International Journal of New Technology and Research (IJNTR)
ISSN: 2454-4116, Volume-5, Issue-6, June 2019 Pages 01-08

Cost-Effectiveness of Waste Polythene Bag Modified Asphalt Concrete Submerged In Moisture

C. G. Otto, K. I. Amadi-Oparaeli

Abstract— **Fatigue distress is one of the major distress forms occurring in road flexible pavements. And water has been seen to facilitate this form of distress in the Niger Delta Region of Nigeria as a result of submergence during the raining season. As a result engineers have done several research works to improve the fatigue performance of flexible pavement under this condition by the addition of some modifiers. In this study, Waste Polythene Bags (WPB) was used to modify asphaltic concrete in soaked and un-soaked conditions from 0 to 5days. A laboratory testing program was carried out on two mixtures: unmodified and WPB modified. The results from the laboratory tests and fatigue analysis indicated that the WPB modified mixtures had much longer fatigue cycles compared to the unmodified mixture in both soaked and un-soaked conditions. In addition a cost-effectiveness analysis study in respect to the fatigue performance on the two mixtures was carried out. Generally, the analysis exposed that the WPB modified asphalt mixture exhibited significantly a higher cost-effectiveness ratio of 1.52 times higher than the unmodified mixture in both conditions.**

***Index Terms*—Waste Polythene Bag, Cost-effectiveness**

I. Introduction

Increase in flooding during rainy season for the last decade in Abua-Odual local government area of Rivers State and Niger Delta region at large, in addition with insufficient degree of road maintenance, has caused an accelerated deterioration of road infrastructural systems in the region. This flooding is associated to lack of road drains, blocked drainages, inadequate drainage channels and poor drainage management. However engineers in this region have carried out several studies to understand the effect of this flooding and also improve the performance of the road pavements (flexible pavement) using some modifies. To deal with the problems related to moisture in Niger Delta, a study need to be conducted to find a way to increase the resistance of flexible pavement against moisture damage. Alternative methods should be identified to be used in the construction and maintenance of roads.

Having an asphalt concrete with a good resistance to moisture induced damage is necessary. According to [11], moisture-induced damages causes weakening or loss of adhesive bond between the aggregate surface and the asphalt binder.

Captain G. Otto, Department of Civil Engineering, Rivers State University, Port Harcourt, Rivers State Nigeria.
Kemejika I. Amadi-Oparaeli, Department of Civil Engineering, Rivers State University, Port Harcourt, Rivers State Nigeria.

When this happens, the pavement life (fatigue) reduces. In a study carried out by [9], it was revealed that the presence of moisture reduces the stiffness of the flexible pavement has a result of the loss of adhesive bond. This stiffness also known as dynamic modulus has direct effect on the fatigue performance. As the stiffness reduces, the fatigue performance reduces. Also [5] investigated the extent to which the submergence of flexible pavement affects swelling index for 14days. The study showed that an asphalt concrete mixture submerged in moisture has higher swelling index which in turn increases the pore-spaces and this leads to total failure. As the number soaking day increases, the swelling index also increases.

The modification of asphalt concrete has shown a better fatigue performance. According to [13] addition of waste polythene bag to asphalt concrete at 3%, the resistance against the effect of moisture in terms of the Index of Retained Stability (IRS) was better than the normal asphalt concrete. In a study by [8], it was discovered that recycled polythene from grocery bags are very useful in asphaltic concretes. This study exposed to the body of knowledge that fatigue rutting and cracking of the pavement surface are reduced. The research has shown that fatigue performance and life can be improved by the use of recycled polyethylene from grocery bags.

The improved performance of waste polythene bag modified asphalt pavements compared with unmodified asphalt pavements is relatively better as a result of its water proofing property. When asphaltic concrete pavement is modified, the modifier can have measurable benefits to road maintenance and construction in terms of better-performance and longer lasting roads, as well as cost savings in the service life of the roadway. A detailed comparison between the unmodified asphalt concrete and waste polythene bag modified asphalt concrete is needed to quantify the true cost effectiveness in relation to fatigue performance which relates directly with repetitive traffic loading. It is one of the most important distress types noticeable in flexible pavements. A lot of works have been done showing how fatigue can occur and how fatigue performance can be improved under repetitive traffic loading condition [16]-[7]-[4]-[2].

