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Comparative Cost-Effectiveness of Modified Asphalt Concrete Submerged In Moisture as Related To Fatigue Performance

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Abstract
The fatigue performance of a flexible pavement is very important. In recent times, fatigue distress is increasing as a result of submergence of the pavement during the wet season. As a result,pavements fail on time before its life span. To improve the fatigue performance, researchers have done several studies to improve the fatigue performance of road pavement in the presence of moisture by the addition of modifiers. In this study, Candle Wax (CW), Shredded Tyre Chips (STC) and Waste Polythene Bags (WPB) were used to modify the asphalt concrete mix in soaked conditions from 0 to 5days. The aim of this study, was to carry out cost-effectiveness analysis of the fourmixes. That is, theunmodified and modified using CW, STC and WPB modifiers. The fatigue analysis indicated that the STC modified asphalt concrete had a better performance followed by the WPB modified mix and the CW modified mixcompared to the unmodified mixture in soaked conditions. Finally,the cost-effectiveness scrutiny in relation to the fatigue performance of the four mixeswas carried out. The study exposed that STC modified asphalt had a cost-effectiveness ratio of 1.76 higher than the unmodified and WPB modified asphalt mixture had cost-effectiveness ratio of 1.36 times higher than the unmodified mixture while the CW modified mix had a cost-effectiveness ratio of 1.31.

Keywords: Fatigue performance, Shredded tyre Chips, Candle Wax and Waste Polyethene Bag.

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I. Introduction

The use of sustainable and cost-effective substitutions for asphalt wearing course have beenemphasized in the past and present as a result of the continuous unpredictability of oil prices in Nigeria and the upsurge in environmental awareness in relation to flooding. Remarkableenhancement ofpavement performances in terms of fatigue has been realizedin the area ofmix design by material selection and modification using different modifiers. However, most of these improvements are expensive and require special equipment and attentionduring construction.

In the Niger Delta region of Nigeria, flooding has been observed to be a major environment challenge causing premature pavement failures. This occurs during raining seasons (Otto and Amadi 2020). According to Mehari (2007), the presence of water causes the weakening and loss of adhesive bonding ability between the aggregate and binder which causes a reduction in pavement life.This was confirmed in Igwe et al (2016). To deal with this problem, a number of studies have been carried outusingmodifiers in asphalt concrete mix design.

Modified asphalt concrete mixes have shown better fatigue performances in many studies. Studies using rubber have shown a lot of usefulness in asphaltic concrete mixes. This has been shown in Igwe et al (2016) and Igweand Ottos (2016)

In a study carried out byOttos and Amadi-Oparaeli (2018) waste polythene bags were used modify asphalt concrete.The modified asphalt concrete mix at 3%, showed a better resistance against moisture in terms of the Index of Retained Stability (IRS). Also, Flynn (1993)discovered that recycled polythene bags are very beneficial in asphaltic concrete mixes. The studies have shown that fatigue performance and life span of pavements can be improved by the use of recycled polyethylene bags.

Candle wax also has been seen to be useful in asphaltic concrete. This was shown in a study carried out by Igwe et al (2016). In this study air voids and flow were reduced there by increasing the fatigue performance of the concrete. In a recent study carried out by Otto and Akpila (2020) using candle wax as modifier in submerged condition, the candle wax exhibited a waterproofing behavior with a better fatigue performance at 4% modification when submerged in moisture.

Shredded tyre chips also has been found to be useful in asphaltic concrete as a modifier. Igwe (2015) carried out a study on the use of shredded tyre chips as a filler material in asphalt concrete mix. In this study, the shredded tyre chips improved the dynamic modulus of the asphalt concrete pavement. To confirm this, Otto et al

(2020) also used shredded tyre chips. In this study, it was revealed that shredded tyre chips does not just act as a filler material but a waterproofing agent in submerged conditions of moisture.

The objective of this present study is to assess the cost-effectiveness of shredded tyre chips, waste polythene bag and candle wax modified asphalt concrete mixes as related to fatigue performance in submerged conditions. The paper considered the fatigue results using the elastic properties of asphaltic concrete mixes.

