Available online www.jsaer.com

Journal of Scientific and Engineering Research, **2017, 4(9):210-216**

ISSN: 2394-2630
CODEN(USA): JSERBR

Research Article

A Proof of Moisture Damage on Fatigue Life of Flexible Pavement Submerged in Water: A Practical Case for a Medium Volume Road

Enwuso A. Igwe, Kemejika I. Amadi-Oparaeli

Department of Civil Engineering, Rivers State University of Science and Technology, Nkpolu Oroworukwo, P.M.B 5080, 5080, Port Harcourt, Rivers State, Nigeria

Abstract The present study focused on determining changes that will occur in the life of a flexible pavement with respect to fatigue when submerged in moisture over a period of time under repeated traffic loads and varying frequencies of loading. The study was simulated in the laboratory by using asphalt concretes for analysis which is believed to have associate behaviour with flexible pavements under similar conditions. The study thus revealed that under moisture the tensile strains in the pavement layer increased considerably continuously between Day 0 – Day 5 submergence in moisture. Alternately, the increase in strains resulted in considerable and continuous decrease in pavement stiffness between Day 0 – Day 5 submergence in moisture. On the overall, this resulted in significant and continuous decrease in pavement fatigue therefore a reduction in the life of the pavement between Day 0 – Day 5 submergence in moisture. In summary it is concluded that moisture has a damaging effect on flexible pavement life when under submergence over a period of time.

Keywords Flexible Pavement, Moisture Damage & Fatigue Life

1. Introduction

Highway flexible pavements suffer from four main factors namely – moisture, oxidation rates, temperature variation and traffic loading. Many times the effect and impact of moisture has been grossly overlooked on the assumption that pavements are designed and constructed on the ideals of well provided drainage facilities. However, on the other hand and in particular in most developing nations of the world over 70% of the roads have no drainage facilities.

The government in most of these nations only concern themselves with providing a wearing course over a base course and a sub-grade without due attention to drainage facilities. Appendix 1 is a typical example of a road subjected to moisture and its impact on the road pavement. The present study was concerned with the aftermath on fatigue life of a flexible pavement when subjected to moisture over a period of time resulting from poor or no drainages at all.

Road pavements are one of the largest infrastructure components in most of the developed nations of the world [1]. Thus, buttress the need for the science and technology of road pavements. Moreover, without an adequate drainage facility, road pavements when subjected to traffic under excessive moisture conditions will fail sooner than the design life and adversely affect the ease of transportation of goods, services and people. It is common knowledge to say that nearly every form of transportation system apart from sea transportation will require a road pavement; therefore the need for proper pavement analysis, evaluation and performance.

One of the desirable properties of flexible pavement is that of resistance to moisture induced damages and traffic loads. Mehari (2007) [2] explained moisture-induced damages (typically known as stripping) as the weakening or eventual loss of the adhesive bond between the aggregate surface and the asphalt binder in a HMA pavement or mixture, usually under the presence of moisture. His study further revealed that the resistance to moisture damage under the presence of moisture in the mixture is complex and the degree mainly depends on the properties of each material in the mixture. In addition, the type and use of mix, environment, traffic, construction practice, and the use of anti-strip additives also affect the degree of resistance.

Fatigue, associated with repetitive traffic loading, is considered to be one of the most significant distress modes in flexible pavements. The fatigue life of an asphalt pavement is related to the various aspects of hot mix asphalt (HMA). Previous studies have been conducted to understand how fatigue can occur and fatigue life be extended under repetitive traffic loading [3-6]. When an asphalt mixture is subjected to a cyclic load or stress, the material response in tension and compression consists of three major strain components: elastic, visco-elastic, and plastic. The tensile plastic (permanent) strain or deformation, in general, is responsible for the fatigue damage and consequently results in fatigue failure of the pavement. In addition, fatigue life of pavement is also directly associated with fatigue cracking which in turn is controlled by pavement stiffness and tensile strains in the asphalt bound layer of the pavement. Thus, it is common knowledge to say that when there is excessive strain resulting from either air, water or a combination of both in the pavement layer, fatigue cracking is easily mobilized [7]. This phenomenon will in direct measure result in loss of stiffness of the pavement materials (*i.e.* the ability of the pavement materials to hold together) which will cause early failure due to fatigue.

