Fatigue Performance of Asphalt Pavement Wearing Course in Submerged Condition Modified with Shredded Tyre Chips

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Abstract— Improving the fatigue performance of flexible pavement wearing course subjected to submergence has been one of the major concerns of civil engineering professionals in Nigeria especially among the Niger Delta people due to flooding. Pavement have been observed to be submerged in water perpetually causing rapid failure which has made the government to spend huge amount of money on road rehabilitation and construction yearly. Based on this, the current study was aimed at assessing the fatigue performance and life span of flexible pavement using shredded tyre chips modified asphalt pavement in submerged conditions. This was achieved by modifying the hot mix asphalt at 1%, 2%, 3%, 4% and 5% and also carrying out a traffic study along Port Harcourt Aba Expressway to determine the Design Equivalent Single Axial Load (ESAL) which was used as a base to check the fatigue performance. The modified asphalt concrete was submerged in water for 0 day to 5days. From the findings made in this study, the fatigue performance was enhanced with an extension of life span ranging from 21 to 33years at 5% modification as the number of soaking days and frequencies increases.

Keywords—Shredded Tyre Chips (STC), Hot Mix Asphalt (HMA) and Fatigue Performance.

1 INTRODUCTION

There are various factors that tend to affect the design life of asphalt concrete pavements and to name but a few are; poor design, poor construction, inadequate maintenance plan, improper usage and lots more. Damages resulting from moisture can easily be associated with any of the following listed above. In a study carried out by [10], moisture and traffic frequency has been established as one of the factors affecting pavement performance. Moisture in recent studies carried out within the Niger Delta region of Nigeria has been revealed to contribute heavily towards pavement deterioration [7][6][5]. According [11], the progressive deterioration of asphalt mixes in the presences of moisture causes loss of adhesion between the asphalt binder and aggregate surface or loss of cohesion within the binder due to the solvent properties of water. This process described is known as **stripping**. Since moisture is ever present as a result of rainfall and the absence of a functioning drainage system to eliminate water, the pavement is submerged for hours, days and even weeks. Hence, drastically reducing the pavement performance and therefore hindering it from being serviceable through its design life which ideally should span between 15-30 years and 5-20 years for overlays.

In the quest to improve the performance and lifespan of the flexible pavement in submerged conditions, various research works have been carried out using additives/modifiers. [8] used waste polythene bags in melted form as modifier in asphalt concrete pavement. The study revealed that the modifier can act as a waterproofing agent at 3% addition resisting the effect of moisture in terms of the Index of Retained Stability. A further study by [9] revealed that waste polythene bags are economical when used to modify asphalt.

Over the years, some modifiers or additives have been incorporated into the asphalt concrete mixtures to improve the fatigue life under normal conditions not considering submergence as it is in the Niger Delta region of Nigeria. Some of the additives or modifiers used, include polymers, recycled plastics such as polyethylene, blast furnace slags, municipal waste combustion ash, and scrap tires. In a study carried out by [4], shredded tyre chips were used as filler materials to improve the dynamic modulus of asphalt concrete pavement. The study revealed that the dynamic modulus increases linearly with increase in amount of shredded tyre chips addition considering the frequencies of 0.1 -25Hz.

The objective of this present study is to improve the performance of flexible pavement submerged in water using shredded tyre chips knowing that it can improve dynamic modulus as revealed in [4] and that dynamic modulus has direct effect on fatigue performance using Port Harcourt-Aba Expressway as a case study.

In this study, the foundation of the complete findings is based on the objective stated above with a well-defined assumption which could be viewed as the limiting conditions of the study.

These assumptions include;

i. That the pavement life span is 20 years.
ii. That only vehicular loads ≥ 80kN can cause pavement failure.
iii. Passenger cars do not contribute to pavement value.

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iv. That pavement performance in real life is similar with the performance of hot mix asphalt (HMA) concrete in the laboratory.

v. That the actual fatigue life of a pavement is the number of load repetitions ≥ 80kN single axle load

vi. That traffic loads and moisture are the only contributors to pavement damage.

