A Study on Fatigue Performance of Asphalt Using AMPT

Yuan Jie Kelvin Lu, Amin Chegenizadeh

Abstract**—**Asphalt pavement itself is a mixture made up of mainly aggregates, binders, and fillers that acts as a composition used for pavement construction. An experimental program was setup to determine the fatigue performance test of Asphalt with three different grades of conventional binders. Asphalt specimen has achieved the maximum optimum bulk density and air voids with a consistent bulk density of 2.3 t/m3, with an air void of 5% ± 0.5, before loading into the Asphalt Mixture Performance Tested (AMPT) for fatigue test. The number of cycles is defined as the point where phase angle drops, which is caused by the formation of cracks due to the increasing micro cracks when asphalt is undergoing repeated cycles of loading. Thus, the data collected are analyzed using the drop of phase angle as failure criteria. Based in the data analyzed, it is evident that the fatigue life of asphalt lies on the grade of binder. The result obtained shows that all specimens do experience a drop in phase angle due to macro cracks in the asphalt specimen.

Keywords**—**Asphalt binder, AMPT, CX test, simplified–viscoelastic continuum damage (S-VECD).

I. Introduction

PAVEMENT design itself is a complex process as it takes into the account of various factors. The Empirical Design approach whose relationship between design inputs and pavement failure were solely determined empirically such as using experiences, experimentation or even a combination of both until the time of World War II (Mid 1940's) [1]. However, pavement materials do not exhibit isotropic linear elastic behavior, instead flexible pavements exhibit nonlinearities, time, and temperature features. Thus mechanistic design approach is required to relate pavement behavior and performances to traffic loadings and other factors. Thus, it is very important to understand the viscoelastic properties of the asphalt pavement itself in order to provide a solution to this never-ending problem faced by the community.

The aim of this study is to determine the fatigue life of Asphaltic Concrete AC10-75 pavement with three different conventional binders by using the Direct Tension Method called Simplified – Viscoelastic Continuum Damage (S-VECD).The objectives that have to be completed to achieve the aim of the research are as follow:

- To achieve the optimum particle size distribution as stated in the Australian Standard for the ratio of aggregates in the asphalt pavement.
- To determine the dynamic modulus as well as the fatigue failure criteria of the asphalt specimen.
- To obtain the phase angle curve of the asphalt specimen in order to compare with dynamic modulus to predict the fatigue life of the asphalt mixture. [7]

Yuan Jie Kelvin Lu is student in Curtin University, Australia (e-mail: yuanjie.lu@student.curtin.edu.au).
Amin Chegenizadeh is with Curtin University, Australia (corresponding author; phone: +6192662491; e-mail: Amin.Chegenizadeh@curtin.edu.au).

A. Simplified Fatigue Test (Implementing Viscoelastic Continuum Damage Model)

Flexural Bending Test, or also known as the four point load bending test are empirical in nature, thus researchers and asphalt industries are implementing mechanistic approaches that include more rigorous theoretical considerations in asphalt pavement design. S-VECD is a method that uses the asphalt fundamental properties that are able to shorten the testing time and consider a large amount of different conditions and affect the fatigue life of the asphalt pavement.

The major advantage of this S-VECD method is that the testing period is much shorter, and is able to take account of many different conditions condition and variables based on its nature as well as the capability to differentiate the material properties from the structural component.

Uniaxial fatigue testing is grounded on continuum damage theory which has been presented in several publications [2]-[4].

B. Controlled Crosshead Cyclic Test (CX Cyclic Test)

Controlled crosshead (CX) cyclic test is employed to study the fatigue performance characterization test where each specimen is loaded with a controlled cyclic test in order to reach a constant peak level of 10 Hz. However due to machinery inadequacy, the programmed strain level is higher than the actual on-specimen strain [2]. Nevertheless, the CX cyclic tests are to be performed to complete strain failure to better predict the failure mode of the asphalt concrete.

C. Failure Definition in Cyclic Test

In the CX cyclic test, the dynamic modulus as well as the phase angle is tracked throughout the whole fatigue performance testing of the asphalt pavement. It is stated by [5], that the sharp drop in phase angle is stated as the number of cycles at failure (N_f).

D. Failure Types in Constant Cyclic Test

In a testing of controlled constant cyclic load test, there are two major types of fatigue failure patterns, which they are categorized into the mid-failure pattern as well as the end-failure pattern. As asphalt material fails, it is not possible to separate the fatigue contribution form the part due to creep flow accumulation as the force is always applied in the same direction with the accumulation of deformation with the help of viscoelastic flow characteristic of the asphalt material [6].

This paper is part of an ongoing research in Curtin University and extracted from the first author's thesis. [7]

II. METHODOLOGY

This section provides the methodology that is carried out to achieve the aims and objective of this Research Project by conducting the Fatigue Performance of Asphalt Pavement using the Direct Tensile Test with the Asphalt Mixture Performance Tester (AMPT).

A. Properties of Asphalt Mixes

Typical properties and limits of the hot mix asphalt (HMA) in Australia are given in [8].

B. Final Marshal Mix Design

A mix design is obtained through [8] as mentioned above. The final mix design is summarized as shown in Table I and is prepared as shown in Fig. 1.

TABLE I
FINAL MARSHALL MIX DESIGN

Laboratory Mixing Batch Size (g) 7050		
Material	**%**	**Mass (gr)**
Bitumen	4.9	345.5
10mm	43.7	3084
5mm	11.4	805
Dust	39.9	2816
Total	**100.0**	**7050**

C. Lab Procedure

Fig. 1 Marshall Mix Design Preparations [7]

Fig. 2 Final Aggregate Mixture in Asphalt Oven [7]

Fig. 3 Aggregate Mixing with Bitumen [7]

Fig. 4 Molding the Asphalt Sample [7]

Fig. 5 Gyratory Compaction of Asphalt Specimen [7]

The Gyratory Compaction, as shown in Fig. 5, is specified in [9], which is usually used for laboratory determination of the volumetric properties, which can be used in associate with

International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:9, No:12, 2015

a range of new mechanical tests in order to determine the performance characterization of asphalt after the aggregates are prepared and mix thoroughly as shown from Figs. 2-4.

Fig. 6 Asphalt Specimen Undergoing Core Drill [7]

Fig. 7 Asphalt Specimen Undergoing Slab and Core Drill [7]

Fig. 8 Water Bath [7]

The asphalt specimens are compacted to achieve a sample diameter of 150mm with a height of 170 mm, the specimens are then later cored and cut into a diameter of 100 mm with a height of 150 mm for testing as shown in Figs. 6 and 7. After the coring and cutting process, the samples' air void ratio is determined using the Pre-saturation Method as referred to [9]. The process is shown in Fig. 8.

Before the sample is loaded into the AMPT for testing, sensors are mounted onto gauge points that were glued to the specimen at 3 specific locations of 120˚ apart as shown in Fig. 9. These sensors, also known as linear variable differential transformers (LVDT) type is attached to the sample that is lying on its side by using a spring force that is not strong enough to force the gauge points. The asphalt specimen is then later insert into the AMPT for fatigue testing as shown in Figs. 10 and 11.

Fig. 9 Final Asphalt Specimen Underwent Gluing Process [7]

Fig. 10 Final Asphalt Specimen [7]

Fig. 11 Final Asphalt Specimen in AMPT [7]

III. Results

This section comprise of Fatigue Failure results obtained from the AMPT, it is observed that all asphalt specimen has a consistent bulk density of 2.3 t/m^3, with an air voids of 5% ± 0.5. This shows that the fabricated asphalt specimens are all satisfactory and achieved the maximum optimum bulk density and air voids. [7]

A. Lab Result Summary [7]

In order to summarize the results obtained from each of the specimen, Fig. 12 was plotted to compare the results of all 6 specimens. From Fig. 12, it can be seen that the C170 can sustain higher cyclic loading with a lower grade of binder, then C320 Grade binder and then follow by C600 Grade binder. The data obtained are summarized in Table II. The bulk density and the air void of the sample are maintained at a consistent bulk density of 2.3 t/m^3, with an air void of 5% ± 0.5.

IV. Discussion

Based in the data analyzed, it is evident that the fatigue life of asphalt pavement lies exclusively on the grade of binder. As seen from the Figs. 13 and 5, C170 Specimen 3 and 4 is the most sustainable sample as they are the only ones that are able to sustain at least 140,000 cyclic loads before experiencing fatigue failure. An average value of number of cycles to failure (N_f) were calculated and plotted into a graph as shown in Fig. 13.

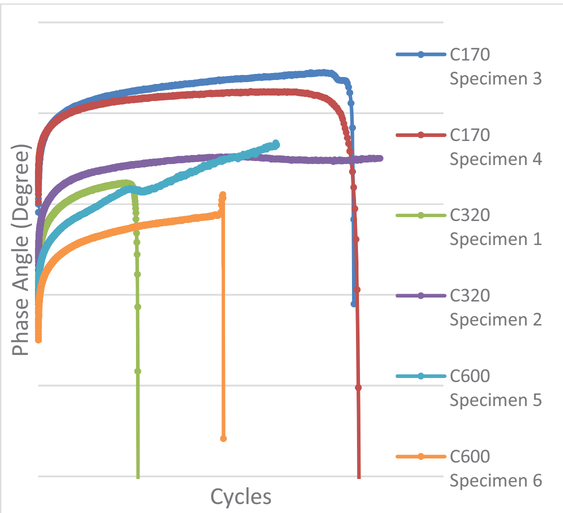

Fig. 12 Comparison of Phase Angle for 6 Specimen

TABLE II
Summary of Number of Cycles to Failure

Asphalt Specimen	Number of Cycles to Failure
C170 Specimen 3	148,000
C170 Specimen 4	140,000
C320 Specimen 1	44,000
C320 Specimen 2	100,000
C600 Specimen 5	48,000
C600 Specimen 6	92,000

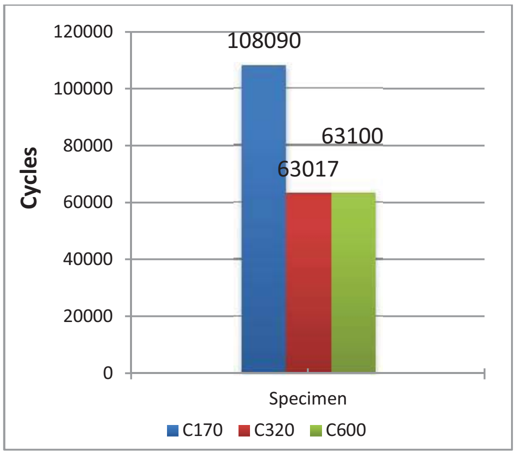

Fig. 13 Comparison of Summary of Cyclic Failure Points

A. Failure Condition

Failure Condition of the asphalt specimen are one of the factors that affects the gradient of the phase angle. In order to obtain the stress and strain amplitude (Dynamic Modulus) and phase angle during test, the signals of all loading cycles are recorded and processed in order to plot figures by using the on-specimen LVDT displacement measurement which is measured by using 3 mean LVDTs positioned at 120 ° apart in the axis of the cylindrical sample [10]. This is because the LVDT can only measure the displacement of the specimen caused by micro cracking in the experimental measurement range, the end-failure that occurs in the specimen are not recorded by the LVDT, which are able explains the sudden spike of phase angle in some case of the experiment such as Specimen 5.

V. Conclusion

Three different grades of binders were used as a controlling factor in the experiment in order to provide a platform to further investigate the dynamic modulus and phase angle of asphalt pavement. Uniaxial Fatigue Testing Method is applied through the usage of Asphalt Mixture Performance Tester (AMPT) to run experiments on the asphalt specimens of 1 to 6. Generally, Bitumen Grade C170 shows the most promising data as they have the most consistent cycles of failure in conjunction with the drop of phase angle as shown.

- The cycle of failure for bitumen grade C170 asphalt specimen reached an average of 140,000 cycles, the highest cycle of failure for all 3 grades of bitumen.
- The cycle of failure is determined by the drop of phase angle, which signified that macro cracks have appeared in the specimen.
- The dynamic modulus is compared with the phase angle when determining the cycle of failure of a specimen.

Acknowledgment

The authors would like to express their appreciation to Mr. Darren Isaac for his helps during the lab testing.

REFERENCES

[1] Schwartz., C. W. and R. L. Carvalho, "Implementation of the NCHRP 1-37A Design Guide final report Volume 2: Evaluation of mechanistic-empirical design procedure," The University of Maryland, Maryland, 2007.

[2] T. Hou, "Fatigue Performance Prediction of North Carolina Mixtures Using Simplified Viscoelastic Continuum Damage Model," Graduate Faculty of North Carolina State Univerisity, Raleigh, North Carolina, 2009.

[3] R. Kim, G. Chehab, R. Schapery, M. Witczak and R. Bonaquist , "Characterization of Asphalt Concrete in Uniaxial Tension Using a Viscoelastoplastic Continuum Damage Model.," *Journal of the Association of Asphalt Paving Technologists*, pp. 315-355, 2003.

[4] H.-J. Lee and R. Kim , "Viscoelastic Constitutive Model for Asphalt Concrete Under Cyclic Loading," *Journal of Engineering Mechanics*, pp. 32-40, 1998.

[5] R. Reese, "Properties of Aged Asphalt Binder Related to Asphalt Concrete Fatigue Life," *Journal of the Association of Asphalt Paving Technologists*, pp. 604-632, 1997.

[6] L. F. d. A. L. Babadupulos, J. B. Soares and V. T. F. C. Branco, "Interpreting Fatigue Tests in Hot Mix Asphalt (HMA) Using Concepts from Viscoelasticity and Damage Mechanics," *Transport*, pp. 85-94, 2015.

[7] K. Y. J. Lu, "Fatigue Performance of Asphalt with Different Conventional Binders," Thesis, Curtin University, Perth, 2015.

[8] Standard Australia, Methods 2.2: "Sample Preparation - Compaction of Asphalt Test Specimen using a Gyratory Compactor,"Australia: SAIGlobal, 2014.

[9] Standard Australia, Method 9.2: "Determination of Bulk Density of Compacted Asphalt - Presaturation Method, "Australia: SAIGlobal, 2014.

[10] D. H. Timm, M. M. Robbins, R. J. Willis, N. Tran and A. J. Taylor, "Evaluation of Mixture Performance and Structural Capacity of Pavements Utilizing Sheel Thiopave, Comprehensive Laboratory Performance Elaboration," National Center for Asphalt Techonology, Auburn, 2012.