Several studies however, have proved that fatigue life is a function of the stiffness and strains in the pavement layer [8-13]. It can therefore be argued that whatever affects stiffness or strain in turn will affect fatigue life of the pavement.

Little and Jones (2003) [14] studied the effect of moisture on road pavement structures and concluded that moisture created excessive air voids in the structure which resulted in loss of stiffness and strength in the pavement therefore increasing tensile strains in the asphalt concrete layer. Deductively since fatigue life has already been proved as a function of stiffness and strain we can therefore conclude that fatigue life would have been greatly reduced under such condition of moisture intrusion causing excessive voids.

A similar study by Santucci (2003) [15] buttressed the study by Little and Jones aforementioned. His study revealed that moisture causes excessive air voids when road pavements are submerged for sustained periods and thus causes weakening of the bond between asphalt and aggregates.

Cheng et al (2003) [16] also studied the effect of moisture on flexible pavement structure using hot asphalt concrete mixtures. His study revealed that moisture can reach the asphalt-aggregate interface and cause stripping by diffusing through the asphalt. Stripping is a phenomenon described by Mehari (2007) [2] as foretasted.

A recent study by Magdi, (2014) also revealed that one of the major contributors to pavement failure is moisture when allowed to settle longer that should be on the pavement.

In summary, the present study seeks a practical explanation of the effect and impact that moisture creates on fatigue life of flexible pavement by analyzing hot mix asphalt concretes in the laboratory.

2. Materials and Methods

2.1. Sampling of Materials used

Materials used for the preparation of the asphalt concrete samples in order to simulate actual flexible pavement behaviour under investigation were collected from different sources. The asphalt cement or bitumen used was obtained from Setraco; a Construction Company in Port Harcourt City in Rivers State, Nigeria. On the other hand the aggregates (gravel and sand) used were obtained directly from market dealers at Mile 3 Diobu Port Harcourt, Rivers State, Nigeria.

2.2. Classification Tests

The method to achieving the purpose of the present study involved first the classification of the materials used – asphalt cement and aggregates. That is, the specific gravity of both the asphalt cement and aggregates were determined as presented in section 3. Also classification test of bitumen was done to determine penetration, viscosity and softening point of the bitumen used –See section 3 for results.

2.3. Sample Preparation

The asphalt concrete samples used for simulation were prepared in accordance with the guidelines as stated by Bruce Marshal for Mix Design Procedures as presented [18-21].

The procedure 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 2-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 asphalt concrete samples, the aggregates were first heated for about 5 minutes before asphalt (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 50 blows (indicating medium traffic volume road) using a 6.5kg-rammer freely falling from a height of 450mm. Compacted specimens were subjected to bulk specific gravity test (ASTM D2727), stability and flow, density and voids analyses at a temperature of 60^0C and frequencies of 1, 5 and 10Hz respectively as specified by **AASHTO Design Guide** (2002) [22]. The results obtained were used to determine the optimum asphalt content of the asphalt concrete. Also results from air voids variation together with other properties of both the aggregates and asphalt (bitumen) were used to compute stiffness and fatigue life as number of load repetitions to failure using Asphalt Institute models.

2.4. Model Equations

(a) Asphalt Institute Model for Stiffness

$$E^* = 100{,}000\ (10^{\beta_1}) \tag{1}$$

$$\beta_1 = \beta_3 + 0.000005\beta_2 - 0.00189\beta_2 f^{-1.1} \tag{2}$$

$$\beta_2 = \beta_4{}^{0.5} T^{\beta_5} \tag{3}$$

$$\beta_3 = 0.553833 + 0.028829\left(P_{200} f^{-0.1703}\right) - 0.03476 V_a + 0.07037\lambda + 0.931757 f^{-0.02774} \tag{4}$$

$$\beta_4 = 0.483 V_b \tag{5}$$

$$\beta_5 = 1.3 + 0.49825 \log f \tag{6}$$

$$\lambda = 29{,}508.2\ (P_{77°F})^{-2.1939} \tag{7}$$

Where;

