THE EFFECT OF BITUMEN RHEOLOGY TO THE PERMANENT DEFORMATION OF AN ASPHALT CONCRETE MIXTURE

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KOLEJ UNIVERSITI TEKNOLOGI TUN HUSSEIN ONN
THE EFFECT OF BITUMEN RHEOLOGY TO
THE PERMANENT DEFORMATION OF AN ASPHALT CONCRETE MIXTURE

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This dissertation is submitted as a fulfillment of
the requirements for the award of the degree of
Master in Civil Engineering

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This work is dedicated to
my beloved husband, ROHMANI HI. TASARI,
Also to my kids, ALIF RAHIMI and ADHAM RAFIQ,
For the love, patience, understanding and invaluable support.............
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Bitumen which functions as a binder in asphalt concrete mixture is also a visco-elastic and thermoplastic material. The characteristics are also influenced by the temperature. It is because in hot condition or at high temperature, bitumen acts like a viscous liquid. In cold climate or at low temperature, bitumen behaves like an elastic solid. Even though bitumen is an elastic solid at low temperatures, it may become too brittle and crack when excessively loaded. However, the characteristic of an asphalt concrete are influenced by the rheology of bitumen which having two important properties; resistance to permanent deformation and fatigue. In this study, the most important thing to measure is the rheology of two different types of bitumen. The measurement was done using the Dynamic Shear Rheometer to obtain the visco-elastic properties of bitumen. The bitumen was then used in preparing an asphalt concrete mixture in order to test the rutting or permanent deformation using the Static Creep test. An analysis was done to verify the correlation between the rheology of two different types of bitumen and the rate of permanent deformation of the asphalt concrete mixture. Results obtained showed that both bitumens having a different rheology. Moreover, rutting parameter, G*/sin δ could predict the different of creep performance. However, bitumen with identical value of G*/sin δ at a different temperature would not necessarily produce mixture with the same creep compliance under the related temperature. Therefore, for further study it is recommended to focus on the load effect to the creep compliance.
Bitumen yang berfungsi sebagai bahan pengikat di dalam campuran konkrit asfalt juga merupakan suatu bahan yang visco-elastic dan thermoplastic. Sifat-sifatnya juga banyak dipengaruhi oleh suhu. Ini kerana dalam keadaan suhu yang tinggi atau cuaca panas, bitumen bertindak seperti cecair yang likat. Pada cuaca yang sejuk atau pada suhu yang rendah pula, bitumen akan menjadi bahan anjal yang padat. Walaupun bitumen adalah merupakan bahan anjal yang padat pada suhu rendah, ia boleh menjadi terlalu rapuh dan retak apabila dikenakan beban yang banyak atau melampau. Walau bagaimanapun, ciri-ciri campuran konkrit asfalt lebih dipengaruhi oleh reologi (sifat perubahan bentuk bahan akibat tegasan) bitumen yang mana mempunyai dua ciri penting iaitu ketahanan terhadap perubahan bentuk yang kekal akibat kesan roda atau tayar kenderaan dan ciri lesunya. Di dalam projek ini, perkara penting yang diukur adalah reologi daripada dua jenis bitumen yang berbeza. Pengukuran dilakukan menggunakan peralatan Dynamic Shear Rheometer untuk mendapatkan ciri-ciri anjal dan likat bitumen terbabit. Selanjutnya, bitumen tersebut digunakan untuk membuat sampel campuran konkrit asfalt untuk menguji ciri-ciri ketahanannya terhadap perubahan bentuk yang kekal menggunakan uji kajian Static Creep. Suatu analisis telah dibuat untuk menjelaskan hubungkait antara reologi bitumen dan ciri-ciri perubahan bentuk yang kekal campuran konkrit asfalt tersebut. Keputusan daripada uji kajian yang telah dibuat menunjukkan bahawa kedua-dua jenis bitumen mempunyai reologi yang berbeza. Seterusnya, parameter lekukan turapan, $G*/\sin \delta$ dapat menggambarkan perubahan dalam creep performance. Walau bagaimanapun, bitumen yang mempunyai nilai $G*/\sin \delta$ yang sama pada suhu yang berbeza belum tentu dapat menghasilkan campuran konkrit dengan nilai creep performance yang sama. Maka, untuk kajian yang akan datang adalah dicadangkan agar kajian kesan dari pada beban terhadap creep performance dapat dilakukan.
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<tr>
<td>$\delta$</td>
<td>phase angle of asphalt binder</td>
<td></td>
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<tr>
<td>$G^*$</td>
<td>complex shear modulus of asphalt binder</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon_f$</td>
<td>failure strain</td>
<td></td>
</tr>
<tr>
<td>$\Delta L$</td>
<td>change in length</td>
<td></td>
</tr>
<tr>
<td>$\sigma$</td>
<td>stress</td>
<td></td>
</tr>
<tr>
<td>$S_{\text{mix}}$</td>
<td>mix stiffness</td>
<td></td>
</tr>
<tr>
<td>$S_{\text{bit}}$</td>
<td>bitumen stiffness</td>
<td></td>
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<td>ASTM</td>
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CHAPTER I

