Determining the significant factor of Resilient Modulus (MR) Measurement of Bituminous Mixtures by Indirect Tension Test

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ABSTRACT

Resilient modulus (MR) is an important property for asphalt concrete design and for mechanistic analysis of pavement response under traffic loading. This study investigates the different factors affecting the MR of hot mix asphalt. A full factorial design of experiment was carried out to investigate four factors. Each factor was studied at two levels. These factors are: number of cyclic loading, loading frequency, Poisson's ratio, and sample position.

Analysis of the factorial experimental design showed that the sample position is the most important factor affecting the resilient modulus. In order to simplify the statistic model, only the main effect are consider inside the model. The power transformation is needed by the model in order to meet IIDN assumption. The model after transformation is:

\[ Y^{-1} = 7.2 E^{-4} - 6.4E^{-5}x_2 - 1.1 E^{-4}x_4 \]

Keywords: resilient modulus, indirect tension, pavement mixture

I. INTRODUCTION

Asphalt is the oldest construction material used by man since the beginning of civilization. The use of asphalt as a construction material is largely based on its cost efficiency, durability and recyclability. To develop design a long lasting pavement, it is very imperative to approximate the actual field situation in design phase of asphalt concrete pavements. For example, better structural performance depends on a good projection of future traffic and accurate representation of field conditions, i.e., temperature.

Traffic loads are represented by cyclic loads in the performance testing of asphalt mixtures, and the resilient modulus is used to explain the stress-strain performance of asphalt concrete under cyclic traffic loading. It is the most significant material parameter in the design procedure of asphalt concrete pavements characterizing the complete structural performance of pavement structure. Hence, the accurate estimation of resilient modulus directly affects the layer thickness, service life and the overall cost of the pavement construction (Canser 2010).

The AASHTO Pavement Design Guide (1993), in addition to other revisions, incorporated the resilient modulus (MR) concept to characterize pavement materials subjected to moving traffic loads. MR values may be estimated directly from laboratory testing, indirectly through correlation with other laboratory/field tests, or back calculated from deflection measurements. The testing procedure for the determination of MR consists of the application of a repeated deviator stress (ζd), under a constant cell pressure and then measuring the resilient axial strain. Under repeated load tests, it is observed that as the number of load cycles increases, the secant modulus increases. After a number of load cycles, the modulus becomes nearly constant, and the response can be presumed to be elastic. This steady value of modulus is defined as the resilient modulus (Rahim, 2005, Canser 2010). As the number of load applications increases, the plastic strains due to load repetition decreases (Huang, 1993). It can be
observed from the figure that the permanent deformation rate approaches to zero with the increasing number of load repetitions (Çöleri E., 2007). Stiffness modulus of bituminous mixes can either be measured in the laboratory or predicted from properties of mix components, namely, aggregate and bitumen. There are a number of well-known empirical models that were developed by various researchers and relate resilient modulus to bituminous mix properties (Suhaibani et al., 1997). The resilient modulus can be performed on laboratory prepared specimens or field cores. For consistency in design, results obtained from laboratory prepared specimens should match with results obtained from field cores (Katicha, 2003). Resilient modulus measured in the indirect tensile mode (ASTM D 4123-82) has been selected by most engineers as a method to measure the resilient modulus of asphalt mixes (Brown et al., 1989).

The objective of this study is to understand the level of significant of several factors that might affect the MR measurement from the asphalt pavement in the field and develop a statistical model to predict the values of MR. In this study, the effect observed limited to:
- Load (number of cyclic loading and the loading frequency) apply to sample on the resilient modulus of a bituminous material measurement,
- The choices of Poisson’s ratio value, which recommended by ASTM testing procedure, in this case, we was investigating the significant effect of the high and low Poisson’s ratio value suggested by ASTM standard.

II. STATE OF ART

The indirect tensile resilient modulus (MR) is a measure of the stiffness of hot mix asphalt. It is incorporated in AASHTO 1993 pavement design guide that is widely used in Taiwan. Resilient modulus is defined as the ratio of the applied stress to the recoverable strain when a dynamic load is applied. In this test, a cyclic load in form of a haversine wave is applied along the diametral axis of a cylindrical specimen for 0.1 seconds along with a rest period of 0.9 seconds, thus the cylindrical specimen receives one load cycle per second. The load is applied along the diametral axis of the specimen leaving the specimen to be in tension along the vertical diameter in line with the load. The resilient modulus is an important parameter to determine the response of pavements due to the application of traffic loads. Figure 1 shows the experiment setup for the MR test. The resilient modulus was calculated using Equation 1. The resilient modulus value was reported as an average of four sides of the cored specimens.

\[
M_R = \frac{P}{H \times t} (0.27 + \mu) \quad \text{Equation 1}
\]

where,
- \(M_R\) = resilient modulus, MPa (or psi)
- \(P\) = cyclic load, N (or lbf)
- \(H\) = horizontal deformation, mm (or inches)
- \(t\) = sample thickness, mm (or inches)
- \(\mu\) = Poisson’s ratio
III. RESEARCH METHODOLOGY

In order to achieve the objectives of this research, a sample was taken directly from the real asphalt pavement. The specimen was obtained from Tai Zi Road, at station of 0+600 by taking a core simple.

