Global Advanced Research Journal of Engineering, Technology and Innovation (ISSN: 2315-5124) Vol. 4(5) pp. 098-104, September, 2015
Available online http://garj.org/garjeti/index.htm

Full Length Research Paper

Influence of Candle Wax on Stiffness Property (E*) of Hot Mix Asphalt (HMA) Concrete: Light Traffic Case Study

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.

Accepted 06 September 2015

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. It is on this basis, that the present study explored techniques that will improve the performance of flexible road pavement by modifying its stiffness; in particular dynamic modulus, E* using candle wax. The results of the study revealed that the introduction of candle wax into the asphalt concrete mixture produced positive significant changes in the stiffness of the concrete. Results showed that the dynamic modulus increased from 60,638.48 PSI to 65,903.37 PSI at 0.1Hz; 84,834.77 PSI to 91,903.88 PSI at 1Hz; 107,625.86 to 116,594.12 at 5Hz; 122,74.06 PSI to 132,571.25 PSI at 10Hz and 157,266.77 PSI to 170,371.57 PSI at 25Hz. However, threshold candle wax content to attain maximum stiffness corresponded to 15% by weight of the asphalt at optimum at the loading frequencies investigated; that means further addition of candle wax resulted in reduction in the value of modulus. Also Candle Wax influence on the modulus of the asphalt concrete showed similar patterns irrespective of loading frequency.

Keywords: Candle Wax, Modifier, Dynamic Modulus and Asphalt Concrete

INTRODUCTION

One of the key elements of Mechanistic-Empirical (M-E) flexible pavement design is the characterization of material properties. One of such material property in particular is the dynamic modulus of HMA concretes, E* which influences tensile strain levels; therefore it is necessary to investigate this property to successfully predict fatigue cracking. 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, the Mechanistic-Empirical Pavement Design Guide (MEPDG), 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, E* 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, the four most recent including: Asphalt Institute as presented in Respersion Engineering Model (2008), Hirsch, Witczak 1-37A, and Witczak 1-40D (Bari and Witczak, 2006) (Christensen et al., 2003). To predict E* from one of these four 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 as it is subjected to cyclic compressive loading and unloading (Rowe et al, 2008); 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 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 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.

Even though, bitumen is a good binder material for road construction due to its cementing ability; Othmer (1963) however observed 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. 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 (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). 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 (Igwe et al, 2009) and (Igwe et al, 2010). There is, however, a dearth of information on the use of candle wax for the modification of material property such as dynamic modulus of asphalt concrete. The present study, therefore, focused on the stiffness and in particular dynamic modulus modification of Hot Mix Asphalt (HMA) concretes using candle wax for a light traffic category in Nigeria.

MATERIALS AND METHODS

Sample Collection

The materials used for this study were candle wax, bitumen or asphalt, coarse and fine aggregates. The candle wax and aggregates used were obtained from market dealers at Mile 3 Diobu, in Port Harcourt City Local Government Area of Rivers State, Nigeria. On the other hand the bitumen/asphalt used was collected from a private asphalt plant company H & H situated at Mbiama, in Ahoada West Local Government Area of Rivers State, Nigeria. 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 as presented in

Table 1. Laboratory test results of stated materials

Material	Candle wax	asphalt	Sand	Gravel
Specific gravity	0.80	1.05	2.52	2.86
Grade of binder material	-	40/50	-	-
Mix proportion (%)	-	-	41	59
Viscosity of binder (poise)	-	$1.45^*(10^{-6})$	-	-
Softening point	-	50ºC	-	-
Penetration value	-	53mm	-	-

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	2310	19.95	2071	3.5	29.8
5.5	2870	17.3	2120	3.6	26.2
5.0	3270	15.0	2260	3.9	21.78
4.5	3060	13.2	2240	4.3	22.1
4.0	2236	11.80	2050	4.9	28.8

Table 3. Mix design properties for candle wax modified asphalt concrete at 4.9% optimum asphalt content

Candle Wax (%)	Stability (N)	Flow (0.25mm)	Density (kg/m^3)	Air voids (%)	VMA (%)
0.0	3,228	14.64	2,256	4.4	22.00
5	3,455	12.42	2,412	4.0	16.90
10	4,126	11.24	2,532	3.8	12.99
15	4,390	10.64	2,586	3.4	11.37
20	3,980	11.75	2,445	3.9	16.43
25	3,410	12.54	2,325	4.2	21.74

