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/ijeter01392015.pdf

Comparative Study on the Effect of Some Non Bituminous Modifiers on HMA Concrete Stiffness Modulus: Study on Optimal Performance for Heavy Traffic

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.

ABSTRACT

Enhancing pavement life has become a paradigm in highway engineering requiring modifications of pavement properties such that fatigue life can be improved. However, fatigue life of pavement is mainly controlled by tensile strains whereas these strains are greatly determined by **stiffness modulus** of pavements. On this basis the present study sought to investigate by comparative analysis how pavement stiffness will respond under the effect of different types of modifier for optimal performance. The research was carried out for heavy traffic case at test frequencies of 0.1, 1, 5, 10 and 25Hz respectively using candle wax, waste polythene bag and shredded tire chips as modifiers. The result obtained revealed that both candle wax and waste polythene bag modified asphalt concretes had average percentage increase in stiffness modulus of 4.9% corresponding to threshold modifier content of 15% for both modifiers for all test frequencies. On the other hand results obtained revealed that shredded tire chips modified asphalt concrete had percentage increase in stiffness modulus of 8.3% at 25% modifier content for all test frequencies. Overall, it is concluded that shredded tire chips addition will produce flexible pavement having grater resistance to external loads due to better stiffness modulus.

Key words: Comparative Effect, Non Bituminous Modifier, Hot Mix Asphalt, Stiffness Modulus and Optimal Performance.

1. INTRODUCTION

It has been possible to improve the performance of bituminous mixtures used in the surface course of road pavements with the incorporation of various modifiers and or additives into the bituminous mixtures. Some of these additives can be mainly classified as **Non Bituminous**: meaning that bitumen cannot be derived or obtained from them. Examples include polymers, crumb rubber-treated with some chemicals including recycled plastics mainly polyethylene as in the manufacture of polymer modified asphalt cement. Other modifiers include the use of blast furnace slags, steel slags, glass cutlets, municipal waste combustion ash, scrap tires, carpet fibre waste, and roofing shingle wastes. Coal Combustion by-products, Coal fly ash, bottom ash, combined ash and flue gas desulphurization waste are other additives that has also been used in modifying bituminous mixtures.

In line with the concept of using modifiers in bituminous mixtures, the study by Flynn (1993) revealed that recycled polyethylene from grocery bags proved useful in asphaltic (bituminous) pavements resulting in reduced permanent deformation in the form of rutting and reduced low–temperature cracking of the pavement surface. The corollary of his finding posits that pavement performance and life can be enhanced by the use of additives (modifiers). Buttressing the study by Flynn, Zoorob (2000), Zoorob and Suparma (2000) showed that recycled plastics composed predominantly of polypropylene and low density polyethylene can be incorporated into conventional asphaltic or bituminous road surfacing mixtures. Their separate studies revealed that the addition of recycled plastics resulted in greater durability and fatigue life in the modified mixes as compared to the conventional mixes. In addition, it further buttresses the studies of Collins and Ciesielski (1993), and Federal Highway Administration (1993). Furthermore, Khan et al (1999) also strengthens the findings of Flynn (1993); Zoorob (2000); Zoorob and Suparma (2000) in the use of waste plastics as already discussed. The effects of using waste plastics in asphalting roads were studied and it was concluded that the incorporation of plastics into bituminous mixtures (concrete mixes) improved the performance of the pavement in terms of stability and fatigue life and other desirable properties of the pavement. A more recent study by Igwe and Ekwulo (2011) revealed that the inclusion of rubber latex to hot mix asphalt concrete increased the stiffness of the concrete for all categories of test frequencies up to 0.5%rubber latex addition.

