Reducing Damaging Effect on Elastic Properties of Asphalt Concretes Exposed to High Curing Temperatures through Increased Compaction

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Abstract – The behaviour of flexible pavements which can be explained from the behaviour of asphalt concretes in the laboratory is one that is usually complex due to the configuration of the pavement structure having different modulus of elasticity and Poisson's ratio. Secondly, during service life the pavement is exposed to certain severe maladies such as traffic loads having different axle configuration, moisture intrusion in cases were drainage measures are poor or absent and lastly changes in temperature particularly in arid regions. As a result these impediments asphalt pavement usually require as a precedence proper characterization and evaluation in order to mitigate these external factors. The present study had considered one of the most damaging factors to asphalt concrete – change in curing temperature; its effect on the elastic properties of asphalt concrete and how to reduce the damaging effect it creates through increased compaction. The methodology involved preparing asphalt concrete samples in the laboratory using the Marshal Design Procedure. In addition, the samples were prepared using varying compaction efforts of 35, 50, 75 and 100 blows before subjecting the samples to varying curing temperatures between 60 -100℃ and finally crushing to failure. The elastic properties of the concrete samples were investigated under the conditions above with respect to tensile and compressive elastic modulus. The results obtained revealed that tensile elastic modulus increased linearly with increasing compaction between 35 – 100 blows having an average increase of 97.94%, 105.80%, 117.52%, 132.98% and 160.28 for 60, 70, 80, 90 and 100℃ respectively. The same was true for compressive elastic modulus having average increase between 35 – 100 blows of 87.24%, 99.73%, 118.34%, 134.67% and 138.32% for 60, 70, 80, 90 and 100℃ respectively.

Key words: Asphalt concrete, Elastic Properties, Temperature and Increased Compaction

1.0 INTRODUCTION

One the most important hot-mix asphalt (HMA) property influencing the structural response of a flexible pavement is the HMA stiffness modulus (Garcia and Thompson, 2007). Therefore, flexible pavement design methods based on elastic theories need that the elastic properties of the pavement materials be known (Brown and Foo, 1989). In an earlier study by Michael and Ramsis (1988) it was concluded from their work that among the common methods of measurement of elastic properties of asphalt concrete mixes (which are Young's, shear, bulk, dynamic modulus, double punch, resilient, and Shell Nomo graph modulus), the resilient modulus is more appropriate for use in multilayer elastic theories. This had been supported by the separate study of Baladi and Harichandran (1988) who posited that resilient modulus measurement by indirect tensile test gives the best result in terms of repeatability.

However, the present study focused on the elastic modulus of flexible pavement simulated in the laboratory using asphalt concrete samples prepared using increased compaction effort and subjected to varying curing temperatures in order to simulate true field exposure conditions during service life. As a simple definition elastic modulus of a material is the ratio of stress to strain within the elastic region and also known as Young's modulus of elasticity. Furthermore, it is a measure of the linear stiffness of a material subjected to applied load or stress within the elastic region of the material (Igwe and Nyebuchi, 2017a).

Traxler (1963) listed a number of effects which may reduce the binding properties of asphalt which in turn affects stability and flow of asphalt concretes. The study revealed that time and temperature parameters are the reason of many long term aging factors.

In similar further works the effect of different levels of mixing time and mixing temperature on asphalt aging both for short and long term have been studied by other researchers such as Lee, (1973); Kim et al., (1986); Mallick and Brown (2004); Lee et al., (2009); Wu et al., (2009) and Yu et al., (2009).

In a more recent study Igwe and Nyebuchi (2017b) investigated thermal effects on elastic and rigidity modulus of asphalt pavement wearing course using laboratory simulation of asphalt concrete samples. Their work revealed that increase in temperature engendered separation between the materials that make up the concrete. A careful analysis further showed that as curing temperature increased there was a corresponding reduction in the bonding between asphalt cement and the aggregates making up the concrete which in turn reduced the stiffness of the material. The study concluded that increase in curing temperature produced adverse effect on pavement stiffness.

On this basis the present research was focused on mitigating the damaging effect caused by high curing temperatures on elastic modulus of asphalt concrete mixtures through increased compaction on the concrete.