E^* = dynamic modulus (psi)

F =loading frequency (Hz)

T = temperature (°F)

V_a = volume of air voids (%)

λ = asphalt viscosity at 77°F or use equation 7 (10^6 poise)

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

(b) Asphalt Institute Model for Fatigue

$$N_f = 0.0796(\varepsilon_t)^{-3.291}(E)^{-0.845} \tag{8}$$

Where;

N_f = number of load repetitions to failure

E = stiffness modulus

ε_t = horizontal tensile strain at the bottom of the asphalt bound layer

3. Results (See Tables 1 – 3 & Figures 1 - 3)

Table 1: Classification Test Results of Materials used

Material		Asphalt	Sand	Gravel
Specific gravity		1.06	2.60	2.82
Grade of binder material	-	40/50	-	-
Mix proportion (%)	-	-	42	58
Viscosity of binder (poise)	-	5.7*(10^{-4})	-	-
Softening point	-	41.5ºC	-	-

Penetration value	-	51.3mm	-	-

Table 2: Schedule of Aggregates Used For Mix Proportion in Accordance With ASTM 1951: C136

Sieve size (mm)	**Specification limit**	**Aggregate A (Gravel)**	**Aggregate B (Sand)**	**Mix proportion (0.58A+0.42B)**
19.0	100	100	100	100
12.5	86-100	99.27	100	99.58
9.5	70-90	53.45	100	73.00
6.3	45-70	26.69	100	57.48
4.75	40-60	13.56	98.88	49.18
2.36	30-52	5.90	92.56	42.30
1.18	22-40	3.77	79.12	35.42
0.6	16-30	2.65	43.70	19.89
0.3	9-19	1.85	10.84	5.63
0.15	3-7	0.40	0.02	0.24
0.075	0	0.11	0	0.06
PAN	0	0.01	0	0

Table 3: Stiffness (E*) & Fatigue (N_f) Values at varying Frequencies

		1Hz		**5Hz**		**10Hz**	
Moisture (Days)	**Tensile Strain (10^{-4})**	**E*(lb/in^2) (10^4)**	**N_f**	**E*(lb/in^2) (10^4)**	**N_f**	**E*(lb/in^2) (10^4)**	**N_f (10^4)**
0	2.30	15.31	3,112,883	20.58	2,424,406	23.62	2,157,969
1	2.35	14.82	2,981,000	19.93	2,320,839	22.87	2,066,088
2	2.4	14.36	2,856,554	19.30	2,225,061	22.15	1,980,601
3	2.45	13.89	2,745,264	18.68	2,137,244	21.44	1,902,316
4	2.5	13.45	2,639,503	18.09	2,054,740	20.76	1,829,091
5	2.6	12.25	2,510,503	16.47	1,954,923	18.90	1,740,306

Note: N_f = Number of load cycles before pavement failure - used to describe fatigue life

