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Influence of Rubber Latex on Dynamic Modulus of Hot Mix Asphalt Concrete

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ABSTRACT

Characterization of material property is fundamental in the Mechanistic-Empirical design of flexible pavement. One of such key material property is the modulus of the material which influences tensile strain levels and also necessary for the prediction of fatigue cracking of asphalt pavement. It is on this basis, that the present study was directed towards exploring techniques that will improve the performance of flexible road pavement by modifying the asphalt concrete modulus; in particular dynamic modulus, E through rubberization. The results of the study revealed that the addition of rubber latex into the asphalt concrete mixture produced positive significant changes in the dynamic modulus of the asphalt concrete at varying loading frequencies. Result showed that the dynamic modulus increased from 68,098.83 PSI to 73,188.27 PSI at 0.1Hz; 98,371.65 PSI to 105,719.22 PSI at 1Hz; 126,497.49PSI to 135,945.83PSI at 5Hz; 144,215.28 PSI to 154,987.01 PSI at 10Hz and 184,893.58 PSI to 198,703.64 PSI at 25Hz. However, threshold rubber latex content to attain maximum dynamic modulus corresponded to 0.5% at the loading frequencies investigated, that means further addition of rubber latex resulted in reduction in the value of the modulus. The Asphalt Institute Dynamic Modulus prediction model was adopted in the study.*

Key words: Rubber Latex, Dynamic Modulus, Asphalt Concrete.

INTRODUCTION

One of the key elements of Mechanistic-Empirical (M-E) design of flexible pavement is the characterization of material properties. One of such material property is the dynamic modulus of HMA concretes, E* which influences tensile strain of asphalt concrete pavements, therefore it is necessary to investigate this property to successfully predict fatigue cracking in asphalt pavement. E* can be determined directly by laboratory testing or it can be estimated using predictive equations as a function of mixture properties. The more recently developed M-E design program[1], the Mechanistic-Empirical Pavement Design Guide offers both methods to characterize E*. Furthermore, in M-E pavement design, accurate representation of material characteristics is imperative to a successful and reliable design: in particular is the HMA dynamic modulus which helps to define the visco-elastic nature of HMA by quantifying the effects of temperature and frequency on stiffness under dynamic loading. This is necessary to accurately predict the in-situ pavement responses to varying speeds, and temperatures throughout the pavement's cross-section. E* can be determined in the laboratory through the AASHTO TP-62 procedure or it can be predicted by one of many E* predictive models[2,3,4,5]. To predict E* from one of these models, no laboratory testing is required beyond viscosity testing, determination of gradation information and rudimentary volumetric testing. In addition, the dynamic modulus of an asphalt mixture which is a significant parameter that determines the ability of material to resist compressive deformation when it is subjected to cyclic compressive loading and unloading. HMA concrete dynamic modulus test has been suggested as a simple performance test (SPT) to verify the performance characteristics of Super-pave mixture designs[6]. It has also been suggested as the potential quality control-quality assurance parameter in the field[7]. Dynamic modulus is also an input to the Mechanistic-Empirical Pavement Design guide[8] and supports the predictive performance models developed as part of Nationla Cooperative Highway Research Program (NCHRP) project 1-37A [9].

Although E* can be measured directly in the laboratory, it is very difficult to accurately measure it in the field. However, knowledge of E* is imperative in developing relationships between pavement response and material properties[10]. Given the difficulty of direct measurements, focus should be placed on the factors that influence changes in dynamic modulus. Due to the visco-elastic nature of HMA, the dynamic modulus is heavily influenced by three factors viz, rate of loading, temperature, and depth within the pavement structure[11]. Temperature and pavement depth are relatively easy parameters to measure in the field. Rate of loading on the other hand is much more difficult to quantify in the field. In the laboratory, rate of loading can be correlated to the applied testing frequency. During laboratory testing, controlling and measuring rate of loading is a simple task, but in the field it is much more arduous due to the shape of the loading waveforms transmitted throughout the pavement. Because of the complexity in measuring frequency, some design procedures simply use a fixed value such as the Asphalt Institute which assumes a value of 10Hz regardless of the conditions[2]. Other factors that affect dynamic modulus are aggregate size and binder type. Studies which involved testing the dynamic modulus of seven different super-pave mixtures revealed that all mixtures had different modulus values owing to variations in aggregate size and in particular binder types[12].

