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RESEARCH ARTICLE

EFFECT OF LOADING FREQUENCY ON DYNAMIC MODULUS OF RUBBER LATEX-MODIFIED ASPHALT CONCRETE

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ABSTRACT

One of the key material properties in Mechanistic design of flexible pavement design is the dynamic modulus of asphalt concrete. In order to improve the performance of asphalt pavement, various techniques of modifications of the physical properties of bitumen have evolved over the years using different materials like natural rubber (rubber latex). Research has also proved that dynamic modulus of asphalt concrete is influenced by loading frequency. It is on this basis that the present study was indented to investigate the effect of loading frequency on the dynamic modulus of rubber latex-modified asphalt concrete. The result of the study showed that the dynamic modulus of the modified asphalt concrete at 0.5%, 1%, 1.5%, 2%, 2.5% and 3% rubber latex increased from 73,188.27 to 198,703.64 PSI, 70,879.34 to 192,442.87 PSI, 69,197.70 to 187,877.09 PSI, 65953.17 to 179,067.94 PSI, 64,388.41 to 174,819.48 PSI and 64,388.41 to 160,086.18 PSI at loading frequencies of 0.1HZ, 1HZ, 5Hz, 10Hz and 25Hz respectively. This behaviour is comparable with that of unmodified asphalt concrete indicating that rubber latex-modified asphalt concrete is adequate for design and construction of asphalt pavement. The result however, showed an optimum dynamic modulus at 0.5% rubber latex at all loading frequencies investigated.

INTRODUCTION

Since the early 1800's when the first paved highways were built, construction of roads has being on the increase as well as improved method of construction. The need for stronger, long-lasting and all-weather pavements has become a priority as a result of rapid growth in the automobile traffic and the development of modern civilization. But despite advancements in pavement engineering, there still exists gap in understanding which needs to be examined through the measurement of the mechanical and rational material properties of pavements. Most attention has been given to material technology and construction techniques and less was given to material properties and their behaviour. One of the key material properties in Mechanistic or rational design of flexible pavement design is the dynamic modulus of asphalt concrete which influences tensile strain and fatigue cracking of asphalt pavements. Therefore, it is necessary to investigate this property to adequately predict fatigue cracking in asphalt pavement. In mechanistic pavement design, material characterization requires the determination of the material stiffness as defined by the dynamic modulus and Poisson's ratio. In some cases where there is need for laboratory testing, the method of testing the modulus should reproduce field conditions as accurately as possible. Accurate representation of material characteristics is imperative to a successful and reliable design. The Hot Mix Asphalt (HMA) dynamic modulus 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. Asphalt concrete dynamic modulus 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, the Mechanistic-Empirical Pavement Design Guide (NCHRP 1-37A, 2004), offers both methods to characterize dynamic modulus. Dynamic modulus can be determined in the laboratory, it can also be predicted by one of many dynamic modulus predictive models; the Asphalt Institute (1999), Bari and Witczak (2006), Witczak *et al.* (2002) and Christensen *et al.* (2003) models. Prediction of dynamic modulus requires viscosity testing, determination of gradation information and volumetric testing. Dynamic modulus of an asphalt mixture is a significant parameter that determines the ability of material to resist compressive deformation when subjected to cyclic compressive loading and unloading (Rowe *et al.,* 2008).

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Research carried out by NCHRP Projects 9-19 and 9-29 suggests dynamic modulus as a simple performance test (SPT) to verify the performance characteristics of Super-pave mixture designs (Witczak and Pellinen, 2000). It has also been suggested as the potential quality control-quality assurance parameter in the field Bonaquist (2003). Dynamic modulus is also an input to the Mechanistic-Empirical Pavement Design guide (MEPDG) – Design Guide (2003) and supports the predictive performance models developed as part of NCHRP project 1-37A Witczak (2005). Although dynamic modulus can be measured directly in the laboratory, it is very difficult to accurately measure it in the field. Given the difficulty of direct measurements, focus should be placed on the factors that influence changes in the dynamic modulus of asphalt concrete. Dynamic modulus has been proven to be dependent on two parameters: temperature and loading frequency (rate of loading). The decrease in dynamic modulus with increase in temperature and decrease in loading frequency has been consistently reported by researchers for many years (Tashman and Elangovan, 2007). While temperature is a relatively easy parameters to measure in the field, rate of loading frequency is much more difficult to measure in the field. This is due to the shape of the loading waveforms transmitted throughout the pavement. Because of the complexity in measuring frequency of loading, some design procedures simply use a fixed value for frequency regardless of the conditions (Asphalt Institute, 1999). Other factors that affect dynamic modulus are aggregate size and binder type.