One the most important hot-mix asphalt (HMA) property influencing the structural response of a flexible pavement is the HMA stiffness modulus (E_{HMA}) (Garcia and Thompson, 2007). 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) in a previous study concluded from their work that among the common methods of measurement of elastic properties of asphalt mixes (which are Young's, shear, bulk, dynamic modulus, double punch, resilient, and Shell Nomo graph modulus), the resilient modulus is more appropriate for use in multilayer elastic theories. This had been supported by the separate 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 modulus. Some of the tests employed are tri-axial tests (constant and repeated cyclic loads), cyclic flexural test, indirect tensile tests (constant and repeated cyclic loads), and creep test. Although, there are different kinds of stiffness modulus as already stated for purpose of the present study, we shall be limiting our stiffness modulus to the **DYNAMIC MODULUS** of hot mix asphalt concrete. 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 modulus and nearly simulates true field condition. It is pertinent to state here that other forms of determining stiffness is by the use of predictive models - Bonnaure et al (1997); Christensen et al (2003); Bari and Witczak (2006) based on simple laboratory tests like the **Marshal** test procedure. For the test, basic parameters required for prediction included – loading frequency, test temperature, volume of air voids, asphalt viscosity, optimum asphalt content, penetration and percent by weight of aggregates passing 75micron sieve. For simplicity, the present study adopted the **Asphalt Institute Model** (Huang 1993) for predicting stiffness for the category of traffic under investigation – **Heavy Traffic**. The modifiers used were – **Candle Wax, Shredded Tire Chips and Waste Polythene Bag;** whereas the test frequencies used for prediction were – 0.1, 1, 5, 10 and 25 Hz respectively.

2. MATERIALS AND METHODS

2.1. Sample collection

The materials used for this study were candle wax, shredded tire chips, waste polythene bag, asphalt cement, coarse and fine aggregates. The candle wax used was obtained as wastes from domestic use of candles whereas the shredded tire chips used was obtained from condemned tires of vehicles. Also the polythene bags used were obtained as wastes from the University of Science and Technology Campus (RSUST), Port Harcourt, Nigeria. 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 asphalt cement 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 asphalt and sieve analysis of the aggregates used for mix-proportioning by straight line method - were carried out. This was followed by preparing samples for both unmodified and modified asphalt concrete mixtures.

2.2. Sample preparation

Samples were prepared using Marshal Design Procedures for asphalt concrete mixes as presented in Asphalt Institute (1981), 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 75 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 25 Hz respectively as specified by AASHTO Design Guide (2002). The results obtained were used to determine the optimum asphalt content of the pure asphalt concrete. The mix design for the non bituminous modifiers involved additions of the modifiers at varying amounts (5 – 25 percent by weight of the asphalt at optimum) to the samples at optimum asphalt content and then re-designing using the same Marshal Design Procedures already stated above to produce modified concretes having varying mix design properties particularly air voids content which greatly affected tensile strains and stiffness (i.e. dynamic modulus).

2.3. Theory

The optimum asphalt content (O.A.C.) for the unmodified concrete was obtained using equation 1, according to the Marshal Design Procedure cited in (Asphalt Institute, 1982; 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 predictive model for stiffness and in particular dynamic modulus was used for the study and presented in Huang's Pavement Analysis and Design textbook (1993) as in **Equations 2 - 7**:

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

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

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

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

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

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

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. RESULTS (TABLES 1-8 and FIGURES 1 - 5)

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

Table 1: Laboratory Test Results of Materials

Material	Candle Wax	Tire Chips	Polythene Bag	Asphalt	Sand	Gravel
Specific gravity	0.80	1.18	0.92	1.05	2.52	2.86
Grade of binder	-	-	-	40/50	-	-
Mix proportion (%)	-	-	-	-	41	59
Viscosity of binder (poise)	-	-	-	$1.45*(10^{-6})$	-	-
Softening point (°C)	-	-	-	50	-	-
Penetration value (mm)	-	-	-	53	-	-

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 modifiers (candle wax, tire chips and polythene bag) used for carrying out the Marshal Mix Design for each concrete.

Table 2: Mix Design Properties for Unmodified Asphalt Concrete for Heavy Traffic

Asphalt Content (%)	Stability (N)	Flow (0.25mm)	Density (kg/m^3)	Air voids (%)	VMA (%)
6.0	6750	15.40	2125	3.10	27.48
5.5	7990	13.40	2220	3.20	23.88
5.0	8960	11.60	2280	3.40	21.10
4.5	8400	10.30	2270	3.70	21.05
4.0	6690	9.50	2210	4.10	22.76

The above schedule (**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).**

By applying Equation 1, the optimum asphalt content used for designing the non bituminous modified concretes according to National Asphalt Pavement Association (1982) was obtained as 4.6%. The results obtained for mix proportion used for the fine aggregate (sand) and the coarse aggregate (gravel) is as presented in Table 3 below. The mix ratio was used together with the asphalt cement for preparing asphalt concrete samples

Table 3: 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

Table 3 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.