Even though, bitumen is a good binder material for road construction due to its cementing ability, research has shown that the limitations of bitumen as a road-paving material are associated with the problems of oxidation, which results in the cracking of the pavement and its instability with respect to local temperature variations[13]. Due to these problems, various forms of modifications of the physical properties of bitumen have evolved over the years using different materials like natural rubber ([14,15, 16], recycled polyethylene from grocery bags[17], recycled plastics composed predominantly of polypropylene and low density polyethylene[18, 19, 20, 21, 22] and processed plastic bags[23]. Researches carried out so far on the use of natural rubber (also known as rubber latex) and indeed other materials for the modification of this type of road-paving material (bitumen) have been concentrated on modifying its physical properties like penetration, solubility, viscosity, ductility, flash point, fire point among others and mix design properties like stability, flow, density and VMA[24, 25]. There is, however, a dearth of information on the use of rubber latex for the modification of material property such as dynamic modulus. The present study, therefore, focused on the material property modification of Hot Mix Asphalt (HMA) concretes using the Asphalt Institute prediction model.

MATERIALS AND METHODS

Sample collection

The materials used for this study were rubber latex, bitumen, coarse and fine aggregates. The rubber latex used was obtained from Ikot Essien in Ibiono Ibom Local Government Area of Akwa Ibom State in Nigeria while the bitumen used was collected from the Federal Ministry of Works in Rivers State, Nigeria. Commercial aggregates were, however, used. After sampling of the materials, laboratory tests - specific gravity, grading of bitumen and sieve analysis of the aggregates used for mix-proportioning by straight line method - were carried out.

Sample preparation

Samples were prepared using Marshal Design Procedures for asphalt concrete mixes [26, 27]. 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 pure or unmodified asphalt concrete samples, the aggregates were first heated for about 5 minutes before bitumen was added to allow for absorption into the aggregates. After which the mix was poured into a mould and compacted on both faces with 35 blows using a 6.5kg-rammer falling freely from a height of 450mm. Compacted specimens were subjected to bulk specific gravity test, stability and flow, density and voids analyses at a temperature of 60^0C and frequencies of 0.1, 1, 5, 10 and 25Hz respectively[8]. The results obtained were used to determine the optimum asphalt content of the pure asphalt concrete. Rubber latex was then added at varying amounts (0.5 – 3.0 percent) to the samples at optimum asphalt content and then redesigned using the same Marshal Design Procedures already stated above to produce rubberized concretes having varying mix design properties particularly air voids content which greatly affects dynamic modulus. The varying values of air voids content obtained by rubber latex introduction into the asphalt concrete was inputted into our Asphalt Institute model equation to obtain varying E* values. Tensile strains, εt were also obtained as maximum at the point of failure of the asphalt concretes under loading from the stabilometer machine.

Theory

The optimum asphalt content (O.A.C.) for the pure concrete was obtained using equation 1, according to the Marshal Design Procedure [26] as follows:

$$Q.A.C. = \tfrac{1}{3}\left(A.C._{\max.\, stability} + A.C._{\max.\, density} + A.\,C_{median\ \lim its\ of\ air\ voids}\right) \qquad (1)$$

The Asphalt Institute developed a method for design in which the dynamic modulus is determined from the following equations[28]

$$E^* = 100,000\ (10^{\beta_1}) \qquad (2)$$

$$\beta_1 = \beta_3 + 0.000005\ \beta_2 - 0.00189\ \beta_2\ f^{-1.1} \qquad (3)$$

$$\beta_2 = \beta_4^{\ 0.5}\, T^{\beta_5} \qquad (4)$$

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

$$\beta_4 = 0.483\ V_b \qquad (6)$$

$$\beta_5 = 1.3 + 0.49825\ \log\ f \qquad (7)$$

Where;
E^* = dynamic modulus (psi)
F =loading frequency (Hz)
T = temperature (°F)
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

The values of dynamic modulus, E* at various frequencies were obtained by applying equations 2-7. To obtain various E*, the values of changing air voids due to rubberization were inserted into the equations at various frequencies while all other parameters remained constant.

RESULTS AND DISCUSSION

The result of the variation of Dynamic Modulus E* with Rubber Latex content at varying frequencies are presented in Table 5 and Figures 1 to 5. From Figure 1, result showed that at a loading frequency of 0.1Hz the Dynamic Modulus of the asphalt concrete increased linearly with increasing Rubber Latex content from 68,098.83 PSI to a maximum of 73,188.27 PSI corresponding to 0.5% rubber latex as the threshold value to attain maximum dynamic modulus. Further addition of rubber latex resulted in reduction in modulus of the asphalt concrete.

