The Influence of Thermal Property on the Elasticity and Rigidity of Flexible Pavement Wearing Course

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Abstract *To model the behavior of a flexible pavement under real-world settings, a laboratory examination of flexible pavement was conducted utilizing samples of asphalt and concrete. The investigation was conducted to identify the alterations that will occur in the elastic and stiffness (**shear**) modulus of flexible pavement under circumstances of rising temperature (thermal effect). The work is important because the stiffness and stresses of the pavement must be determined for proper mechanistic design of flexible pavement. However, only elastic and rigidity modulus stiffness was considered for the purposes of the current study. As the temperature disparity increased from 20 to 60 degrees Celsius, samples were prepared for three separate traffic classifications. The obtained findings showed that the viscosity of the binder (asphalt cement) is considerably lowered with rising temperature, consequently diminishing cohesiveness of the composite mix for all kinds of traffic taken into consideration. Additionally, the decrease in viscosity had a detrimental impact on the stiffness (bonding of asphalt cement with aggregates) behavior of the pavement, which in turn had a direct impact on the decline in the pavement's elastic and rigidity moduli for all types of traffic under consideration.*

Keywords: asphalt concrete, elastic modulus, rigidity modulus, temperature

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INTRODUCTION

In mechanistic design of flexible pavement, it is required as input in the design, the determination of stresses and strains. These stresses and strains control the overall behaviour and performance of the pavement with respect to fatigue and rutting deformations [1]. In addition, the ratios of stresses and strains are further used to determine different types of modulus of the pavement material, thus the need for their assessment.

One the most important hot-mix asphalt (HMA) property influencing the structural response of a flexible pavement is the HMA stiffness modulus (EHMA) [2]. Therefore, flexible pavement design methods based on elastic theories need that the elastic properties of the pavement materials be known [3]. Michael and Ramsis (1988) [4] in a previous study concluded from their work that among the common methods of measurement of elastic properties of asphalt 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) [5] who posited that resilient modulus measurement by indirect tensile test gives the best result in terms of repeatability. However, this has been contradicted by more recent research proposed by AASHTO Design Guide 2002 [6] as presented in Clyne et al

(2003) [7] which proposes the use of the dynamic modulus of asphalt mixtures as a parameter in the design procedure; the dynamic modulus emerging as a lead parameter for Simple Performance Test to predict rutting and fatigue cracking in asphalt pavements. In addition, different test methods and equipment have been developed and employed to measure these different moduli. Some of the tests employed are tri-axial tests (constant and repeated cyclic loads), cyclic flexural test, indirect tensile tests (constant and repeated cyclic loads), and creep test. Although, there are different kinds of stiffness modulus as already stated for purpose of the present study, we shall be limiting our stiffness modulus to elastic and shear modulus of hot mix asphalt concrete.

The present study was aimed at investigating the changes that will occur in a flexible pavement with respect to linear and shear deformations when subjected to increasing temperature conditions. In other words, the study assessed the stiffness in terms of elastic modulus and rigidity interms of shear modulus of flexible pavements under these external conditions of increased temperature and traffic loads. However, Determination of elastic and shear modulus in the field can be very complicated and expensive; therefore, the present study undertook a laboratory approach in investigating how flexible pavement can vary under increased temperature and traffic loads with respect to its stiffness (modulus of elasticity) and rigidity (modulus of rigidity or shear).

It is pertinent to mention that a realistic prediction of the long-term service life of asphat pavements is one of the most challenging tasks for pavement engineers in Highway Engineering. It is general knowledge among pavement engineers that the performance of flexible pavements is closely related to the performance of asphalt concrete. Thus, proper evaluation of the performance and behavior of asphalt concrete is of great importance; therefore, performance models of asphalt concrete provide the links among various processes involved in asphalt mix design, pavement structure design, construction, and rehabilitation [8].

The elastic modulus of a material is simply defined as the ratio of stress to strain within the elastic region and is 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. There are several methods of determining elastic modulus of materials such as the use of wave propagation techniques, electrical resistivity methods and indirect tensile testing methods and the use of prediction models using mechanical and physical properties of the materials. For purpose of the present study the latter was adopted (i.e. using predictive models) in determination of elastic modulus of the asphalt concrete mixtures in the laboratory used to simulate actual field conditions.