2.0: Materials and Methods

2.1. Collection of Samples

Materials such as coarse and fine aggregates, asphalt binder (bitumen), modifier (shredded tyre chips) were used during this research. The coarse aggregates were obtained directly from Akamkpa stone crush in Cross River State while the fine aggregates (River Sand) was gotten from Omukwa river in Abua/Odual area of Rivers State. The Bitumen was obtained from Setraco Construction Company, Port Harcourt while the burnt shredded tyre chips used as modifier was obtained from market dealers in Ikokwu, Mile 3, Diobu, Port Harcourt. After the sampling of the materials was done, laboratory tests such as specific gravity, grading of asphalt and sieve analysis of the aggregates used for mix-proportioning (adopting the straight-line method) were carried out.

2.2. Sample Preparation

Bruce Marshal Mix Design Procedure for asphalt concrete mixes as presented in [2] and [12] was adopted in the preparation of samples for this study. It involved the preparation of a series of test specimens for a range of varying asphalt (bitumen) contents as such highlighting well defined peak values. The preparation of test samples was carried out on the bases of 0.5 percent addition of asphalt content with at least 3-asphalt contents above and below the optimum bitumen content. In a bid to ensure the reliability of the data provided, the test specimen prepared for each set of asphalt content used were replicated in threes. In course of the preparation of the conventional asphalt concrete samples, the aggregates were first heated and stirred properly for about 5 minutes before the addition of asphalt to allow for homogeneity and absorption of the binder into the aggregates. Afterwards the mix was subsequently transported into a mould and compacted on both faces with 75 blows (being a laboratory representation of the heavy traffic volume) using a 6.5kg-rammer falling freely from a height of 450mm. The compacted specimens were subjected to the bulk specific gravity test, stability and flow, density and voids analyses at a temperature of 60^0C and frequencies of 1Hz, 5Hz, and 10Hz respectively as specified by [1]. The results obtained were used to determine the optimum asphalt content of the unmodified asphalt concrete. Burnt shredded tyre chips content were then added at varying amounts (1-5 percent by weight of the overall asphalt concrete mix of 1200g) to the samples at optimum asphalt content and then re-designed using the same Marshal Design Procedures already stated above to produce burnt shredded tire chips modified concretes having varying mix design properties.

2.3. Theory

2.3.1 Determination of the Optimal Binder Content

The optimum binder content (O.B.C.) for the conventional bituminous concrete was obtained using equation 1, in according to the Marshal Mix Design Procedure referenced in (Asphalt Institute, 1956; National Asphalt Pavement Association, 1982) as follows:

$$O.B.C = 0.3\,(A.C._{max.\ stability} + A.C._{max.\ density} + A.C._{median\ limits\ of\ air\ void}) \quad (2.1)$$

2.3.2 Determination of Dynamic Modulus

a) Using Asphalt Institute Model (1993)

The Asphalt Institute developed a method for design in which the dynamic modulus is determined from the following equations, as presented in Huang's (1993) as shown in equations 2.2 – 2.8:

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

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

$$\beta_2 = \beta_4^{0.5} T^{\beta_5} \quad (2.4)$$

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

$$\beta_4 = 0.483V_b \quad (2.6)$$

$$\beta_5 = 1.3 + 0.49825 \log f \quad (2.7)$$

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

Where;

E^* = dynamic modulus (psi)

f =loading frequency (1Hz, 5Hz and 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 (%)

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V_b = volume of bitumen
$P_{77°F}$ = penetration at 77°F or 25°C

2.3.3 Determination of Fatigue Life Using Asphalt Institute (1982)

Asphalt Institute in 1981 developed a model but had some limitations. However, to curb the effects of shift factors S_f, seen as limitations, the Asphalt Institute model was further modified to accommodate shift factors from various combinations of asphalt binder types and grades (Asphalt Institute, 1982). The resulting equation is of the form below which was adopted in this work;

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

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

The **horizontal tensile strains** were gotten from direct measurements of all the samples while the **stiffness modulus** were determined using equations 2.2 to 2.8.