Table 1: Properties of HMA Concrete materials

Material	Rubber	asphalt	Sand	Gravel
Specific gravity	0.90	1.36	2.66	2.90
Grade of binder material	-	40/50	-	-
Mix proportion (%)	-	-	42	58
Viscosity of binder (poise)	-	$0.45*(10^{-6})$	-	-
Softening point	-	48°C	-	-
Penetration value	-	44mm	-	-

Table 2: Mix design properties for unmodified asphalt concrete

Asphalt Content (%)	Stability (N)	Flow (0.25mm)	Density (kg/m^3)	Air voids (%)	VMA (%)
6.0	722	17.4	2410	3.6	19.0
5.5	909	21.6	2420	4.0	18.0
5.0	936	21.2	2440	4.0	17.0
4.5	1979	17.8	2460	4.0	16.0
4.0	1952	17.04	2430	5.8	16.5
3.5	1284	16.4	2380	7.0	17.8
3.0	936	13.4	2330	8.3	19.0

Also from Figure 2 it was observed that at a loading frequency of 1Hz , the Dynamic Modulus increased linearly with increasing Rubber Latex content from 98,371.65 PSI to a maximum of 105,719.22 PSI corresponding to 0.5% rubber latex as the threshold value to attain maximum dynamic modulus. Again further addition of rubber latex resulted in reduction in stiffness of the asphalt concrete.

Similarly, from Figure 3, at a loading frequency of 5Hz, the Dynamic Modulus increased linearly with increasing Rubber Latex content from 126,497.49 PSI to a maximum of 135,945.83 corresponding to 0.5% rubber latex.

Table 3: Mix design properties for rubberized asphalt concrete at 4.72% optimum asphalt content

Rubber Content (%)	Stability (N)	Flow (0.25mm)	Density (kg/m^3)	Air voids (%)	VMA (%)
0.0	1520	17.6	2450	4.0	16.4
0.5	2326	15.0	2510	2.7	13.8
1.0	2941	13.6	2520	3.1	13.4
1.5	3290	13.4	2530	3.4	13.0
2.0	1551	13.0	2500	4.0	14.0
2.5	1451	12.6	2470	4.3	15.0
3.0	321	10.4	2440	5.4	16.0

Table 4: Schedule of Aggregates used for mix proportion

Sieve size (mm)	Specification limit	Aggregate A (Sand)	Aggregate B (Gravel)	Mix proportion (0.42A+0.58B)
19.0	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 5: Variation of Dynamic Modulus E* with Rubber Latex (%) at varying frequencies

Dynamic Modulus E* (lb/in^2)							
% Rubber Latex F(Hz)	0%	0.5%	1%	1.5%	2%	2.5%	3%
0.1	68,098.83	73,188.27	70,879.34	69,197.70	65,953.17	64,388.41	64,388.41
1	98,371.65	105,719.22	102,388.21	99,959.01	95,272.15	93,011.78	85,173.00
5	126,497.49	135,945.83	131,662.44	128,538.70	122,511.79	122,511.79	109,525.16
10	144,215.28	154,987.01	150,103.66	146,542.40	139,671.34	136,357.58	124,865.74
25	184,893.58	198,703.64	192,442.87	187,877.09	179,067.94	174,819.48	160,086.18

Figures 4 and 5 shows that at a loading frequency of 10Hz and 25Hz respectively, the Dynamic Modulus increased linearly with increasing Rubber Latex content from 144,215.28 PSI to a maximum of 154,987.01 PSI and 184,893.58 PSI to a maximum of 198,703.64 PSI respectively corresponding to 0.5% rubber latex. This implies that addition of 0.5% rubber latex resulted in about 7.5% increase in dynamic modulus asphalt concrete. Further addition of rubber latex resulted in reduction in dynamic modulus of the asphalt concrete.

In general, the addition of rubber later to asphalt concrete increased the dynamic modulus with the maximum value attained at 0.5% latex content for all the loading frequencies investigated.

