Global Advanced Research Journal of Engineering, Technology and Innovation (ISSN: 2315-5124) Vol. 4(5) pp. 080-085, September, 2015
Available online http://garj.org/garjeti/index.htm

Full Length Research Paper

Contribution of Shredded Tire Chips as Filler Material on Stiffness of HMA Concrete

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 was directed towards exploring techniques that will improve the performance of flexible road pavement by modifying its material stiffness; in particular dynamic modulus, E* through modification using candle wax. The results of the study revealed that the introduction of shredded tire chips as a filler material into the asphalt concrete mixture produced positive significant changes in the dynamic modulus of the concrete. In addition, it was evident that the relationship was linearly elastic for all ranges of frequency investigated. That is, the dynamic modulus of the concrete linearly increased with increasing shredded tire chips content within the limits of percentage investigated. Also shredded tire chips influence on the asphalt concrete showed similar patterns irrespective of loading frequency; however rate of influence of candle wax on the modulus of the asphalt concrete increased as frequency increased from 0.1-25 Hz.

Keyords: Shredded tire Chips, Filler, 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 stiffness which influences tensile strain levels; therefore it is necessary to investigate this property to successfully predict fatigue cracking. Research has shown that there are various forms of measuring elastic properties of asphalt concrete mixes such as young's modulus, bulk modulus, shear modulus, resilient modulus, elastic modulus and so on. However, more recent research has posited that the dynamic modulus, E* closely simulate true field conditions and thus is more reliable for use in design (Clyne et al. 2003).

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 several 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. 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. The present study focused on the use of shredded tire chips as a filler material introduced at the optimum design at varying amounts. The philosophy is drawn from the fact that most predictive models used in the determination of dynamic modulus, E* give credence to percent of fines as a contributor to stiffness (Asphalt Institute 1999; Bari and Witczak, 2006). Thus, the present study explored the use of shredded tire chips as fine or filler material to ascertain its contribution to dynamic modulus, E* of asphalt concrete.

MATERIALS AND METHODS

Sample collection

The materials used for this study were rubber latex, bitumen or asphalt, coarse and fine aggregates. The shredded tire chips used was obtained from condemned tires of spoilt vehicles while the 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 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 60^0C 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. Shredded tire chips was then

Table 1. Laboratory test results of stated materials

Material	Shredded tire chips	asphalt	Sand	Gravel
Specific gravity	1.18	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 shredded tire chips modified asphalt concrete at 4.9% optimum asphalt content

Shredded Tire chips (%)	Stability (N)	Flow (0.25mm)	Density (kg/m^3)	Air voids (%)	VMA (%)
0.0	3,228	14.64	2,256	3.9	21.90
5	3,230	13.50	2,336	3.8	21.78
10	3,634	12.60	2,360	3.6	21.41
15	3,856	12.50	2,390	3.56	21.38
20	4,970	12.10	2,407	3.54	21.20
25	5,116	11.60	2,421	3.52	20.38

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

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 shredded tire chips introduction into the asphalt concrete was inputted into our Asphalt Institute model equation to obtain varying E* values.

Table 5. Variation of Dynamic Modulus E* with Shredded Tire Chips Content (%) at varying frequencies

% Shredded Tire Chips	Dynamic Modulus, E* (lb/in^2)					
	0%	5%	10%	15%	20%	25%
Frequency (Hz)						
0.1	63,114.38	63,621.56	64,648.18	64,855.48	64,959.38	65,063.45
1	88,296.61	89,008.17	90,444.44	90,734.46	90,879.82	91,025.42
5	112,020.28	112,920.46	114,742.59	115,110.53	115,294.94	115,479.65
10	138,803.86	139,919.28	142,177.07	142,632.98	142,861.48	143,090.35
25	176,693.14	178,113.02	180,987.12	181,567.48	181,858.36	182,149.71

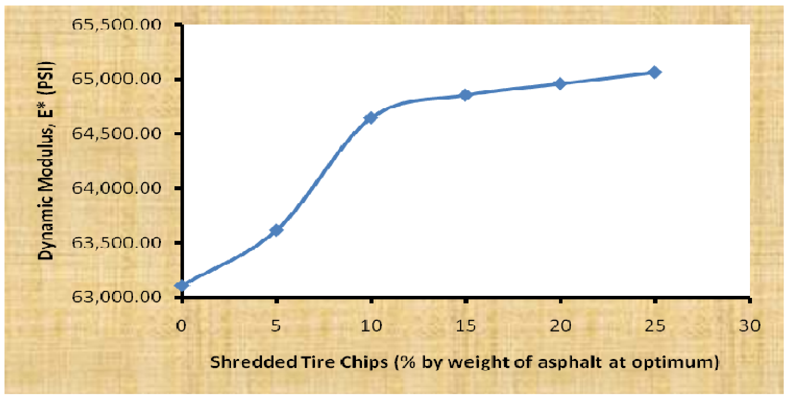

Figure 1. Variation of Dynamic Modulus with Shredded Tire Chips Content at 0.1Hz

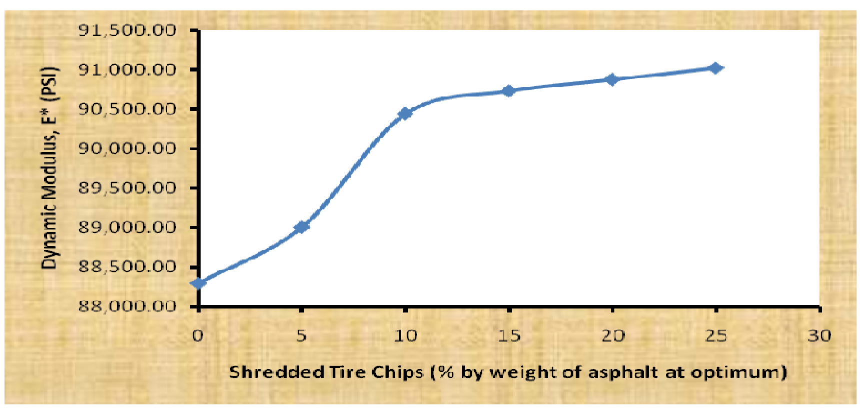

Figure 2. Variation of Dynamic Modulus with Shredded Tire Chips Content at 1Hz

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 cited in (Asphalt Institute, 1956; National Asphalt Pavement Association, 1982) as follows:

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

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):

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

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

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

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

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

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

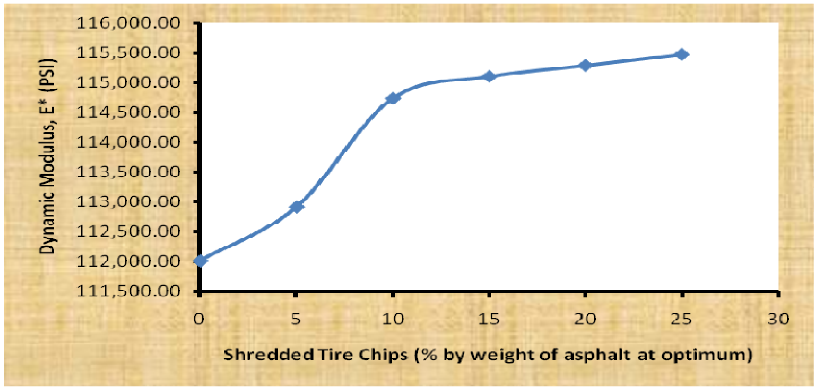

Figure 3. Variation of Dynamic Modulus with Shredded Tire Chips Content at 5Hz

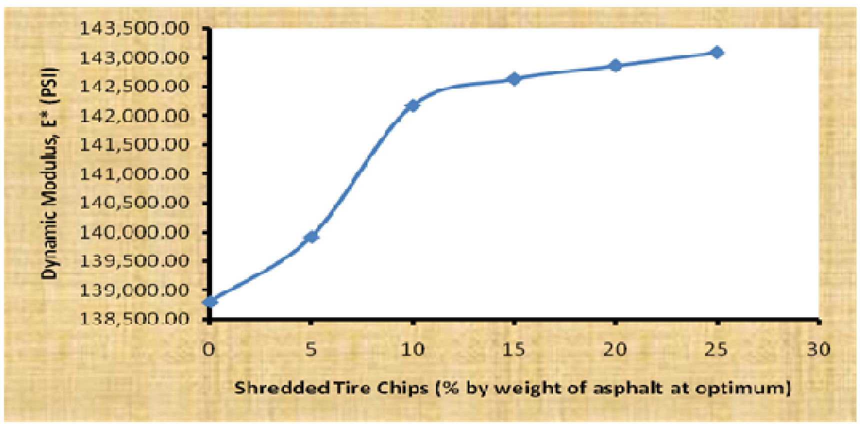

Figure 4. Variation of Dynamic Modulus with Shredded Tire Chips Content at 10Hz

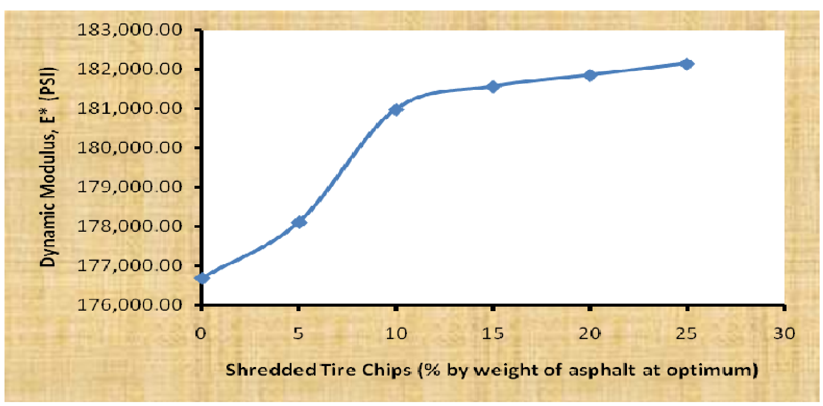

Figure 5. Variation of Dynamic Modulus with Shredded Tire Chips Content at 25Hz

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 Figures 1 -5 it was observed that at the various frequencies of loading of 0.1 -25Hz the Dynamic Modulus, E* increased linearly with increasing shredded tire chips content up to 25% addition. The reason was that the shredded tire chips acted as filler materials closing up the void spaces in the asphalt concrete that resulted in increased stiffness due to increase in density for all frequencies investigated and within the limits of the additive introduced. Also, the values of stiffness increased with increasing frequency from 0.1 -25Hz.

CONCLUSIONS

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

- The dynamic modulus of the asphalt concrete increased linearly with increase in shredded tire chips addition within the limits of percentage investigated for frequencies between 0.1 -25Hz.
- Shredded tire chips influence on the dynamic modulus of the asphalt concrete showed similar patterns irrespective of frequency of loading.
- Rate of influence of shredded tire chips on the 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 (1999). '*Thickness Design, Asphalt Pavements for Highways and Streets Report', MS-1*, Asphalt Institute, 1982. (re-printed in 1999)

Bari J, 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.

Clyne TR, Li X, Marasteanu MO, and Skok EL (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.

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.

*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.

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

National Asphalt Pavement Association (1982). 'Development of Marshall Procedures for Designing Asphalt Paving Mixtures', *National Asphalt Pavement Association*,

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

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.