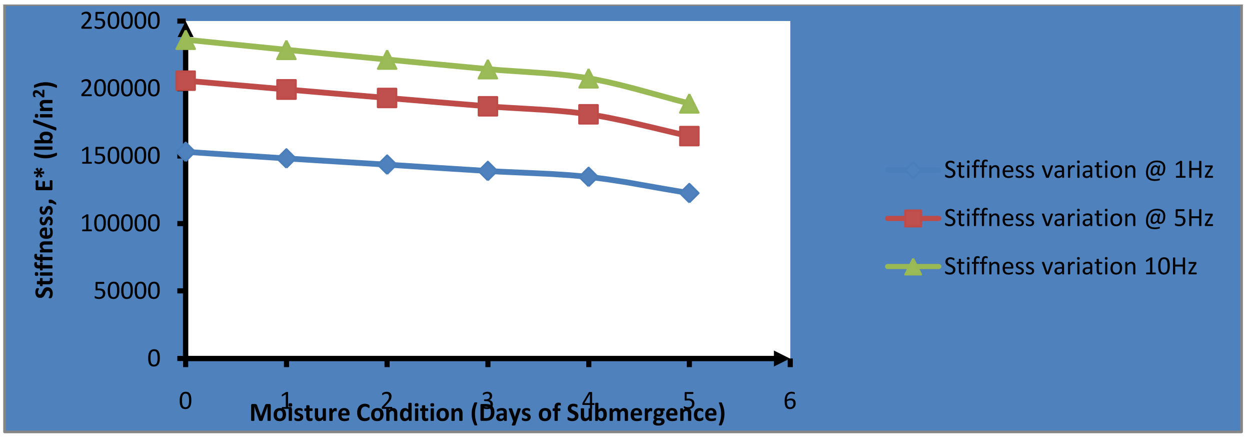

Figure 1: Variation of Stiffness with Moisture Period of Submergence

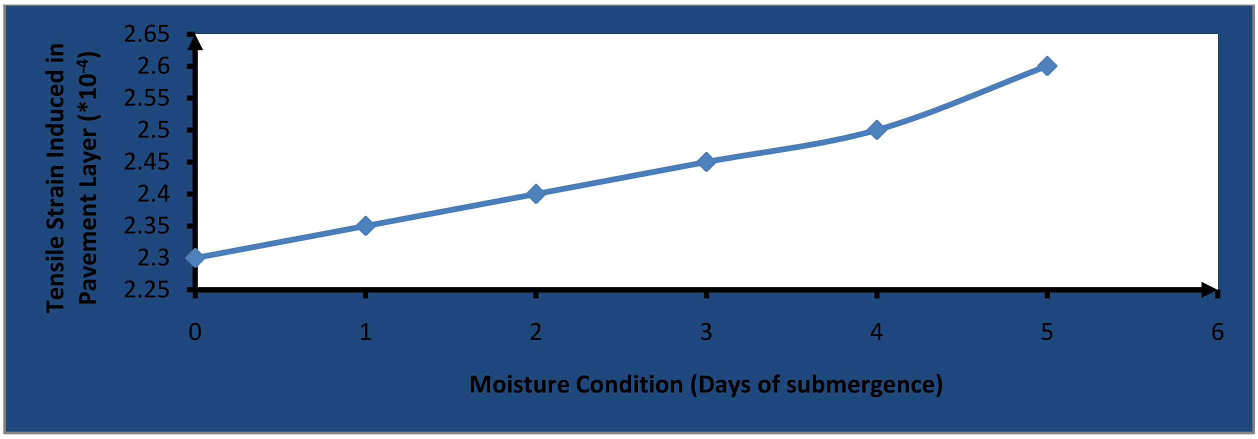

Figure 2: Variation of Tensile Strain with Moisture Period of Submergence

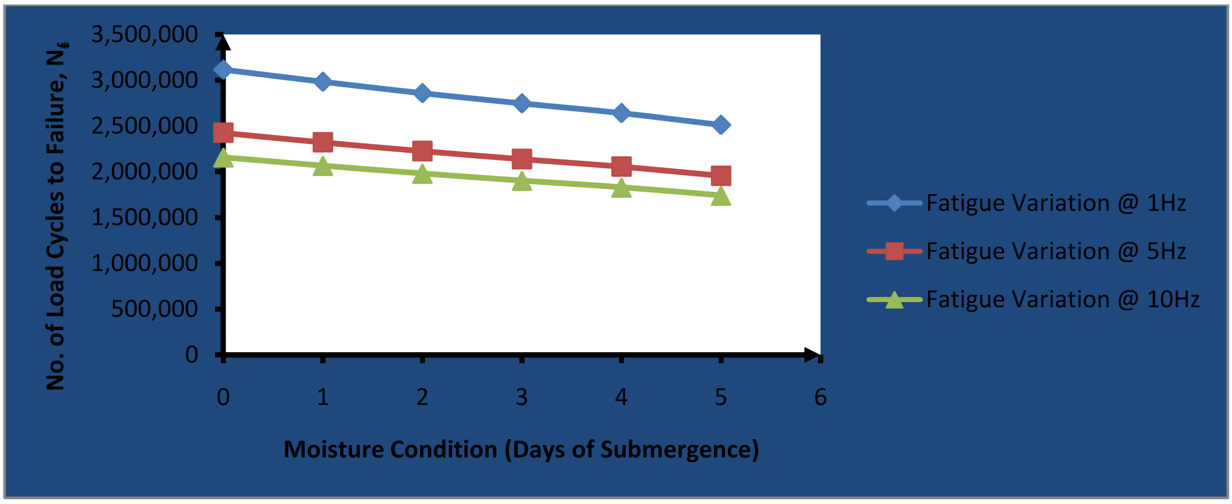

Figure 3: Variation of Fatigue Life with Moisture Period of Submergence

4. Discussions

(a) Changes in Stiffness (Dynamic Modulus, E*)