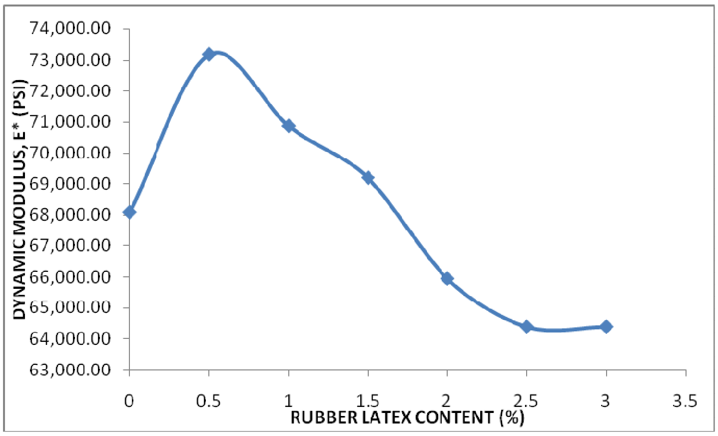

Figure 1: Variation of Dynamic Modulus with Rubber Latex at 0.1Hz

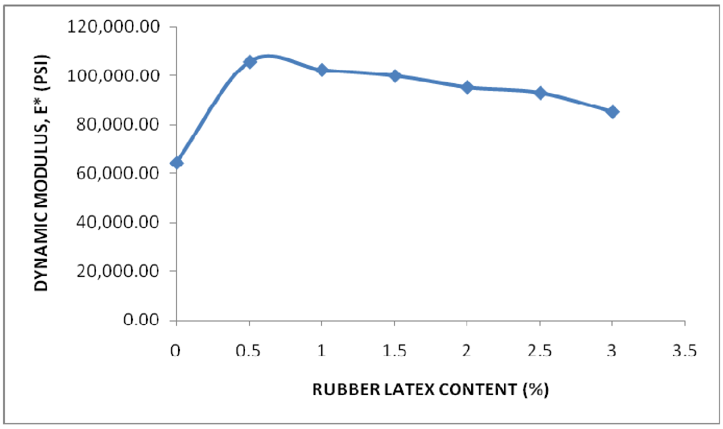

Figure 2: Variation of Dynamic Modulus with Rubber Latex at 1Hz

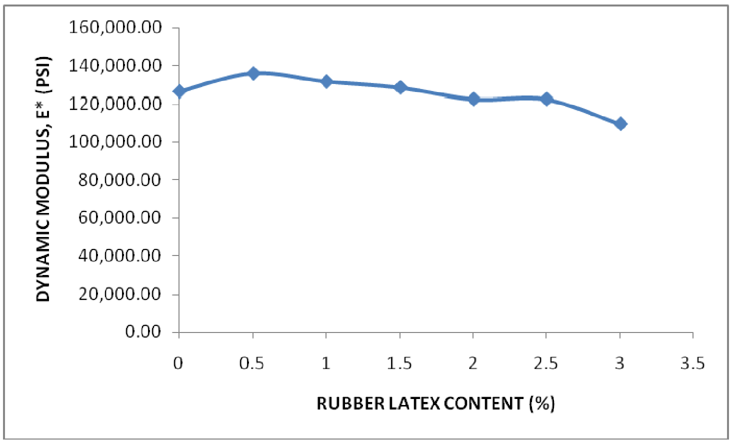

Figure 3: Variation of Dynamic Modulus with Rubber Latex at 5Hz

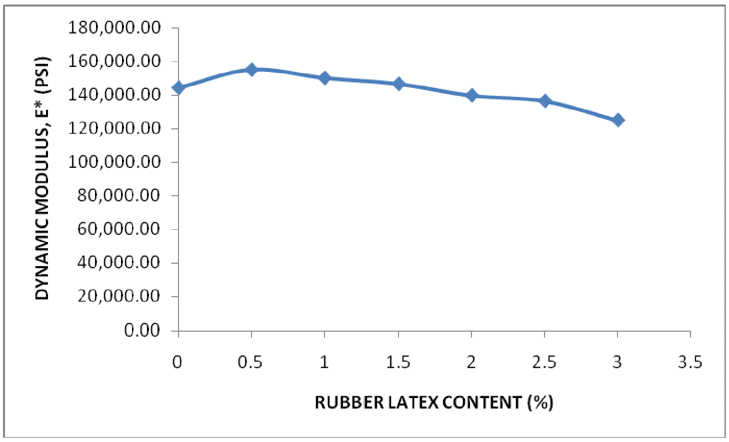

Figure 4: Variation of Dynamic Modulus with Rubber Latex at 10Hz

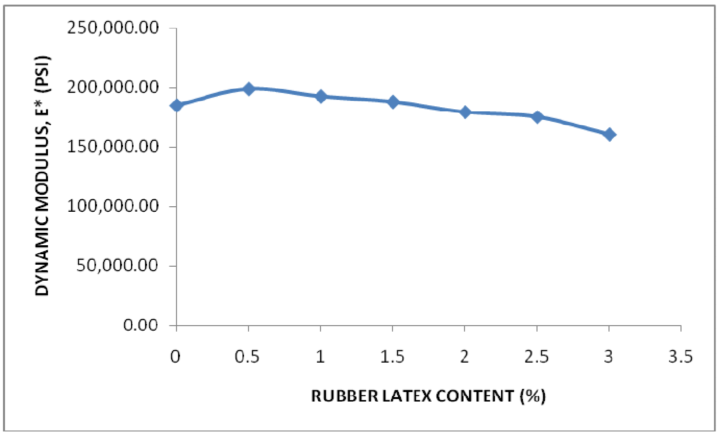

Figure 5: Variation of Dynamic Modulus with Rubber Latex at 25Hz

CONCLUSION

From the laboratory investigations of rubberized HMA concrete, it is evident that:

- The addition of rubber latex to asphalt concrete increased the Dynamic Modulus of the asphalt concrete.
- Threshold rubber latex content to attain maximum Dynamic Modulus corresponds to 0.5%; that means further addition of rubber latex resulted in reduction in modulus value.
- Rubber latex influence on the asphalt concrete Dynamic modulus showed similar patterns irrespective of frequency of loading.
- Rate of influence of rubber latex on Dynamic Modulus of HMA increased as frequency increased from 0.1-25Hz.

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