By applying Equations 2 – 7 the results for stiffness obtained for the non bituminous modifiers at the loading frequencies of tests is presented in Tables 4 – 8 below;

Table 4: Results of Stiffness for Non Bituminous Modifiers at F = 0.1 Hz

Percent modification	Candle Wax	Tire Chips	Polythene Bag
0	72, 705.14	72, 705.14	72, 705.14
5	72, 705.14	73, 878.34	75, 070.46
10	74, 472.01	75, 070.46	75, 673.72
15	76, 281.83	76, 894.82	76, 281.83
20	76, 281.83	78, 135.63	75, 673.72
25	72, 125.54	78, 763.52	75, 070.46

Table 5: Results of Stiffness for Non Bituminous Modifiers at F = 1 Hz

Percent modification	Candle Wax	Tire Chips	Polythene Bag
0	100, 150.34	100, 150.34	100, 150.34
5	100, 150.34	101, 766.40	103, 408.54
10	102, 584.18	103, 408.54	104, 239.52
15	105, 077.18	105, 921.57	105, 077.18
20	105, 077.18	107, 630.76	104, 239.52
25	99, 351.95	108, 495.67	103, 408.54

Table 6: Results of Stiffness for Non Bituminous Modifiers at F = 5 Hz

Percent modification	Candle Wax	Tire Chips	Polythene Bag
0	125, 710.17	125, 710.07	125, 710.17
5	125, 710.17	127, 738.68	129, 799.92
10	128, 765.18	129, 799.92	130, 842.98
15	131, 894.42	132, 954.31	131, 894.42
20	131, 894.42	135, 099.71	130, 842.98
25	124, 708.03	136, 185.36	129, 799.92

Table 7: Results of Stiffness for Non Bituminous Modifiers at F = 10 Hz

Percent modification	Candle Wax	Tire Chips	Polythene Bag
0	142, 171.07	142, 177.07	142, 177.07
5	142, 171.07	144, 471.29	146, 802.54
10	145, 632.25	146, 802.54	147, 982.23
15	149, 171.40	150, 370.12	149, 171.40
20	149, 171.40	152, 796.55	147, 982.23
25	141, 043.66	154, 024.41	146, 802.54

Table 8: Results of Stiffness for Non Bituminous Modifiers at F = 25 Hz

Percent modification	Candle Wax	Tire Chips	Polythene Bag
0	180, 987.12	180, 987.12	180, 987.12
5	180, 987.12	183, 907.60	186, 875.20
10	185, 385.46	186, 875.60	188, 376.91
15	189, 890.69	191, 416.64	189, 890.69
20	189, 890.69	194, 505.41	188, 376.91
25	179, 544.32	196, 068.43	186, 875.20

Tables 4 – 8 shows the results of calculated stiffness at varying frequencies for the 3 different set of modifiers used for each asphalt concrete specimen.

