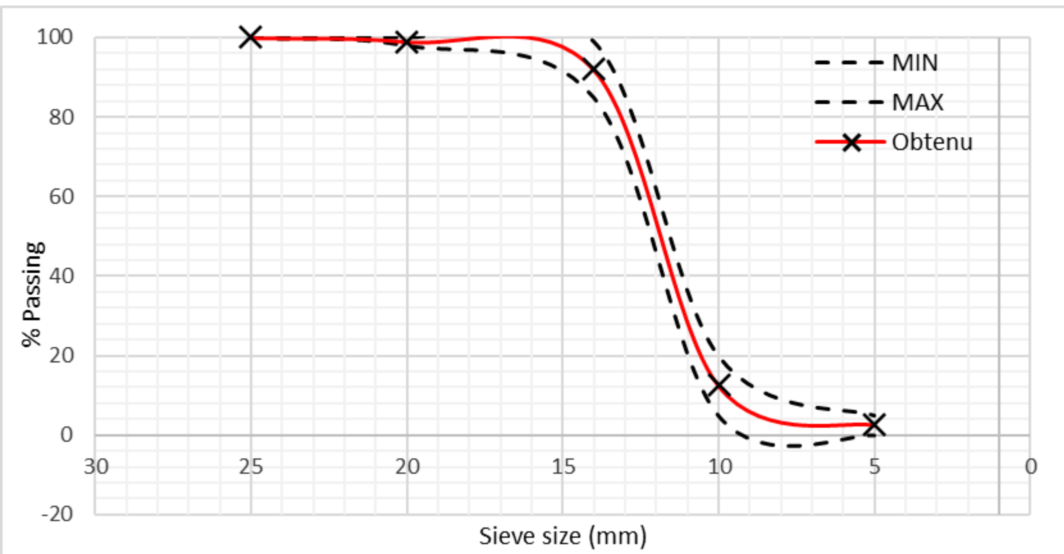

Figure 3: Graphical data for 0/6 GSA

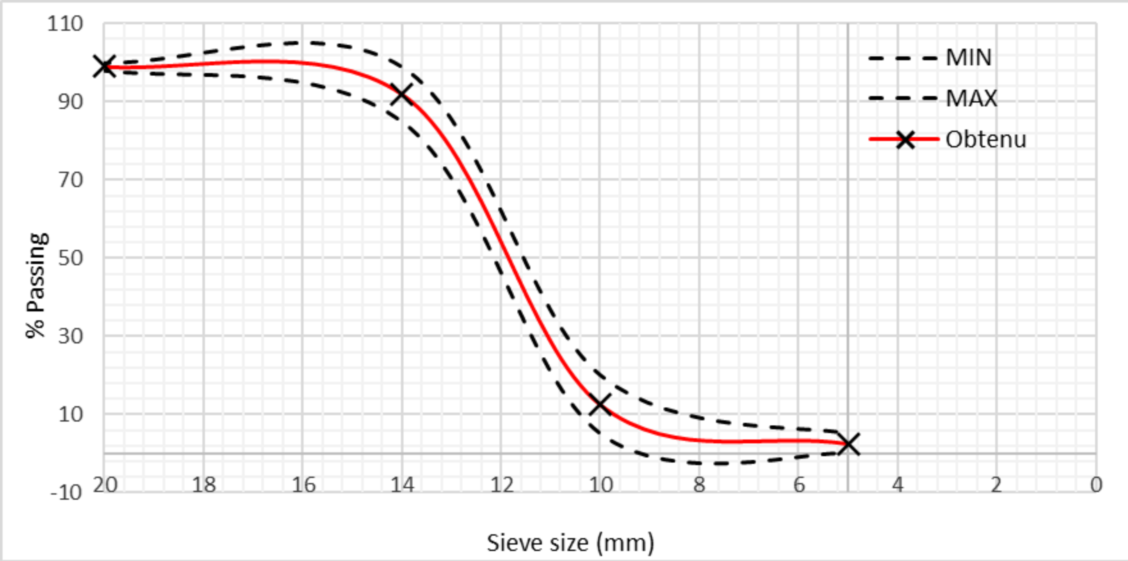

Figure 0: Graphical representation of GSA data (10/14

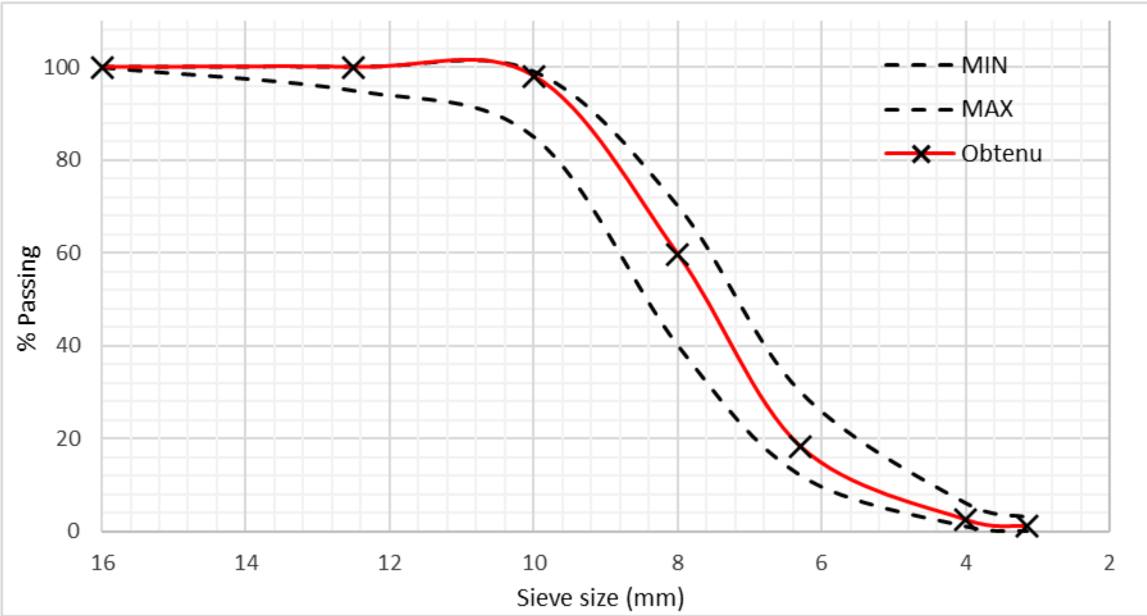

Figure 5: GSA Graph for Gravel 6/10

PET Modified Bitumen Properties

Softening Point

The softening point of PET-modified bitumen showed average temperatures ranging from 56.0°C to 61.0°C, measured under the same conditions as pure bitumen. Detailed results are presented in Table 2

Table 2: Softening point result for all samples

SOFTENING POINT FOR EACH SAMPLE					
DESIGNATION	% of PET Polymer				
%		3	6	9	12
S.P ^{0}C		56.0	59.4	60.1	61.0

The results of the softening point test indicated a gradual increase in the softening point temperature, ranging from 55.0°C to 61.0°C. At 9% and 12% PET content, the softening point values shifted the modified bitumen to a higher grade, placing it in the 20/30 bitumen classification. However, this shift is not conclusive, as the penetration values remain within the 35/50 bitumen range. These findings align with the study by [15].