Table 4: Schedule of Aggregates used for mix proportion (ASTM: 1951)

Sieve size (mm)	**Specification limit**	**Aggregate A (Gravel)**	**Aggregate B (Sand)**	**Mix proportion (0.59A+0.41B)**
19.0	100	99.1	100	99.45
12.5	86-100	86.1	100	91.80
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

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

Table 5. Variation of Dynamic Modulus E* with Candle Wax (%) at varying frequencies

	Dynamic Modulus, E* (lb/in²)					
% Candle Wax	0%	5%	10%	15%	20%	25%
Frequency (Hz)						
0.1	60,638.48	62,611.24	63,621.56	65,691.37	63,114.38	61,616.96
1	84,834.77	87,594.71	89,008.17	91,903.88	88,298.61	86,203.69
5	107,625.86	111,127.27	112,920.46	116,594.12	112,020.28	109,362.56
10	122,374.06	126,355.27	128,394.19	132,571.25	127,370.65	124,348.73
25	157,266.77	162,383.15	165,003.43	170,371.57	163,688.05	159,804.48

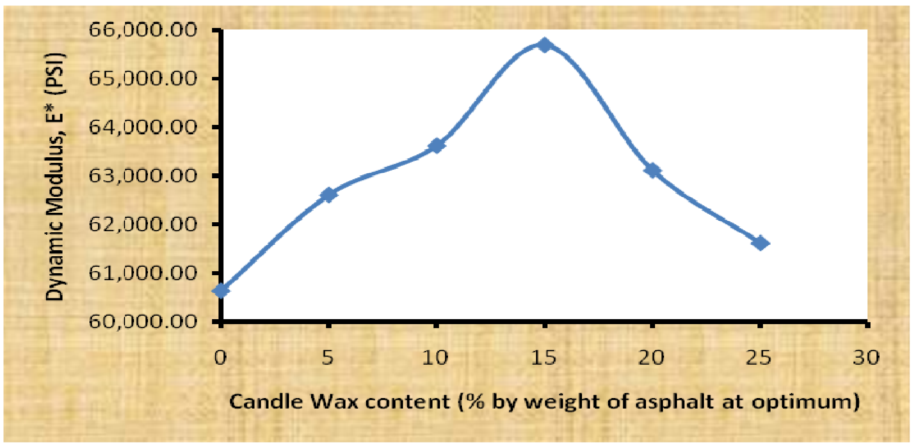

Figure 1. Variation of Dynamic Modulus with Candle Wax content at 0.1Hz

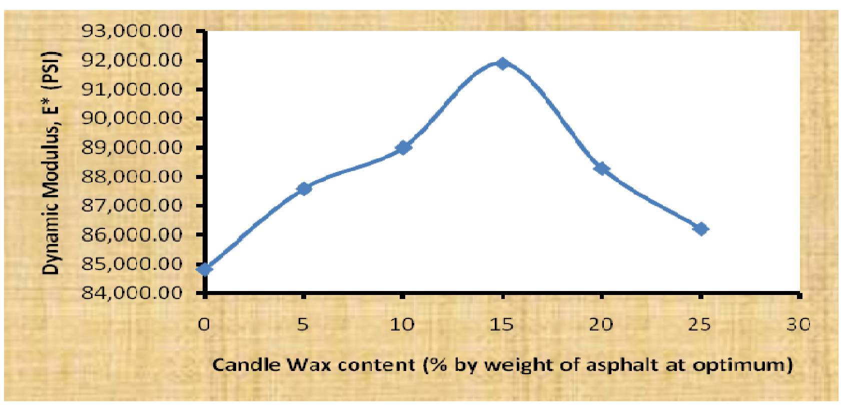

Figure 2. Variation of Dynamic Modulus with Candle Wax content at 1Hz

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 as specified by Design Guide (2002). The results obtained were used to determine the optimum asphalt content of the pure asphalt concrete. Candle wax was then added at varying amounts (5 – 25 percent by weight of the bitumen at optimum) 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 candle wax 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.