2.0 Materials and Methods

2.0.1 Materials
(i) Bitumen – used as cement binder
(ii) Gravel – used as coarse aggregate
(iii) Sand – used as fine aggregate

2.0.2 Method
In general the methodology adopted involved laboratory programmes of different experiments as presented below;

2.0.2.1 Material Characterization/Classification
Sequel to material characterization sampling was carried out and all the materials used were locally sourced within Rivers State. See Table 1.

(i) Bitumen – classification test of the bitumen used involved the following;

- Specific Gravity Test
- Penetration Test
- Viscosity Test
- Softening Point Test

(ii) Coarse and Fine Aggregates – classification test for coarse and fine aggregates were carried out as follows;

- Specific Gravity Test
- Sieve Analysis Test

2.0.2.2 Blending of Aggregates for Mix Proportion
Aggregate blending was carried out in accordance with ASTM – C136; 1951 in order to meet grading requirement for purpose of the research study (See Table 2)

2.0.2.3 Preparation of Bituminous Concrete Samples
The bituminous concrete samples used for simulation were prepared in accordance with the guidelines as stated by Bruce Marshal for Mix Design Procedures as presented in Asphalt Institute (1981), Chapius; Kim et al; Shuler and Huber; - (1992), Roberts et al; (1996) and ASTM (2010) for varying curing temperature (60 – 100 C) and compaction (35 – 100blows).

2.0.2.4 Determination of Elastic Modulus in Tension and Compression
The results of elastic modulus both in tension and compression was carried out using indirect tensile testing method on the bituminous concretes for varying curing temperature (60 – 100℃) and compaction efforts (35 – 100blows).
The static indirect tensile strength of each specimen was determined using the procedure outlined in ASTM D 6931 were a loading rate of 51mm/minute was adopted causing Tensile failure to occur in the sample rather than the compressive failure. The test involved loading 102 mm diameter and 64mm thick specimen using a 13 mm wide strip to provide a uniform loading in order to produce uniform stress distribution through the diametral axis. The

applied load through the diametral axis indirectly created tensile stress in the horizontal direction and corresponding compressive stress in the vertical direction of the sample and the peak load at failure of specimen was recorded. Furthermore, strains in both the horizontal and vertical directions were also measured using strain gauges.

The Timoshenko's stress-strain model for Elastic Modulus in two dimensional stress system was adopted as presented in Equations 1- 4 below;

a) Elastic Modulus in Tension (Timoshenko and Goodier, 1951 and ASTM, 1973)

$$E_x = \frac{1}{\varepsilon_x}\left(\sigma_x - \mu\sigma_y\right) \qquad 1$$

b) Elastic Modulus in Compression (Timoshenko and Goodier, 1951 and ASTM, 1973)

$$E_y = \frac{1}{\varepsilon_y}\left(\sigma_y - \mu\sigma_x\right) \qquad 2$$

Where: Stresses in Tension and Compression according to Timoshenko (1934) and Chong et al; (1979) are as presented below;

$$\sigma_x = \frac{2p}{\pi dt} \qquad 3$$

$$\sigma_y = -3\sigma_x \qquad 4$$

E_x = Elastic Modulus in Tension (MPa)
E_y = Elastic Modulus in Compression (MPa)
ε_x = Horizontal Tensile Strain
ε_y = Horizontal Tensile Strain
σ_x = Horizontal Tensile Stress (MPa)
σ_y = Vertical Compressive Stress (MPa)
μ = Poisson's Ratio

3.0 Results (Tables and Figures)
The results from the laboratory experiments and analysis of the laboratory results are presented in the Tables and Figures below;

Table 1: Results of Material Classification

Material		Bitumen	Sand	Gravel
Specific gravity		1.04	2.66	2.95
Grade of binder material	-	60/70	-	-
Mix proportion (%)	-	-	38	62
Viscosity of binder (S)	-	69.3	-	-
Softening point	-	49.5ºC	-	-
Penetration value	-	66.7mm	-	-