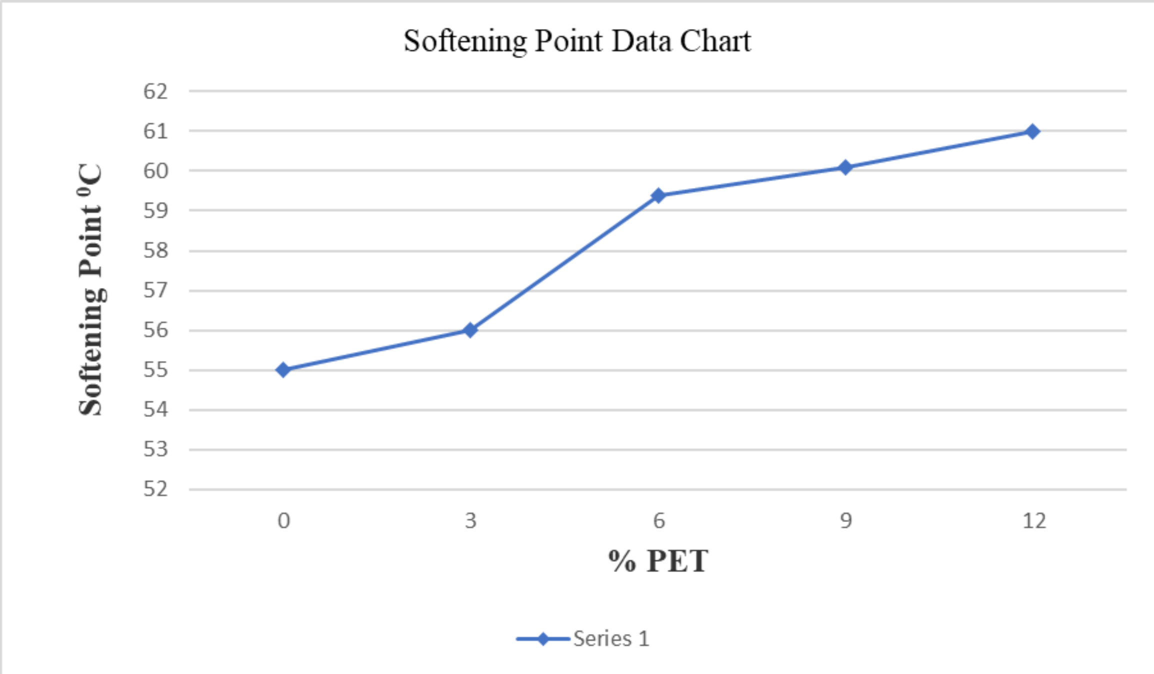

Figure 6: Graphical Illustration for Comparative Softening point results

Penetration Test for PET modified Bitumen

The penetration test for PET-modified bitumen resulted in penetration values ranging from 36.1 to 42.2 at 0.1 mm. All results are presented in Table 3 below.

Table 3: Penetration test results for all samples

Penetration at 0.1 mm for all samples				
Designation (%)	% of PET			
	3	6	9	12
Penetration (mm)	42.2	40.0	38.3	36.1

Similar to pure bitumen, we conducted the penetration, softening point, and Marshall stability tests to characterize the modified bitumen. It was observed that as the percentage of PET increased, significant changes occurred in the results of all three tests. Samples with 3%, 6%, 9%, and 12% PET by pure bitumen mass were prepared at room temperature. The penetration values showed a steady decrease with increasing PET content, ranging from 43.0 to 36.1 mm. This trend is consistent with the findings of [4].

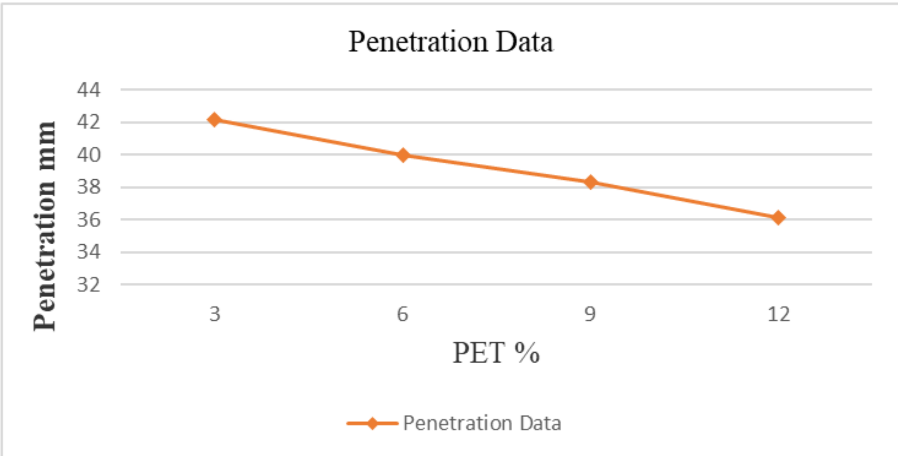

Figure 7: Comparative Graphical Results for Penetration

Rolling Thin Film Oven test

The rolling thin film oven test was carried for each of the chosen samples of modified bitumen and the following results were obtained.

Table 0: Modified Bitumen RTFO data report

Mass of empty flask = 165.6 g					Specification
PET %	3	6	9	12	
Initial mass (g)	200.35	199.97	200.55	200.43	
mass after hardening (g)	200.25	199.88	200.46	200.35	
Change in mass (%)	0.29	0.05	0.04	0.04	≤ 0.5
Penetration (mm)	65.3	65.1	64.8	64.7	≥ 53
Softening point (°C)	59	62	64	63	≥ 52
Augmentation in SP	3	3	4	2	≤ 8

The rolling thin film oven test results for modified bitumen all fell within the acceptable aging range for bitumen used for the production of asphalt concrete. This assures the users that the PET modified bitumen will not fail during processing of asphalt concrete.

The results obtained from the adhesion test was simillar to the RTFO test. We observed a significant reduction in the % mass loss as PET content was increased.

Similarly, the Marshall stability value exhibited a steady increase in its load bearing capacity with increase in PET content. However, it had a slight decrease at 12% PET content. Meanwhile, the deformation increased steadily with increase in PET content. The deformation value ranged from 19.0 – 30.7 mm and the MSV ranged from 13.5 – 18.1 kN

Adhesion Test

The adhesion properties of the modified bitumen were as follows;

Table 5: Adhesion Test Data for PET modified bitumen

S/N	% PET			
	3	6	9	12
Mass before boiling	29.2	32.3	35.0	28.7
Mass after	28.9	32.1	34.9	28.6
% mass loss	0.8	0.6	0.3	0.3

Marshall Stability Test

The Marshall stability test resulted in a steady increase in deformation between 3-9 % and then a slight reduction at 12%. Detailed results shown on table 6.

Table 6: Marshall Stability results

Marshall Stability for all samples				
Designation (%)	% of PET			
	3	6	9	12
Deformation (0.1 mm)	21.0	24.8	37.4	30.7
Stability (kN)	13.5	16.4	18.1	16.7

Comparative Results Between the Physico-Mechanical Properties of The Pure Bitumen and Modified Bitumen

In other to properly illustrate the differences or compare the above results, tabular and graphic illustrations give an adequate picture of the differences. The comparative results for the Penetration, softening point and Marshall test results are illustrated below.

Comparative Analysis Between Pure Bitumen and Modified Bitumen

We observed that with every increase in PET content, Penetration and softening point exhibited an inverse relation. As PET content increases, penetration values reduce meanwhile softening point values increase. This is consistent with the study by [16] where they stipulated that PET modification causes increases in softening point and reductions in penetration. Since, the decreased penetration, and increased softening point temperature indicate increased stiffness (hardness) of the PMBs, the results demonstrate that the asphalt mixtures prepared with the PET PMBs may be less sensitive to permanent deformation. This complements studies done by [7] and [4]

The Rolling thin film oven test assesses short-term aging of bitumen. Short-term ageing is deemed to represent the ageing a bituminous binder undergoes during handling, storage, mixing, and laying of asphalt mixtures [21]. Although many different factors contribute to asphalt binder aging, the key component of concern for the RTFO is the loss of volatiles. The loss of smaller molecules from the asphalt binder, often termed "volatiles" increases an asphalt's viscosity (Pavement, 2023). Asphalt binders typically lose volatiles during the manufacturing and placemen processes. The elevated temperature of these processes ages the asphalt binder by driving off a substantial number of volatiles. Field tests have shown that in-place asphalt binder does not lose a significant number of volatiles over its life [17]. We can deduct from this that the lesser the % change in mass of bitumen, the more durable it is. Therefore, from the results obtained from the RTFOT, we observed a significant reduction in % mass loss with increase in PET content. That is; pure bitumen had a 0.29% loss in mass after the test while PET modified bitumen had a 0.03% loss in mass at 9% and 12% PET content.

Similar to RTFO test, a slight addition of PET into bitumen does not have a significant effect on its adhesion with gravel. However, we observed a significant drop in percentage loss compared to pure bitumen with the 6%, 9% and 12% PET addition. This drop ranged from 0.8% at 0% PET content to 0.3% at 12% PET content.

In the case of the Marshall stability test, there was an overall increase in stability as compared to pure bitumen. We observed an appreciable increase from 12 kN to 18 kN. This is consistent with similar studies carried out by [8],[18]. This is due to void reduction by PET, increasing the compacity of the concrete. This helps reduce water absorption and reduces rutting. At 9% PET we got the best of results. However, the flow values conflict with the results from a study by [1],[19].

Bitumen grade 35/50 was used for study, unlike other studies in which either bitumen grade 60/70 or 70/100 is used. Overall, modified bitumen showed significant augmentation to the physical and mechanical properties of bitumen when compared to pure bitumen. Despite the fact that obtaining the fatigue (long-term aging) was not possible, this study still is unique for the exploration of the effect of PET modified bituminous concrete on its short-term aging and adhesiveness of the material with aggregates. Both properties are key factors of the durability of asphalt concrete.

Softening Point Test

The obtained results from all samples exhibited some differences with addition of PET. This variations in results are illustrated in the table 7 and graphs below.

Table 7: Comparative Softening point results

SOFTENING POINT FOR EACH SAMPLE					
DESIGNATION %	% of PET Polymer				
	0	3	6	9	12
S.P ^{0}C	55.0	56.0	59.4	60.1	61.0

Penetration Test

Similar phenomena were observed for the penetration as for softening point. However, the effect was rather inverse. Details below;

Table 8: Comparative Results for Penetration

PENETRATION FOR EACH SAMPLE					
DESIGNATION %	% of PET Polymer				
	0	3	6	9	12
PENETRATION	43.0	42.2	40.0	38.3	36.1

Rolling Thin Film Oven test

This test is not a classical test providing results, but an ageing/conditioning procedure for bituminous binders. The following results were obtained.

Table 9: Rolling Thin Film Test Data and results

Mass of empty flask = 165.6 g						Specification
PET %	0	3	6	9	12	
Initial mass (g)	200.21	200.35	199.97	200.55	200.43	
mass after hardening (g)	200.11	200.25	199.88	200.46	200.35	
Change in mass (%)	0.29	0.29	0.05	0.04	0.04	≤ 0.5
Penetration (mm)	65.4	65.3	65.1	64.8	64.7	≥ 53
Softening point (ºC)	57.5	59	62	64	63	≥ 52
Augmentation in SP	3	3	3	4	2	≤ 8

Adhesion Test

Table 10: Comparative results for PET – Bitumen admixture Adhesion

S/N	% PET				
	0	3	6	9	12
Mass before boiling	32.8	29.2	32.3	35.0	28.7
Mass after	32.3	28.8	32.1	34.9	28.6
% mass loss	1.5	1.4	0.6	0.3	0.3

Marshall Stability Test

Table 11: Comparative Results for Marshall Stability

MARSHALL VALUE FOR EACH SAMPLE					
Designation	% of PET Polymer				
%	0	3	6	9	12
Deformation (0.1 mm)	16.3	19.0	22.8	26.4	30.7
Stability (kN)	12.02	13.5	16.4	18.0	16.3

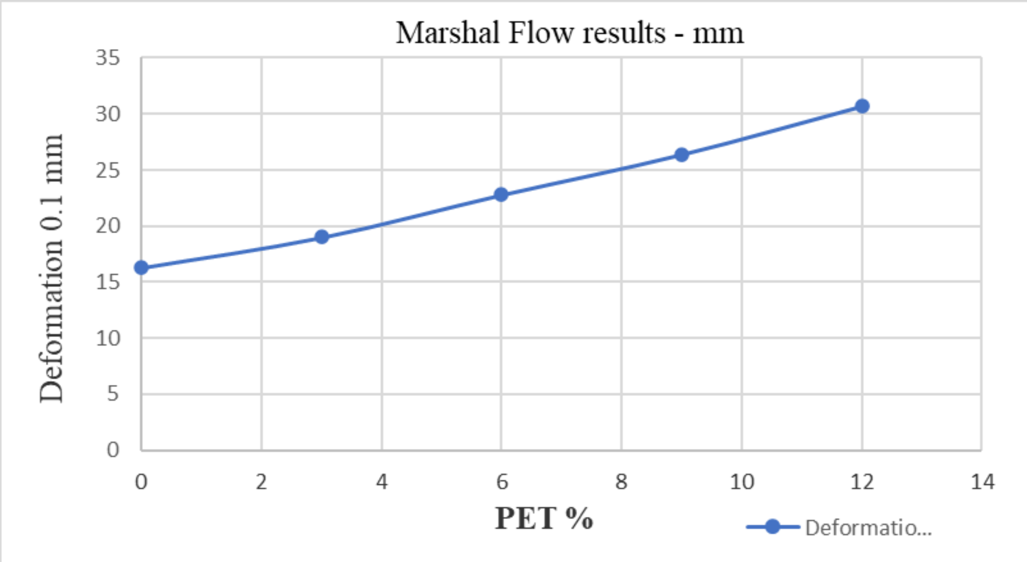

Figure 8: Comparative Graphical Results for Marshall Stability

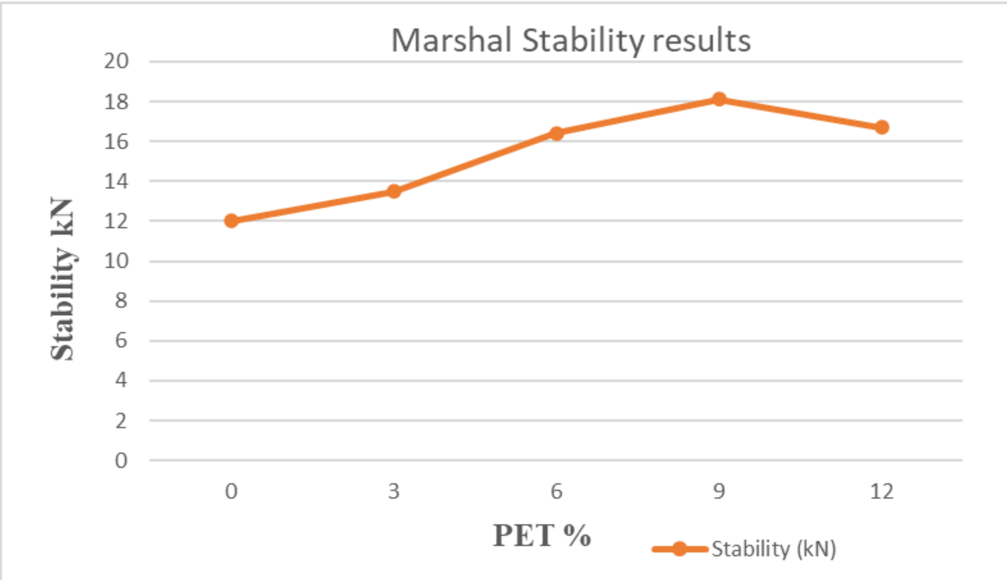

Figure 9 Graph of Marshal test results

IV. Conclusion

Faced with degraded roads and the demand for more paved roads that are constantly expensive and with waste Polyethylene terephthalate (PET) plastic that is also an environmental problem due to population growth and industrial expansions. This work aims investigating if modifying pure bitumen with PET yields favourable physical and mechanical properties on bitumen. Based on laboratory results and discussions, the following conclusions were made.

Pure Bitumen Properties

The pure bitumen was identified as a dark, sticky, thick and heavy material. Produced from the refinery process of crude oil. Based on the penetration grading system it was found to be 35/50 grade bitumen.

PET Modified Bitumen

The penetration test for modified bitumen ranged from 43.0 – 36.1 mm with increased PET content. On the other hand, softening point value ranged from 55.0 – 61.0 ^{0}C with increase in PET content. Overall, the Marshall stability test which is considered to simulate with field conditions showed a general increase with all additions of PET. It ranged from 21 – 30.7 mm.

Comparative Analysis

Analysing both pure bitumen and modified bitumen we observed clearly the effects of PET on the bitumen. As PET content was increased, softening point increased while penetration reduced. Pure bitumen had an average softening point of 55.0 ^{0}C and an average penetration of 43.0 mm. Meanwhile, PET modified bitumen exhibited a steady increase in its softening point (55.0 – 61.0 ^{0}C) and steady decrease of penetration (43.0– 36.1 mm). The Marshall flow values and stability values for PET modified bitumen were found to significantly improved. That is; deformation increased from about 16 mm to 30.7 mm and the stability value from 12 kN to 18 kN. Similarly, from the rolling thin film test and adhesion tests which are key actors in the durability of bitumen and its products showed appreciable improvements.

This study used PET obtained from Supermont bottles and from the obtained results, there was significant and appreciable improvements on the physical and mechanical properties of asphalt concrete. Implying that, if this is applied in real time projects, we can see a huge decrease in plastic waste in our communities. The optimum admixture was at 9% PET content. This is similar to work done by Fokwa et al, whose optimum was at 10% and that of Adama et al, though having his optimum at 7% PET addition. Overall, with every percentage PET increase, stability increased, increasing compacity, increasing water resistance, reducing void ratio and increasing affinity to aggregate surface. This has the capacity to save the government plenty of money. Therefore, it is safe to conclude that adding PET into asphalt concrete 0/14 contributes to an appreciable increase in strength and mechanical properties of bituminous mixes and can greatly reduce plastic waste from our communities.

The following recommendations were arrived at from the findings of this study:

- PET modified bitumen can be applied to all type's flexible pavement projects, irrespective of the traffic specifications. Its property improvements will improve the lively hood of any kind of flexible road design with asphalt.
- Based on ease of handling, application and energy management, I will recommend the use of 9% PET in asphalt concrete pavements.
- In other to apply this to full scale construction projects, stake holders such as the government, local authorities, private industries must fully engage in proper waste collection, sorting and recycling. To produce a ton of molten PET or even shredding them requires massive industrial input in terms of producing huge furnaces to heat the plastic waste or making huge and effective shredding equipment to shred the plastic waste.

Data Availability

The raw data needed to replicate these findings cannot be disclosed at this moment, as it is part of an ongoing study.

Conflict Of Interest

The authors have no conflicts of interest related to the publication of this paper.

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