2.3.4 Determination of Design Equivalent Single Axial Load (ESAL) for Port Harcourt-Aba Expressway

To determine the Design ESAL for Port Harcourt-Aba Expressway, the Annual Average Daily Traffic (AADT) was determined manually each day from 6am to 6pm for a year period. The count was done and vehicles with weight of 80KN and above were classified accordingly. According to the Federal Highway Administration, Washington (FHWA), to determine ESAL per year, the load equivalency factor, truck factor and traffic growth factor are multiplied by the first year ESA value to give the total actual number of load repetition needed to cause failure during the pavement design life. The equation below was used to the determine the Design ESAL in this study in line with FHWA procedure at 8% annual growth rate for 20years design period.

$$\text{Design ESAL} = \text{ESAL/year} \times [(1+g)^n-1]/g \qquad (2.10)$$

Where:
g = Annual growth rate
n = design period (years)

3.0: RESULTS

The tables and figures below are results obtained from this study.

Table 3.1: Schedule of Aggregates Used for Mix Proportion in Accordance with ASTM 1951: C136

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

Table 3.2: Laboratory test results showing the properties of all the materials used

Materials	Shredded Tyre Chips	Asphalt Binder	Coarse Aggregates (A)	Fine Aggregates (B)
Specific Gravity	1.18	1.05	2.80	2.56
Grade of Binder		50/60		
Mix Proportion			58%	42%
Viscosity of binder		14.5		
Soften Point		50^0C		
Penetration Value		53		

Table 3.3 Mix Properties Unmodified Asphalt Concrete

Asphalt Content (%)	Stability (N)	Flow(mm) (0.25mm)	Density (Kg/m³)	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

In a bid to determine the optimum binder content, equation 2.1 was applied in line with figures after analysis of the preliminary results. The optimum binder content obtained from the result above was **4.95%.** This was the value used for the production of the conventional sample and modified sample.

Table 3.4: Fatigue Results at Frequency = 1Hz

	Soaking Day					
% STC	0	1	2	3	4	5
0	32432351.78	28270623.5	26258722.3	24796819	24335807	24162251.11
1	36079824.23	32059351.3	29386453.2	27957682	27386359	27145983.69
2	40980051.28	36248566.3	33094243.2	31374181	30675679	30405701.59
3	46300030.94	40719790.6	37042053.3	35054845	34170397	33851494.12
4	51926479.86	45432404.2	41170247.9	38861391	37810904	37428033.89
5	57821768.74	50333892.1	45490779.1	42777106	41898937	37686065.06

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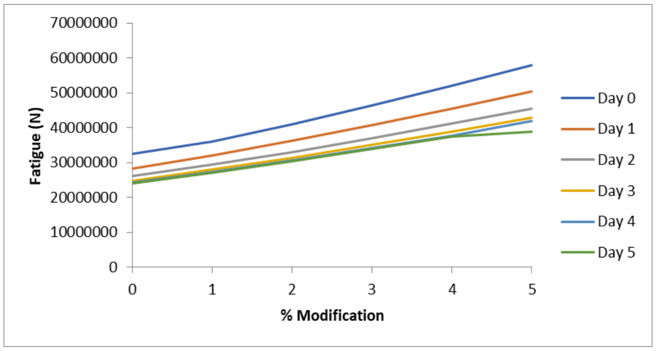

Figure 3.1: Variation of Fatigue against % STC Modification at 1Hz

Table 3.5: Fatigue Results at Frequency = 5Hz

% STC	Soaking Day 0	1	2	3	4	5
0	25408433.71	22148017.5	20571835.2	19426538	19065369	18929400.1
1	28265968.77	25116214.7	22605605.3	21902850	21455259	21266942.17
2	32104947.09	28398166.8	25926979.6	24579433	24032207	23820699.11
3	36272771.66	31901052.9	29019806.6	27462971	26770069	26520231.48
4	40680693.24	35593048.9	32253953.1	30445129	29622147	29322194.93
5	45299232.34	39433014.7	35638781.5	33512812	32824830	29524345.06