Nijboer (1957) [9] proposed the use of stability-flow ratios as a means of determining elastic modulus of asphalt concretes. His study suggested that the units of elastic modulus be in kg/cm^2. However, McLeod (1964) [10] modified the study by Nijboer to accommodate English units such that values of elastic modulus become lb/in^2 (see Equation 1). The present study adopted the study by McLeod (1964) [10] and modified units to accommodate SI units in N/mm^2 or Mpa.

On the other hand rigidity (shear) modulus can simply be defined as the elastic modulus of a material used for the deformation which takes place when a force or load is applied parallel to one face of the material while the opposite face is held fixed by another equal force [11,12].

Also, studies have revealed that for a linear, homogeneous and isotropic material the rigidity (shear) modulus is related to elastic modulus as presented in Equation 2 below [11, 13].

MATERIALS AND METHODS

Sample Collection

The materials used for this study were asphalt cement, coarse and fine aggregates and gravel dust. The asphalt cement and gravel dust used were collected from a private asphalt plant company H & H situated at Mbiama, in Ahoada West Local Government Area of Rivers State, Nigeria. On the other hand, the coarse and fine aggregate used were obtained from a private construction site at Rumuagholu in Obio/Akpor Local Government Area of Rivers State. After sampling of the materials, laboratory tests – specific gravity, grading of asphalt and sieve analysis of the aggregates used for mix- proportioning by Rothfuch's method – were carried out.

Sample Preparation

Samples preparation was preceded by aggregate gradation and blending. The Rothfuch's method of blending which

allows for more than two aggregates to be blended was adopted. After aggregate gradation and blending Marshal Design Procedures for asphalt concrete mixes as presented in National Asphalt Pavement Association (1982) [14], Asphalt Institute (1993) [15] and Roberts et al (1996) [16] was adopted for mix design.

The procedures 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 bases of 0.5 percent increments of asphalt content with at least 3- asphalt contents above and below the optimum asphalt content. In order to provide adequate data, three replicate test specimens were prepared for each set of asphalt content used. During the preparation of the unmodified asphalt concrete samples, the aggregates were first heated for about 5minutes before asphalt was added to allow for absorption into the aggregates. After which the mix was poured into a mouldand compacted on both faces with 35, 50 and 75 blows representing light, medium and heavy traffic respectively using a 6.5kg-rammer falling freely from a height of 450 mm – see appendix 1, Figure 1. Compacted specimens were subjected to bulk specific gravity test, stability and flow, density and voids analyses at varying temperatures between 20 and 60°C at increments of 10°C. Optimum binder contents of asphalt cement were obtained as 4.6%, 4.8% and 4.9% respectively for light, medium and heavy traffic categories respectively. The properties of the asphalt concretes used for analysis were obtained for the varying temperature conditions.

Theory

(a) Determination of elastic modulus was by adopting McLeod (1964) as follows:

$$E = 40\left(\frac{Stability}{Flow}\right) \qquad (1)$$

Where; E = elastic modulus in pounds per square inch (lb/in^2)
Stability = load at failure in pounds (lbs)
Flow = inches (in)

(b) Determination of Rigidity (Shear) modulus was from material property relationship as follows:

$$G = \frac{E}{2(1+\mu)} \qquad (2)$$

where G = Rigidity or Shear modulus in N/mm^2 or MPa, E = Elastic modulus in N/mm2 or MPa, μ = Poisson's ratio.

Results

Results obtained from preliminary laboratory tests are given in Tables 1–5 as follows (see Figures 1, 2).

Table. 1. *Laboratory test results of stated materials*

Material	Gravel dust	Asphalt	Sand	Gravel
Specific gravity	2.93	1.03	2.80	3.07
Grade of binder material	-	60/70	-	-
Mix proportion (%)	35	-	22	43
Viscosity of binder (poise)	-	$1.16*(10^{-6})$	-	-
Softening point	-	44°C	-	-
Penetration value	-	66mm	-	-

Table. 2. *Schedule of aggregates used for mix proportion (ASTM: 1951).*

Sieve size (mm)	Specification limit	Aggregate gravel 0.43A	Aggregate sand 0.22B	Aggregate gravel dust 0.35C	Mix proportion 0.43A+0.22B + 0.35C
19	100	100	100	100	100
13.2	80–100	100	85.20	100	96.74
9.5	70–90	100	46.57	100	88.25
6.7	45–70	100	10.83	97.44	60.76
4.5	48–65	91.18	0	90.48	52.08
2.30	35–50	75.37	0	69.23	40.81
1.18	22–40	56.62	0	56.78	44.22
0.60	16–30	33.09	0	45.42	30.00
0.30	13–23	11.40	0	27.47	14.52
0.15	7–15	1.11	0	4.76	2.14
0.075	0	0	0	0	0