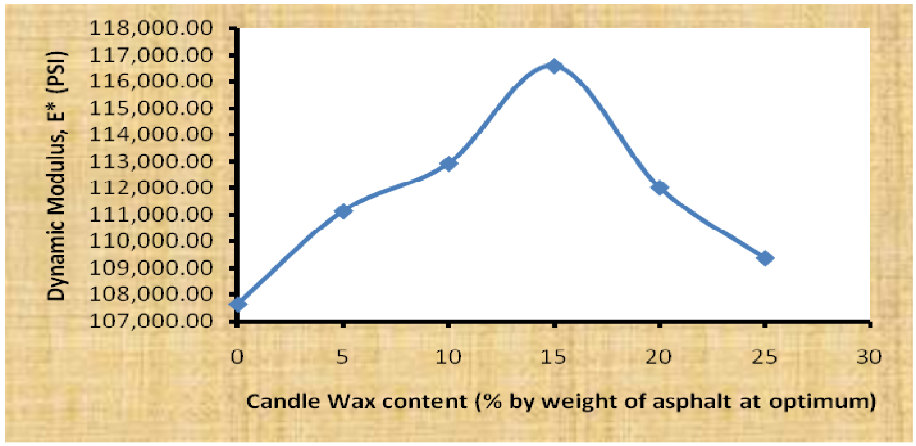

Figure 3. Variation of Dynamic Modulus with Candle Wax content at 5Hz

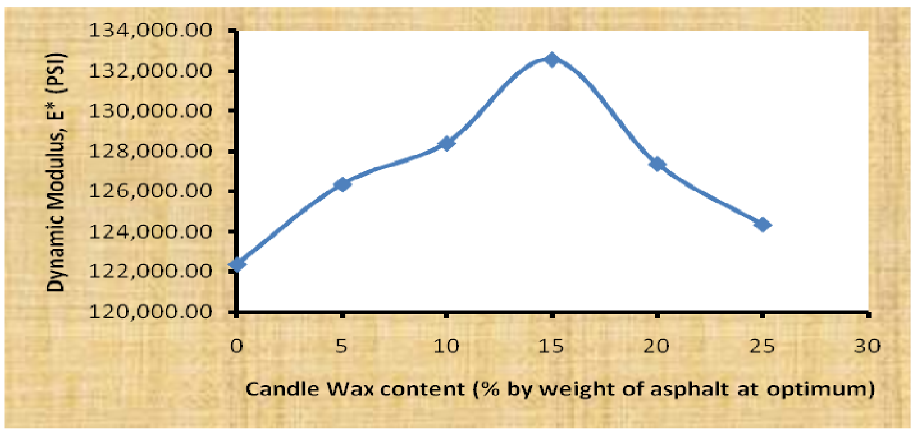

Figure 4. Variation of Dynamic Modulus with Candle Wax content at 10Hz

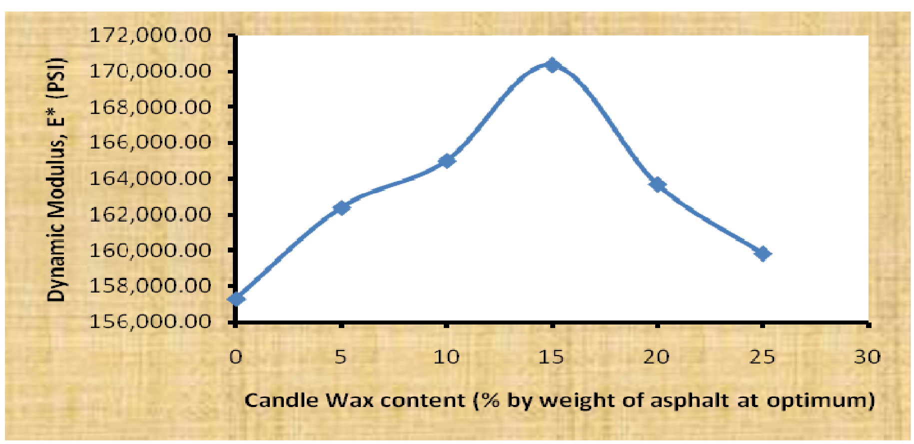

Figure 5. Variation of Dynamic Modulus with Candle Wax content at 25Hz

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, 1956; 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

Results (see Tables 1-5)

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

RESULT DISCUSSIONS

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. See Table 5.