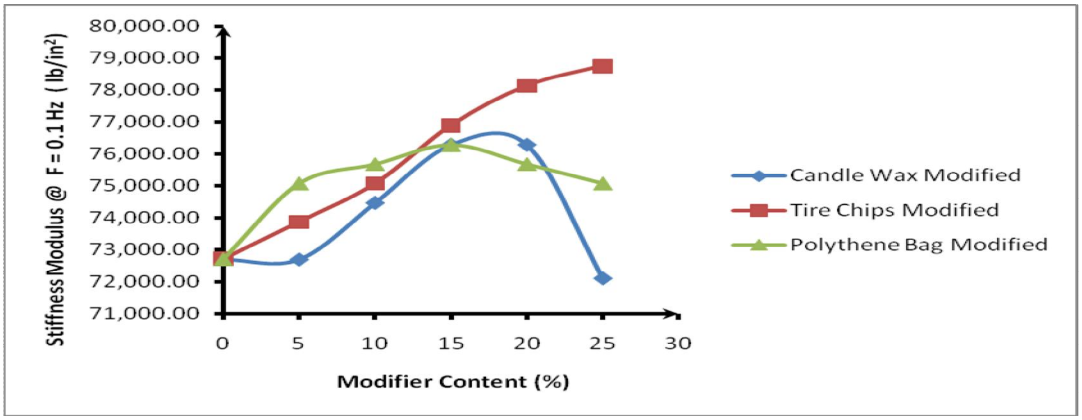

Figure 1: Variation of Stiffness Modulus against Modifier Content @ F = 0.1 Hz

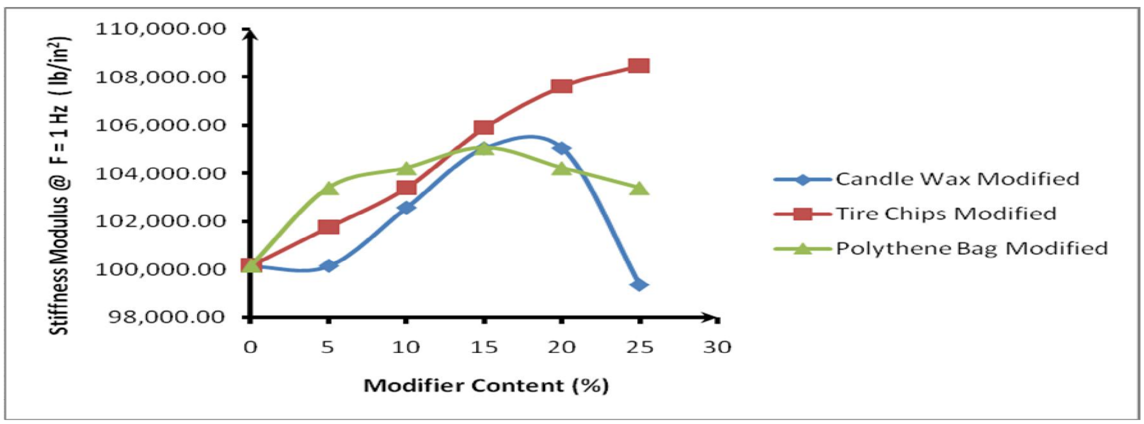

Figure 2: Variation of Stiffness Modulus against Modifier Content @ F = 1 Hz

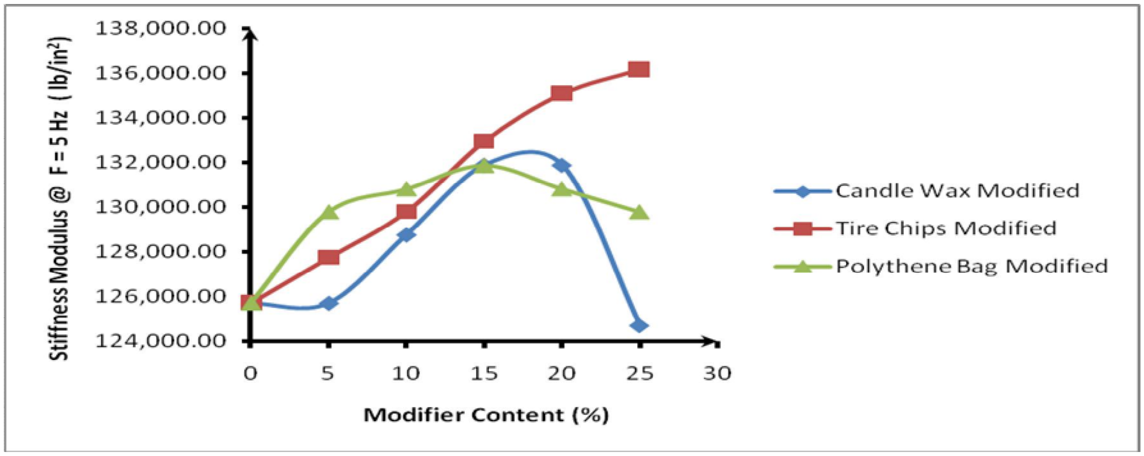

Figure 3: Variation of Stiffness Modulus against Modifier Content @ F = 5 Hz

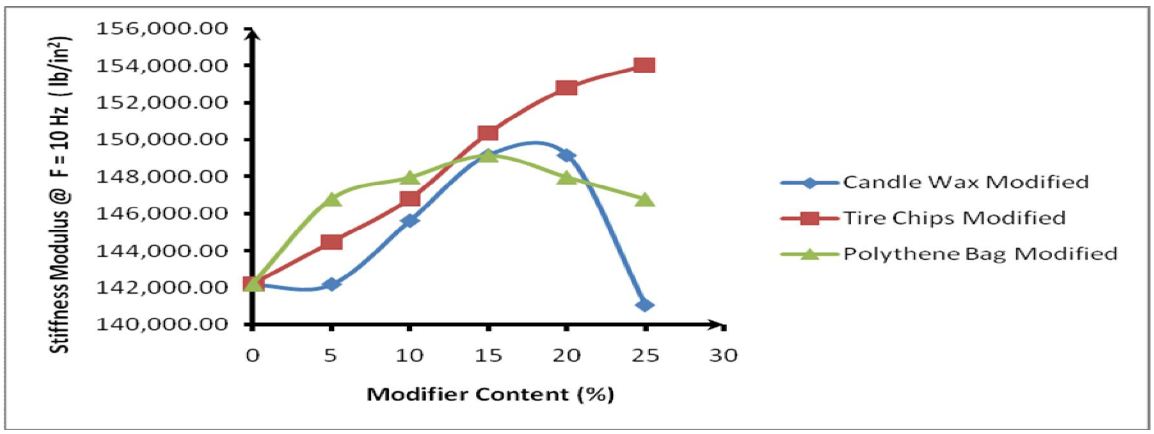

Figure 4: Variation of Stiffness Modulus against Modifier Content @ F = 10 Hz

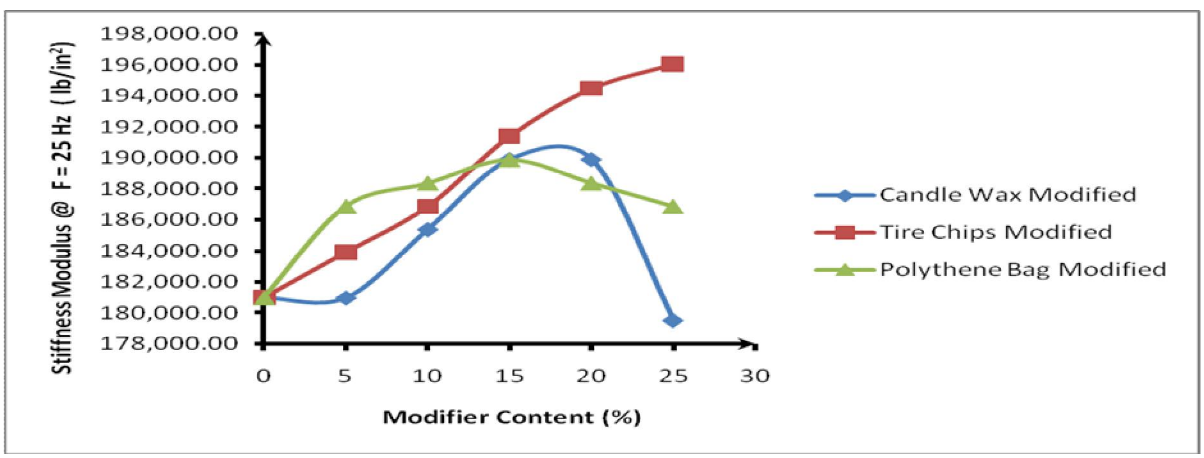

Figure 5: Variation of Stiffness Modulus against Modifier Content @ F = 25 Hz

4. RESULT DISCUSSION

The results as presented in Figures 1 – 5, revealed that the changes that occurred in stiffness modulus (for the study in question, **Dynamic Modulus**) follow a similar behavioural change pattern for the individual modifier for all categories of frequencies. Secondly, the results revealed that changes in stiffness modulus for both candle wax and waste polythene bag modified asphalt concrete increased with increasing modifier content up to 15%; after which further increase in modifier content resulted in either no change or decrease in stiffness modulus. Whereas, modifications due to shredded tire chips addition revealed that stiffness modulus of the asphalt concrete increased continuously with increasing tire chips content up to 25%.

