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Reducing Asphalt Pavement Swell and Loss in Stability Due To Submergence in Moisture Using Polystyrene As Hydro-Carbon Additive: Study On Nigerian Roads In The Niger Delta Region

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ABSTRACTS: *Laboratory investigation of asphalt pavement was carried out in order to ascertain the properties of swell and loss in stability that will occur when under submergence of water between 1 – 5 days. Secondly, the study was to also assess the contribution of polystyrene as a hydro carbon in asphalt pavements when fully submerged during the aforesaid duration. The focus of the study was limited to the Niger Delta Regions of Nigeria owing to the fact that the region constantly experiences excessive rainfalls annually leading to pavement submergence most times. The study was simulated by using hot mix asphalt concretes in the laboratory which is used synonymously with asphalt pavements. The results revealed that the addition of polystyrene to asphalt concrete mixture up to 2.5% reduced swell by 60.61% at day 1 soaking; 63.52% at day 2 soaking; 66.52% at day 3 soaking; 66.90% at day 4 soaking and 65.60% at day 5 respectively. Similarly, loss in stability was reduced by 24.05% at day 1 soaking; 27.66% at day 2 soaking; 35.75% at day 3 soaking; 42.39% at day 4 soaking and 50.38% at day 5 respectively.*

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I. INTRODUCTION

Asphalt concrete (sometimes referred to as "hot mix asphalt" or simply "HMA") is a paving material that consists of asphalt binder and mineral aggregate. The asphalt binder, which can be asphalt cement or modified asphalt cement, acts as a binding agent to glue aggregate particles into a cohesive mass. Since it is impervious to water, the asphalt binder also functions to waterproof the mixture. When bound by the asphalt binder, mineral aggregate acts as a stone framework to impart strength and toughness to the system. In addition, because HMA contains both asphalt binder and mineral aggregate, the behaviour of the mixture is affected by the properties of the individual components and how they react with each other in the system (McGennis et al, 1995).

Most roads in Nigeria are constructed with asphalt concrete as paving material. However, road failure has been of great concern to both government and the people of Nigeria especially in the Niger Delta. The reason simply premised on the fact that the Niger Delta Region in Nigeria consists of deltaic layout of rivers and creeks with both fresh and salt water having a flat topography with high intensity rainfall occurring almost through half of the year resulting to persistent flooding over constructed roads. As a result of these factors the intensity of weathering and other environmental conditions have their toll on the soils, which makes them to be poor as a material for road construction because they become expansive in nature (Alayaki, 2015).

During the tropic seasons these expansive soils tend to easily and quickly loose moisture in the pores resulting from high temperature of the sun and thus causing excessive shrinkages. These shrinkages result in depressions which quickly become a type of distress on the pavement thereby impeding performance on the asphalted roads (Igwe and Amadi-Oparaeli, 2017).

It is worthy to note that the performance of asphalted roads (HMA concretes) depend heavily on the stability of the asphaltic mixture. Therefore, as moisture drains from the underlying soil creating excessive shrinkages leading to depressions; this phenomenon in turn causes loss in stability of the pavement thus causing premature failure (Igwe et al, 2016).

Swelling is one of the many distress types in asphalt or flexible pavement. It is a localized upward movement in a pavement due to swelling of the sub-grade caused by a number of factors such as expansive soils that swell due to moisture in the sub-grade, or frost heave due to ice under the pavement.

On the other hand stability which is a strength property of asphalt pavement (Igwe and Agunwamba) defines the resistance that a pavement offers against traffic loading, temperature changes, moisture and oxidation problems (Othmer, 1963; Oguara, 1985 and Oguara, 2001).

Several materials have been used in the modification of either asphalt cement (bitumen used in road construction) or the asphalt concrete mixture (HMA). Examples include the use of rubber latex in the modification of either the rheological or mechanical properties of asphalt concrete (Van-Rooijen, 1938; Decker and Nijveld, 1951; Mason et al, 1957; Mummah and Muktar, 2001).

Other recent studies on the modification of asphalt roads using rubber latex include the study by Igwe and Ekwulo (2011) which involved the modification of the dynamic modulus of asphalt concrete mixtures which resembles highway flexible pavements. Another more recent study on the use of rubber latex involved the modification of the tensile strength of asphalt concrete mixtures (HMA) – Igwe et al (2016).