The objective of this study therefore, was to assess the cost-effectiveness of waste polythene bag modified asphalt concrete as related to fatigue performance. The paper considers the results of the fatigue analysis done using the elastic properties of asphaltic concrete through laboratory evaluations.

II. Materials and Methods

A. Materials

Materials used in the study were collected from three different places. The asphalt used was gotten from Reynold Construction Company (RCC) while the coarse aggregates were gotten from Calabar Cross River State. For the river sand and waste polythene bags (WPB), they were gotten from Central Abua in Abua-Odual Local Government Area of Rivers State, Nigeria.

B. Classification Test

In achieving this work classification of the materials used such as the asphalt cement and aggregates were carried out. Specifically, the specific gravity of both the asphalt binder and aggregates were determined as presented in table 3. Thereafter, aggregate blending was done using the straight line method to determine the percentages of fine aggregates and coarse aggregates needed to obtain a good concrete (see table 2) Also the classification test of asphalt was done to determine the penetration, viscosity and softening point of the asphalt used. See table 2 for results.

C. Sample Preparation

The asphalt concrete samples used as models were prepared in accordance with the procedures stated by Bruce Marshal in respect of Mix Design of asphalt concretes [6]-[10]-[15] and [14]. To achieve this work, preliminary tests were carried out on the bases of 0.5 additions of asphalt content (4.0, 4.5, 5.0, 5.5 and 6.0) in order to determine the optimum binder content. In ensuring that the data was adequate for each binder content, three replicate test specimens were prepared. In preparing the asphalt concrete samples, the aggregates were heated for about 5 minutes first before asphalt was added to allow for proper absorption into the aggregates and mixed. Thereafter, the mix was poured into a mould and compacted with 75 blows on the two faces of the sample using a 6.5kg-rammer falling freely from a height of 450mm. Bulk specific gravity test in accordance to ASTM D2727 was carried out on the compacted samples. Also, stability, flow, density and air voids analyses at a temperature of 60^0C and a frequency of 10Hz as specified by [1] was carried out. The results gotten were used to determine the optimum asphalt content of the asphalt concrete samples. After the determination of the optimum asphalt content, 15 unmodified samples of asphalt concretes were produced using the optimum binder content and soaked for 0 to 5 days. Also 75 waste polythene bag modified asphalt concretes were produced and soaked for 0 to 5 days. The modification was at the rate of 0%, 1%, 2%, 3%, 4%, and 5% after waste polythene bags have been melted to liquid at 255^0C. The modification was done considering the entire weight of the sample (see table 1). Also results from air voids variation together with other properties of both the aggregates and asphalt were used to calculate dynamic modulus using Asphalt Institute model while the strains were measure for each sample as the flow and stability values were gotten. Thereafter the fatigue results were determined.

The Optimum Asphalt Content (O.A.C) was determined using equation 2.1 as presented by Bruce Marshal Design Procedure cited in [3] and [12].

$$O.A.C = \tfrac{1}{3}(x + y + z) \quad \ldots\ldots\ldots\ldots.2.1$$

Where:

- (x) is Asphalt content at maximum stability
- (y) is Asphalt content at maximum density
- (z) is Asphalt content at median limits of air voids (i.e. at 4% air voids)

D. Determination of Dynamic Modulus Using Asphalt Institute Model (1993)

The Asphalt Institute developed a model to determine the dynamic modulus as presented in Huang's (1993) as shown in equations 2.2 – 2.8 was adopted in obtaining the dynamic modulus in this study.

$$E^* = 100{,}000(10^{\beta_1}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots2.2$$

$$\beta_1 = \beta_3 + 0.000005\ \beta_2 - 0.00189\ \beta_2 f^{-1.1} \quad \ldots.2.3$$

$$\beta_2 = \beta_4{}^{0.5} T^{\beta_5} \ldots\ldots\ \ldots\ldots\ \ldots\ldots\ 2.4$$

$$\beta_3 = 0.553833 + 0.028829\left(P_{200} f^{-0.1703}\right) - 0.03476V_a + 0.07037\lambda + 0.931757 f^{-0.02774} \quad \ldots\ldots\ldots\ldots2.5$$

$$\beta_4 = 0.483V_b \quad \ldots\ldots\ldots\ldots\ldots2.6$$

$$\beta_5 = 1.3 + 0.49825\ \log f \ldots\ldots\ \ldots\ldots\ ..2.7$$

$$\lambda = 29{,}508.2\ (P_{77°F})^{-2.1939} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots2.8$$