HMA has two main components: aggregate and binder. Each component has numerous properties which influence the overall response of the mixture. It is common knowledge that bitumen is a good binder material for asphalt pavement construction due to its good cementing ability. Research has shown that the limitations of bitumen as a road-paving material are associated with the problems of oxidation Othmer (1963), which results in the cracking of the pavement and its instability with respect to local temperature variations, hence, various forms of modifications of the physical properties of bitumen have evolved over the years using different materials like natural rubber (Van-Rooijen, 1938; Decker and Nijveld, 1951; Mason *et al*., 1957; Mummah and Muktar, 2001), recycled polyethylene from grocery bags (Flynn,1993), recycled plastics composed predominantly of polypropylene and low density polyethylene (Collins and Ciesielski, 1993; Federal Highway Administration, 1993; Khan *et al*., 1999; Zoorob, 2000; Zoorob and Suparma, 2000) and processed plastic bags (Punith, 2001). It is also logical that the properties of the modified binder may influence the dynamic modulus of the mixture. While it is necessary to modify bitumen in order to improve the mechanistic properties of asphalt concrete, is also it is necessary to investigate factors such as loading frequency that influence changes in the dynamic modulus of asphalt concrete, in this case rubber latex-modified asphalt concrete. The present study, therefore, is geared towards investigating the effect of loading frequency on the dynamic modulus of rubber latex-modied asphalt concrete.

MATERIALS AND METHODS

The materials used for this study were bitumen, rubber latex, 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 such as specific gravity, grading of bitumen and sieve analysis of aggregates. The Straight line method was adopted in the mix-proportioning of the aggregates. Samples were prepared using Marshal Design Procedures for asphalt concrete mixes (Asphalt Institute 1999; and Roberts *et al.,* 1996). 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 based on 0.5 percent increments of asphalt content with at least 3-asphalt contents above and below the optimum asphalt content. Three replicate test specimens were prepared for each set of asphalt content used. The test specimen were prepared with a compacting effort of 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 as specified by Design Guide (2002). 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 asphalt concretes having varying mix design properties particularly air voids content which greatly affects dynamic modulus. The optimum asphalt content (O.A.C.) for the pure concrete was obtained using equation 1, in accordance with the Marshal Design Procedure (Asphalt Institute, 1999) as follows:

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

Dynamic modulus E* =100,000 ($10^{\beta}{}_1$) (2)

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

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

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

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

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

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 varying values of air voids were used to determine the dynamic modulus using the Asphalt Institute dynamic modulus prediction model in equations 2-7 at loading frequencies of 0.1, 1, 5, 10 and 25Hz.

RESULTS AND DISCUSSIONS

The result of the effect of loading frequency on the Dynamic Modulus of Rubber Latex-modified asphalt concrete is presented in Table 5 and Figure 1 – 8. From Figure 1, result

Table 1: 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 2: Laboratory test results of asphalt 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	-	48ºC	-	-
Penetration value	-	44mm	-	-

Table 3: 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

Table 4: Mix design properties for rubberized bituminous 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 5: Variation of Dynamic Modulus E* with Rubber Latex (%) at varying frequencies (Hz)

	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	64,388.41	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