The core sample was then divided into two part, top and bottom using stone cutter. The top part is the sample section which had a direct contact with vehicle tire, while the other identify as the bottom part. To complete the sample preparation, the sample then bring to the testing temperature (25°C) by stored in air bath for minimum of 6 (six) hours.

After the sample preparation completed, the test was carried using 2 level factorial designs. In this study, 4 factors are investigated in 2 levels. The result of every combination was analysed using XLISP statistical software which is useful to quantify the effect of each factor and their interactions.

The effect of the main factor and their interaction is used to develop a model for predicted MR value. The statistical normality and residual of the model then checked in order to obtain simpler and statistically accurate model. To sum up, Figure 2 shows the flowchart of experimental design for this study.
IV. RESULT AND ANALYSIS

The experimental runs were conducted randomly. The random order was obtained from www.random.org. Table 1 shows the $2^4 = 16$ experimental results for this study. The “-“ and “+” values are represented specific levels that assigned to particular factors which mean high and low respectively. While for the sample position, “-“ and “+” represented the “bottom” and “top” respectively.

Table 1 2^4 Factorial Design Experiment Results

<table>
<thead>
<tr>
<th>EXP. Run</th>
<th>Standard Order</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>$M_R$ (kgf/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>928.38</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1492.81</td>
</tr>
<tr>
<td>12</td>
<td>3</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>1128.79</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>182.24</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>1058.32</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>1041.74</td>
</tr>
</tbody>
</table>
However, to make sure that there is no effect of run time or the timing when the test is conducted, we need to plot the testing result in experimental run order. As shown on Figure 3, the testing result are randomly distributed, show we can conclude that there is no significant effect of experimental run order.

After assuring that there is no experimental run order effect, the data were analyze using XLISP statistical computer program.

Yate’s Algorithm

The full model:

\[ y_i = \bar{y} + \frac{A}{2} x_1 + \frac{B}{2} x_2 + \frac{A}{2} x_3 + \frac{C}{2} x_4 + \frac{A}{2} x_1 x_2 + \frac{B}{2} x_2 x_3 + \frac{C}{2} x_3 x_4 + \frac{A}{2} x_1 x_2 x_3 + \frac{D}{2} x_4 \]

where:

\[ y_i = \text{Experimental Result} \]

\[ x_1, x_2, x_3, x_4 = \text{Experimental Run} \]

\[ \bar{y} = \text{Yate’s Algorithm} \]

\[ A, B, C, D = \text{Coefficients} \]
Table 2 shows the mean, main effect and interaction effect which are needed to develop a prediction model for Mr measurement. Based on Table 2 result, the statistic model can be formulated as follow:

Full Model of Mr estimation:

\[
y = 1541.58 - \frac{203.20}{2} x_1 + \frac{371.93}{2} x_2 - \frac{400.35}{2} x_1 x_2 + \frac{231.18}{2} x_3 - \frac{192.40}{2} x_1 x_3
\]

\[
- \frac{17.01}{2} x_2 x_3 - \frac{136.68}{2} x_1 x_2 x_3 + \frac{588.05}{2} x_4 - \frac{426.89}{2} x_1 x_4 + \frac{137.43}{2} x_2 x_4
\]

\[
- \frac{350.12}{2} x_1 x_2 x_4 + \frac{425.67}{2} x_2 x_4 + \frac{216.34}{2} x_3 x_2 x_4 + \frac{16.92}{2} x_2 x_3 x_4
\]

\[
- \frac{18.44}{2} x_1 x_2 x_3 x_4
\]

Table 2 Estimate effect of each factor and their interactions

<table>
<thead>
<tr>
<th>Effect</th>
<th>Estimate</th>
<th>Effect</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{y} )</td>
<td>1541.58</td>
<td>D</td>
<td>588.05</td>
</tr>
<tr>
<td>A</td>
<td>-203.20</td>
<td>AD</td>
<td>-426.89</td>
</tr>
<tr>
<td>B</td>
<td>371.93</td>
<td>BD</td>
<td>137.43</td>
</tr>
<tr>
<td>AB</td>
<td>-400.35</td>
<td>ABD</td>
<td>-350.12</td>
</tr>
<tr>
<td>C</td>
<td>231.18</td>
<td>CD</td>
<td>425.67</td>
</tr>
<tr>
<td>AC</td>
<td>-192.40</td>
<td>ACD</td>
<td>216.34</td>
</tr>
<tr>
<td>BC</td>
<td>-17.01</td>
<td>BCD</td>
<td>16.92</td>
</tr>
<tr>
<td>ABC</td>
<td>-136.68</td>
<td>ABCD</td>
<td>-18.44</td>
</tr>
</tbody>
</table>

*Source: XLIPS calculation*

Significant Effect

Based on the estimated effect value from Table 2, XLISP is used to determine the significant effect among the estimated effect value. As seen on Figure 4, there are no significant effect appears, since there is no plot that out of the normal distribution based on Loh effect.