Where;

E^* = dynamic modulus (psi)

f = loading frequency (10Hz)

T = temperature (°F) (Mixing Temperature)

V_a = volume of air voids (%)

λ = asphalt viscosity at 77°F (10^6 poises)

P_{200} = % by weight of aggregates passing No. 200 (%)

V_b = volume of bitumen

$P_{77°F}$ = penetration at 77°F or 25°C

E. Determination of Fatigue Life Using Asphalt Institute (1982)

The asphalt institute (Asphalt Institute, 1982) suggested that the relationship between fatigue cracking and tensile strain is represented by the number of load repetition and the resulting equation is of the form which shall was adopted in this work;

$$N_f = 0.0796(\varepsilon_t)^{-3.291}(E)^{-0.845} \quad \ldots2.9$$

where;
N_f = number of load repetitions to failure
E = stiffness modulus
ε_t = horizontal tensile strain at the bottom of the asphalt bound layer

F. Cost-Effectiveness Analysis

Cost-effectiveness analysis is an economic evaluation method used when comparing cost to benefit for the purpose of alternatives. In this study, the cost-effectiveness of unmodified asphalt concrete and the waste polythene bag modified asphalt concrete was done in terms of fatigue by dividing the expected fatigue performance by its cost. Before the cost analysis, the material quantities for the pavement were determined using the design density of 2243kg/m^3 obtained from the laboratory analysis.

$$\text{Cost-Effectiveness} = \frac{\textit{Fatigue performance}}{\textit{Cost of HMA Concrete}} \quad ....2.10$$

III. Results and Discussions

The results obtained in this study are presented in the tables and figures below.

In order to determine the optimum asphalt content or design asphalt content, equation 2.1 was applied in line with figures 1, 2 and 3 respectively as shown below. The optimum asphalt content obtained from the result above was 4.95%. This was the value used for the production of the control sample and modified sample.

Table 1: Mix Design Proportion of the materials used in weights

(A) % Modification	(B) Weight of sample (g)	(C) Weight of WPB (AxB) (g)	(D) Weight of Asphalt at 4.95%(B-C) (g)	(E) Weight of Fine Aggregates 42%(B-C-D) (g)	(F) Weight of Coarse Aggregates 58%(B-C-D) (g)
0	1200	0	59.40	479.05	661.55
1	1200	12	58.81	474.26	654.93
2	1200	24	58.21	469.47	648.32
3	1200	36	57.62	464.68	641.70
4	1200	48	57.02	459.89	635.09
5	1200	60	56.43	455.10	628.47

Table 2: Aggregates Mix Proportion from Sieve Analysis

Sieve Size (mm)	**Specification limit**	**Aggregates (A) sand**	**Aggregates (B) Gravel**	**Mix Proportion (0.42A + 0.58B)**
19	100	100	100	100
12.5	86-100	100	97	98
9.5	70-90	100	62	78
6.3	45-70	100	26	57
4.75	40-60	99	10	47
2.36	30-52	96	0	40
1.18	22-40	90	0	38
0.6	16-30	73	0	31
0.3	9-19	23	0	10
0.15	3-7	3	0	1.26
0.075	0	0	0	0

Table 3: Laboratory test results of materials used

Materials	**Waste Polythene bags**	**Asphalt Binder**	**Fine Aggregates (A)**	**Coarse Aggregates (B)**
Specific Gravity	0.92	1.05	2.56	2.80
Grade of Binder		50/60		
Mix Proportion			42%	58%
Viscosity of binder		14.5		
Soften Point		50^{0}C		
Penetration Value		53		

Table 4 Mix Properties Unmodified Asphalt Concrete

Asphalt Content (%)	Stability (N)	Flow (0.25mm) (mm)	Density (kg/m^3)	Air Voids (%)	VMA (%)
4.0	4590.621	8.56	2252	5.14	14.52
4.5	5006.316	9.94	2279	4.84	12.69
5.0	7098.273	10.44	2311	3.68	10.5
5.5	5817.483	11.63	2278	3.6	10.79
6.0	5786.025	12.94	2249	3.5	11.04