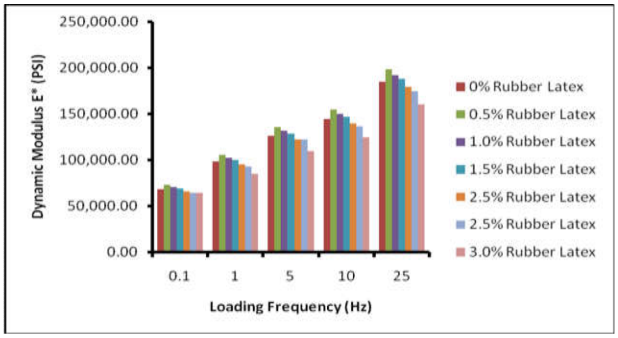

Fig.1: Variation of Dynamic Modulus with Loading Frequency

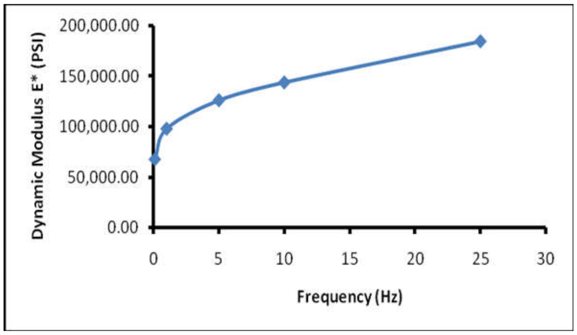

Fig. 2: Variation of Dynamic Modulus with Frequency at 0% Rubber Latex

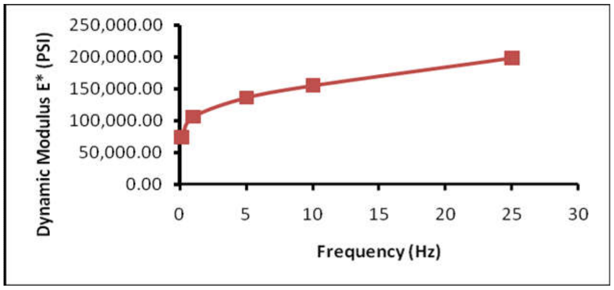

Fig. 3: Variation of Dynamic Modulus with Frequency at 0.5% Rubber Latex

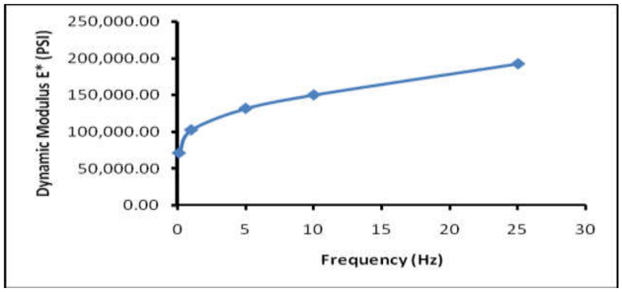

Fig. 4: Variation of Dynamic Modulus with Frequency at 1% Rubber Latex

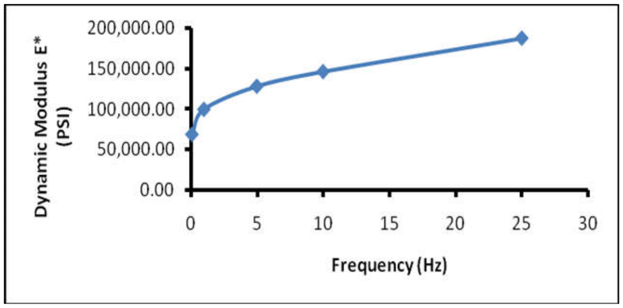

Fig. 5: Variation of Dynamic Modulus with Frequency at 1.5% Rubber Latex

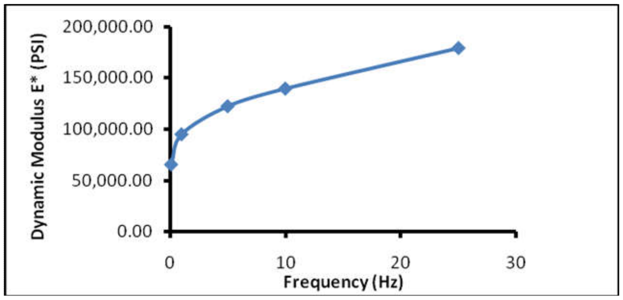

Fig. 6: Variation of Dynamic Modulus with Frequency at 2% Rubber Latex

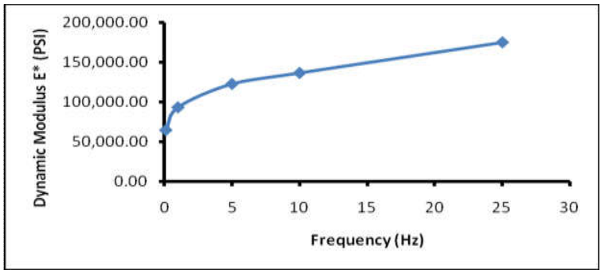

Fig. 7: Variation of Dynamic Modulus with Frequency at 2.5% Rubber Latex

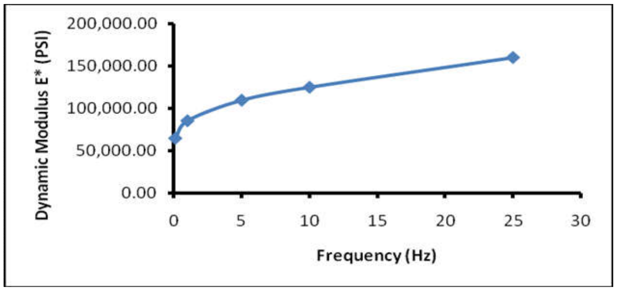

Fig. 8: Variation of Dynamic Modulus with Frequency at 3% Rubber Latex

showed that at a loading frequency of 0.1Hz the Dynamic Modulus increased from 68,098.83 PSI at 0% rubber latex content to a maximum of 73,188.27 PSI at 0.5% rubber latex and decreased to 64,388.41 PSI at 3% rubber latex content. The same trend was observed for frequencies of 1Hz, 5Hz, 10Hz and 25Hz with optimum dynamic modulI values of 105,719.22 PSI, 135,945.83 PSI, 154,987.01 PSI, and 198,703.64 PSI respectively at 0.5% rubber latex content. From Figure 2, result indicated that the dynamic modulus of the unmodified asphalt concrete (0% rubber latex) increased as the loading frequency increases; i.e the dynamic modulus increased from 68,098.83 PSI at 0.1Hz to 184,893.58 PSI at 25Hz. Also, from Figures 3 – 8 for the modified asphalt concrete at 0.5%, 1%, 1.5%, 2%, 