II. Materials and Methods

2.1 **Material Sampling**

The materials used in the present study were gotten from different places. The asphalt used was gotten from Reynold Construction Company (RCC). The coarse and fine aggregates were gotten from Mile 3 market in Port Harcourt River State. The waste polythene bag (WPB) was gotten from Rivers State University environment, while the shredded tyre was gotten from Vulcanizer's around Abaili motor park in Port Harcourt. For the candle wax, it was bought directly from dealers in Mile 3 market.

2.2 **Classification Tests**

In accomplishing this study, classification of materials used were carried out. Specifically, the specific gravity of all the materials used were determined. Thereafter, aggregate combination was carried out using straight line method to determine the percentage of fine and coarse aggregates needed to obtain the best concrete mix.Also,the classification test of the binder (asphalt) was carried out to determine the viscosity,penetration and softening point.

2.3 **Sample Preparation**

The asphalt concrete samples used were prepared in accordance with the procedures stated by Bruce Marshal for Mix Design of asphalt concretes found in Roberts et al., (1996). 270 samples ofmodified asphalt concretes were produced and soaked for 0 to 5 days. 90 each of the three modifiers. The modification was at the rate of 4% for candle wax (CW) and waste polythene bag (WPB) and 5% for Shredded tyre chips (STC). This modification was done base on the previous studies carried out by Otto and Akpila (2020), Otto et al (2020) and Ottos and Amadi-Oparaeali (2019). For the waste polythene bags, it was melted to liquid at 255^{0}C. The shredded tyre chips were burned to powdered form while the candle wax as melted to liquid form.The modification was done considering the entire weight of the sample. Also results from air voids distinctions together with other properties of both the aggregates and asphalt were used to determine the dynamic modulus using Asphalt Institute model while the strains were measure directly for each sample as the flow and stability values were gotten. Thereafter the fatigue results were determined using the fatigue model steed in Equation 2.9. The Optimum Asphalt Content (O.A.C) was obtained using equation 2.1 as presented by Bruce Marshal Design Procedure cited in Asphalt Institute, (1956) and National Asphalt Pavement Association (1982)

$$O.A.C = \frac{1}{3}(x + y + z) \qquad 2.1$$

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)

2.4 **Determination of Dynamic ModulusUsing Asphalt Institute Model (1993)**

The Asphalt Institute model developed in 1993 was adopted in the study to determine dynamic modulus. See equations 2.2 – 2.8.

$$E^* = 100{,}000\,(10^{\beta_1}) \qquad 2.2$$

$$\beta_1 = \beta_3 + 0.000005 \quad \beta_2 - 0.00189 \quad \beta_2 f^{-1.1} \; 2.3 \; \beta_2 = \beta_4{}^{0.5} T^{\beta_5} \qquad 2.4$$

$$\beta_3 = 0.553833 + 0.028829 \left(P_{200} f^{-0.1703}\right) - 0.03476 \; V_a + 0.07037 \; \lambda + 0.931757 \; f^{-0.02774} \qquad 2.5$$

$$\beta_4 = 0.483 \; V_b \qquad 2.6$$

$$\beta_5 = 1.3 + 0.49825 \; \log f \qquad 2.7$$

$$\lambda = 29{,}508.2\,(P_{77°F})^{-2.1939} \qquad 2.8$$

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} = percentage by weight of aggregates passing No. 200 (%)
V_b = volume of bitumen
$P_{77°F}$ = penetration at 77°F or 25°C

2.5 **Determination of Fatigue Life Using Asphalt Institute (1982)**
In determining the fatigue performance of the asphalt concrete samples in the laboratory, the model stated in equation 2.9 was adopted. This model shows the relationship between fatigue and tensile strain.

$$N_f = 0.0796 \ (\varepsilon_t)^{-3.291} \ (E)^{-0.845} \qquad 2.9$$

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

2.6 **Cost-Effectiveness Analysis**
Cost-effectiveness analysis is one of the waysof choosing or selecting a material by comparing the cost to benefit ratio of alternatives. In this work, the cost-effectiveness analysis of unmodified asphalt concrete samples was compared to the modified asphalt concrete samples in terms of fatigue performance by dividing the projected fatigue performance gotten by the cost of the pavement. To achieve this, the material quantities for each sample was determined. The equation stated in 2.10 was used in the analysis.

