ISSN 2347 - 3983
Volume 3, No.9, September 2015
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter02392015.pdf

# Effects of Air Voids Variation on Stiffness Property of HMA Concrete Modified with Rubber Latex

**Enwuso A. Igwe**
Department of Civil Engineering
Rivers State University of Science and Technology, Nkpolu Oroworukwo
P.M.B 5080, 5080, Port Harcourt, Rivers State, Nigeria
(Tel: +2348037077751; Email: igwe2002@yahoo.com)

## ABSTRACT

Two fundamental material properties of asphalt concrete are stiffness and strain. Both of which determines the behaviour or response of the pavement under external loads: and in particular traffic loads constituting the major part of pavement damage. However, the present study focussed on changes that occur with stiffness of asphalt concrete under external load. The stiffness under examination was the dynamic modulus of asphalt concrete for full depth asphalt concrete of 102mm. In addition, the asphalt concrete was modified with rubber latex to obtain varying air voids content at optimum asphalt content and the result of dynamic modulus determined at these various air voids content at frequencies of 0.1, 1, 5, 10 and 25Hz. Furthermore, the logarithm of the dynamic modulus at these different air voids content and frequencies were determined. Results obtained revealed that in general the logarithm of the dynamic modulus increases with decreasing air voids content at all levels of frequency; thus the relationship between log E* and air voids is inversely linear for a rubberized asphalt concrete pavement.

**Key words: Dynamic Modulus, Air voids, Rubber Latex and Asphalt Concrete**

## 1. INTRODUCTION

Characterization of material property is fundamental in the Mechanistic-Empirical design of flexible pavement. One of such key **material property** is the **stiffness** of the pavement which influences tensile strain levels and also necessary for either the determination or prediction of fatigue cracking synonymous with pavement life. Another material property of HMA concrete is the **Poisson's Ratio**; defined as **the ratio of the strain normal to the applied stress to the strain parallel to the applied stress** (Emesiobi 2000: p234). However, research has shown that this particular material property does not vary much under any form of external loads. For example the study by O'flaherty (1974) revealed that the Poisson's Ratio of most materials in general approximately ranges from 0-0.5. For asphalt concretes various agencies like Shell, Asphalt Institute and Kentucky Highway Department use Poisson's Ratio of 0.5, 0.4 and 0.4 respectively (Oguara, 1985 as presented in Emesiobi 2000: p266). On this basis the present study focussed on the stiffness of HMA concrete which is believed to vary under external loads such as temperature, traffic (i.e. both intensity and rate of loading) and oxidation (Othmer (1963:pp. 762 – 765).

Garcia and Thompson (2007) posited that the most important hot-mix asphalt (HMA) property influencing the structural response of a flexible pavement is the HMA stiffness modulus ($E_{HMA}$). Thus, flexible pavement design methods based on elastic theories require that the elastic properties of the pavement materials be known; Brown and Foo (1989). Michael and Ramsis (1988) concluded from their work that among the common methods of measurement of elastic properties of asphalt mixes (which are Young's, shear, bulk, dynamic complex, double punch, resilient, and Shell Nomograph moduli), the resilient modulus is more appropriate for use in multilayer elastic theories. This had been supported by the separate latter 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 this has been contradicted by a more recent research proposed by AASHTO Design Guide 2002 as presented in Clyne et al (2003) 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.

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 load), and creep test. Although, there are different kinds of stiffness moduli as already stated for purpose of the present study we shall be limiting our stiffness moduli to **dynamic modulus; (E*)**. The reason is simply predicated on the fact that the study by Clyne et al (2003) presents a more current approach of the AASHTO Design Guide of 2002 indicating that the dynamic modulus gives a better indication of pavement performance and response than other types of moduli. **The dynamic modulus of an asphalt mixture is a significant parameter that determines the ability of material to resist compressive deformation as it is subjected to cyclic compressive loading and unloading** (Rowe et al, 2008). The dynamic modulus test has been suggested by NCHRP Projects 9-19 and 9-29 as a simple performance test (SPT) to verify the performance characteristics of Super-pave mixture designs (*1*). It has also been suggested as the potential quality control-quality assurance parameter in the field (*2*). Dynamic modulus is also an input to the Mechanistic-Empirical Pavement Design guide (MEPDG) and supports the predictive performance models developed as part of NCHRP project 1-37A (200*4*).