2.5% and 3% rubber latex content, the dynamic modulus increased from 73,188.27 to 198,703.64 PSI, 70,879.34 to 192,442.87 PSI, 69,197.70 to 187,877.09 PSI, 65953.17 to 179,067.94 PSI, 64,388.41 to 174,819.48 PSI and 64,388.41 to 160,086.18 PSI at loading frequencies of 0.1HZ, 1HZ, 5Hz, 10Hz and 25Hz respectively. This results indicates that the rubber latex-modified asphalt concrete showed similar behaviour as the normal (unmodified) asphalt concrete. In general, the dynamic modulus of rubber latex-modified asphalt concrete increased with increase in loading frequency, however, with an optimum value attained at 0.5% latex content for all loading frequencies.

CONCLUSIONS

From the result of both the unmodified and rubber latex-modified HMA concrete, it is evident that the dynamic modulus of both unmodified and rubber latex-modified asphalt concrete increases with increase in loading frequency. This result is in line with result of previous researches (Robbins, 2009; Yoon *et al.,* 2010) on unmodified asphalt concrete.

From the above result, the following conclusions are made:

1. Dynamic modulus of rubber latex-modified asphalt concrete increases with increase in loading frequency.
2. The effect of loading frequency on dynamic modulus of asphalt concrete is comparable with that of unmodified asphalt concrete.
3. The optimum dynamic modulus of the investigated rubber latex-modified asphalt concrete is obtained at 0.5% rubber latex content.
4. Rubber latex-modified asphalt concrete is adequate for design and construction of asphalt pavements as it relatively increases the dynamic modulus of asphalt concrete.

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