Table 2: Result of Coarse and Fine Aggregate Blend

Sieve size (mm)	Specification Limit	% Passing Aggregate A (Gravel)	% Passing Aggregate B (Sand)	Mix Proportion (0.62A+0.38B)
19.1	100	100	100	100
12.7	76-92	90.4	100	94.0
9.5	64-79	41.6	100	63.8
4.75	40-60	17.1	98.9	48.2
1.18	23-37	8.6	83.0	36.9
0.425	7-20	6.3	13.0	8.8
0.30	5-13	4.8	3.0	4.1
0.075	3-8	3.8	0.2	2.4

Table 3: Results of Tensile Elastic Modulus (MPa) for Varying Compaction and Curing Temperature

	Compaction (No. of Blows)			
Temp ⁰C	35	50	75	100
60	76	125.02	206.98	545.94
70	70.44	92.41	192.54	534.97
80	49.85	74.05	169.83	466.45
90	40.46	64.28	155.12	463.41
100	31.23	50.07	123.69	461.95

Table 4: Results of Compressive Elastic Modulus (MPa) for Varying Compaction and Curing Temperature

	Compaction (No. of Blows)			
Temp ⁰C	35	50	75	100
60	65.66	95.63	186.63	412.32
70	58.73	72.98	171.08	411.44
80	43.46	60.94	150.61	403.13
90	33.64	52.56	141.22	394.12
100	25.67	41.09	112.76	316.26

Table 5: Percentage change in Tensile Elastic Modulus Due to Increase in Compaction Level under Varying Curing Temperature

	Change in Compaction Level (No. of Blows)			
Temp ℃	35 -50	50 -75	75 - 100	Average Change (%)
60	64.5	65.56	163.76	97.94
70	31.19	108.35	177.85	105.8
80	48.55	129.35	174.66	117.52
90	58.87	141.32	198.74	132.98
100	60.33	147.03	273.47	160.28

Table 6: Percentage change in Compressive Elastic Modulus Due to Increase in Compaction Level under Varying Curing Temperature

	Change in Compaction Effort (No. of Blows)			
Temp ℃	35 -50	50 -75	75 - 100	Average Change (%)
60	45.64	95.16	120.93	87.24
70	24.26	134.42	140.5	99.73
80	40.22	147.14	167.66	118.34
90	56.24	168.68	179.08	134.67
100	60.07	174.42	180.47	138.32

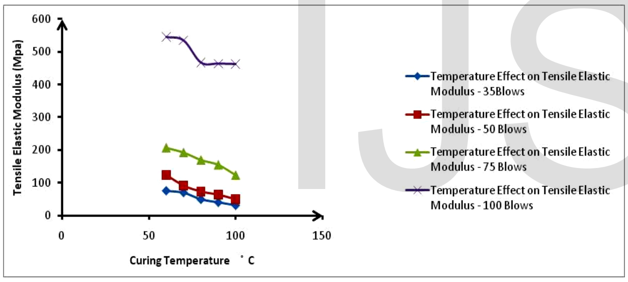

Figure 1:Variation of Tensile Elastic Modulus with Curing Temperature at Different Compaction Efforts (35 – 100 Blows)

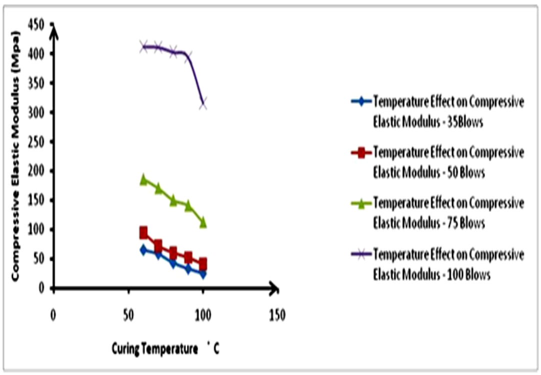

Figure 2: Variation of Compressive Elastic Modulus with Curing Temperature at Different Compaction Efforts (35 – 100 Blows)