From Figure 1 it was observed that at a frequency of loading of 0.1Hz the Dynamic Modulus, E* increased linearly with increasing Candle Wax content from 60,638.48 PSI to a maximum of 65,691.37 PSI corresponding to 15% candle wax content as the threshold value to attain maximum dynamic modulus. Further addition of candle wax resulted in reduction in stiffness of the asphalt concrete.

Also from Figure 2 it was observed that at a frequency of loading of 1Hz the Dynamic Modulus, E* increased linearly with increasing Candle Wax content from 84,834.77 PSI to a maximum of 91,903.88 PSI corresponding to 15% candle wax content as the threshold value to attain maximum dynamic modulus. Again further addition of candle wax resulted in reduction in stiffness of the asphalt concrete.

Similarly, from Figure 3 it was observed that at a frequency of loading of 5Hz the Dynamic Modulus, E* increased linearly with increasing Candle Wax content from 107,625.86 PSI to a maximum of 116,595.12 corresponding to 15% candle wax as the threshold value to attain maximum dynamic modulus. Similarly, further addition of candle wax resulted in reduction in stiffness of the asphalt concrete.

In addition, from Figure 4 it was observed that at a frequency of loading of 10Hz the Dynamic Modulus, E* increased linearly with increasing Candle Wax content from 122,374.06 PSI to a maximum of 132,571.25 PSI corresponding to 15% as the threshold value to attain maximum dynamic modulus. Further addition of candle wax resulted in reduction in stiffness of the asphalt concrete. .

Lastly, from Figure 5 it was also observed that at a frequency of loading of 25Hz the Dynamic Modulus, E* increased linearly with increasing Rubber Latex content from 157,266.77 PSI to a maximum of 170,371.57 PSI corresponding to 15% candle wax as the threshold value to attain maximum dynamic modulus. Again further addition of candle wax resulted in reduction in stiffness of the asphalt concrete.

CONCLUSIONS

From the laboratory investigations of both the unmodified and rubberized HMA concrete it is evident that the addition of candle wax into the mixture produced significant changes in the stiffness of the asphalt concrete. However, the following points are note worthy;

- Threshold candle wax content to attain maximum stiffness corresponds to 15% by weight of the asphalt at optimum; that means further addition of candle wax resulted in reduction in the value of stiffness (dynamic modulus).
- Candle Wax influence on the dynamic modulus of the asphalt concrete showed similar patterns irrespective of frequency of loading.
- Rate of influence of candle wax on the dynamic modulus of the HMA concrete increased as frequency increased from 0.1-25Hz.

REFERENCES

American Society for Testing Materials (1951). "Triaxial Testing of soils and Bituminous Mixtures". Special Technical Publication No. 16, Philadelphia.

Asphalt Institute (1956). 'Mix Design methods for Hot-mix Asphalt Paving'.

Asphalt Institute (1999). '*Thickness Design, Asphalt Pavements for Highways and Streets Report', MS-1*, Asphalt Institute, 1982. (re-printed in 1999)

Bari J and Witczak MW (2006). "Development of a New Revised Version of the Witczak E* Predictive Model of Hot Mix Asphalt Mixtures", *Journal of the Association of Asphalt Paving Technologist*, 75,381–424.

Bonaquist RF (2003). 'Simple Performance Tester for Super-pave Mix Design', *Quarterly Progress Report. NCHRP Project 9-29*.

Transportation Research Board of the National Research Council, Washington, D.C. *Bridges*. (58)2; 32 – 41.

Christensen DW, Pellinen T, Bonaquist RF (2003). "Hirsch Model for Estimating the Modulus of Asphalt Concrete", Journal of the Association of Asphalt Paving Technologist, 72, 97–121.

Collins RJ and Ciesielski SK (1993). '*Recycling of Waste Materials and by Products in Highway Construction'*, (1 & 2); Office of Research and Development, U.S. Federal Highway Administration. Washington, DC.

Decker HCJ and Nijveld HAW (1951). 'Influence of Rubber Additions on Some Mechanical Properties of Asphaltic Bitumen', *Proc. III World Pet. Congress* Section VII*)*, Leiden, Holland. p496.

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

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.

