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Studying the Sustainable Application of Waste Polystyrene and Water Sachet in Hot Mix Asphaltic Concrete

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Abstract: *This paper looked at how including waste polystyrene and water sachet to hot mix asphaltic concrete affected performance and sustainability. Hot bitumen mix was produced by weighing 60/70 penetration grade bitumen into 10 containers before heating. The study then generated unaltered hot bitumen mixes. Adding waste polystyrene and water sachet at 2–18% at 2% intervals changed the hot bitumen mix samples. The laboratory evaluated bitumen, aggregates, unmodified and modified hot mix asphaltic concrete. Tests included penetration, softening point, ductility, flash and fire point, sieve analysis, aggregate crushing, impact, flakiness, elongation, and Marshall stability. The mix design to meet requirements employed waste polystyrene and water sachet modifications from 0% to 20% by weight of bitumen. The study discovered that hot mix asphaltic concrete's performance was enhanced by adding waste polystyrene and water sachet. Waste polystyrene and water sachet content enhanced the Marshall stability of asphaltic concrete, reaching at 12% with 26.9 kN, better than the control mix. Indicating good workability, the flow measurements were 8–18 mm with optimal flow at 12% polystyrene. The revised mix demonstrated lower load deformation and greater Marshall stability, suggesting improved rutting resistance. Air and mineral aggregate voids were up to standard. Under traffic stresses, the Marshall quotient—which gauges flow stability—also got better. Stability, rutting resistance, and shear deformation resistance were all enhanced by adding 12% waste polystyrene to asphaltic concrete. This research proposes a sustainable alternative for increasing engineering features of hot mix asphaltic concrete while addressing waste management challenges*

***KEYWORDS*:** *Waste Polystyrene, Waste Water Sachet, Bitumen, Hot Mix Asphaltic Concrete, Marshall Stability*

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1. INTRODUCTION

Increased axle loading, among other things, has been widely documented as causing early pavement failures on Nigerian roads (Akinleye & Tijani, 2017, Akinleye et al., 2025a; 2025b, Salami et al., 2025a; 2025b). This trend has stretched construction materials and traditional design methods to their limits. Sustainable building materials are therefore of utmost importance. A major field of study meant to improve the performance and sustainability of asphalt pavements has been the modification of Hot Mix Asphalt (HMA) with several additives. Two such additives are waste water sachet and polystyrene. When applied in asphalt modification, every one of these materials has certain advantages and poses particular issues.

Made from the monomer styrene, polystyrene is a synthetic aromatic hydrocarbon polymer. Its stiffness and insulating qualities make it quite common in many uses, including packaging and insulation. Polystyrene can be used to asphalt alteration either as a crumb or as expanded polystyrene (EPS) beads. Polystyrene modification can enhance mechanical qualities of asphalt including stiffness and resistance to distortion at high temperatures (Goh et al., 2015, Akinleye et al., 2023, Salami et al., 2025b). This can increase the lifetime of pavement in operation and help to resist rutting. Incorporating EPS beads also helps to lower the total weight of the asphalt mix, which could help to lower the load on pavements and underlying structures (Yuan et al., 2017, Ajayi et al., 2025).

The use of waste water sachet in hot mix asphaltic concrete, however, is a creative way to solve environmental and performance issues in asphalt pavement building. Often utilized in many areas for drinking and other activities, waste water sachet creates major disposal problems. Including this trash into asphalt could provide environmental advantages as well as possible financial savings. Including waste from water sachet into hot mix asphaltic concrete can lower the environmental effect of waste sachet by diverting it from landfills, therefore lowering pollution and converting waste to riches (Osei et al., 2021). This strategy supports circular economy initiatives and helps to control waste sachets more sustainably.