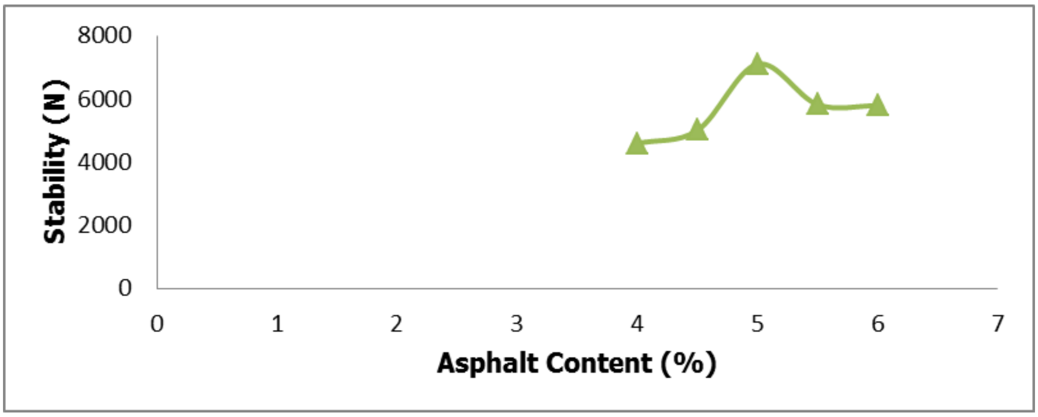

Figure 1: Stability against Asphalt content

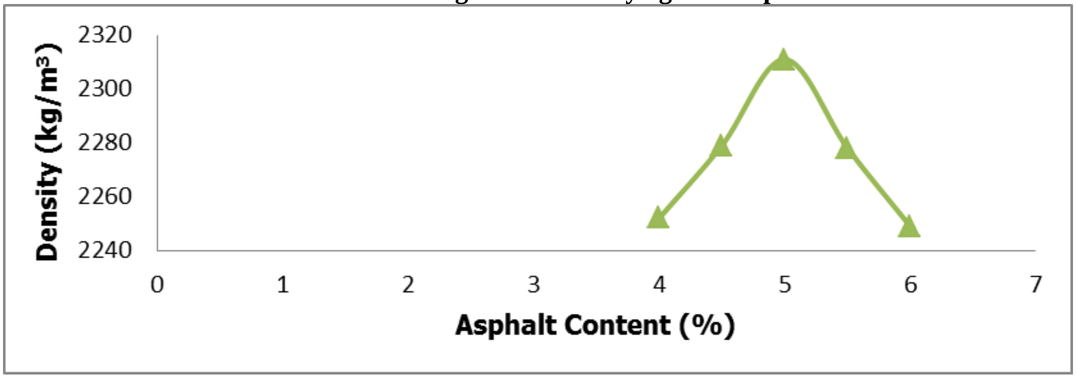

Figure 2: Density against Asphalt content

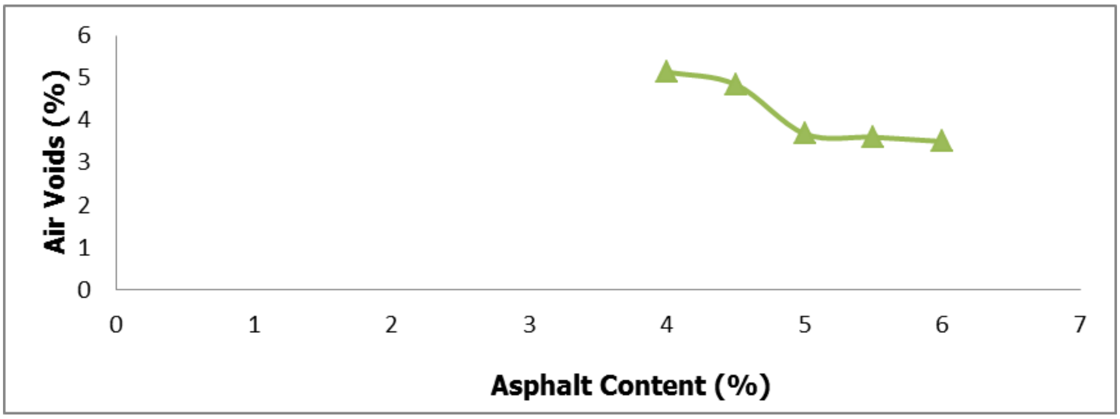

Figure 3: Air Voids against Asphalt content

Table 5: FATIGUE RESULTS OBTAINED

FATIGUE RESULTS

SOAKING DAYS	% WPB modification	Dynamic Modulus	Strains	Fatigue
	0	240,511.59	0.00011286	22128085.9
	1	242,056.54	0.00010858	24994856.01
	2	243,611.41	0.00010481	27925966.94
	3	245,176.26	0.00010145	30919204.04
	4	246,948.74	0.000098346	34040662.79
Day 0	5	246,553.75	0.000099269	33054762.65
	0	237,831.63	0.00011713	19768712.51
	1	239,359.36	0.00011287	22211584.52
	2	240,896.90	0.0001091	24704976.21
	3	242,444.32	0.00010573	27244543.4
	4	244,197.05	0.00010263	29865418.32
Day 1	5	243,806.47	0.00010353	29058750.83
	0	233,680.47	0.00012033	18361855.49
	1	235,181.53	0.0001164	20371644.83
	2	236,692.24	0.0001126	22600327.26
	3	238,212.65	0.00010927	24812538.09
	4	239,934.79	0.00010617	27112047.23
Day 2	5	239,551.02	0.00010707	26404928.66