Table. 3. *Properties of asphalt concrete at varying temperatures @ O.A.C in English Units according to McLeod (1964).*

Temperature (°C)	Flow (in)			Stability (lb)		
	Light	Medium	Heavy	Light	Medium	Heavy
20	0.959104	1.024128	1.2192	739.2135	1607.416	2106.966
30	0.959104	1.105408	1.349248	656.2921	1430.112	1801.124
40	1.089152	1.430528	1.495552	600.6742	1006.067	1488.09
50	1.186688	1.54432	1.528064	578.427	736.8539	1272.135
60	1.528064	1.739392	1.658112	573.3708	534.1573	1199.775

Table. 4. *Elastic modulus E, of asphalt concrete at varying temperatures @ O.A.C.*

Temperature (°C)	E (lb/in^2)			E (MPa)		
	Light	Medium	Heavy	Light	Medium	Heavy
20	30829.34	62781.84	69126.18	211.74	431.194	474.7677
30	27371.05	51749.65	53396.38	187.988	355.4234	366.7334
40	22060.25	28131.35	39800.42	151.5127	193.2098	273.3545
50	19497.19	19085.52	33300.57	133.9093	131.0819	228.7127
60	15009.08	12283.77	28943.16	103.0843	84.36655	198.7854

Note: The results of Table 4 were obtained by applying Equation 1.

Table. 5. *Shear modulus, G of asphalt concrete at varying temperatures @ O.A.C.*

Temperature (°C)	E (lb/in^2)			E (MPa)		
	Light	Medium	Heavy	Light	Medium	Heavy
20	10630.81	21648.91	23836.61	73.01379	148.6876	163.713
30	9438.293	17844.71	18412.54	64.82345	122.5598	126.4598
40	7606.983	9700.466	13724.28	52.24576	66.62407	94.26017
50	6723.169	6581.214	11482.96	46.17562	45.20066	78.86645
60	5175.545	4235.783	9980.4	35.54631	29.09191	68.54669

Note: The results of Table 5 were obtained by applying Equation 2 with a Poisson's ratio of 0.45 for the asphalt concrete as *determined from ratio of lateral-vertical strain in the laboratory.*