However, the ultimate product's safety and value may be compromised by HMA concrete. The problem is the effective regulation of water content to prevent adverse effects on the asphalt mix, including probable increased moisture sensitivity, compromised structural integrity, and decreased workability (Hassan et al., 2019, Salami et al., 2025a, 2025b). Consequently, the objective is to evaluate the performance and feasibility of incorporating polystyrene and waste water sachets into HMA concrete, with a particular emphasis on the final product's environmental sustainability, lifetime, and physical attributes. So, this investigation investigated the impact of waste polystyrene and water sachets on hot mix asphaltic concrete.

II. MATERIALS AND METHOD

2.1 Materials

Samples of crushed granite was sourced from an indigenous quarry in Ede, Osun. The samples have been evaluated for physical and mechanical qualities. Among the tests conducted were sieve analysis, specific gravity, water absorption capacity, aggregate abrasion, crushing, and impact values. With most of the particles under 5 mm, fine aggregates are usually composed of natural sand or broken stone. Sharp sand from a nearby Ede quarry was the fine aggregate employed. Sieve analysis and particular gravity are among tests run. A nearby quarry Ede, Osun State provided quarry dust. Sieve analysis, moisture content and specific gravity were tests run. Electronic dumpsites around Ede provided the polystyrene needed. The obtained polystyrene was then shredded into tiniest sizes. Waste water sachet came from landfills surrounding Adeleke University, Ede, Nigeria. A temperature controlled hot plate was used to melt the waste sachets. The asphaltic concrete was made using grade 60/70 asphalt cement. Obtained from Ogun State bitumen facility, the bitumen was tested for Penetration, Flash point, Ductility and softening point.

2.2 Method

To ensure uniformity in quality and specification compliance, a sieve analysis test was conducted. It shows the mass proportions of the parts of an aggregate sample. The study employed the dry sieve analysis methodology. The aggregates were acquired for sampling and sieve analysis done following British Standard 812 - 103.1 (1985). Dividing the aggregate density by the density of water gave the Specific Gravity (Gs). The pycnometer container technique following BS 1377-2 (1990) was used to compute the SG of the aggregate. The Aggregate Crushing Value (ACV) test was then carried out to assess Coarse Aggregate (CA) resistance to pulverization under a progressive compressive force. Crushed granite samples' aggregate crushing value was computed using BS 812 - 110 (1990). Dividing the aggregate density by the density of water gave Gs. The Gs of the aggregate was computed following BS 1377 - 2 (1990) utilizing the pycnometer container technique. The CA's abrasion resistance was assessed using the Aggregate Impact Value (AIV) in line with the BS 812 - 112 (1990) criteria. The flakiness test was also conducted to assess the material's relevance according the BS 812 - 105.1 (1989) criteria. At last, the CA was tested for Elongation Index (EI). This test met the BS 812 - 105.1 (1989) criteria. The materials used are shown in Fig. 1.

(a) Bitumen sample

(b) Coarse aggregate sample

(c) Fine aggregate sample

(d) waste water sachet

Fig. 1: Materials used

III. RESULT AND DISCUSSION

3.1 Characterization of Aggregate Materials Used for Asphalt Mix Production

Fig. 2 shows the grain size distribution of mineral filler, fine aggregates, and CA. The statistics reveal the distribution of specific particle sizes. The fine aggregate's D_{10}, D_{30}, and D_{60} were 0.33, 0.56, and 0.9 mm, respectively, with corresponding calculated values of Cu (D60/D10) and Cc ($D_{30}^2/[D_{60} \times D_{10}]$) of 2.7 and 1.06, respectively. ASTM D-2487 indicates that the fine-grained aggregates are badly graded since Cu < 6. Likewise, the mineral filler particle size values are 0.16, 0.22, and 0.25 mm with Cu and Cc of 1.6 and 1.19 respectively. Furthermore, since $1 \leq Cc \leq 3$, mineral filler soil categorization from ASTMD-2487 is a satisfactorily graded sample. The coarse aggregates are 5.3, 6.85 and 9 mm with Cu and Cc of 1.7 and 0.98 respectively. The ASTMD-2487 soil classification for a properly graded material of $1 \leq Cc \leq 3$ was also met by this result. The mineral filler's 85% criteria of finer than 75 microns was also met at 92%. The other factors used to assess the coarse aggregate are physical and mechanical characteristics. Coarse aggregates were shown to be suitable as aggregates for the production of the hot and warm asphalt mixes used in this work since they contain all the desired characteristics.