	0	228,136.31	0.0001232	17339595
	1	229,601.76	0.0001189	19384987.68
	2	231,076.63	0.00011513	21437190.02
	3	232,560.96	0.00011177	23504502.39
	4	234,242.24	0.00010867	25627665.62
Day 3	5	233,867.58	0.0001096	24952660.96
	0	220,241.94	0.00012503	17017223.89
	1	221,656.68	0.00012077	18970792.96
	2	223,080.50	0.00011697	20961862.2
	3	224,513.48	0.00011363	22934313.06
	4	226,136.58	0.0001105	24989897.11
Day 4	5	225,774.88	0.00011143	24342947.21
	0	216,397.79	0.00012587	16895862.55
	1	217,787.83	0.0001216	18826009.53
	2	219,186.81	0.0001178	20786708.95
	3	220,594.77	0.00011447	22720651.78
	4	222,189.54	0.00011137	24718232.14
Day 5	5	221,834.16	0.00011227	24104667.14

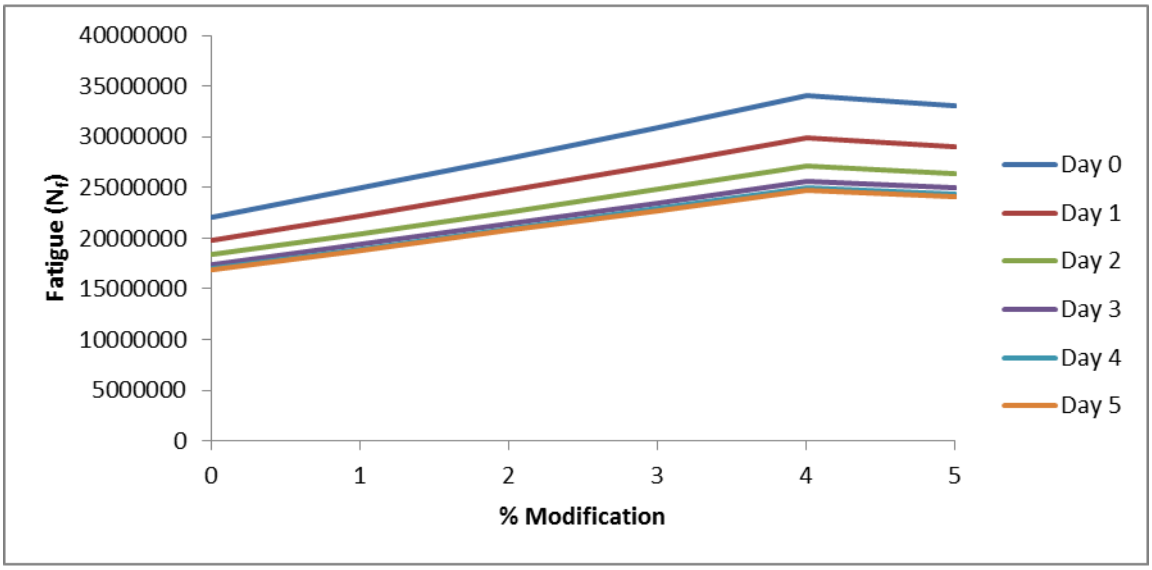

Figure 4: Fatigue results against % WPB Modification

Table 6: Fatigue Results at Optimum (4%) Modification

Samples	**Soaking Days**					
	0	1	2	3	4	5
Unmodified	22,128,085.9	19,768,712.51	18,361,855.49	17,339,595	17,017,223.89	16,895,862.55
WPB Modified	34,040,662.79	29,865,418.32	27,112,047.23	25,627,665.62	24,989,897.11	24,718,232.14

