Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 5, Issue 3; January-March, 2018, pp. 186-192

http://www.krishisanskriti.org/Publication.html

Fatigue Life Prediction models in Asphalt Materials

Ayan Dutta[1] and Khwairakpam Lakshman Singh[2]

[1,2]NIT SILCHAR
E-mail: [1]ayan92dt@gmail.com, [2]lakshman_kh@yahoo.com

Abstract—*The performance of an asphalt pavement is mainly affected by rutting, fatigue and low temperature cracking. Fatigue cracking is considered to be the most important type of distress effecting the performance of an asphalt pavement. Fatigue cracking reduces the service life of an asphalt pavement drastically. The main objective is to study the combined effect of loading frequency, mix type , initial stiffness modulus and strain level on fatigue life of an asphalt pavement. Here in this study four point bending test apparatus is used for performing the fatigue test on three different types of asphalt mixes; namely Semi Dense Bituminous Macadam (SDBC), Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM). Asphalt mixes were prepared by using the optimum bitumen content as obtained from Marshall Stability Test with a 80/100 penetration grade asphalt binder and locally available crushed aggregates. The four point bending test was conducted at the strain controlled mode of loading using seven strain levels : 100µE, 150µE, 200µE, 250µE, 300µE, 350µE and 400µE ; three loading frequencies of 6Hz, 8Hz and 10Hz representing heavy truck loading at 25kmph to 45kmph, at a temperature of 30°C. For each type of asphalt mix twenty one numbers of fatigue tests were performed. A total of sixty three samples were tested in the four point bending test appartus. Results of this study showed that fatigue life increases with increase in loading frequency and decrease in strain level for each type of asphalt mix.A correlation is developed using EViews software to relate fatigue life with strain level, loading frequency and initial stiffness modulus.*

1. INTRODUCTION

The phenomena in which an asphalt pavement is subjected to cracking due to repeated tensile stress or tensile strain below the ultimate strength of the material under repeated action of traffic loads is known as fatigue. Environmental factors are also responsible for fatigue cracking in asphalt pavements.The cracks initiates from the bottom of asphalt layer and with further loading it propagates towards the top layer; thus it also known as Bottom-Up cracking[1,2].The fatigue strength of an asphalt mix is defined as its ability to withstand repeated traffic loads under existing environmental conditions without significant cracking or premature failure[3]. For efficient designing and maximum service life of an asphalt pavement, determination of its fatigue life is of utmost importance. Fatigue equations are usually developed from laboratory test results and after that the results are calibrated with the help of certain shift factors to get an idea of the field fatigue life. The present paper attempts to develop correlations of laboratory fatigue life with loading frequencies, sttrain levels and initial stiffness modulus for three different types of asphalt mixes. Here in this study the fatigue life of asphalt beam specimens having dimension of 350mm length, 63mm breadth and 50 mm thickness; is determined from four point bending test apparatus as per the American Specifications (AASTHO-T321-14)[11]. The asphalt beam sample is placed in between four clamps of fatigue test apparatus and a bottom –up sinusoidal loading is applied to it in the form of pneumatic pressure generated with the help of an air compressor assembled with it. The test is continued till the initial stiffness modulus value of a particular specimen gets reduced by 50%. The number of cycles corresponding to that 50% reduced value of initial stiifness modulus is reported as laboratory fatigue life of that particular specimen[11].

2. OBJECTIVES

The objectives of this research paper are as follows:

A] To Study the effects of mix types, loading frequency, strain level and initial stiffness modulus on the fatigue life of an asphalt pavement.

B] To develop correlation of fatigue life with strain level, loading frequency and initial stiffness modulus for each of the three different types of mixes tested over here.