On this basis the present study sought other measures by which asphalted roads can be modified by reducing swell and loss of stability in the asphalt pavement using polystyrene as a hydro carbon additive to the mixture.

Polystyrene is a long chain hydrocarbon where alternating carbon centres are attached to phenyl groups, the aromatic ring benzene. According to polystyrene's chemical formula (C8H8), there are chemical elements carbon and hydrogen. Polystyrene is a vinyl polymer, made from the styrene monomer by free radical vinyl polymerization (Ahmed and Salih, 2016). There are two widely used types of polystyrene: EPS (expanded polystyrene and XPS (extruded polystyrene). They are made of same plastic, but the manufacturing processes are different. Polystyrene is solid or glassy at normal temperature; it is actually transparent plastic that is rigid. When heated, it flows and can be used for extrusion and moulding, and it becomes solid again when cools off. Polystyrene has no colour and has limited flexibility. It can also be transparent or made in different colour. It has more thermal coefficient of expansion and more value of modulus in comparison with ceramics and metals (Ahmed and Salih, 2016).

In summary due to the dominant presence of hydrogen and carbon compounds that make-up polystyrene it is presumed that it can be a good modifier to asphaltic mixtures which also have dominant composition of hydrogen and carbon compounds. Van-Rooijen (1938) argued that hydrogen and carbon compounds have high miscibility with other compounds having similar make-up.

II. MATERIALS AND METHODS

2.1 Sampling of Materials used

Materials used for the preparation of the asphalt concrete samples in order to simulate actual flexible pavement behaviour under investigation were collected from different sources. The asphalt cement or bitumen used was obtained from Setraco; a Construction Company in Port Harcourt City in Rivers State, Nigeria. On the other hand the aggregates (gravel and sand) used were obtained directly from market dealers at Mile 3 Diobu Port Harcourt, Rivers State, Nigeria.

2.2 Classification Tests

The method to achieving the purpose of the present study involved first the classification of the materials used – asphalt cement and aggregates. That is, the specific gravity of both the asphalt cement and aggregates were determined as presented in section 3. Also classification test of bitumen was done to determine penetration, viscosity and softening point of the bitumen used – See section 3 for results.

2.3 Sample Preparation

The asphalt concrete samples used for simulation were prepared in accordance with the guidelines as stated by Bruce Marshal for Mix Design Procedures as presented in (**Chapius**, **Kim et al**, **Shuler** and **Huber** - 1992) and **Roberts et al**, (1996).

The procedure involved the preparation of a series of test specimens for a range of asphalt (bitumen) contents such that test data curves showed well defined optimum values. Tests were scheduled on the basis of 0.5 percent increments of asphalt content with at least 2-asphalt contents above and below the optimum asphalt content. During the preparation of the asphalt concrete samples, the aggregates were first heated for about 10 minutes before asphalt (bitumen) was added to allow for absorption into the aggregates. After which the mix was poured into a mould and compacted on both faces with 75 blows (indicating heavy trafficked volume road) using a 6.5kg-rammer freely falling from a height of 450mm. Compacted specimens were subjected to bulk specific gravity test (ASTM D2727), stability and flow, density and voids analyses at a temperature of 60^0C. The results obtained were used to determine the optimum asphalt content of the asphalt concrete. After obtaining the optimum asphalt content; fresh concrete mixes were prepared using the optimum values which were then submerged in moisture at varying time durations simulating submerged conditions. After each day of curing the samples were crushed and the stability value obtained and also the volume of moisture absorbed recorded indicating swell of the concrete. Lastly a third type of concrete were also prepared using the optimum asphalt content previously obtained plus additions in varying percentages of polystyrene as modifier into the composite mixture and then submerged at varying times. Again the results of stability and moisture absorption were obtained and recorded.