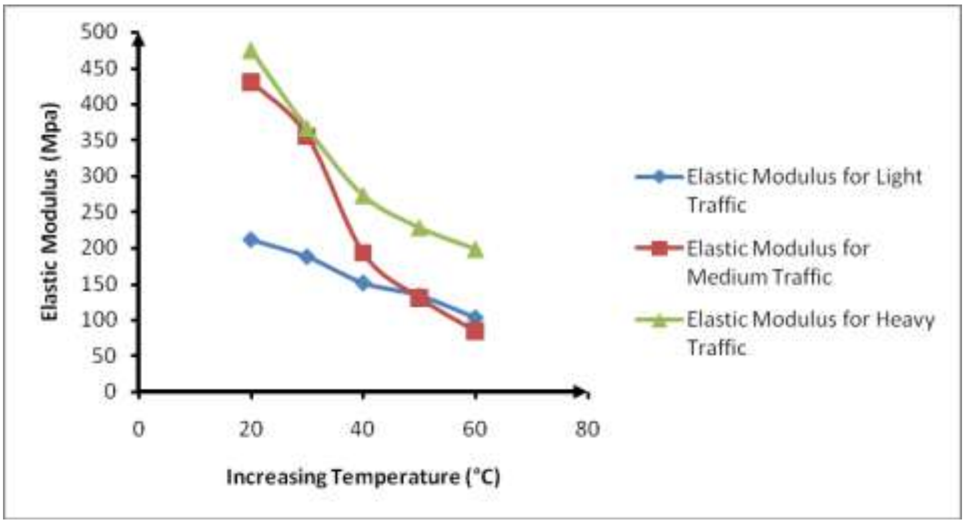

Fig. 1. *Variation of elastic modulus with temperature.*

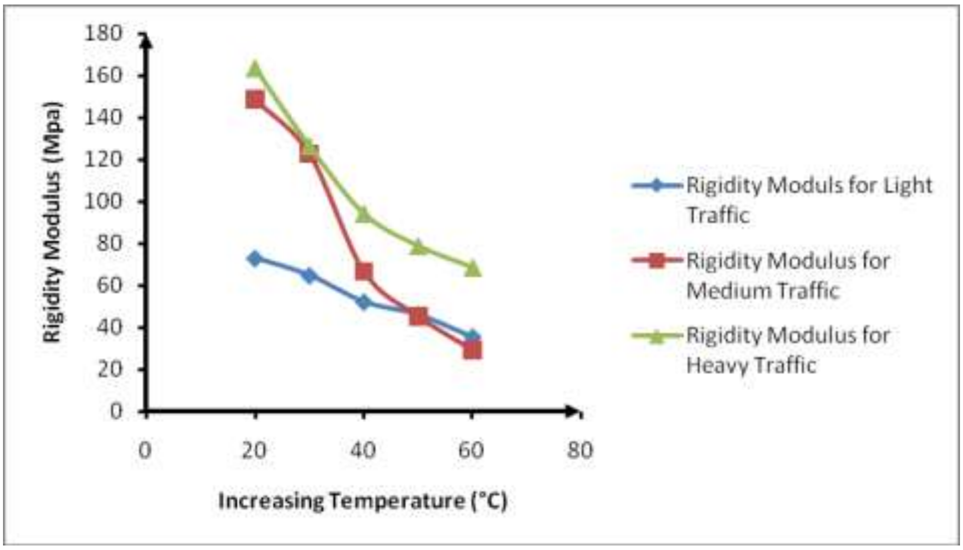

Fig. 2. *Variation of rigidity modulus with temperature.*

RESULT AND DISCUSSION

Temperature Effect on Elastic Modulus

As afore defined that elastic modulus is a measure of the linear stiffness of a material subjected to applied load or stress within the elastic region of the material. The results from Table 4 and Figure 1 revealed that as asphalt concrete specimens were subjected to differential increase in temperature the ability to resist linear deformation was reducing. The ability to resist linear deformation describes thelinear stiffness of a material within elasticregion. From the results, it is clearly seenthat linear stiffness of the concretes constantly reduced with increasing temperature loading from 20 to 60°C for the three categories of traffic considered.

This behaviour can be explained with respect to previous studies [17–19]. These other studies concluded that viscosity of asphalt cement reduces under high temperatures and in turn results in bleeding or flushing of the pavement due to reduction in the binding ability of the asphalt cement with the aggregates in the composite mixture. Under these circumstances the ability of the pavement to resist linear deformation which comes from binding action between asphalt cement and aggregates is grossly reduced;

thus, resulting to reduced stiffness of the pavement. For linear deformation, the stiffness property of the pavement is called elastic or Young's modulus. In summary therefore, it elastic modulus of the asphalt concretes simulating flexible pavements reduced constantly under increasing temperature from 20 to 60°C for all traffic categories considered.

Temperature Effect on Rigidity Modulus

Rigidity (shear) modulus can simply be defined as the elastic modulus of a material used for the deformation which takes place when a force or load is applied parallel to one face of the material while the opposite face is held fixed by another equal force. The results from Table 4 and Figure 2 revealed that increasing the mix temperature of the asphalt concretes 20– 60°C resulted in decreased rigidity of the asphalt concretes for the three categories of traffic considered. The theory can be explained from the relationship between elastic modulus and rigidity or shear modulus of materials. From Equation 2, according to the study by Timoshenko (1934) [11] there exists a linear relationship between elastic modulus and rigidity modulus. Therefore, since elastic modulus decreased with increasing temperature conditions; it becomes only logical that rigidity modulus will also decrease with increasing temperature conditions as s seen above. All of these can be further explained by the fact that viscosity of asphalt cement will continuously decrease under increasing temperature which causes the asphalt cement to flow away from the aggregates thereby causing segregation of the pavement resulting in weak rigidity.

CONCLUSION

With respect to the observations and findings of the present study, the following conclusions were made:

(1) That flexible pavements when subjected to increasing field temperature can suffer from reduced asphalt binder viscosity as investigated in the laboratory using asphalt concretes – that is a phenomenon were the asphalt cement (binder) flows away from aggregates thus reducing cohesion of the composite mix.

(2) That the phenomenon in 1 above result in reduced elastic modulus of flexible pavements as investigated in the laboratory using asphalt concretes.

(3) That the phenomenon in 1 and 2 above further results in reduced rigidity modulus of flexible pavements as studied in the laboratory using asphalt concretes.

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