Cost Effectiveness = $\frac{Fatigue\ performance}{Cost\ of\ HMA\ Concrete}$ ……………………………………..2.10

III. Results

The Fatigue results obtained are presented in the table below.

Table: 1.0 Fatigue Results

Samples	Soaking Days					
	0	1	2	3	4	5
Unmodified	24,791,358.08	22,148,017.49	20,571,835.22	19,426,538.24	19,065,368.53	18,929,400.10
Candle Wax Modified	32,849,103.00	28,855,249.00	26,257,723.00	24,808,924.00	24,204,749.00	23,975,738.00
Waste Polythene Bag Modified	34040662.79	29865418.32	27112047.23	25627665.62	24989897.11	24718232.14
Shredded tyre Chips modified	45,299,232.34	39,433,014.74	35,638,781.46	33,512,812.16	32,824,829.81	29,524,345.06

3.1 Cost Comparison Analysis Based on Fatigue Performance
In order to analyze the cost benefit ratio of the asphalt concrete mixes in this study, a 61Km road with a width of 7.5m and thickness of 0.1m was adopted. From the laboratory study the density of the asphalt obtained was 2243Kg/m^3.

3.2 Quantities for the 61Km Road
Length of road = 61km
Width = 7.5m
Thickness = 0.1m
Density = 2243kg/m^3
Volume of Asphalt = 61000m x 7.5m x 0.10m = 45750m^3
Mass of Asphalt = Density x Volume
= 2243kg/m^3 x 45750m^3 = 102,617,250kg
Weight in tons = $\frac{102{,}617{,}250kg}{907.185} = 113116.123\ tons$

3.3 Determination of Quantities and Cost of Unmodified Asphalt Concrete Mix
Asphalt = $\frac{4.5}{100}\ x\ 113116.123 = 5090.225tons$
Coarse Aggregates = $\frac{58}{100}\ x\ (113116.123 - 5090.225) = 62655.021tons$
Fine Aggregates = $\frac{42}{100}\ x\ (113116.123 - 5090.225) = 45370.877tons$
Cost of Asphalt at N5,000/ton = 5090.225tons x N5000
= N25,451,125.00

Cost of coarse aggregates at N8200/ton = 62,655.021tons x N8,200
= N513,771,172.20
Cost of fine aggregates at N1500/ton = 45,370.877tons x N1500
= N68,056,315.50
Total cost = 25,451,125.00 + 513,771,172.20 + 68,056,315.50
=N607,278,612.70

3.4 Determination of Quantities and Cost of CW and WPB Modified Asphalt Concrete Mix

Modifier Content = $\frac{4.0}{100}\ x\ 113116.123\ = 4524.65tons$

Asphalt Content = $\frac{4.5}{100}\ x\ (113116.123 - 4524.65) = 4{,}886.62tons$

Coarse Aggregates = $\frac{58}{100}\ x\ (113116.123 - 4524.65 - 4886.62)$
$= 60{,}148.81tons$

Fine Aggregates = $\frac{42}{100}\ x\ (113116.123 - 4524.65 - 4886.62) = 43{,}556.04tons$

Cost of modifier at N3000/ton = 4524.65 tons x N3000
= N13,573,950.00
Cost of Asphalt at N5,000/ton = 4886.62 tons x N5000
= N24,433,100.00
Cost of coarse aggregates at N8200/ton = 60,148.81tons x N8,200
= N493,220,242.00
Cost of fine aggregates at N1500/ton = 43,556.04tons x N1500
= N65,334,060.00
Total cost = 13,573,950.00+ 24,433,100.00 + 493,220,242.00 + 65,334,060.00 = N596,561,352.00
Cost savings = N607,278,612.70 - N596,561,352.00 = N10,717,262.70 only
Cost Savings in percentage = 1.76%