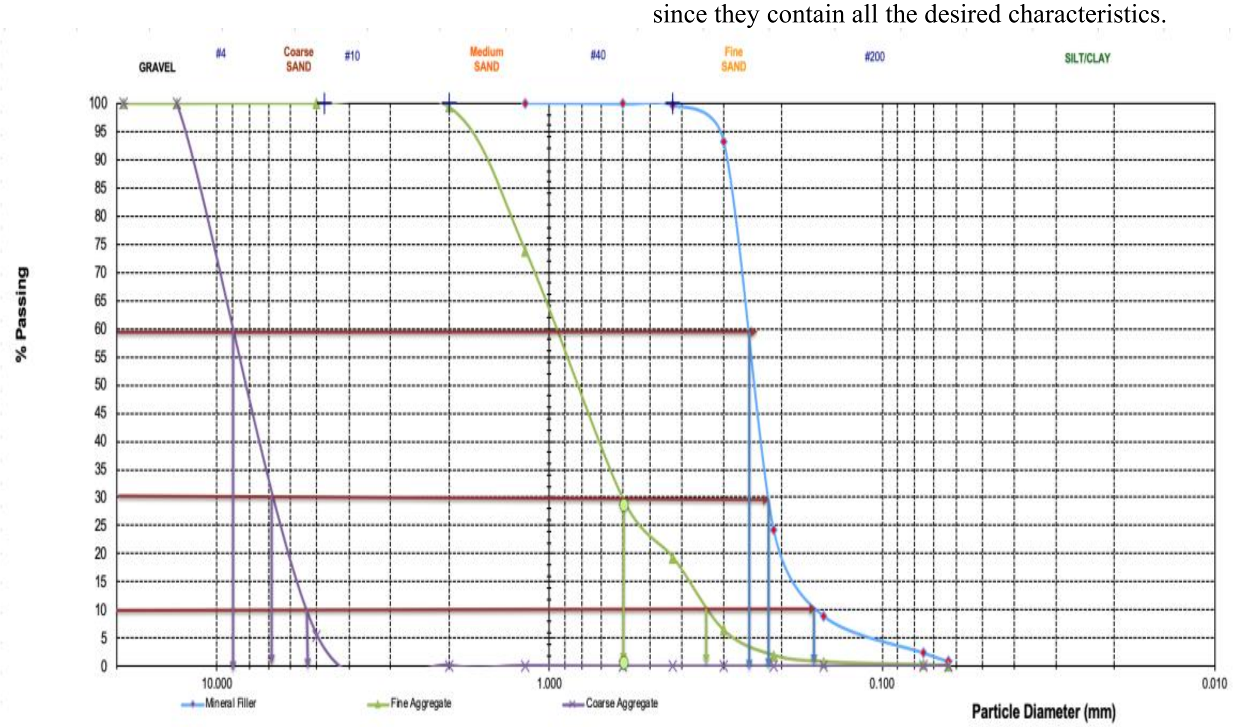

Fig. 2: Sieve analysis graph of aggregates

3.2 Test Results on Bitumen

The test findings of bitumen used in this study are shown in Table 1. The table indicates an average penetration value of 66mm for the bitumen utilized, which conforms with both FMW and ASTM criteria for bitumen penetration range between 60-70 as indicated in Table 1. The softening point value of the bitumen, however, only meets ASTM standard. Moreover, the 88cm ductility value meets the FMW and BIS criteria. Moreover, while differing from FMW norm, the particular gravity of 0.98 falls in the range of ASTM standard. The flash point value also fits ASTM standard criteria; the viscosity complies with BIS standard. The general outcomes obtained indicate that the qualities of the bitumen used for the discovery fit the criteria of the standards.