From Figure 1, the results of dynamic modulus E* representing stiffness for the present study adopted for traffic cases under sinusoidal and haversine loading obtained by using Asphalt Institute Model for stiffness revealed that stiffness (dynamic modulus) of the asphalt concretes reduced constantly with respect to moisture variation from Day 0 – Day 5 for all frequencies of traffic loading considered (See Table 3 above).

The implication of the result is that flexible pavements when submerged in moisture over a period of time will begin to lose cohesion between aggregates and asphalt cement which is the binder. This phenomenon is technically known as stripping. Thus, the longer a pavement remains submerged under moisture the resulting effect is continuous stripping. The reason is because moisture which contains air in form of oxygen will usually intrude into the pavement pores creating increased air voids and mineral volume such that the binding relationship between asphalt cement and the aggregates in the pavement will be overly reduced. Since fatigue has been established as a function of stiffness, it therefore follows that reduced stiffness may likely result in premature pavement failure due to reduction in fatigue life.

(b) Changes in Tensile Strains in Asphalt Pavement Layer

From Figure 2, the results of tensile strains in the asphalt concrete layer increased constantly with respect to moisture variation from Day 0 – Day 5 (See table 3 above).

The corollary from the result is that as the pavement stays submerged in moisture for sustained period of time moisture percolates into the pavement pores washing away the asphalt cement that binds the aggregates thus creating excessive air voids which in turn results in increased strain of the pavement structure. It is common deduction that when a material is strained its functionality is reduced. Thus, we conclude that moisture damage results in increased pavement strain which further results in early failure of pavement due to reduction in fatigue life.

(c) Changes in Fatigue Life due to Reduction in No. of Load Cycles to Pavement Failure

In pavement design fatigue life is determined as a function of fatigue cracking. In other words as external loads impact on the pavement over a period crack initiations begin from top to bottom. These cracks are majorly a function of the load cycles or number of repetitive loads that design trucks make on the pavement before it fails. Therefore, fatigue life is classified with respect to load repetitions to failure.

From Figure 3, the results of fatigue life represented as No. of load cycles before pavement failure obtained by using Asphalt Institute Model for fatigue revealed that fatigue life of the pavement analysed using asphalt concretes reduced constantly with respect to moisture variation from Day 0 – Day 5 for all frequencies of traffic loading considered (See Table 3 above).

Owing to the definition of fatigue which is a function of stiffness and strain, it can be said that as far as stiffness and strains in the pavement are adverse on the pavement due to moisture submergence, it is a reasonable argument to say that fatigue life will be adversely affected also. The results of fatigue from the present study reveal a practical deduction of moisture damage on fatigue life of flexible pavement.

5. Conclusion

From the results and observations of the present study the following conclusions were made:

i) That submergence of flexible pavement in moisture over a period of time can damage the fatigue life considerably before design life is achieved.

ii) That submergence of flexible pavement in moisture over a period of time significantly reduces the binding action between the aggregates and the asphalt cement therefore reduces the stiffness of the flexible pavement.

iii) That submergence of flexible pavement in moisture over a period of time creates increased voids in the pavement therefore increases the tensile strains in the flexible pavement.

References

[1]. Kim, Y. R. (2008) “Modeling of Asphalt Concrete”, Chapter 1.

[2]. Mehari, Z. B. (2007) “Effect of Different Types of Filler Materials on Characteristics of Hot-Mix-Asphalt Concrete”, A thesis submitted to School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Road and Transport Engineering).