3.5. Determination of Quantities and Cost of STC Modified Asphalt Concrete Mix

Modifier Content = $\frac{5.0}{100}\ x\ 113116.123\ = 5{,}655.81tons$

Asphalt Content = $\frac{4.5}{100}\ x\ (113116.123 - 5{,}655.81) = 4{,}835.71tons$

Coarse Aggregates = $\frac{58}{100}\ x\ (113116.123 - 5{,}655.81 - 4{,}835.71)$
$= 59{,}522.26tons$

Fine Aggregates = $\frac{42}{100}\ x\ (113116.123 - 5{,}655.81 - 4{,}835.71) = 43{,}102.33tons$

Cost of modifier at N3000/ton = 5,655.81tons x N3000
= N16,967,430.00
Cost of Asphalt at N5,000/ton = 4,835.71tons x N5000
= N24,178,550.00
Cost of coarse aggregates at N8200/ton = 59,522.26tons x N8,200
= N488,082,532.00
Cost of fine aggregates at N1500/ton = 43,102.33tons x N1500
= N64,653,495.00
Total cost = N16,967,430.00 + N24,178,550.00 + N488,082,532.00 + N64,653,495.00 = N593,882,007.00
Cost savings = N607,278,612.70 - N593,882,007.00 = N13,396,605.70 only
Cost Savings in percentage = 2.21%

Table 2: Cost Effectiveness Ratio of Soaked HMA for 61Km Road at 10Hz

Modifier	Soaking Days	cost of 61Km (N)	Fatigue (Nf) (Cycles)	cost-effectiveness (cycles/cost)	Average Cost Effectiveness	Average cost Effectiveness ratio
	0	607,278,613	24,791,358.08	0.040823697		
	1	607,278,613	22,148,017.49	0.036470933		
Unmodified	2	607,278,613	20,571,835.22	0.033875448	0.034287534	1

	3	607,278,613	19,426,538.24	0.031989498		
	4	607,278,613	19,065,368.53	0.031394764		
	5	607,278,613	18,929,400.10	0.031170866		
	0	596,561,352	32,849,103	0.055064082		
	1	596,561,352	28,855,249	0.04836929		
	2	596,561,352	26,257,723	0.044015126		
	3	596,561,352	24,808,924	0.041586542		
	4	596,561,352	24,204,749	0.04057378		
CW	5	596,561,352	23,975,738	0.040189895	0.044966452	1.311451912
	0	596,561,352	34040662.79	0.057061462		
	1	596,561,352	29865418.32	0.05006261		
	2	596,561,352	27112047.23	0.045447207		
	3	596,561,352	25627665.62	0.042958977		
	4	596,561,352	24989897.11	0.041889903		
WPB	5	596,561,352	24718232.14	0.041434518	0.04647578	1.355471615
	0	593,882,007	45,299,232.34	0.076276486		
	1	593,882,007	39,433,014.74	0.066398736		
	2	593,882,007	35,638,781.46	0.060009869		
	3	593,882,007	33,512,812.16	0.056430085		
	4	593,882,007	32,824,829.81	0.055271635		
STC	5	593,882,007	29,524,345.06	0.04971416	0.060683495	1.769841326

IV. Discussions

In Table 1, the fatigue result presented as shown that STC modified asphalt concrete has a better fatigue performance not minding the number of soaking days. This is because the STC acts as both waterproofing agent and filler. This is in line with the study carried out by Otto et al (2020). Also, the results presented in Table 2, as shown that STC has a better cost-effectiveness ratio. The cost-effectiveness of STC wasobserved to be 1.77 times higher than that of the unmodified asphalt concrete, while the WPB modified asphalt concrete was 1.36 times higher than the unmodified and CW modified asphalt concrete was 1.31 times higher than the unmodified HMA concrete.

In summary, shredded tyre chips has proven to be more cost effective than polythene bag and candle wax. It is better than melted polythene bag while polythene bag is better than candle wax.

V. Conclusion

In this study, it is clear that at the point of preparing the asphalt, modified asphalt concrete mixes have a better cost saving and also has a better fatigue performance in the long run with a better cost-effectiveness ratio as shown in Tables 1 and 2. The cost savings are 2.21% for STC modified asphalt mix while for CW and WPB the cost savings was 1.76%.

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