Table 1: Bitumen Attributes for Asphalt Production

Standard	Penetration (mm)	Softening (°C)	Ductility (cm)	Viscosity (secs)	Flash Point (°C)	Fire Point (°C)	Specific Gravity
	66	58	88	2668	245	282	0.98
FMW	60-70	48-56	≤100	-	Min.250	-	1.01-1.06
ASTM	60-70	47-58	-	-	Min. 230	-	0.97-1.06
BIS	-	-	≥75	≥70	-	-	-
AI	-	>50	5-100	-	-	-	

3.3 Marshall Stability Tests Results on Waste Polystyrene and Water Sachet Modified Hot Mix Asphaltic Concrete

This study seeks to identify the ideal percentage of polystyrene in the manufacture of HMA concrete and warm bitumen mix. The Optimum Bitumen Content (OBC) that was changed satisfies the FMW (2016) specification stated need for binder and wearing course. Values of volume of voids (Vv) for every polystyrene proportion change fall within the range of 3–8% and 3–5% set by the FMW (2016) and Asphalt Institute (1991) standard standards, respectively. Moreover, values for Void Filled with Bitumen (VFB) fall within the range of 65–82% and 65–80% set by FMW (2016) and AI (1991), respectively. The chart also indicated that when the polystyrene concentration in the asphalt concrete rose, the Stability measures got better. This suggests that the polystyrene content can be used up to 12% modification in a quest for maximum stability. All the values obtained for stability satisfy the requirement of FMW (2016) and AI (1991). The flow values for 0, 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20% polystyrene alterations were 5.5, 4.8, 4.1, 3.8, 3.6, 3.2, 3, 3.4, 4, 4.3 and 4.8 mm correspondingly. From 0 to 12% polystyrene modification, flow values drop; from 14% to 20% they rise somewhat. Moreover, all the flow values fall within the 2–6 mm requirement array, as specified by the FMW (2016). All the numbers acquired, however, differ from AI (1991) standard specification of 8 to 16 mm, which results from different assessment techniques used by FMW (2016) and Asphalt Institute (1991) for Marshall stability.

3.4 Discussion on Marshall stability Test Results

Based on the results acquired as depicted in Fig. 3a, marshal stability rises with rising polystyrene percentage, reaching a maximum stability value of 26.9 kN at 12% polystyrene proportion. On the other hand, after the 12% polystyrene proportion indicating the peak value, the value began to decline back to 20% replacement, which recorded 24 kN stability value; this is supported by the work of Ajagbe *et al.* (2020), Asebiomo *et al.* (2024), Salami *et al.* (2025a), Salami *et al.* (2025b), Ajayi *et al.* (2025). The 0% polystyrene fraction recorded the lowest stability value of 20.9 kN. All the values obtained, meantime, fit within the standards specifications; so, polystyrene is found to be quite efficient in stability value of asphaltic concrete.

3.5 Flow Test Results

The flow value for the polystyrene modified asphaltic concrete is shown in Fig. 3b; the data indicates that until 12% modification the flow value drops with rise in percentage polystyrene modification, then it starts to rise marginally until the 20% modification. The data reveals a maximum of 5.5 mm at 0% modification and a minimum of 3 mm at 12% polystyrene; this supports the findings obtained by Ajagbe *et al.* (2020), Akinleye *et al.* (2020), Akinleye *et al*. (2025a;2025b), Salami *et al*. (2025a).

3.6 Marshall Quotient

The Marshall quotient values increase as the polystyrene concentration increases, as illustrated in Fig. 4. The Marshall quotient values range from 3.8 to 8.9 kN/mm. There was a slight decrease, with a change from 14% to 20%. Asebiomo *et al.* (2024), Salami *et al.* (2025b), and Ajayi *et al.* (2025) have all confirmed the findings of the data depicted in Fig. 4, which indicates that the 12% polystyrene modification has the highest Marshall quotient of 8.96 kN/mm. The modification with the highest Marshall quotients yields the most optimal performance. Additionally, the Marshall quotient, which evaluates shear deformation resistance and rutting, was employed by Choudhary *et al.* (2020) to ascertain the rutting resistance of bituminous concrete. Therefore, the optimal performance is achieved with a 12% polystyrene modification. Consequently, the most efficient polystyrene content for HMA synthesis is 12% polystyrene modification.