1.1 Introduction

Pavement design is essentially a structural evaluation process, ensuring that the traffic loads are so distributed that the stresses and strains developed at all levels in the pavement and the subgrade are within the capabilities of the materials at those levels. The objective of pavement design is to produce an engineering structure that will distribute traffic loads efficiently, whilst minimizing the whole-life cost of the pavement, i.e. both initial construction and maintenance costs. It involves the selection of materials for the different layers and the calculation of the required thickness. The load-carrying capacity of a pavement is a function of both the thickness of the material and its stiffness.

The mechanical properties of the materials comprising the layers in a pavement are important for designing the structure. Climatic conditions influence the performance of the whole pavement. Moisture affects the subgrade, sub-base or unbound base and the temperature affects the bitumen-bound materials; therefore it is essential that design methods take account of climatic conditions.

It is generally accepted that a well-designed, well-constructed, modern trunk road pavement should at least meet the following basic performance criteria:
a. The finished carriageway should have good skid resistance and provide the motorist with a comfortable and safe ride,
b. The pavement should be able to carry its design traffic without excessive deformation
c. Its component layers should not crack as a result of the stresses and strains imposed on them by heavy commercial vehicles or climatic conditions
d. A pavement's foundation (including its subbase and any capping layer that might be required to protect the subgrade) should have enough load-spreading capability for it to provide a satisfactory platform for construction vehicles whilst the road is being built.

Bituminous pavement is one of the most popular methods used in the construction of new road pavements. This is because some advantages claimed for bituminous pavements generally include the following, when compared with concrete pavements (O'Flaherty, 1967):

a. In new major roads, bituminous surfacings generally provide a better riding quality when opened to traffic, especially if the transverse joints in the concrete slab are closely spaced and not well formed.
b. Bituminous surfacings are traditionally considered to be quieter and are preferred for use in locales where noise is deemed a problem. (However, a low noise concrete paving has now been developed that gives a much quieter ride)
c. Bituminous pavements can be opened to traffic as soon as compaction is completed and the surfacings have cooled to the ambient temperature, whereas concrete ones formed from conventional mixes cannot be opened until they have gained sufficient strength. (However, it should be noted that 'fast-track' process has now been developed which uses rapid-hardening cement in association with high-temperature curing to allow concrete pavements to be opened to traffic within 12 hours of their construction).
Increased traffic factors such as heavier loads, higher traffic volume and higher tire pressure demand higher performance pavements. Truck loading is increasing worldwide, resulting in more permanent deformation of asphalt concrete pavements. It is therefore necessary to ensure pavements can withstand this loading without rutting, which requires improvements to mix design and analyses. The effects of different tyre types were found to have significant effect on the development of rutting.