Table 7: Cost Effectiveness Analysis of Modified and Unmodified Asphalt Concrete Mixes

Sample	Soaking Days	cost of 12Km (₦)	Fatigue (Nf) (Cycles)	cost-effectiveness (cycles/cost of 12km)	Average Cost Effectiveness	Average cost Effectiveness ratio
unmodified	0	55,732,108.00	22,128,085.90	0.397043763	0.333474244	1
	1	55,732,108.00	19,768,712.51	0.354709578		
	2	55,732,108.00	18,361,855.49	0.329466373		
	3	55,732,108.00	17,339,595	0.311123975		
	4	55,732,108.00	17,017,223.89	0.305339678		
	5	55,732,108.00	16,895,862.55	0.303162094		
WPB modified	0	54,748,979.00	34,040,662.79	0.62175886	0.506414081	1.518600283
	1	54,748,979.00	29,865,418.32	0.545497265		
	2	54,748,979.00	27,112,047.23	0.495206444		
	3	54,748,979.00	25,627,665.62	0.468093946		
	4	54,748,979.00	24,989,897.11	0.456444989		
	5	54,748,979.00	24,718,232.14	0.451482979		

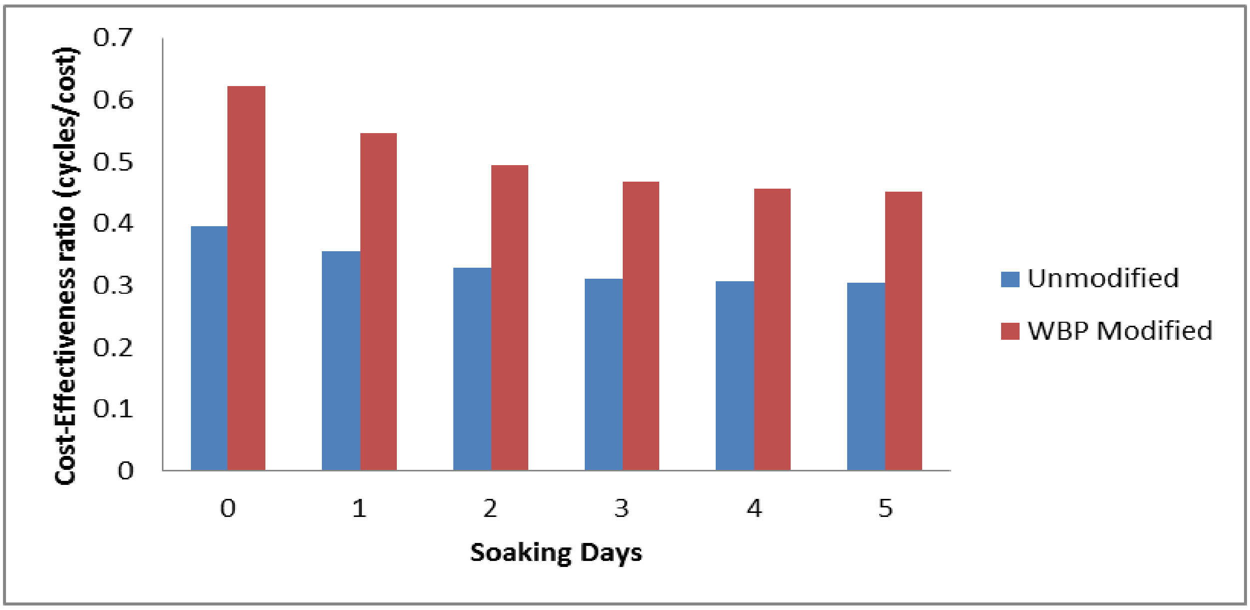

Figure 5: Cost Effectiveness of Modified and Unmodified Asphalt Concrete Mixes

The WPB modified HMA had a better fatigue result. That is, fatigue life increased linearly up to 4% of the WPB content after which further additions of the modifier resulted in a decrease of fatigue life and reduces as the soaking day increases. See tables 5 and 6, and figure 4 as references. The fatigue life (N_f) and dynamic modulus were observed to have the same behavior. This behavior is expected since WPB has water proofing characteristics.