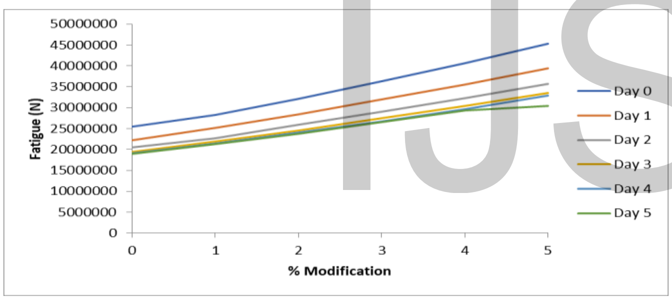

Figure 3.2 Variation of Fatigue against % STC Modification at 5Hz

Table 3.6: Heavy Traffic Results at Frequency = 10Hz

% STC	Soaking Day 0	1	2	3	4	5
0	22678870.67	19768712.5	18361855.5	17339595	17017224	16895862.55
1	25229427.93	22418043.1	20177143	19549883	19150375	18982288.47
2	28655994.07	25347423.6	23141710	21938926	21450488	21261701.78
3	32376079.95	28474003.1	25902282	24512694	23894228	23671230.49
4	36310469.86	31769377.6	28788993.4	27174486	26439914	26172186.15
5	40432850.36	35196825.6	31810196.9	29912615	29298541	26352618.91

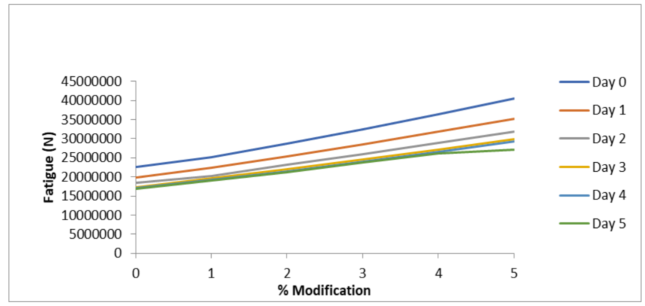

Figure 3.3: Variation of Fatigue against % STC Modification at 10Hz

Table 3.7: ESAL per Year for Port Harcourt - Aba Expressway

Vehicle Type	Vehicle/Day	Distribution Factor	Days/Year	ESALs/ Veh	ESALs/ Year
Buses/Coaches	4100	0.8	365	0.57	682404
2-axle/6tire Trucks	250	0.8	365	0.26	18980
3-axle single	110	0.8	365	0.42	13490.4
4 or less axle	80	0.8	365	0.3	7008
6 or more axle	72	0.8	365	1.2	25228.8
6-axle multi trailer trucks	81	0.8	365	1.06	15476
7 or more axle	52	0.8	365	1.39	19076.36
Total	4745				781,663.56

Table 3.8: Fatigue Performance Check for Unmodified HMA Concrete

Soaking Days	N_f at 1Hz	ESAL = 35,768,925	N_f at 5Hz	ESAL = 35,768,9245	N_f at 10Hz	ESAL = 35,768,925
0	31,644,691.50	Not ok	24,791,358.08	Not ok	22,128,085.90	Not ok
1	28,270,624.53	Not ok	22,148,017.49	Not ok	19,768,712.51	Not ok
2	26,258,722.25	Not ok	20,571,835.22	Not ok	18,361,855.49	Not ok
3	24,796,818.53	Not ok	19,426,538.24	Not ok	17,339,595.00	Not ok
4	24,335,806.66	Not ok	19,065,368.53	Not ok	17,017,223.89	Not ok
5	24,162,251.11	Not ok	18,929,400.10	Not ok	16,895,862.55	Not ok

Table 3.9: Fatigue Performance Check for STC Modified HMA Concrete

Soaking Days	N_f at 1Hz	Design ESAL = 35,768,925	N_f at 5Hz	Design ESAL = 35,768,925	N_f at 10Hz	Design ESAL = 35,768,925
0	57,821,768.74	Ok	45,299,232.34	Ok	40432850.36	Ok
1	50,333,892.13	Ok	39,433,014.74	Ok	35196825.62	Not ok
2	45,490,779.08	Ok	35,638,781.46	Not ok	31810196.92	Not ok
3	42,777,106.16	Ok	33,512,812.16	Not ok	29912615.43	Not ok
4	41,898,936.84	Ok	32,824,829.81	Not ok	29298541.36	Not ok
5	37,686,065.06	Ok	29,524,345.06	Not ok	26352618.91	Not ok