A higher performance pavement requires bitumen that is less susceptible to high temperature rutting or low temperature cracking and has excellent bonding to stone aggregates. The chemical composition of the bitumen has a significant effect on its visco-elastic properties and hence on its performance as road paving materials in asphalt concrete mixture.

With increasing traffic loadings and more demanding performance requirements, the need to be able to predict long-term behavior is essential. Performance on the road depends on many factors including the design, application and the quality of the individual components. The most important pavement materials are bitumen and tar, cement and lime, soil and rock, gravel and slag aggregates. Although bitumen is, in terms of its volume, a relatively minor component of a bituminous mix, it has a crucial role acting as a durable binder and conferring visco-elastic properties to the mix. Satisfactory performance of bitumen on the road can be ensured if four properties are controlled. Those properties are rheology, cohesion, adhesion and durability.

Highway engineers recognized that improved durability would be achieved using dense, impermeable mixes. The gradual increase in the use of BS 594 rolled asphalt for trunk roads and the development of dense bitumen macadam, which first appeared in the 1961 edition of BS 1621, reflected this awareness. Since the mid sixties both the volume and axle weight of vehicles on the roads in the United Kingdom have increased dramatically, and in the early seventies it was realized that
recipe mixes, which had hitherto given long and satisfactory performance, were
deforming under the increasing numbers of heavier vehicles.

Therefore, bituminous mixes have to fulfill a wide range of requirements for
today’s traffic, in particular the ability to:

1. resist permanent deformation
2. resist fatigue cracking
3. be workable during laying, enabling the material to be satisfactorily
   compacted with the available equipment
4. be impermeable, to protect the lower layers of the road from water
5. be durable, resisting abrasion by traffic and the effects of air and water
6. contribute to the strength of the pavement structure
7. be easily maintained and most importantly, must be cost-effective.

In addition to the above, wearing course materials must also fulfill the
following tyre/pavement interaction requirements:

1. provide a skid-resistant surface under all weather conditions
2. have an acceptable level of rolling resistance
3. provide a surface which under trafficking, produces an acceptable
4. provide a surface of acceptable riding quality

In 1987, Congress established the Strategic Highway Research Program
(SHRP) to sponsor several coordinated research projects that were directed at
improving the performance and durability of roads in United States. From October
1987 through March 1993, a $50 million Strategic Highway Research Program
(SHRP) project was conducted to develop new ways to specify, test and design
asphalt paving materials. The results of this research effort are collectively referred to
as ‘Superpave’ (Kennedy et. al., 1994). The percentages of hot-mix asphalt projects
designed using the Superpave system over the past four paving seasons are shown in
Figure 1.1 below. From 1996 to 1999, the percent of projects designed using the
Superpave system increased from one percent (1%) to 41 percent (41%).
Though the use of Superpave mix design procedures are becoming more and more common, it has always been felt that there was a need for a strength test to validate the volumetric mix design procedure. A good strength test would serve to calm the fears of concerned agencies and contractors. The static creep test is one such test that could be used to validate the Superpave volumetric mix design procedures.

1.2 Statement of Problem

The performance of bitumen-bound mixes in practice is significantly influenced by the rheological (or mechanical) properties and to a lesser extent the chemical constitution of the bitumen. The latter is particularly important at the road surface because the constitution of the bitumen influences the rate of oxidation of thereby how rapidly the bitumen is eroded by traffic. These factors are, in turn, influenced by changes due to the effect of air, temperature and water on the bitumen. There are, of course, many factors influencing behavior, including the nature of the aggregate, mix composition, bitumen content (ie bitumen film thickness), degree of compaction, etc, all of which influence long term durability.
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1. Asphalt Institute, “Performance Graded Asphalt Binder Specification and Testing”. Superpave Series No. 1 (SP-1), USA.