![Normal-distribution from original effects (Daniel’s plot)](image)

![Normal-distribution based on Loh effects; 2 point selected](image)

*Figure 4 (a) Normal-distribution from original effects (Daniel’s plot) and (b) Normal-distribution based on Loh effects; 2 point selected*
However, there are 4 points that located near to the edge of Loh effects line, which are:
- Effect of D (sample position)
- Interaction of CD (Poisson’s ratio and sample position)
- Interaction of AB (number of load and load frequency)
- Effect of B (load frequency)

But, in order to simplify the model, the interaction of 2 effects will not consider inside the model. So, in this study, the main effect B and D was chosen. Therefore, experimental model is set as:
\[ y = 1541.58 + 185.96x_2 + 294.025x_4 \]

**IIDN assumption checking**
- The normality assumption of the model was performed by analyzing normal-quantile plot to see if residuals fall into straight line. Observing Figure 5(a), overall plots are mostly near to a straight line although some points are off. Hence, normal distribution assumption is satisfied.
- Figure 5(b) is use for checking the independent and identical assumption. It’s shown residuals plot against fitted value, which are distributed unevenly and do not have constant errors. It means independent and identical assumptions are not fulfilled. Therefore, data transformation should be done.

![Figure 5 (a) Normal-distribution checking and (b) residuals plot](image)

**Data Transformation**

By performing power transformation function in XLISP, we can see that in Figure 6 the closest lambda (λ) value to 0 is \( \lambda = -1 \). Thus all Mt result is transformed into \( M_t^{-1} \) and the statistical analyses are re-performed. Table 3 shows the estimation of effect and interaction value of each factor after transformation was performed.
Figure 6 Power transformation plots

Table 3 Estimate effect of each factor and their interactions after transformation

<table>
<thead>
<tr>
<th>Effect</th>
<th>Estimate</th>
<th>Effect</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ý</td>
<td>7.24E-4</td>
<td>D</td>
<td>-2.31E-4</td>
</tr>
<tr>
<td>A</td>
<td>2.51E-5</td>
<td>AD</td>
<td>1.50E-4</td>
</tr>
<tr>
<td>B</td>
<td>-1.28E-4</td>
<td>BD</td>
<td>1.88E-5</td>
</tr>
<tr>
<td>AB</td>
<td>1.34E-4</td>
<td>ABD</td>
<td>6.35E-5</td>
</tr>
<tr>
<td>C</td>
<td>-7.11E-5</td>
<td>CD</td>
<td>-1.60E-4</td>
</tr>
<tr>
<td>AC</td>
<td>8.73E-5</td>
<td>ACD</td>
<td>-1.60E-4</td>
</tr>
<tr>
<td>BC</td>
<td>2.54E-5</td>
<td>BCD</td>
<td>1.51E-5</td>
</tr>
<tr>
<td>ABC</td>
<td>1.17E-5</td>
<td>ABCD</td>
<td>-2.52E-5</td>
</tr>
</tbody>
</table>

Normal distribution from original effect and Loh effect plot after transformation are shown in Figure 7. It is shows that there are no significant effect after performing the power transformation. However, in order to create a prediction model, the previous significant effects were used in the new model. Thus, the new model can be written as follow:

\[ y^{-1} = (7.24 \times 10^{-4}) - (6.4 \times 10^{-5} x_2) - (1.15 \times 10^{-4} x_4) \]

Figure 7 (a) Normal-distribution from original effects (Daniel’s plot) and (b) Normal-distribution based on Loh effects; no significant effect found

The normality checks on Figure 8 (a) shows that overall plots are mostly near to a straight line although some points are off. Hence, normal distribution assumption is satisfied. In addition, the
independent and identical assumption also satisfied as seen on Figure 8 (b) the error are constant since the points are evenly distributed. Therefore, the model is acceptable since it is fulfil the IIDN assumption.

![Figure 8](image)

**Figure 8** (a) Normal-distribution checking and (b) residuals plot after transformation

V. **CONCLUSION**

- The most significant effect in measuring $M_R$ is the sample position, $M_R$ value in top portion is greater than the bottom portion, and this implies that the top portion has better properties than the bottom portion.
- The aforementioned result might happen because of the bottom portion of sample consist by the older pavement while the top portion consists by the newer pavement.
- With higher loading frequency, the $M_R$ measurement relatively become higher, this might cause by the time for sample to recover from previous loading.
- In order to simplify the statistic model, only the main effects are considered. In this study, the significant effects are the loading frequency (factor 2) and the sample position (factor 4).
- The power transformation is needed by the model in order to meet IIDN assumption. The model after transformation is:

$$y^{-1} = 7.2 \ E^{-4} - 6.4 \ E^{-5}x_2 - 1.1 \ E^{-4}x_4$$
VI. REFERENCE