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 (Robbins, 2009). Given the difficulty of direct measurements, focus should be placed on the factors that influence changes in E*. Due to the visco-elastic nature of HMA, the dynamic modulus is heavily influenced by three factors: rate of loading, temperature, and depth within the pavement structure (Eres, 2003). 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 (Asphalt Institute, 1999). Other factors that affect dynamic modulus are aggregate size and binder type. The study by Tashman and Elangovan (2007) which involved testing the dynamic modulus of seven different super-pave mixtures revealed that all mixtures had different modular values owing to variations in aggregate size and in particular binder types.

Another factor that is believed to affect dynamic modulus is air voids content (Rowe et al, 2008). **Air voids in asphalt concrete mixture is defined as the ratio of the difference between the maximum specific gravity of the mixture and bulk specific gravity of the mixture to the maximum specific gravity of the mixture**. On this premise the present study carried out an investigation on the changes that results in material property of asphalt concrete and in particular dynamic modulus, at varying air voids content. It is pertinent to state here that the varying air voids content obtained were as a result of the inclusion of varying amounts of rubber latex from 0 - 3% at the optimum asphalt content of the asphalt concrete mixture. In addition, the dynamic moduli of the rubberized concretes were determined at varying frequencies of 0.1, 1, 5, 10 and 25Hz respectively. The study was done for a full depth asphalt concrete of 102mm depth using the method of Asphalt Institute (1982).

## 2. MATERIALS AND METHODS

### *2.1. 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.

### *2.2. Sample preparation*

Samples were prepared using Marshal Design Procedures for asphalt concrete mixes as presented in Asphalt Institute (1956), National Asphalt Pavement Association (1982) 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 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 $60^0$C and frequencies of 0.1, 5, 10 and 25Hz respectively as specified by AASHTO 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 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.

### *2.3. Theory*

The optimum asphalt content (O.A.C.) for the pure concrete was obtained using equation 1, according to the Marshal Design Procedure cited in (Asphalt Institute, 1999; National Asphalt Pavement Association, 1982) as follows:

$$O.A.C. = \frac{1}{3}\left(A.C._{max.\ stability} + A.C._{max.\ density} + A.C._{median\ limits\ of\ air\ voids}\right) \quad (1)$$

The Asphalt Institute developed a method for design in which the dynamic modulus is determined from the following equations, as presented in Huang's Pavement Analysis and Design textbook (1993):

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

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

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

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

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

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

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

## 3. (TABLES 1-5)

Results obtained from preliminary laboratory tests are tabulated in the following tables as follows;

**Table 1: Laboratory test results of stated 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 1 above reveals the physical properties of the materials (asphalt, sand and gravel) that make up the asphalt concrete specimens and the properties of the modifier (rubber latex) used for carrying out the Marshal Mix Design for each concrete.

**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 |

The above (**Table 2)** shows the results of the mix design properties of the test specimens at varying asphalt content for each unmodified concrete. The mix design properties include **Stability, Flow, Density, Air Voids and Volume in Mineral Aggregates (VMA).**

**Table 3: Mix design properties for rubberized bituminous concrete at 4.5% optimum asphalt content**

| Rubber Content (%) | Stability (N) | Flow (0.25mm) | Density ($kg/m^3$) | Air voids (%) | VMA (%) |
|---|---|---|---|---|---|
| 0.0 | 1520 | 17.6 | 2450 | 3.6 | 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 |

The above schedule (**Table 3)** shows the results of the mix design properties of the test specimens at varying asphalt content for each modified concrete at various rubber latex additions. The mix design properties include **Stability, Flow, Density, Air Voids and Volume in Mineral Aggregates (VMA).**

**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 4** above is the schedule used for proportioning the aggregates used for carrying out the Marshal Mix Design for each specimen before compaction of the specimens on both faces according to traffic category. Secondly, it reveals the percentage of each aggregate passing on each sieve size.