2.4 Measuring Swell and Loss of Stability

Swelling in asphalt concrete pavement can be obtained using an index called swelling index. Swelling index can simply be defined as the percentage increase in the volume of the pavement as a result of absorption of water after submergence for a period of time. It was obtained using equation 1 below:

$$SI = \left(\frac{V_2 - V_1}{V_1} \right) \times 100 \qquad 1$$

Where;
V_1 = Volume of sample before soaking
V_2 = Volume of sample after soaking

On the other hand loss in stability was measured using retained strength index (RSI) of the pavement after period of submergence according to Ali (2013) as presented in equation 2 below;

$$RSI = \left(\frac{S_i}{S_0} \right) \times 100 \qquad 2$$

Where;
RSI = retained strength index
S_i = stability after immersion at time ti or stability of conditioned specimen
S_o = stability before immersion or stability of unconditioned specimen

It is worthy to note that when assessing pavement durability using Retained Strength Index (RSI); the lower the index value the less durable the pavement becomes and the higher the index the more durable the pavement.

III. RESULTS

(See Tables 1 – 5 & Figures 1 - 2)

Table 1: Classification Test Results of Materials

Material		Asphalt	Sand	Gravel
Specific gravity		1.00	2.80	2.56
Grade of binder material	-	40/50	-	-
Mix proportion (%)	-	-	45	55
Viscosity of binder (poise)	-	$2.5*(10^{-4})$	-	-
Softening point	-		-	-
Penetration value	-	50.5ºC 57mm	-	-

Table 2: Schedule of Aggregates Used For Mix Proportion in Accordance With ASTM 1951: C136

Sieve size (mm)	Specification Limit	% Passing Aggregate A (Gravel)	% Passing Aggregate B (Sand)	Mix Proportion (0.55A+0.45B)
19	100	100	100	100
12.7	89-100	68.4	100	82.62
9.5	70-90	51.4	100	73.27
6.3	45-70	26.1	100	59.35
4.75	40-60	19.6	100	55.78
2.36	30-52	13.3	71	39.27
1.18	22-40	10.4	64.2	34.61
0.6	16-30	8.1	29.4	17.68
0.3	9-19	7.4	10.4	8.75
0.15	3-7	3.4	1.4	2.5
0.075	0	1.8	0.2	1.08
PAN	0	0	0	0

Table 3: Marshal Stability Results of HMA Concrete Soaked between 1- 5 Days for 0 -3% Polystyrene addition

Polystyrene content (%)	MARSHAL STABILITY (N)					
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
0	9,910	7,890	7,460	6,830	6,390	5,936
1	21,980	19,594	18,460	17,430	16,450	15,490
1.5	36,160	33,900	32,256	30,712	29,168	27,623
2	44,750	43,380	42,010	40,640	39,270	37,715
2.5	50,810	49,820	48,830	47,540	46,650	45,770
3	37,870	36,380	35,290	34,200	33,210	32,175

Table 4: Retained Marshal Stability Results of HMA Concrete Soaked between 1- 5 Days for 0 -3% Polystyrene addition

Polystyrene content (%)	RETAINED MARSHAL STABILITY (%)				
	Day 1	Day 2	Day 3	Day 4	Day 5
0	79.62	75.28	68.92	64.48	59.90
1	89.14	83.99	79.30	74.84	70.47
1.5	93.75	89.20	84.93	80.66	76.39
2	96.94	93.88	90.82	87.75	84.28
2.5	98.05	96.10	93.56	91.81	90.08
3	96.07	93.19	90.31	87.69	84.96

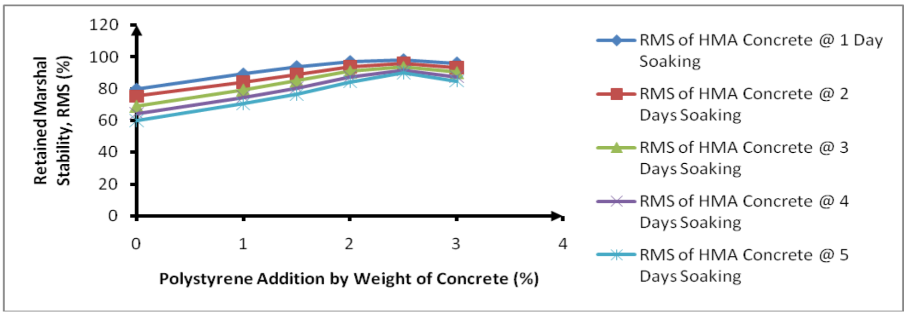

Figure 1: Variation of Retained Marshal Stability against Polystyrene

Table 5: Reduced Index of Swell of HMA Concrete Soaked between 1- 5 Days for 0 -3% Polystyrene addition