Federal Highway Administration (1993). *'Engineering and Environmental Aspects of Recycled Materials for Highway Construction',* (1): Final Report FHWA Contract No. DTFH61-92-COO60, Washington DC.

Flynn L (1993). 'Recycled Plastic Finds Home in Asphalt Binder', *Journal of Roads and*
Bridges. (58)2; 32 – 41.

*Guide for Mechanistic-Empirical Design of New and rehabilitated Pavement Structures (*2003*). NCHRP 1-37A Project*, Transportation Research Board of the National academies, Washington, D.C. *Highway Construction'*, (1 & 2); Office of Research and Development, U.S. Federal Highway Administration. Washington, DC.

Igwe EA, Eme DB And Nwaobakata C (2010). 'Variation of Flow and Air Voids of a Bituminous Concrete under the Influence of Natural Rubber in Nigeria', *Journal of Chemical, Mechanical and Engineering Practice, Vol. 1 Nos. 2 & 3, December 2010*

Igwe EA, Ayotamuno MJ, Okparanma RN, Ogaji SOT, and Probert SD (2009). 'Road Surface Properties affecting Rates of Energy Dissipation from Vehicles' *Journal of Applied Energy,* vol. 86, pp. 1692-1696, Elsevier Publishing.

Khan A, Mohan M, and Raykar V (1999). '*Effective Utilization of Waste Plastics in*
Maryland, Manual Series No.2. Lexington.

Mason PE, Thrower EN and Smith LM (1957). 'Influence of Rubber on the Brittleness and Viscosity of Bituminous Materials'*, Journal of Applied. Chemistry'.* (7); London, p451.

Mummah SN and Muktar S (2001). "Improving road pavements with natural rubber" *Journal of Engineering Technology and Industrial Applications*, Vol. 1, No. 3, pp. 208-220.

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

Othmer K (1963). '*Encyclopaedia of Chemical Technology*', (2nd ed.) (2); Interscience Publishers, A Division of John Wiley & Sons Inc. New York, pp762 – 765.

Punith VS (2001). 'Effect of plastic modifiers on bituminous mix properties', Seminar Report, II Semester in M.E. Highway Engineering, Department of Civil Engineering, Bangalore University, Bangalore, India.

Robbins MM (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 FL, Kandhal PS, Brown ER, Lee DY, and Kennedy TW (1996). Hot-Mix Asphalt Materials, Mixture Design, and Construction. *National Asphalt Pavement Association Education Foundation* Lanham, MD.

Rowe GM, Hakimzadeh S and Blankenship P (2008). 'Evaluation of Aspects of E* Test Using HMA Specimens with varying Void Contents' accessed online.

Tashman L, and Elangovan MA (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. WARD 704.1,
http://www.wsdot.wa.gov/research/reports/fullreports/704.1.pdf

Van Rooijen JM (1938) "The Effect of Rubber upon some Properties of Asphaltic Bitumen" *Rubber Foundation Communication* No. 7, Amsterdam.

Witczak MW (2005). '*NCHRP Report 547: Simple Performance Tests: Summary of Recommended Methods and Database'*, Transportation Research Board of the National Academies, Washington, D.C.

Witczak MW, and Pellinen TK (2000). 'AC Mixture Response comparison to Performance |E*| and Sm Prediction Equation Methodology Results' *Super-pave Support and Performance Models Management, Task C: Simple Performance Test. NCHRP Project 9-19*, Team Report SPT-ALF-2(L), Transportation Research Board of the National Research Council.

Witczak MW, Pellinen TK, and El-Basyouny MM (2002). "Pursuit of the Simple Performance Test for Asphalt Concrete Fracture/Cracking," Association of Asphalt Paving Technologists (AAPT) Annual Meeting, Colorado Springs, CO.

Zoorob SE (2000). 'Laboratory Design and Performance of Improved Bituminous Composites Utilizing Plastics Packaging Waste'. Conference on Technology Watch and Innovation in Construction Industry. Building Research Institute, Brussels, Belgium (April, 2000).

Zoorob SE and Suparma LB (2000). "Laboratory Design and Investigation of proportion of bituminous composite containing waste recycled plastics aggregate replacement (Plastiphalt), CIB Symposium on Construction and Environment: Theory into practic Sao Paulo, Brazil. (November, 2000).