**Table 5: Variation of LOG E* with Air Voids Contents due to Rubber Latex addition at varying frequencies**

| | Rubber Latex (R.L) Air Voids (A.V) | | | | | | |
|---|---|---|---|---|---|---|---|
| | R.L - 0% A.V - 3.6% | R.L - 0.5% A.V - 2.7% | R.L - 1% A.V - 3.1% | R.L - 1.5% A.V - 3.4% | R.L - 2% A.V - 4% | R.L - 2.5% A.V - 4.3% | R.L - 3% A.V - 5.4% |
| F (HZ) | **LOG of Dynamic Modulus (LOG E*) at varying frequencies @ varying Rubber latex content** | | | | | | |
| 0.1 | 4.83313965 | 4.864441482 | 4.85051966 | 4.840092 | 4.819236 | 4.808808 | 4.770572 |
| 1 | 4.99286996 | 5.02415395 | 5.01024995 | 4.999822 | 4.978966 | 4.968538 | 4.930302 |
| 5 | 5.10208191 | 5.133365891 | 5.1194619 | 5.109034 | 5.088178 | 5.07775 | 5.039514 |
| 10 | 5.15901128 | 5.1902953 | 5.17639128 | 5.165963 | 5.145107 | 5.134679 | 5.096443 |
| 25 | 5.26692183 | 5.298205823 | 5.28430183 | 5.273874 | 5.253018 | 5.24259 | 5.204354 |

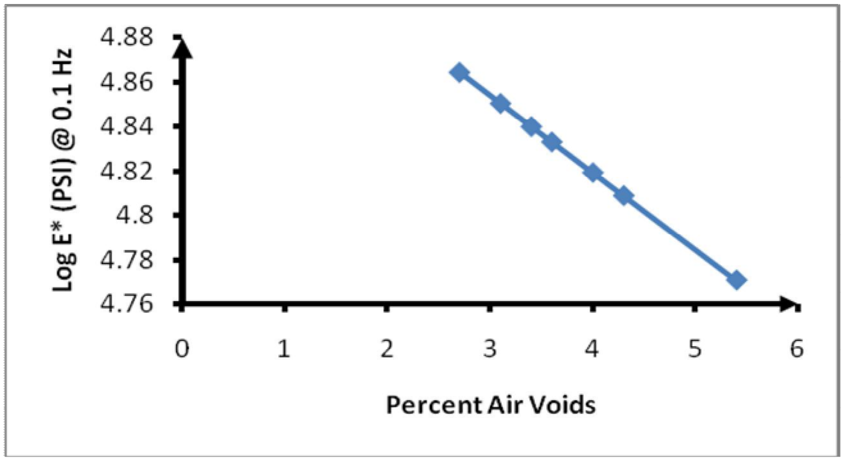


**Figure 1: Variation of Log E* with Air Voids content at 0.1Hz**

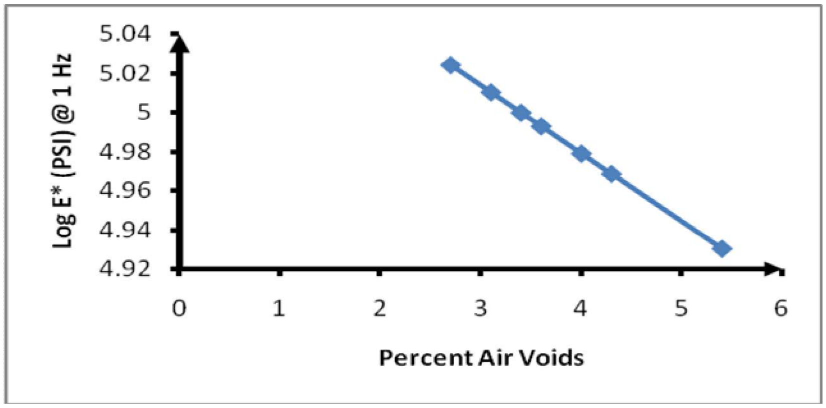


**Figure 2: Variation of Log E* with Air Voids content at 1Hz**

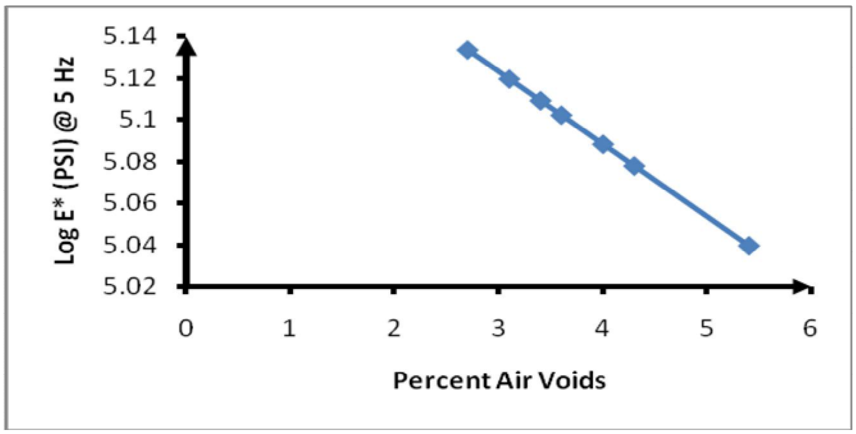


**Figure 3: Variation of Log E* with Air Voids content at 5Hz**

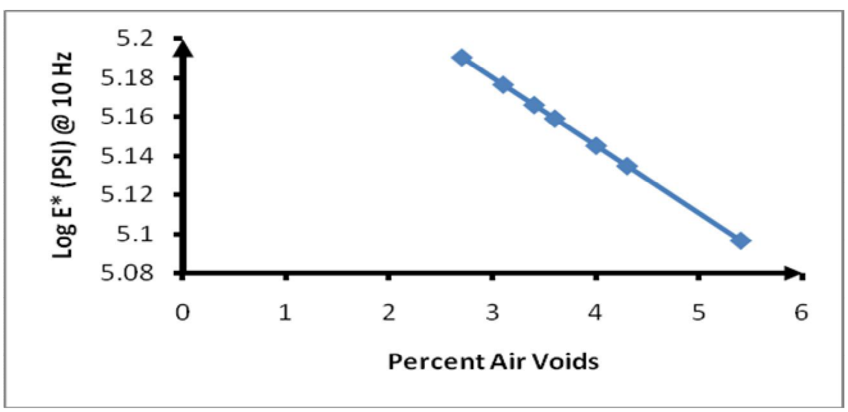


**Figure 4: Variation of Log E* with Air Voids content at 10Hz**

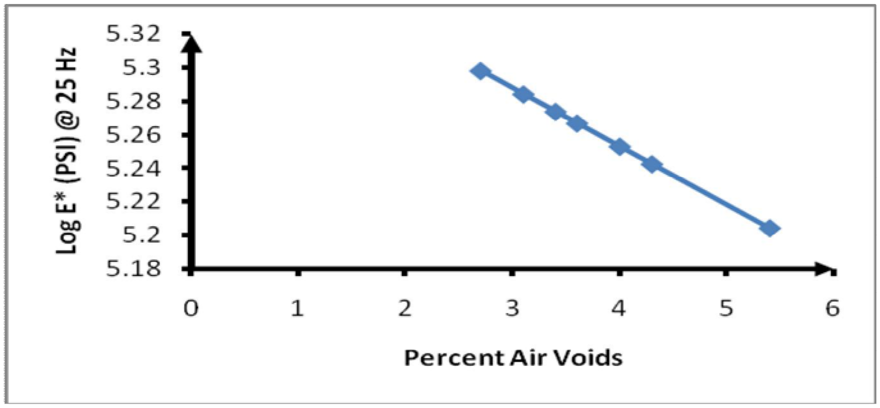


**Figure 5: Variation of Log E* with Air Voids content at 25Hz**

## 4. RESULT DISCUSSIONS

The effect of air voids variation in the material property (dynamic modulus, E*) for rubber latex modified asphalt concrete at varying loading frequencies are as shown in Table 5 and Figures 1-5.

Figure 1 presents the variation of LOG E* with changing air voids content at loading frequency of 0.1Hz. The result indicates that as the percent of air voids is increasing the value of Log E* decreases. Thus dynamic modulus decreases with increasing air voids. The same holds true for dynamic modulus at loading frequencies of 1, 5, 10 and 25Hz (see Figures 2-5).

## 5. CONCLUSION

From the laboratory test results obtained including analysis made it is evident that the material property of asphalt concrete and in particular dynamic modulus E* is influenced by changing air voids content for a rubber latex modified pavement. In addition, the rate of change of log E* with air voids is inversely linear. That is, log E* increases with decreasing air voids content.

## REFERENCES

AASHTO Design Guide Draft (2002) – 2.4 Modulus of Elasticity for Major Material Groups, NCHRP Project 1-37A.

Asphalt Institute (1982) "Research and Development of Asphalt Institutes' Thickness Design Manual", 9th Ed., Research Report 82-2.

Asphalt Institute (1999) "*Thickness Design, Asphalt Pavements for Highways and Streets Report*", *MS-1*, Asphalt Institute, (Re-printed in 1999).

Baladi, G. Y. and Harichandran S. R, (1988) 'Asphalt Mix Design and the Indirect Test': A New Horizon.

Brown, E.R. and Foo, K.Y. (1989) 'Evaluation of Variability in Resilient Modulus Test Results' (ASTM D 41 23) National Centre for Asphalt Technology: Report No. 91-6.

Clyne, T.R.; Li, X.; Marasteanu, M.O.; and Skok, E.L. (2003) 'Dynamic and Resilient Modulus of Mn/DOT Asphalt Mixtures' Final Report, University of Minnesota, Department of Civil Engineering: published by Minnesota Department of Transportation Research Services.

Emesiobi, F.C. (2000) ''Elastic Properties'' ***Testing and Quality Control of Materials in Civil and Highway Engineering***, Port Harcourt, Nigeria, Blue Print Limited, P. 234.

Eres Consultants Division (2003) "Guide For Mechanistic-Empirical Pavement Design of New and Rehabilitated Pavement Structures; Appendix CC-3", Updated Traffic Frequency Calculation for Asphalt Layers, Final Document, NCHRP 1-37A. Tashman, L. and M. A. Elangovan (2007) "*Dynamic Modulus Test - Laboratory Investigation and Future Implementation in the State of Washington*" Washington State Department of Transportation Final Report. Final Research Report No. WA-RD 704.1, http://www.wsdot.wa.gov/research/reports/fullreports/704.1.pdf

Garcia, G., and Thompson M.R., (2008) "Strain and Pulse Duration Considerations for Extended Hot Mix Asphalt Pavement Design", *Proceedings of the 87th Annual Meeting of the Transportation Research Board*, Washington, D.C.

Huang, Y.H. *(*1993) "Pavement Analysis and Design" *1st* Ed., Prentice Hall, Upper River Saddle, N.J Michael, M.S. and Ramsis, S.T. (1988) 'The Modulus of Asphalt Mixtures - An Unresolved Dilemma' Transportation Research Board, 67th annual meeting.

National Asphalt Pavement Association (1982) "Development of Marshall Procedures for Designing Asphalt Paving Mixtures", Information Series 84, *National Asphalt Pavement Association* Lanham, MD

NCHRP (2004) Guide for Rational Design of New and Rehabilitated Pavement Structures, National cooperative Highway Research Programme, Washington D.C.

Oguara, T.M. (1985) ''Mechanistic Approach to Design of Highway Pavements in Nigeria'', ISSFE, Golden Jubilee Publication on Geotechnical Practices in Nigeria, Pp. 139-154.

Othmer, K; (1963) ''***Encyclopaedia of chemical technology***'' second edition, volume 2, Inter-science publishers, A Division of John Wiley and sons Inc. New York, pp. 762-765.

Robbins, M.M. (2009) "An investigation into dynamic complex modulus of Hot Mix Asphalt an it's contributing factor" Thesis presented to the Department of Civil Engineering, University of Toledo, USA, MSc Civil Engineering, Directed by David H. Timm.

Roberts, F.L. Kandhal, P.S., Brown, E.R.; Lee, D.Y. and Kennedy, T.W., (1996) "Hot Mix Asphalt Materials, Mixture Design, and Construction" *National Asphalt Pavement Association Education Foundation* Lanham, MD**.**

Rowe, G.M., Hakimzadeh, S., and Blankenship, P. (2008) ''Evaluation of Aspects of E* Test Using HMA Specimens with Varying Void Content'' Accessed online: March 23 2011.