A. **Cost Comparison Based On Fatigue Life**

In order to evaluate the economic values of all asphalt concrete mixtures based on fatigue performance, the designed density of 2243kg/m^3 was adopted from the laboratory experiments. For this study a 12km road with a carriage width of 7m is considered. Base on this, the required quantities for the pavement are as follows:

Length of road = 12km
Width = 7.0m
Wearing course thickness = 0.05m
Density = 2243kg/m^3
Volume of Asphalt = 12000m x 7.0m x 0.05m = 4200m^3
Mass of Asphalt Concrete = Density x Volume
= 2243kg/m^3 x 4200m^3
= 9,420,600kg

Weight in tons $= \frac{9,420,600kg}{907.185} = 10,384.43\ tons$

B. **Cost of Unmodified Asphalt Concrete**

Asphalt Content

$= \frac{4.95}{100}\ x\ 10,384.43 = 514.03tons$

Coarse Aggregates

$= \frac{58}{100}\ x\ (10,384.43 - 514.03) = 5,724.83tons$

Fine Aggregates

$= \frac{42}{100}\ x\ (10,384.43 - 514.03) = 4,145.568tons$

Cost of Asphalt at ₦5,000/ton = 514.03tons x ₦5000
= ₦2,570,150.00

Cost of coarse aggregates at ₦8200/ton
= 5,724.83tons x ₦8,200
= ₦46,943,606.00

Cost of fine aggregates at ₦1500/ton
= 4,145.568tons x ₦1500
= ₦6,218,352.00

Total cost = ₦2,570,150.00 + ₦46,943,606.00 + ₦6,218,352.00 = ₦55,732,108.00

C. **Cost of WPB Modified Asphalt Concrete**

Modifier content $= \frac{4.0}{100}\ x\ 10,384.43 = 415.38tons$

Asphalt content

$= \frac{4.95}{100}\ x\ (10,384.43 - 415.38) = 493.47tons$

Coarse Aggregates

$= \frac{58}{100}\ x\ (10,384.43 - 415.38 - 493.47)$
$= 5,495.84tons$

Fine Aggregates

$= \frac{42}{100}\ x\ (10,384.43 - 415.38 - 493.47) = 3,979.74tons$

Cost of modifier at ₦3000/ton
= 415.38 tons x ₦3000
= ₦1,246,140.00

Cost of Asphalt at ₦5,000/ton
= 493.47 tons x ₦5000
= ₦2,467,350.00

Cost of coarse aggregates at ₦8200/ton
= 5,495.84tons x ₦8,200
= ₦45,065,888.00

Cost of fine aggregates at ₦1500/ton
= 3,979.74tons x ₦1500
= ₦5,969,610.00

Total cost = ₦1,246,140.00 + ₦2,467,350.00 + ₦45,065,888.00 + ₦5,969,610.00

= ₦54,748,979.00
Cost savings = ₦55,732,108.00 - ₦54,748,979.00
= ₦983,129.00 only
Therefore percentage savings at the point of construction
= 1.76%

Based on the above quantities and cost, equation 2.1 was used in determining the best. The one that provides a better ratio of benefit to the cost with respect to fatigue is the "best." In this study, only the initial cost of materials was used.

From the results presented in table 7, the cost-effectiveness of WPB modified mix was 1.52 times higher than the unmodified asphalt concrete mix. Also looking at figure 5, the cost effectiveness for the WPB modified mix is higher than the unmodified each day of soaking.
In summary, considering soaking and un-soaked conditions WPB modified mix has proven to be more cost effective than the normal asphalt mix.

IV. Conclusion

From the laboratory test results gotten including the fatigue analysis done, it is evident that WPB influenced the fatigue performance of asphalt concrete mixtures at 4% modification when soaked and un-soaked. The positive influenced is about 48% average across the soaking days. In addition, it has a better cost-effectiveness ratio of 1.52 times higher than the unmodified asphalt concrete mix.