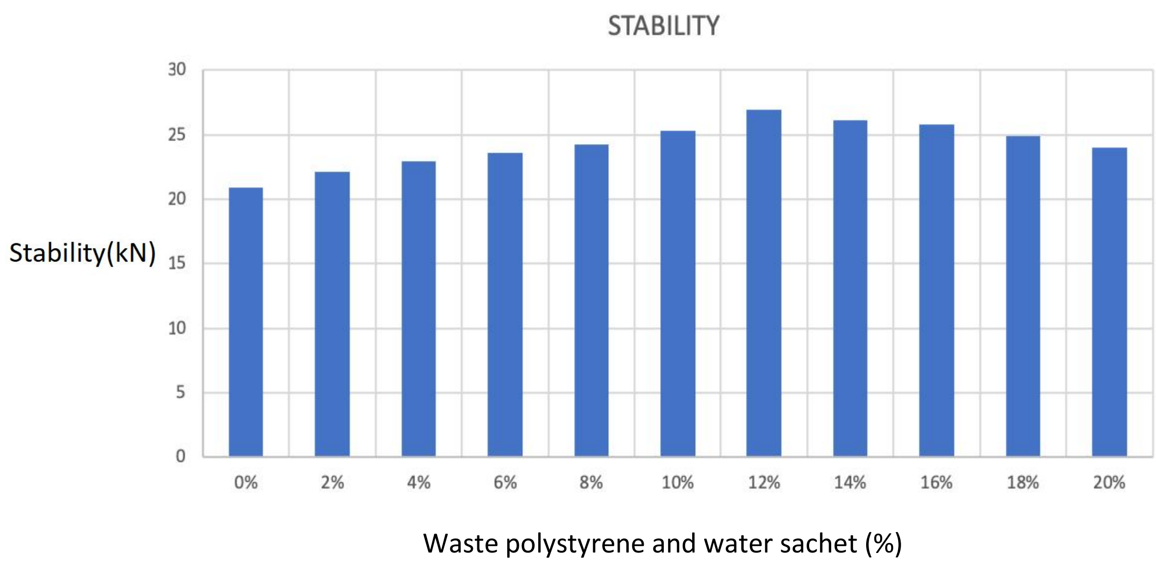

Fig. 3a: Marshall stability values for the modified HMA concrete

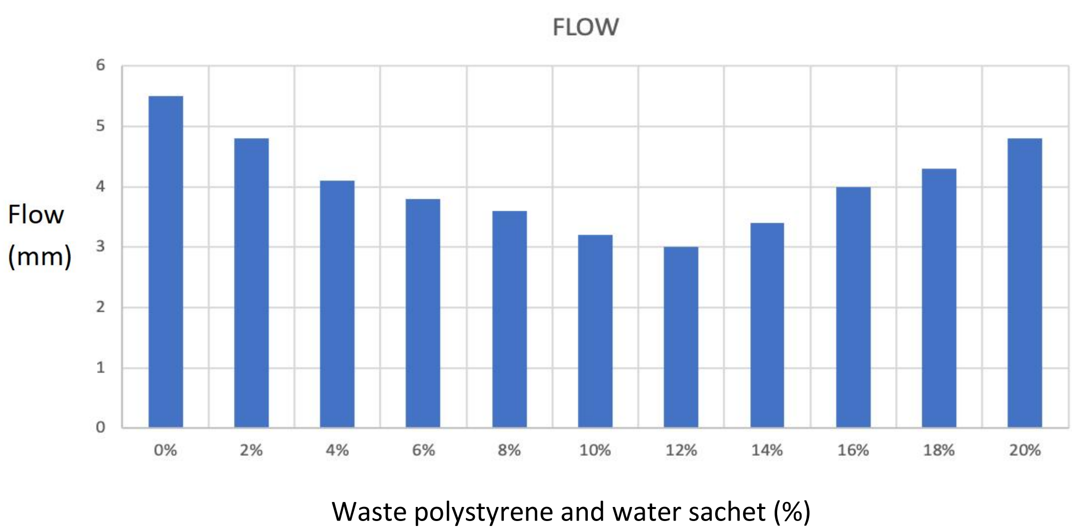

Fig. 3b: Flow values for the modified HMA concrete

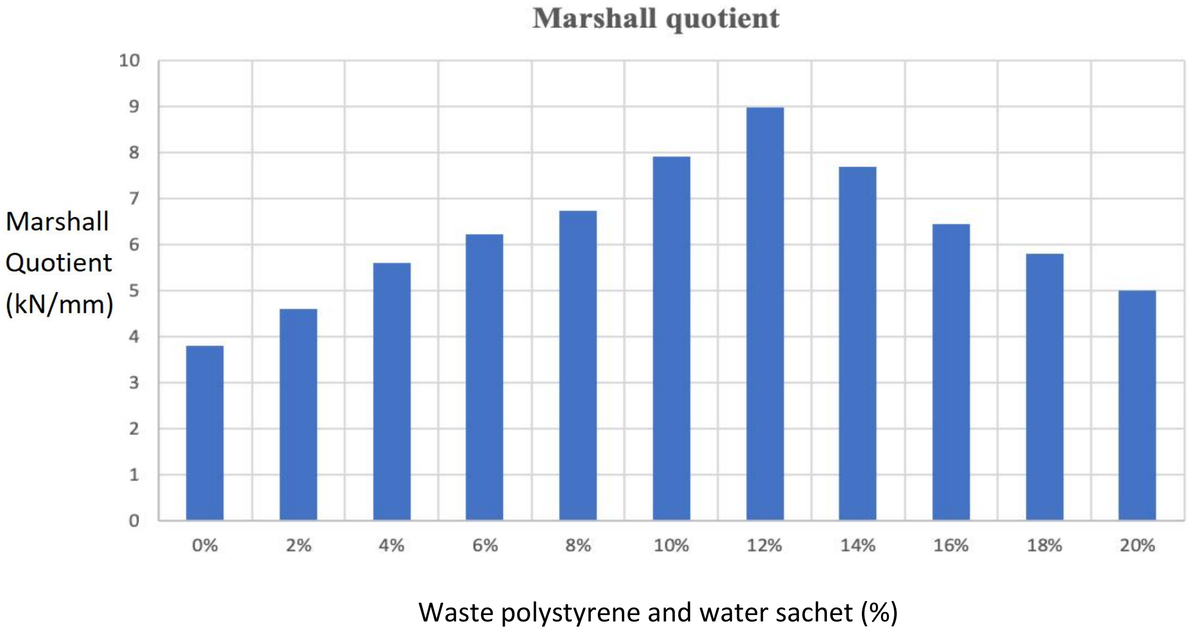

Fig. 4: Marshall quotient values for the modified HMA concrete

IV. CONCLUSION

The study assessed the performance waste polystyrene and waste water sachet on HMA concrete. By weight of 60/70 bitumen, the waste polystyrene and waste water sachet were added in 1:1 proportion from 0 to 20% at 2% intervals. Proportion of waste polystyrene and waste water sachet that gives best performance was established. Bitumen, and Marshall characteristics of asphaltic concrete were found. The investigation led to the following conclusions:

a) The index characteristics of aggregates meet the specification criteria; likewise, the bitumen qualities including ductility, flash and fire point, specific gravity, and softening test all meet the standards' criteria.

b) Waste polystyrene and waste water sachet influenced HMA concrete improved the Marshall characteristics of the HMA concrete.

c) For the HMA concrete, Marshall Stability, Marshall flow and Marshall quotient at 12 wt. % of waste polystyrene with waste water sachet has an optimal performance at 26.9 kN, 5.5 mm and 8.9 kN/mm, respectively.

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