[3]. SHRP (1994) “Standard method of Test for determining the Fatigue Life of Compacted Bituminous Mixtures Subjected to Repeated Flexural Bending M-009. In the Superpave Mix Design System Manual of Specifications Test Methods and Practices, SHRP A 379, Harrigan, E.T. Leahy, R.B. and Youtcheff (eds.) Strategic Highway Research Program, Washington, D.C. 253pp.

[4]. Daniel, J. S., and Kim, R. Y. (2001) “Laboratory Evaluation of Fatigue Damage and Healing of Asphalt Mixtures.” Journal of Materials in Civil Engineering, Vol. 13, pp. 434-440.

[5]. Benedetto, H. D., Soltani, A.A., and Chaverot, P. (1996) “Fatigue Damage for Bituminous Mixtures: A Pertinent Approach.” Proceedings of Association of Asphalt Paving Technologists, Vol. 65, 142-158.

[6]. Anderson, D. A., Le Hir, Y. M., Marasteanu, M. O., Planche, J., and Martin, D. (2001) “Evaluation of Fatigue Criteria for Asphalt Binders.” Transportation Research Record 1766, Transportation Research Board, Washington, D. C. 48–56.

[7]. Igwe, E. A. and Ottos, C. G. (2016) “Investigating the Effect of Air Voids Content in Fatigue Life of Hot Mix Asphalt Mixtures: Case Study of Rubberized Asphalt Concrete”, International Journal of Innovative Science, Engineering & Technology, Vol. 3 Issue 5.

[8]. Shell (1978) “Pavement Design Manual-Asphalt Pavements and Overlays for Road Traffic”, Shell International Petroleum Company Ltd, London, U.K.

[9]. Asphalt Institute (1993) “Mix Design Methods for Asphalt Concrete and other Hot Mix Types”, MS-2, Sixth Edition.

[10]. Tayebali, A. A., Tsai, B., and Monismith, C. L. (1994) "Institute of Transportation Studies, University of California, Berkeley, National Research Council Program, Washington.

[11]. Read, M. J., and Collop, A. C. (1997) "Practical Fatigue Characterization of Bituminous Paving Mixtures." Proceedings of Association of Asphalt Paving Technologists, Vol. 66. 74-108.

[12]. Hossain, M., Swartz, S., and Hoque, E. (1999) "Fracture and Tensile Characteristics of Asphalt Rubber Concrete." Journal of Materials in Civil Engineering, Vol. 1, pp. 287-294.

[13]. Birgisson, B., Sholar, G., and Roque, R. (2005). "Evaluation of Predicted Dynamic Modulus for Florida Mixtures." 84th Annual Meeting of the Transportation Research Board, Paper No. 05-1309, Washington D.C.

[14]. Little, D. N. and Jones IV, D. R, (2003) "Chemical and Mechanical Processes of Moisture Damage in Hot-Mix Asphalt Pavements." Transportation Research Board National Seminar. San Diego, California, pp. 37-70

[15]. Santucci, L. (2003). "Moisture Sensitivity of Asphalt Pavements" Technical Transfer Program, Institute of Transportation Studies, University of California, Berkeley, California.

[16]. Cheng, D.; Little, D.N; Lytton, R.L; and Holste, J.C. (2003) "Moisture Damage Evaluation of Asphalt Mixture by Considering both Moisture Diffusion and Repeated Load Condition" Journal of Transportation Research Record, *Engineering*, vol. 16, Issue 2, pp.140–146.

[17]. Magdi, M. E. Z. (2014). The impact of poor drainage on road performance in Khatoun, international journal of multidisciplinary and scientific emerging research, volume, issue 1.

[18]. Chapuis, R.P. and Legare, P. P., (1992) "A Simple Method for Determining the Surface Area of Fine Aggregates and Fillers in Bituminous Mixtures," Effect of Aggregates and Mineral Fillers On Asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia.

[19]. Kim, Y. R., Kim, N., and Khosla, N. P., (1992) "Effects of Aggregate Type and Gradation on Fatigue and Permanent Deformation of Asphalt Concrete," Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia.

[20]. Shuler, T. S., and Huber, G. A., (1992) "Effect of Aggregate Size and Other Factors on Refusal Density of asphalt Concrete by Vibratory Compaction", Effect of Aggregates and Mineral Fillers On asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia.

[21]. 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.

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