3. LITERATURE REVIEW

Though many researchers have performed various studies on fatigue damage in asphalt materials but very few studies have been done to analyse the combined effect of loading frequency, strain level and mix type on the fatigue life of asphalt pavements. Ghazi G. Al-Khateeb (2013) have studied the effect on fatigue life of asphalt pavement due to combined action of loading frequency, temperature and stress level using the IDT test configuration and it was found that at two test temperatures : 20 and 30°C fatigue life increases with increase in loading frequency and the rate of increase takes place in an exponential manner. The variation of fatigue life at different loading frequencies is lesser at higher strain levels than at lower stress levels.Also it was found that with increase in test temperature the fatigue life decreases[1]. Mohammed Y. Fattah(2015) performed laboratory study to anlayse the effect of degree of compaction, temperature, ageing and asphalt content on fatigue response of asphalt mixes with the help of Nottingham flexural fatigue test apparatus and procedure in control strain mode at three test temperatures of 10±1°C, 20±1°C and 30±1°C at loading frequency of 10Hz.It was found that fatigue life of asphalt mix increases with increase in asphalt content and air-void content within the range tested and decreases with increase in term ageing results. It was also found that increase of air voids from 4% to 7% decreases stiffness and fatigue life by 25 and 69% respectively but increases the energy dissipated by 5%. Increase of asphalt content from 4.5 to 5% increases flexural stiffness by 61% and fatigue life by 28% whereas that from 5% to 5.5% increases flexural stiffness and fatigue life by 58% and 20% respectively[3]. J.C Pais(2010) has evaluated the relationship between the two constants(k_1 and k_2) that were used for expressing the fatigue test results in the form of number of cycles, for Portugese mixtures based on the datas that were obtained from more than 50 different types of asphalt mixtures. However the model obtained here is useful for fatigue testing with one unknown parameter only in fatigue law (k_1)[5].Pabitra Rajbongshi(2011) has suggested an approach to calibrate the laboratory fatigue equation using variable shift factors to get an idea of the field fatigue life by using the LTPP(Long Term Pavement Performance) database. Reliability of the calibrated equation obtained is found statistically and has been concluded that it gives reliable pavement fatigue life[10].Taher Baghaee Moghaddam(2011) has highlighted the variation in fatigue and rutting resistance of AC mix due to the addition of additives and the change in aggregate gradation. It was found that though larger aggregate gradation improves the rutting performance but it also lowers the fatigue resistance of AC mix. Higher asphalt content results in decrease of fatigue life.It was also observed that fibers and polymers due to their capability of absorbing certain amount of distresses due to repeative action of traffic loads increases both the fatigue and rutting performances of AC mix in addition to the restriction they provide to the movement of aggregates because of their three dimensional networking nature[9].ZHU Hong-zhou(2007) has performed three point flexure fatigue test on different types of asphalt mixtures under control strain mode of loading to study the effect of aggregate gradadtion, asphalt content and property and test temperature on the fatigue resistance of asphalt mix. It was reported that the fatigue performance can be improved by the use of suspend-dense mixtures instead of framework-dense mixtures and by the increase of bitumen content from the optimum value determined by Marshall test.It was also observed that the fatigue life is higher for the test conducted at higher temperature than that at lower temperature and for better simulation, test should be performed under control strain mode at a test temperature of 30°C. Modified asphalt mix shows better fatigue performance than conventional mix[6].

4. MATERIALS AND METHODS

4.1 Aggregates

Locally available aggregates that were used during the entire work , were collected from a crusher near NH-54 in Silchar. Various laboratory tests were performed and the properties of aggregates found are shown in Table 1. Here in this study the aggregate gradation for SDBC(layer thickness of 40mm), DBM(layer thickness of 75-100mm) and BC(layer thickness of 50mm) were adopted from IRC:11-2009. Proper sieving of aggregates were done to achieve the aggregate gradation within specified limits.

Table 1: Properties of aggregates

Physical property	Tests Standard	Specified value	Obtained value
Crushing	IS:2386(4)	<30%	26.3%
Impact	IS:2386(4)	<30%	24%
Abrasion	IS:2386(4)	<40%	38%
Specific gravity	IS:2386(3)	2.5-2.9	2.5
Flakiness index	IS:2386(1)	<15%	10.62%
Elongation Index	IS:2386(1)	<15%	13%
Angularity no.	IS:2386(1)	0-11	10

4.2. Bitumen

The bitumen used in this study was collected from a local consultancy. Various tests on the bitumen collected were performed and the properties are shown in Table 2.

Table 2: Properties of bitumen

Physical property	Test standard	Specified limit	Obtained value
Specific gravity	IS:1202	0.97-1.02	1.01
Penetration	IS:1203	80-100	95
Ductility	IS:1208	>75cm	>100cm
Flash point	IS:1209	>175°C	326°C
Softening point	IS:1205	35-70°C	40.2°C
Solubility	IS:1216	0.5%	0.49%

4.3 Marshall Test

Marshall test is performed on the three types of asphalt mixes namely, SDBC ,DBM and BC to determine the optimum binder content for each type of mix. The Marshall tests are done as per The Asphalt Institute Manual MS2. A total number of four marshall samples are prepared and tested for each type of mix i,e a total of twelve numbers of Marshall tests are performed.