Table 3.10: Fatigue Performance in Terms of Years for STC Modified HMA Concrete

Soaking Days	NF at 1Hz	Expected year of failure	Nf at 5Hz	Expected year of failure	Nf at 10Hz	Expected year of failure
0	57,821,768.74	32.33	45,299,232.34	25.33	40432850.36	22.61
1	50,333,892.13	28.14	39,433,014.74	22.05	35196825.62	19.68
2	45,490,779.08	25.44	35,638,781.46	19.93	31810196.92	17.79
3	42,777,106.16	23.92	33,512,812.16	18.74	29912615.43	16.38
4	41,898,936.84	23.43	32,824,829.81	18.35	29298541.36	16.38
5	37,686,065.06	21.07	29,524,345.06	16.51	26352618.91	14.73

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4.0 Discussions

The results presented in Tables 3.4, 3.5 and 3.6 for the STC modified HMA concrete showed that the fatigue life increases linearly with increasing STC content for all the frequencies up to 5%. As the number of soaking day increases, the tensile strains were observed to be increasing while the fatigue and dynamic modulus values reduces. A critical observation of the tables has shown that as the frequency increases from 1Hz to 5Hz and 5Hz to 10Hz, the fatigue value of the asphalt concrete mix reduces at a rate of 21.65% and 30.07% on the average respectively.

From Table 3.7, the ESAL after determining the AADT was 781,663.56. Applying equation 2.10 at 8% traffic growth rate for a design period of 20years, the design ESAL for Port Harcourt-Aba Express is 35,768,925. This shows that traffic growth along this road is increasing yearly when compared to the current ESAL values given in the Nigerian Federal Ministry of Works Highway Design Manual Part 1 volume 3 of 2013, the number of heavy/destructive vehicles per day along Port Harcourt – Aba Expressway is 2200 but with the current traffic studies carried out, the number has increased to 4745 vehicles per day. This is above 100%. This means that with the current traffic growth and rate of pavement constantly submerged in water couple with increasing frequency of destructive vehicles on the pavement, the pavement will perpetually remain in bad condition. This is a true reflection of Port Harcourt Aba Expressway.

In Table 3.8, the number of load repetitions required to cause failure when the HMA concrete was unmodified, was observed to be reducing as the frequency and number of soaking days increases. Looking at the table, none was ok when compared to the design ESAL value. This shows the actual situation along Port Harcourt-Aba Expressway. The number of load repetition along this road has been observed to be increasing as a result of business activities in Aba and the movement of crude oil products to the eastern part of Nigeria because this road is a major link between the south and the east. When the pavement is subjected to submergence and destructive loads come on it with increase in frequency rate, the pavement materials split (Stripping) rapidly causing pot holes. This has been observed in this study.

The results shown for STC modified HMA concrete in Table 3.9 showed a better behavior when compared to the unmodified HMA concrete. Similar behavior of constant reduction in fatigue as the frequency and soaking day increases was observed. However, when frequency was 1Hz, all the load repetitions (fatigue) were ok up to soaking day 5. For frequency of 5Hz it was ok up to soaking day 1 and thereafter further soaking of the pavement reduced its fatigue values. For frequency of 10Hz it was ok for soaking day 1 thereafter, the fatigue values reduced.

In terms of pavement life span, for frequency of 1Hz the life span is above 20years up to the 5th day of soaking. For frequency of 5Hz it was ok up to day 2 soaking and thereafter further soaking of the pavement reduced its life below 20years. For frequency of 10Hz it was ok for soaking day 0 thereafter, the life span reduced. See Table 3.10 as reference.

5.0 Conclusion

Based on the study objective, assumptions and findings, the following conclusions are made:

i. That the inclusion of shredded tyre chips as modifier in hot mix asphalt, enhances the fatigue life at 5% modification for submerged conditions of moisture.
ii. That the inclusion shredded tyre chips increases the life span beyond 20years design period as shown in Table 3.11.
iii. That increase in frequency in the presences of moisture reduces the fatigue life rapidly.
iv. That the current traffic situation along Port Harcourt-Aba Expressway has increased beyond 100%.

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