The results also revealed that the percentage of increase in stiffness modulus of the candle wax modified asphalt concrete is same as those of the waste polythene bag modified asphalt concrete with an average value of 4.9% change in stiffness for all the categories of test frequencies. This percentage change corresponds to the threshold value of 15% modifier content for both modifiers – candle wax and waste polythene bag.

On the other hand the results further revealed that the percentage increase in stiffness modulus for the shredded tire chips modified asphalt concrete was an average of 8.3% change in stiffness for all categories of test frequencies. This percentage change corresponds to 25% modifier content for the shredded tire chips used.

5. CONCLUSIONS

The conclusions from the study are as follows;

1. The percentage increase in stiffness modulus for candle wax modified asphalt concrete was obtained as 4.9% for all test frequencies corresponding to threshold modifier content of 15%.

2. The percentage increase in stiffness modulus for waste polythene bag modified asphalt concrete was obtained as 4.9% for all test frequencies corresponding to threshold modifier content of 15%.

3. The percentage increase in stiffness modulus for shredded tire chips modified asphalt concrete was obtained as 8.3% for all test frequencies corresponding to modifier content of 25%.

4. Finally, it was concluded that tire chips modification of hot mix asphalt concrete mixtures will produce flexible pavements with better stiffness modulus; therefore having greater resistance to external loads such as traffic, temperature, moisture and oxidation rates.

REFERENCES

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

Asphalt Institute (1981) "Thickness Design-Asphalt Pavements for Highways and Streets", Manual Series No. 1.

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

Bari, J. and Witczak, M. W. (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.

Bonnaure, F., Gest, G., Gravois, A., and P. Uge, (1977) "A New Method of Predicting the Stiffness of Asphalt Paving Mixtures," *Proceedings, Association of Asphalt Paving Technologists*, Vol. 46, pp. 64-100.

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.

Christensen, D. W., Pellinen, T. and Bonaquist R. F. (2003) "Hirsch Model for Estimating the Modulus of Asphalt Concrete", Journal of the Association of Asphalt Paving Technologist, 72, 97–121.

Collins, R. J. and Ciesielski, S. K. (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.

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*. Vol.58, No.2; pp32 – 41.

Garcia, G., and Thompson M. R., (2007) "HMA Dynamic Modulus Predictive Models: A Review", Report of the Findings of ICt-R39: Validation of Extended Life HMA design Concepts, Research Report FHWA-ICT-07-005.

Huang, Y. H. *(*1993) "Pavement Analysis and Design" *1st* Ed., Prentice Hall, Upper River Saddle, N.J

Igwe, E. A. and Ekwulo, E. O. (2011) "Influence of Rubber Latex on Dynamic Modulus of Hot Mix Asphalt Concrete", *Archives of Applied Science Research*, Vol. 3, Issue 4, pp. 319 - 327: Available online at http://www.scholarsresearchlibrary.com

Khan, A., Mohan, M. and Raykar, V. (1999) '*Effective Utilization of WastePlastics in Asphalting Roads'.* Project Report, Department of Chemical Engineering, R.V.College of Engineering, Bangalore. India

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

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.

Zoorob, S. E. (2000) "Laboratory Design and Performance of improved Bituminous Composites Utilising Plastics Packaging Waste", *Conference on Technology watch and Innovation in Construction Industry*, Belgium, Building Research Institute, Brussels, Belgium (April, 2000).

Zoorob, S. E. and Suparma, L. B. (2000) "Laboratory Design and Investigation of proportion of Biutminous composite containing waste recycled plastics aggregate replacement (plastiphalt), *CIB Symposium on Construction and Environment*: Theory into practice, Sao Paulo, Brazil (November 2000).