Polystyrene %	Swelling Index (%)				
	Day 1	Day 2	Day 3	Day 4	Day 5
0%	0.99	1.59	2.21	2.81	3.43
1.0%	0.80	1.29	1.81	2.31	2.81
1.5%	0.60	1.01	1.56	1.95	2.37
2.0%	0.59	0.89	1.20	1.49	1.77
2.5%	0.39	0.58	0.74	0.93	1.18
3.0%	0.59	0.88	1.17	1.46	1.77

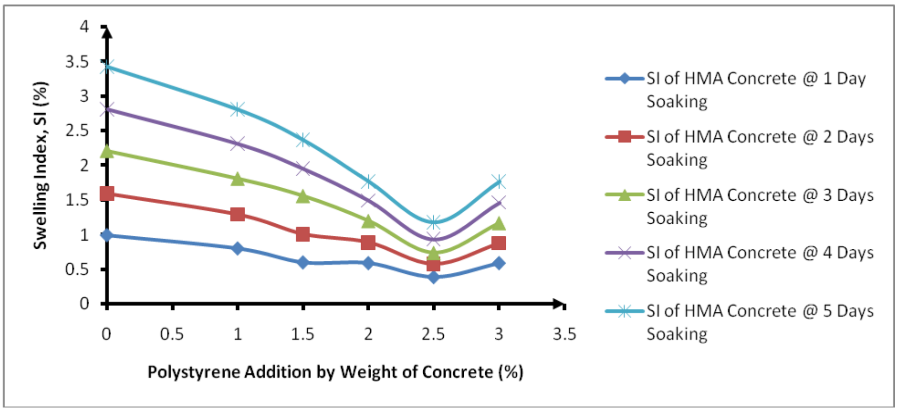

Figure 2: Variation of Swelling Index against Polystyrene

IV. RESULT DISCUSSION

4.1 Retained Marshal Stability

The purpose of the current research was to assess ways in which reduction in the loss of stability of asphalt pavement synonymous with HMA concretes in the laboratory could be achieved using polystyrene as a hydro carbon additive. Using the theory of Retained Marshal Stability (RMS) it was observed that addition of polystyrene reduced loss in stability by increasing RMS between 0 – 2.5% polystyrene content after which RMS began to decline (See Table 4 and Figure 1). From analysis of the results the following observations were made:

(i) The optimum allowable addition of polystyrene cannot exceed 2.5%.

(ii) Secondly the optimum reduction in loss of stability at this threshold value was 24.05% at day 1 soaking; 27.66% at day 2 soaking; 35.75% at day 3 soaking; 42.39% at day 4 soaking and 50.38% at day 5 respectively.

4.2 Swelling Index

In similar manner to the results obtained for reduction in loss of stability; the reduction in swell measured using swelling index revealed that the addition of polystyrene reduced swell by reducing the index of swell between 0 – 2.5% polystyrene content after which the HMA concrete began to rise in swell (See Table 5 and Figure 2). Also from analysis of the results the following observations were made:

(i) The optimum allowable addition of polystyrene cannot exceed 2.5%.

(ii) Secondly the optimum reduction in swell at this threshold value was 60.61% at day 1 soaking; 63.52% at day 2 soaking; 66.52% at day 3 soaking; 66.90% at day 4 soaking and 65.60% at day 5 respectively.

V. CONCLUSION

From the overall results and analysis the following conclusions are made;

1. That the addition of polystyrene to asphalt concrete mixtures up to 2.5% considerably reduced the amount of stability lost due to submergence of concrete. Therefore, since asphalt concretes are synonymous with asphalt pavements the same holds true for the latter.

2. Similarly, the addition of polystyrene to asphalt concrete mixtures up to 2.5% considerably reduced the amount of swell in the concrete due to submergence.

3. Polystyrene is therefore recommended as a good hydro carbon additive for both the reduction in stability loss and swell of asphalt pavements.

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