Softening point (ASTM), °C

Temperature, °C

Penetration, dmm

- Ideal compaction viscosity
- Poor compaction viscosity
- Poor drying of the aggregate
- Excessive hardening of the bitumen
- Bitumen drainage

Mix too weakable

Ideal mixing viscosity

Vegetation

High mixing viscosity

Mix too weakable

Poor compaction viscosity

Draw a line between the softening point (line 'A') and penetration (line 'B') values. The intercept on line 'C' is the PI of the bitumen.
Company: KUITTHO
Operator: KUITTHO
Date/Time: 17.01.2005 / 14:51:35 PM
Substance: RTFO PG64
Sample no: 3
Description: RTFO PG64 Petronas Binder
Density: 1.020 kg/m³

Measure device: RS1
Temperature device: X
Sensor: PP25
A-factor: 325900.000 Pa/Nm
M-factor: 12.498 (1/s)/(rad/s)
Gap: 1.000 mm

ROLLING THIN FILM OVEN PG64

\[ G = f(t_{\text{seg}}) \]
\[ G' = f(t_{\text{seg}}) \]
\[ G'' = f(t_{\text{seg}}) \]
\[ \eta^* = f(t_{\text{seg}}) \]

SHRP: Condition met: \( f = 1.592 \text{ Hz, } |G^*| / \sin (\phi) \cdot m = 2210 \text{ Pa} \)
\( T = 63.50 \degree C \)

Filename: C:\Program Files\RheoWin\JOBS\RTFO PG64.rwi
\[ \begin{align*}
G' &= f(t_{\text{seg}}) \\
G'' &= f(t_{\text{seg}}) \\
|\gamma'| &= f(t_{\text{seg}})
\end{align*} \]
F0 PG64 PetronasBinderTest3.yanti
- t = f (t)

\begin{array}{c}
\text{\textbf{F0 PG64 PetronasBinderTest3.yanti}} \\
\text{- t = f (t)}
\end{array}
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<tr>
<th>t [s]</th>
<th>t seq [s]</th>
<th>τ [Pa]</th>
<th>η [1/s]</th>
<th>T [℃]</th>
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<td>622.4</td>
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<td>63.5</td>
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Date and time: Thursday, March 24, 2005, at 9:24 PM

Timer (hh:mm:ss): 1:00:00
Timer (seconds): 3600

Skin temperature (°C): 29.4
Core temperature (°C): 29.4

Load (kN)  Stress (kPa)  Contact  0.139  17.6
Axial  0.185  23.5
Deviator  0.047  6.0
Ave. deviator  1.196  152.4
Ave. axial  0.3303  3303
Ave. radial  0.0003  6

Creep Modulus (MPa): 46.14
Creep compliance (1/MPa): 0.02167
Flow time: 2144

Deviation time

Ave. axial: 0.3303  3303
Ave. radial: 0.0003  6

Regression range (sec): 10 to 3600
Calculations based on: Ave. Axial

Test Temperature: 54°C

Notes/comments: Static Creep Test for Rubber Modified Sample 1
US: NCHRP Appendix C, Static Creep/Flow Time

Operator: yanti

yanti 3:55:21 PM
UTM_52 V2.01 Static Creep Test
### Specimen Information

**Identification:** ACW14  
**Dimensions**  
- Diameter (mm): Point 1: 100.01, Point 2: 99.81, Point 3: 100.01, Point 4: 100.01, Point 5: 100.01, Point 6: 100.01  
- Height (mm): 69.29  

**Comments/Properties:**  
- Average: 99.9433; 69.29667  
- Sid Dev.: 0.04041452  
- Core/Sample Number: Rubber1  
- Cross-Sectional Area: 7845.023  
- Volume: 543638.1

### Load Parameters

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<th>Parameter</th>
<th>Value</th>
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<th>Linearised</th>
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<td>kN</td>
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<td>Axial static</td>
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<td>Confining</td>
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### Calibration Information

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<td>Confining Pressure</td>
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