The optimum binder content for SDBC, DBM & BC mix are found to be respectively 5.5%, 5% and 5.5% of the total weight of aggregates.

4 Fatigue Test

The fatigue life of each type of above mentioned asphalt mixes are determined with the help of a stand alone servo pneumatic four point bending test apparatus. The tests are performed at a temperature of 30°C under control strain mode of loading. The tests are performed at strain levels of 100,150, 200, 250, 300, 350 and 400 micro-strains and at loading frequencies of 6, 8 and 10 Hz.

Tests specimen for each type of mix are prepared using the optimum bitumen content determined from the Marshall stability test. After proper mixing and preparation of HMA, the specimens are compacted in a mould with inner dimensions of 380×63×70 mm with the help of a self compacting compactor provided by MATEST. The compacted specimen is then allowed to cool sufficiently and then taken out of the mould. The weight of the specimens prepared were approximately 3555gms.

5. RESULTS & DISCUSSION

5.1. Fatigue test results

At first the fatigue tests are performed on SDBC type of asphalt mix at three loading frequencies of 6Hz, 8Hz and 10 Hz and at seven strain levels viz, 100μE, 150μE, 200μE, 250μE, 300μE, 350μE and 400μE. The variation of fatigue life with strain level and loading frequency are shown below.

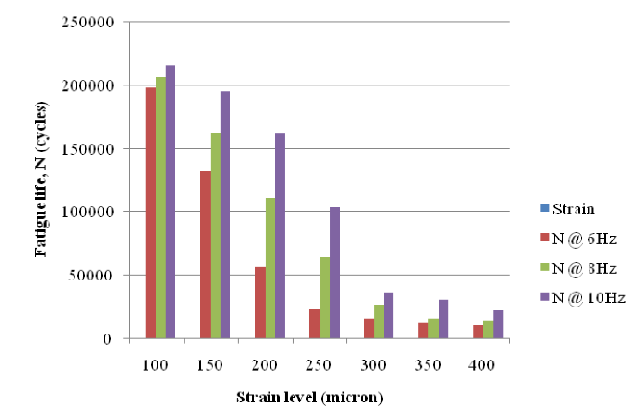


Fig 1 : Variation of fatigue life with strain level and loading frequency in SDBC mix

The similar test procedure is followed for BC type of asphalt mix and the variation of fatigue life with strain level and loading frequency are shown below.

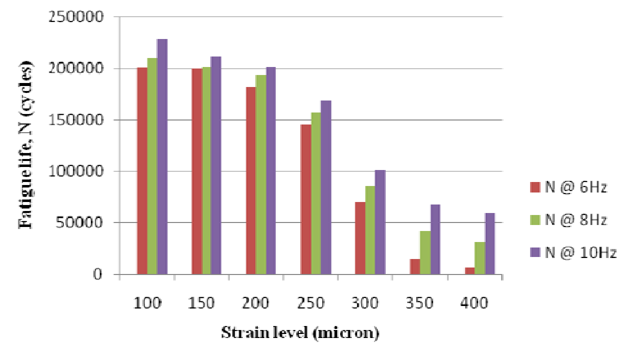


Fig 2 : Variation of fatigue life with strain level and loading frequency in BC mix

Finally for the DBM mix also the test procedure is followed similar to the above two.

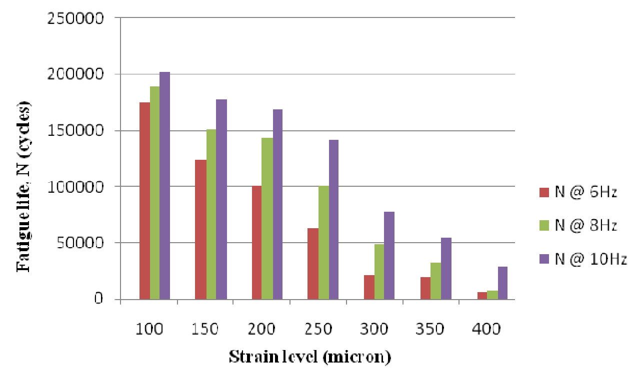


Fig 3 : Variation of fatigue life with strain level and loading frequency in DBM mix

From Fig1, Fig2 and Fig3 it is found that the fatigue life of asphalt mix decreases with increase in strain level and decrease in loading frequency. Now since practically it becomes very difficult to get exactly same values of initial stiffness modulus for diferent samples of same asphalt mix, so attempts are made to draw a graph inorder to obtain the average initial stiffness modulus value for each types of asphalt mixes tested over here.

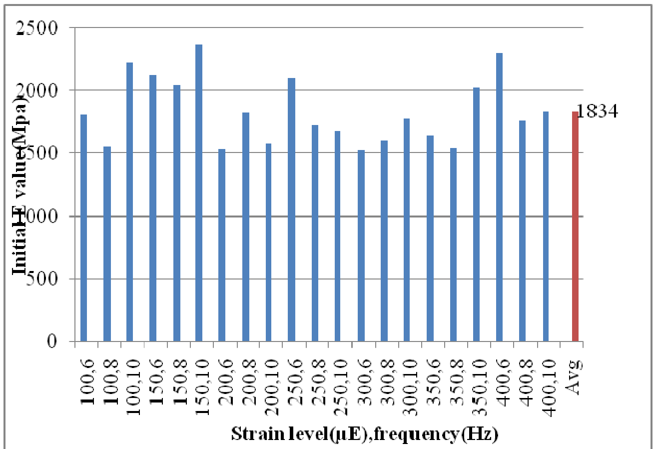


Fig 4 : Average initial stiffness modulus of SDBC mix

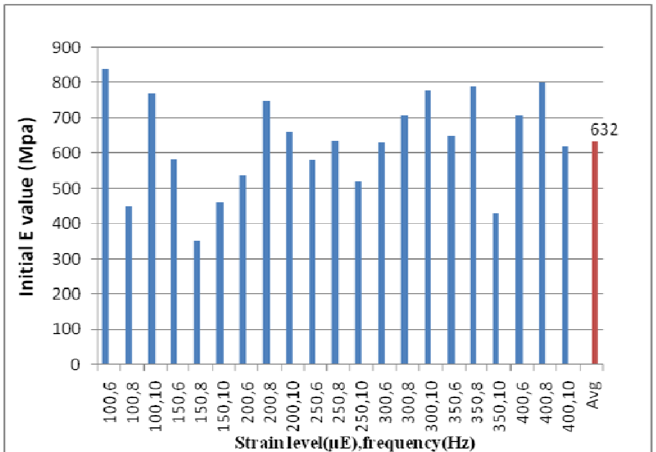


Fig 5 : Average initial stiffness modulus of BC mix

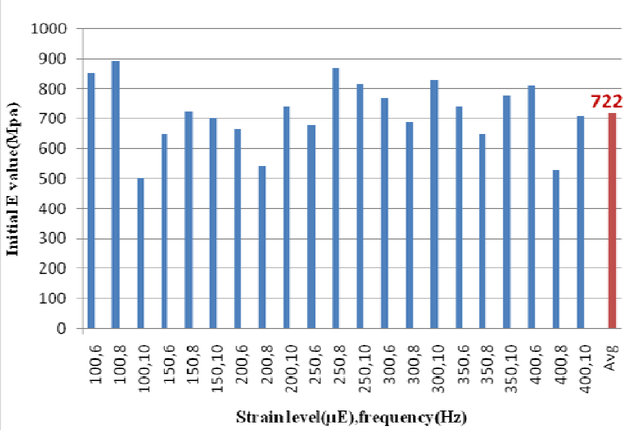


Fig 6 : Average initial stiffness modulus of DBM mix

From Fig 4, Fig 5 and Fig 6 it is found that out of three types of asphalt mixes used in this study, SDBC possess the highest value of initial stiffness modulus followed by DBM and BC possess the lowest value. In a similar manner the fatigue life of different samples of same mix at various strain levels and loading frequencies are averaged and plotted below seperately for the three different types of asphalt mixes tested.

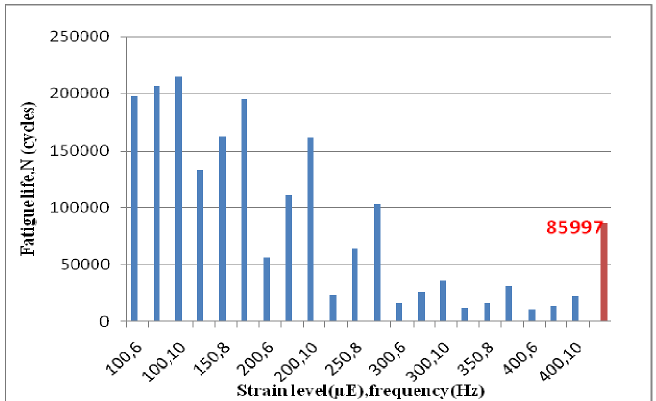


Fig 7 : Average fatigue life of SDBC mix

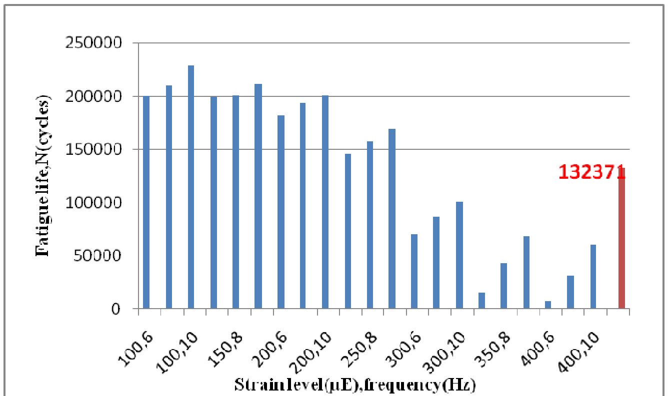


Fig 8 : Average fatigue life of BC mix

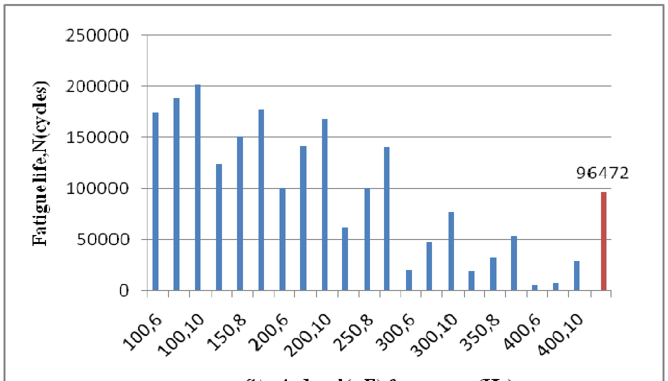


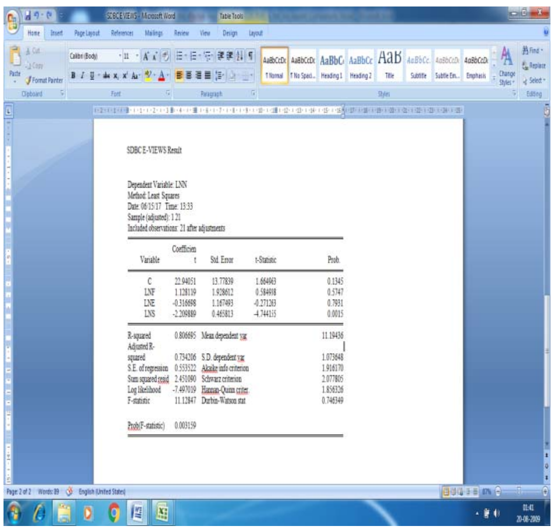
Fig 9 : Average fatigue life of DBM mix

From Fig 7, Fig 8 and Fig 9 it can be said that out of the three asphalt mixes used in this study BC shows the highest fatigue resistance followed by DBM and SDBC possess the lowest fatigue resistance.

5.2 Development of correlation using Eviews software

5.2.1 Development of correlation for SDBC mix

The results obtained after performing the fatigue tests on SDBC mix at various strain levels and loading frequencies are used for the development of correlation of fatigue life with loading frequency, strain level and initial stiffness modulus of the mix. The only dependent variable used is log with base e of fatigue life obtained (LNN). C is the additive constant obtained in the fatigue life equation and is used as an independent variable. The other independent variables used are: log base e of loading frequency (LNF), log base e of strain level and log base e of initial stiffness modulus (LNE). The results obtained from Eviews for SDBC mix are reported as below.


SDBC E-VIEWS Result

Dependent Variable: LNN
Method: Least Squares
Date: 06/15/17 Time: 13:33
Sample (adjusted): 1 21
Included observations: 21 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	22.94051	13.77839	1.664963	0.1345
LNF	1.128119	1.928612	0.584938	0.5747
LNE	-0.316698	1.167493	-0.271263	0.7931
LNS	-2.209889	0.465813	-4.744155	0.0015

R-squared	0.806695	Mean dependent var	11.19436
Adjusted R-squared	0.734206	S.D. dependent var	1.073648
S.E. of regression	0.553522	Akaike info criterion	1.916170
Sum squared resid	2.451090	Schwarz criterion	2.077805
Log likelihood	-7.497019	Hannan-Quinn criter.	1.856326
F-statistic	11.12847	Durbin-Watson stat	0.746349
Prob(F-statistic)	0.003159		

Finally after analysing the results obtained from Eviews, the correlation that can be developed for SDBC mix is

LNN = 22.94051 + 1.128119LNF – 0.316698LNE – 2.209889LNS

Now using the formula obtained above and by putting the values of frequencies, strain levels and initial stiffness modulus used in this study, the corresponding fatigue lives are calculated and is reported as estimated fatigue life. The fatigue results obtained from laboratory tests are designated as observed fatigue life. Now to check the accuracy of formula obtained, estimated fatigue life vs observed fatigue life graph is drawn and the deviation of the points are observed with respect to a 45 degree line drawn from the origin.

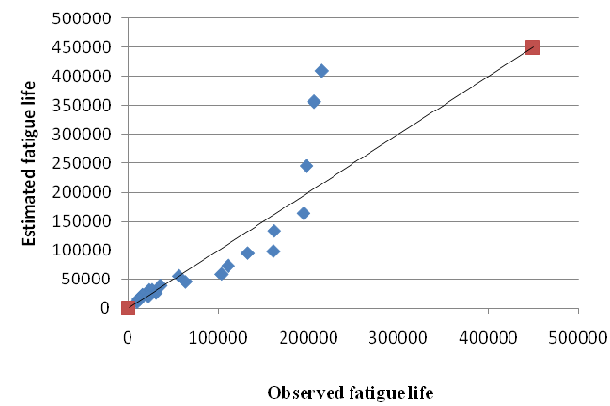
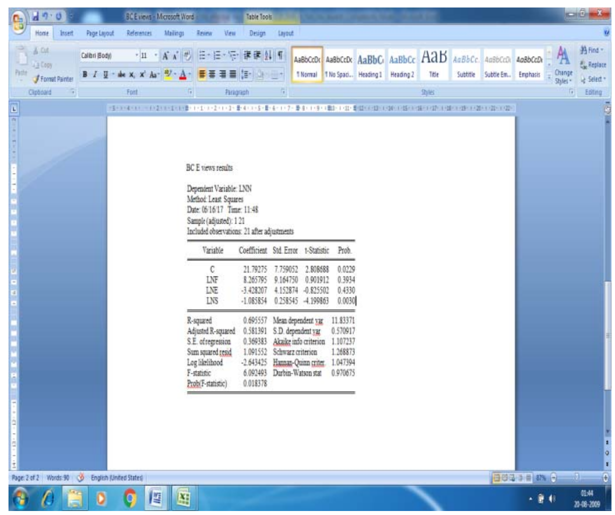


Fig10 : Variation of estimated fatigue life from observed fatigue life for SDBC mix

5.2.2 Development of correlation for BC mix

The fatigue test results for BC mix are used as input for the Eviews software while developing the correlation. The results for BC mix from Eviews are reported as :


BC E views results

Dependent Variable: LNN
Method: Least Squares
Date: 06/16/17 Time: 11:48
Sample (adjusted): 1 21
Included observations: 21 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	21.79275	7.759052	2.808688	0.0229
LNF	8.265795	9.164750	0.901912	0.3934
LNE	-3.428207	4.152874	-0.825502	0.4330
LNS	-1.085854	0.258545	-4.199863	0.0030

R-squared	0.695557	Mean dependent var	11.83371
Adjusted R-squared	0.581391	S.D. dependent var	0.570917
S.E. of regression	0.369383	Akaike info criterion	1.107237
Sum squared resid	1.091552	Schwarz criterion	1.268873
Log likelihood	-2.643425	Hannan-Quinn criter.	1.047394
F-statistic	6.092493	Durbin-Watson stat	0.970675
Prob(F-statistic)	0.018378		

Finally after analysing the results obtained from Eviews, the correlation that can be developed is :

LNN = 21.79275 + 8.265795LNF – 3.428207LNE – 1.085854LNS

Here also the accuracy of the formula obtained is checked by plotting observed fatigue life vs estimated fatigue life graph and observing the deviation of the points from a 45 degree line drawn from the origin.

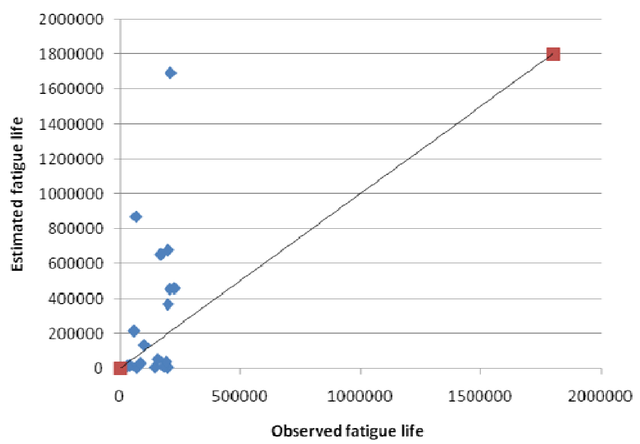
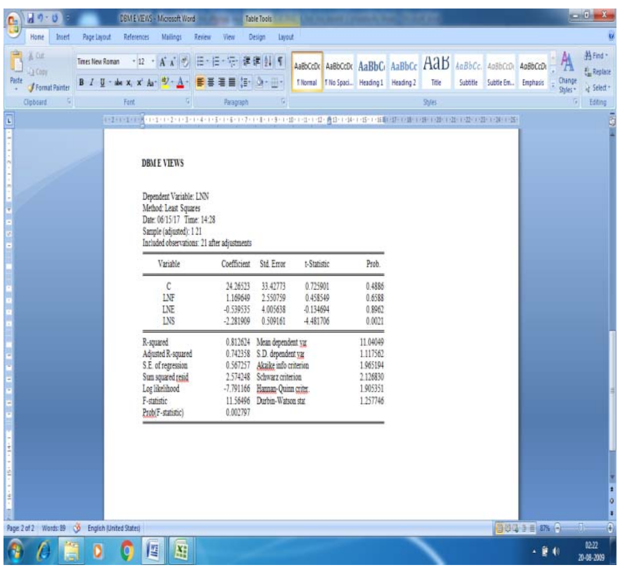


Fig 11 : Variation of estimated fatigue life from observed fatigue life in BC mix

5.2.3 Development of correlation for DBM mix

The fatigue tests results for DBM mix are fetched into the Eviews software to develop a correlation of fatigue life with loading frequency, strain level and initial stiffness modulus of DBM mix. The results obtained from Eviews for DBM mix are reported as below :



DBM E VIEWS

Dependent Variable: LNN
Method: Least Squares
Date: 06/15/17 Time: 14:28
Sample (adjusted): 1 21
Included observations: 21 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	24.26523	33.42773	0.725901	0.4886
LNF	1.169649	2.550759	0.458549	0.6588
LNE	-0.539535	4.005638	-0.134694	0.8962
LNS	-2.281909	0.509161	-4.481706	0.0021

R-squared	0.812624	Mean dependent var	11.04049
Adjusted R-squared	0.742358	S.D. dependent var	1.117562
S.E. of regression	0.567257	Akaike info criterion	1.965194
Sum squared resid	2.574248	Schwarz criterion	2.126830
Log likelihood	-7.791166	Hannan-Quinn criter.	1.905351
F-statistic	11.56496	Durbin-Watson stat	1.257746
Prob(F-statistic)	0.002797		

Finally after analysing the results obtained from Eviews the correlation that can be developed for DBM mix is

LNN = 24.2653 + 1.169649LNF – 0.539535LNE – 2.281909LNS

Now the accuracy of the formula obtained is checked by plotting observed fatigue life vs estimated fatigue life graph and observing the deviation of points from a 45 degree line drawn from the origin.

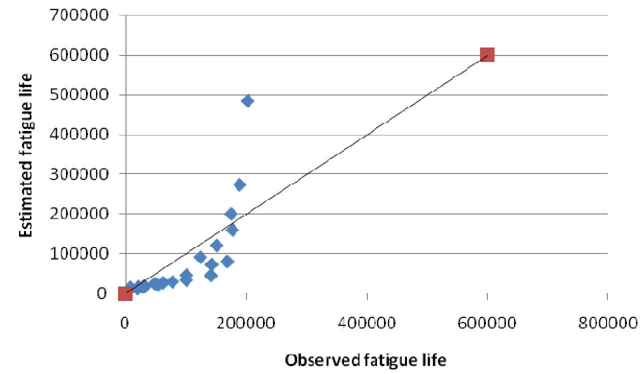


Fig 12 : Variation of estimated fatigue life from observed fatigue life in DBM mix

6. CONCLUSIONS AND SCOPES

Here in this study the combined effect of loading frequency, strain level, mix type and intial stiffness modulus on the fatigue have been studied and then correlations have been adopted with the help of EViews software. After this study the conclusions that can be stated are as follows:

1. With increase in loading frequency, the fatigue life goes on increasing.
2. With increase in strain level, the fatigue life goes on decreasing.
3. Out of the three types of mixes, SDBC have the highest initial stiffness modulus while BC have the lowest initial stiffness modulus,other factors remain the same.
4. Out of three types of mixes, BC possess the highest fatigue resistance while SDBC possess the lowest fatigue resistance,other factors remain the same.

This study have been performed at a temperature of 30°C, but the same study can be performed by taking into account the effect of temperature also.The fatigue tests are performed under control strain mode, hence the study can be performed at control stress mode also and thus these points form the scopes of the present study.

7. ACKNOWLEDGEMENTS

The Authors would like to dedicate this work to Late Dr. Pabitra Rajbongshi, Ex-Associate Professor, Civil Engineering Department, NIT Silchar.

REFERENCES

[1] Ghazi G. Al-Khateeb, Khalid A. Ghuzlan, “The combined effect of loading frequency, temperature, and stress level on the fatigue life of asphalt paving mixtures using the IDT test”, International Journal of Fatigue 59(2014), 254-261.

[2] E.J. Yoder, M.W. Witczak , “Principles of Pavement Design” Second Edition, John Wiley & Sons, Inc.(1975).

[3] Mohammed Y. Fattah, Karim H. Ibrahim Al Helo, Zaynab I. Qasim, "Prediction models for fatigue resistance of local hot mix asphalt", Road Materials and Pavement Design(2015).

[4] Asphalt Handbook, Asphalt Institute, Manual series No.04, Six Edition,KY. 2007.

[5] J.C. Pais, M.J.C. Minhoto, "The prediction of fatigue life of asphalt mixtures using four–point bending tests", 24th ARRB Conference, Melbourne, Australia, 2010.

[6] ZHU Hong-Zhou, HE Zhao-yi, HUANG Xiao-ming, WU Guo-xiong, "Experimental Research on Fatigue Performance of Asphalt-treated Base Mixtures, Journal of Highway and Transportation Research and Development, (2007) 35.

[7] Robert Lundstrom, Herve Di Benedetto, and Ulf Isacsson, "Influence of Asphalt Mixture Stiffness on Fatigue Failure", JOURNAL OF MATERIALS IN CIVIL ENGINEERING ASCE,December 1, 2004.

[8] Pabitra Rajbongshi, "A Critical Discussion on Mechanistic-Empirical Fatigue Evaluation of Asphalt Pavements", Int. J. Pavement Res. Technol.,223-226.

[9] Taher Baghaee Moghaddam, Mohamed Rehan Karim and Mahrez Abdelaziz, "A review on fatigue and rutting performance of asphalt mixes", Scientific Research and Essays, 670-682, 18 February, 2011.

[10] Pabitra Rajbongshi, Animesh Das, "A systematic approach of field calibration of fatigue equation for asphalt pavements", Road Materials and Pavement Design(2009).

[11] AASHTO T321-14, "Standard method of test for determining the fatigue life of compacted asphalt mixtures subjected to repeated flexural bending", The American Association of State Highway and Transportation Officials(2014).