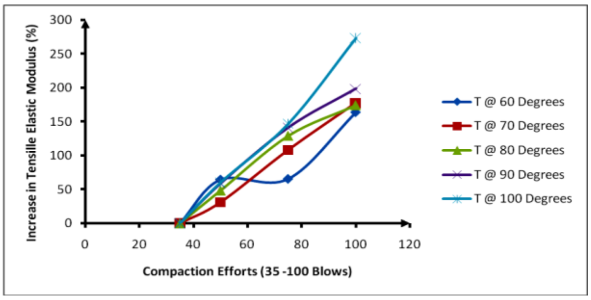

Figure 3: Percent Increase in Tensile Elastic Modulus Due to Increase in Compaction Effort at Varying Curing Temperature

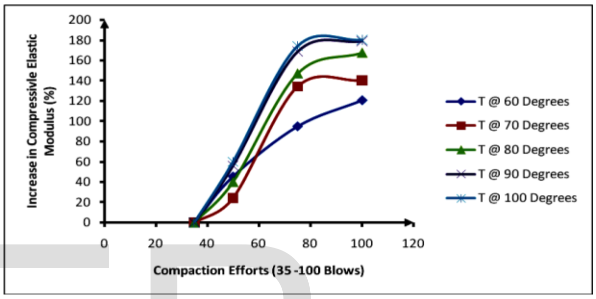

Figure 4: Percent Increase in Compressive Elastic Modulus Due to Increase in Compaction Effort at Varying Curing Temperature

4.0 Discussion of Results

4.0.1 Effect of Curing Temperature on Elastic Modulus in Tension

The result from Figure 1 and Table 3 clearly reveals the damaging effect of temperature on tensile elastic modulus of the bituminous concrete samples for all categories of compaction efforts. It was observed that for 35 blows compaction effort; as curing temperature increased from 60 – 100 ℃ it resulted in corresponding linear reduction in tensile elastic modulus. The same was true for all other categories of compaction.

4.0.2 Effect of Curing Temperature on Elastic Modulus in Compression

The result from Figure 2 and Table 4 clearly reveals the damaging effect of temperature on compressive elastic modulus of the bituminous concrete samples for all categories of compaction efforts. It was observed that for 35 blows compaction effort; as curing temperature increased from 60 – 100 ℃ it resulted in corresponding linear reduction in compressive elastic modulus. The same was true for all other categories of compaction.

4.0.3 Mitigation Effect on Tensile Elastic Modulus Due to Increased Compaction

The result from Figure 3 and Table 5 clearly reveals the mitigation effect of increased compaction on tensile elastic modulus of the bituminous concrete samples subjected to different curing temperatures. It was observed that for 60 ℃ curing temperature increase in compaction effort from 35 – 50; 50 – 75; and 75 - 100blows resulted in corresponding average linear increase in the tensile elastic modulus value by 97.94%. The same was true for all other categories of compaction having 105.8%, 117.52%, 132.98% and 160.28% for 70℃, 80℃, 90 C and 100℃ curing temperatures respectively.

4.0.4 Mitigation Effect on Compressive Elastic Modulus Due to Increased Compaction

The result from Figure 4 and Table 6 clearly reveals the mitigation effect of increased compaction on compressive elastic modulus of the bituminous concrete samples subjected to different curing temperatures. It was observed that for 60 ℃ curing temperature increase in compaction effort from 35 – 50; 50 – 75; and 75 - 100blows resulted in corresponding average linear increase in the compressive elastic modulus value by 87.24%. The same was true for all other categories of compaction having 99.73%, 118.34%, 134.678% and 138.32% for 70℃, 80℃, 90 C and 100℃ curing temperatures respectively.

5.0 Conclusion

From the observations and findings as presented in section four above the following conclusions were made based on the research focus of the present study;

(i) That temperature changes severely affects the elastic modulus of bituminous concretes whether in tension or in compression which is an important parameter in mechanistic design of pavement and in turn negatively affects pavement performance in terms of service life.

(ii) That increase in compaction efforts can adequately help in mitigating the loss in elastic modulus of bituminous concretes whether in tension or compression which positively helps to heal the damages created by temperature effects and in turn enhances pavement service life.

6.0 Recommendation

The findings of the research have afforded the opportunity to clearly recommend that higher compaction efforts be adopted in bituminous construction of pavement particular in arid regions that experience high temperatures.

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