REFERENCES

[1] AASHTO Design Guide Draft (2002) – 2.4 Modulus of Elasticity for Major Material Groups, NCHRP Project 1-37A.

[2] Anderson, D. A., Le Hir, Y. M., Marasteanu, M. O., Planche, J., and Martin, D. (2001) "Evaluation of Fatigue Criteria for Asphalt Binders." Transportation Research Record 1766, Transportation Research Board, Washington, D. C. 48–56.

[3] Asphalt Institute (1956) „Mix Design methods for Hot-mix Asphalt Paving", University of Maryland, Manual Series No.2. Lexington.

[4] Benedetto, H. D., Soltani, A.A., and Chaverot, P. (1996) "Fatigue Damage for Bituminous Mixtures: A Pertinent Approach." Proceedings of Association of Asphalt Paving Technologists, Vol. 65, 142-158.

[5] Captain G. Ottos and Daniel A. Nyebuchi (2018) "Swell Behaviour of Asphalt Pavement Wearing Course with ESAL >10^6 Under Submerged Conditions" International Journal of Trend in Research and Development, Vol. 5, issue 2, pp 242-244. ISSN 2394-9333

[6] Chapuis, R.P. and Legare, P. P., (1992) "A Simple Method for Determining the Surface Area of Fine Aggregates and Fillers in Bituminous Mixtures," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia.

[7] Daniel, J. S., and Kim, R. Y. (2001) "Laboratory Evaluation of Fatigue Damage and Healing of Asphalt Mixtures." Journal of Materials in Civil Engineering, Vol. 13, pp. 434-440.

[8] Flynn, L. (1993) „Recycled Plastic Finds Home in Asphalt Binder", Journal of Roads and Bridges. **(58)**2; 32 – 41.

[9] Igwe, E. A., Ekwulo, E. O. and Ottos, C. G. (2016) "Moisture Effect on Stiffness of Asphalt Concretes for Low Volume Roads: Comparative Study of Asphalt Institute and Witczak 1-40D Models", International Journal of Constructive Research in Civil Engineering (IJCRCE) Volume 2, Issue 4, PP 1-8. ISSN 2454-8693 (Online).

[10] Kim, Y. R., Kim, N., and Khosla, N. P.,(1992) "Effects of Aggregate Type and Gradation on Fatigue and Permanent Deformation of Asphalt Concrete," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger,Ed., American Society for Testing and Material, Philadelphia.

[11] Mehari, Z. B. (2007) "Effect of Different Types of Filler Materials on Characteristics of Hot-Mix-Asphalt Concrete", A thesis submitted to School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Road and Transport Engineering)

[12] National Asphalt Pavement Association (1982) „Development of Marshall Procedures for Designing Asphalt Paving Mixtures", National Asphalt Pavement Association, Information Series **(84)**, Lanham, MD.

[13] Ottos, C. G and Amadi-Oparaeli, K. I. (2018) "Influence of Waste Polythene Bags on the Idex of Retained Stability of Asphalt Concretes Under Moisture for Low Volume Roads " International Journal of Trend in Research and Development, Vol. 5, issue 2, pp 209-214. ISSN 2394-9333

[14] Roberts, F.L. Kandhal, P.S., Brown, E.R., Lee, D.Y. and Kennedy, T.W. (1996). Hot-Mix Asphalt Materials, Mixture Design, and Construction. National Asphalt Pavement Association Education Foundation Lanham, MD.

[15] Sharrour, A. M., and Saloukeh, G.B., (1992) "Effect of Quality and Quantity of Locally Produced Filler (Passing Sieve No. 200) on Asphaltic Mixtures in Dubai", Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia.

[16] SHRP (1994) "Standard method of Test for determining the Fatigue Life of Compacted Bituminous Mixtures Subjected to Repeated Flexural Bending M-009. In the Superpave Mix Design System Manual of Specifications Test Methods and Practices, SHRP A 379, Harrigan, E.T. Leahy, R.B. and Youtcheff (eds.) Strategic Highway Research Program, Washington, D.C. 253pp.

[17] Shuler, T. S., and Huber, G. A., (1992) "Effect of Aggregate Size and Other Factors on Refusal Density of asphalt Concrete by Vibratory Compaction", Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia.