Abstract: Repeated wheel load and temperature thermal stress will cause stress, strain and then deteriorate pavement’s performance. The research aim is to know Hot Mix Asphaltic Concrete (HMA) behavior on surface pavement, which includes tensile stress and strain, and its resilient modulus under load and temperature changes with indirect tensile strength laboratory test using UMATTA. Load varies from 187.5 to 2000 N, while temperature varies between 25, 37.5, and 50 °C under 1 and 0.3 Hz frequency. The results indicated that temperature is the most responsible compared to load and load frequency for HMA performance decrease which is the main cause pavement surfaces deterioration.

Key Words: hotmix asphaltic concrete; temperature changes; resilient modulus

1. INTRODUCTION

Surface layer on flexible pavement which generally made of hot mix asphaltic concrete (HMA) has a specific behavior in responding to loading because of the asphalt properties’ influence as its binder. Loading characteristics of the vehicle wheels, such as singular or dual axis, the contact between the tire with the surface as a function of speed and loading frequency, and temperature acting on the surface’s layer also influence the behavior.

Working temperature on the pavement structure surface is much higher than air temperature because it is influenced by the vehicle wheel’s contact area that produces friction against the length of road’s surface and the speed which affects of friction. The stress that appear by repeated vehicle wheel load resulting stress and strain in the pavement structure coupled with thermal stress due to temperature decrease reduces the performance of asphalt concrete mixtures, starting from fine cracks to rutting.

The research of hot mix asphalt concrete response to changes in temperature and loading is done in the laboratory using UMATTA (Universal Testing Material Machine). The aim is to observe the behavior of asphalt concrete to the effects of loading and temperature variation, in terms of tensile strain, tensile stress and resilient modulus. The parameters used are
temperature, load, and also load frequency variation. The data-collecting was done at Road Materials and Pavement Laboratory, Roads and Bridges Research Center, Republic of Indonesia’s Department of Public Works. The laboratory results was presented then.

2. LITERATURE REVIEW

2.1 Material’s characteristic

2.1.1 The chemical content of asphalt

The asphalt’s maltene and asphaltene composition affects it’s durability towards environmental and loading influences as a function of time. Asphaltene is a solid form hydrocarbon compound has a cement behavior. Maltene is a solvent consisting of acidicaffin 1, acidicaffin 2, Nitrogen and Paraffin to dilute asphaltene. This composition must be balanced to produce good quality asphalt. The composition of that resins and oils stated with Maltene Distribution Ratio (MDR), maximum 1.5. The smaller the MDR value of the asphalt’s quality chemically, the better it will be (Sukirman, 2003).

2.1.2 Asphalt Viscoelastic Behavior

At high temperatures viscous characteristics and elastic material deformation are the asphalt layer controller (Nesnas and Nunn, 1996). The ability to predict the spreading of resulting stress and strain tensile depends on the stiffness modulus of each layer. Usually the stiffness modulus is assumed to be dominated by elastic behavior for non-asphaltic material. At a very low temperature asphalt becomes brittle so that the elastic assumption is acceptable. But at a high temperatures it is dominated by viskous, so that permanent deformation on pavement—which is not the characteristic of elastic pavement—tends to occur.

Strain that occurs when loading is applied to the elastic area shows an instantaneous strain. The rest increases along with the time but the rate is slowed at the viscous area with time deviation between stress and strain (Yin, 2007). Asphalt gel shows consistency (viscocity) changes along with the time change. Deformation increases rapidly together with the increase of the shear stress which causes damaged internal structures. The more that the deformation increases, the less that the resilient modulus will be (Ali, 2007).

2.1.3 Aggregate’s characteristic

What is meant by natural aggregate is mineral materials such as sand and crushed stone which is used with an adhesive such as cement, lime, or asphalt to produce new materials such as concrete, mortar or asphalt concrete (Matthew, 2007).

In asphalt concrete, aggregate fills about 90 percent of the volume, with the result of aggregate’s characteristic greatly affected that asphalt concrete mixture. Aggregate used on the upper layer receives tension due to vehicle wheel load, abrasion and possibly broken. To obtain a good mixture for surface pavement, the aggregate should be cubical, sharp and angular, free from the flattened, elongated, flattened and elongated form, has hardness, abrasion-resistant and has the toughness of not breaking or changing shape under loaded.
Aggregate used must have good adhesion toward asphalt; constant durability toward weather changes, physical and chemical effects of rain and ground water; eligible composition; clean, dry, strong, durable and free from harmful organic substances. (Latifa, 2009).

2.2 Temperature’s and Loading effect

2.2.1 Temperature’s effect

Temperature’s impact that cause damage such as rutting and cracking are important factors that directly influence the pavement structural capacity. Citing Sha’ad, 1989, Kamal (2005) states that the flexible pavements behavior is strongly influenced by environmental conditions. Aschuri (2003) quoting Ahmed (1995) who did research at 5 places in one segment of the road and find that the highest temperature is at 2 cm below the asphalt concrete layer. Cracks in the pavement surface also make water into the base course and subbase that can weaken the foundation strength and initial deterioration of pavement layers begin (Zhong, Geng, 2009).

Even though having the same viscosity and penetration at a given temperature, sensitivity of asphalt to temperature varies depending on the type of which affected by the chemical composition of asphalt (Sukirman, 2003). Sensitivity to temperature changes becomes the basis of differences in the asphalt service time before the asphalt finally cracked and hardened (aging).

In 1990, SJ Biczysko do research which states that above 35°C asphalt performance begins to decline by deformation and below 10°C by vehicle wheel tracking. In line with increasing temperature, the bitumen viscosity decreases and asphalt change seems like sponges. Only the asphalt modulus of mixture layer is significantly influenced by temperature. The higher the temperature, the lower asphalt modulus of mixture layer. While the sub grade modulus and aggregate layers are less affected by temperature (Kosasih, 2008). It is important to know the actual temperature, because on the surface layer pavement is much higher than the air temperature at the same time.

2.2.2 Loading Behavior

The load repetition, type and duration that cause stress on the asphalt concrete layer is simulated as haversine wave, both triangle or square. The loading frequency is determined from the length of rest period between pulse loading. Vehicle speed affect the propagation speed, therefore the loading time length(pulse time) planned to use haversine wave for one cycle loading period of 0.1 seconds and 0.9 seconds recovery for asphalt layer.

At the peak load the maximum deformation occurs. If this cycle occurs repeatedly will form a bigger permanent deformation. Accumulation of permanent deformation will cause cracks and rutting on pavement surface course.

2.3 Asphaltic Concrete characteristic

Asphalt concrete mixture’s behavior is unique because of the asphalt’s viscoelastic influence that serves as an adhesive in the mixture. This behavior’s change depends on the composition, temperature, level and loading frequency itself. At a low temperature, small working load with a high loading frequency repetition has the characteristic of being linear viscoelastic. However at a high temperature, the loading frequency repetition is low but the working load
is large. Therefore the character tends to be nonlinear elastoviscoplastic (Garba & Horvli, 2002).

2.3.1 Tensile stress and strain

As known, the flexible pavement layer is not an elastic material. Permanent deformation occurs whenever loading on the surface happens. However, tensile strain arising from the loading, although much repeatedly and below the maximum load, will always be recoverable that it can be categorized as an elastic material, while compressive strain occurs in the foundation’s basis and above subgrade

Stress, tensile strain and deflection occurs under load vehicle wheel (circular loaded area) on the axis of symmetry where there are three point of stress, \( \sigma_z \), \( \sigma_r \), \( \sigma_t \), and shear stress \( \tau_{rz} \) (Huang, 1993). Tensile strain occurs at the base and the top layer of asphalt and continues to grow because of the asphalt concrete’s rheological behavior. Tensile strain at the base of the asphalt concrete layer is the beginning of the occurrence of micro cracks and greater than the bottom. When repeated loading continues, the strain spread rapidly into cracks that can be seen on the surface layer of asphalt concrete. Research shows that the development of strain on the surface and bottom layer is a function of the characteristics of asphalt pavement structure (Blazejowsky, 1996)

2.3.2 Resilient Modulus

Modulus of resilience is mainly affected by the temperature and frequency of loading (Kamal, et al 2005). Resilient modulus is defined as the ratio of repeated load deviator stress to the tensile strain (recoverable strain). That is directly related to the ability of the material received load distribution associated with the stress and strain and to show how the material deformed by loading. This relationship varies depending on the temperature and vehicles speed per time which shows the behavior of visco elastic material.

Resilient behavior similar to elastic behavior, with the exception of a little permanent deformation after each cycle of loading. Therefore, the term resilient modulus contrast with elastic modulus (Irwin, 2007).

3. LABORATORY INVESTIGATION

The first thing to be done is search for a mix composition between two aggregate gradations above and below the restriction zone which give the best result at the optimal percentage of asphalt with Marshall method, as recommended by the Highways Department of Public Works, 2007 Edition for AC-WC Wearing Course.

The mix composition is made a basis for creating resilient modulus test object using the Universal Material Testing Apparatus (UMATTA) test instrument with variable temperature, load, and load frequency chosen. Temperature for the test is set to be 25\(^{\circ}\)C as a standard temperature for asphalt test, 50\(^{\circ}\)C as an estimation of the maximum temperature which functions the roads surface in Jakarta, and 37.5\(^{\circ}\)C as a midpoint between 25\(^{\circ}\)C and 50\(^{\circ}\)C. Load variation is chosen based on the maximum load that can be accepted by the test instrument according to the test temperature. Load frequency is taken based on what is suggested in ASTM method D4212 and SNI 03-6836-2002.
3.1 Materials

The aggregate used is natural aggregate with stone dust filler. Aggregate testing involves testing of relative density, sieve analysis and materials finer than 200 μm. Asphalt testing include specific gravity, penetration, softening point, ductility and flash points, used asphalt AC with 60/70 penetration. Aggregate sieve analysis results will then be combined in accordance with the upper and lower limit requirements of the gradation of the Highways Department of Public Works, 2007 Edition for Wearing Course Asphalt Cement layer.

3.2 Preparation of the initial conditions with Marshall test

To see the relationship between the testing parameters including variations in temperature, load and load frequency to the performance of hot mix asphalt concrete, same specimen condition is needed so that no new variables occurs from non-uniform condition of the specimens.

The mixing of hot mix asphalt concrete is done from the agregat and asphalt’s testing data, using Marshall method. In order to get the best condition, the used aggregate gradation is taken on the upper and lower limit of AC-WC Highways 2007 Edition’s gradation restriction zone.

After the mix design is calculated, the percentage of the tested asphalt is found to range between 5—7% with 0.5% of intervals. Then stability and flow test with Marshall method is done. From the results of preliminary testing using the upper and lower limit values when looking for best stability, flow and void, it was found that the upper limit of the gradation requirements of the Highways Department of Public Works, 2007 Edition for Wearing Course Asphalt Cement layer provides optimum results which produces 6.4% of asphalt percentage.

Furthermore, the composition of this mixture is used as the basis for making resilient modulus samples based on variations of temperature, loading and loading frequency using UMATTA.

3.3 Sample Preparation for UMATTA test

Samples are made according to the best mixture of asphalt optimum percentage with Marshall’s method before. The specimens made according to the Marshall specimens with thickness ranging from 62 mm and ranging from 101 mm of diameter to be tested with the temperature parameters of 25, 37.5, and 50°C. At a temperature of 25°C load given was 187.5, 250, 450; 600; 1500 and 2000 N. On 37,5°C loads given 187,5; 250; 450 and 600N. At a temperature of 50°C load supplied 187,5 and 250N. Basic loading variations based on the maximum ability test instrument to receive the load according to the working temperature. Each temperature and loading variations are tested with 0.3 and 1Hz of loading frequencies.

3.4 UMATTA test

Tests carried out by using the UMATTA to obtain tensile strain, tensile stress and resilient modulus of hot mix asphalt concrete. Tests conducted with repeated loading refers to the test procedure according to ASTM method D4213 and SNI 03-6836-2002. The process of loading for each specimen consists of two stages, first preconditioning phase and the main testing
phase. Preconditioning phase is required to prepare specimens for reading data produced is in a stable uniform condition.

Input data begins with five conditioning pulses followed by a load of five pulses. The period of 2000 ms conditioning pulse. Pulse period equal to the frequency of loading is taken 1000 and 3000 ms equivalent to 1 and 0.3 Hz. Rise time 40 ms. The maximum load is determined based on 187 to 2000 N. Poisson ratio of 0.4 is taken in accordance with SNI. The sample temperature of the test is 25, 37.5, and 50 °C.

4. RESULTS AND DISCUSSION

4.1. The physical properties of asphalt

Tests on physical properties of asphalt are needed to determine whether the characteristics of asphalt match field conditions where the mixture will spread out, and as preliminary data for the design of asphalt concrete. Asphalt specific gravity, penetration, softening point, ductility and flash point value are a description of the asphaltenes and maltenes composition which determines its adhesiveness nature, generally tested at a temperature of 25°C, except for softening point at a temperature of 5°C and the flash point is obtained in accordance with its resistance when heated until it ignites and then burns. Table 1 shows the results of testing the physical properties of asphalt in accordance with the requirements according to Highways Department of Public Works, 2007 Edition

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>1,01</td>
<td>Min 1,0</td>
</tr>
<tr>
<td>Penetration</td>
<td>61</td>
<td>60-79</td>
</tr>
<tr>
<td>Softening point</td>
<td>53°C</td>
<td>48-58</td>
</tr>
<tr>
<td>Ductility</td>
<td>100 cm</td>
<td>Min 100</td>
</tr>
<tr>
<td>Flash point</td>
<td>340°C – 368°C</td>
<td>Min 200</td>
</tr>
</tbody>
</table>

4.2. The physical properties of aggregate

Designing asphalt concrete mixture and calculate the results of Marshall stability test data requires data of aggregate physical properties, which include relative density, sieve analysis and materials finer than 200 μm. Tests are carried out on coarse aggregate, fine aggregate and stone dust as a filler. From the results of sieve analysis, aggregate blending is performed to obtain the aggregate grading on the upper and lower restriction zone and the percentage of each type of coarse aggregate, fine and filler to be used. Aggregate must be clean as stated in the test of material finer than 200 μm for asphalt to be able to stick properly. Table 2 and 3 show the results of testing the physical properties of aggregate.

Table 2 Aggregate Testing tabulation.

<table>
<thead>
<tr>
<th>Test</th>
<th>Coarse</th>
<th>Fine</th>
<th>Filler</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent Specific Gravity</td>
<td>2,51</td>
<td>2,53</td>
<td>2,52</td>
<td>2,5</td>
</tr>
<tr>
<td>Material finer than 200 μm</td>
<td>1,75 %</td>
<td>2,6 %</td>
<td>2,9%</td>
<td>8 %</td>
</tr>
</tbody>
</table>
Table 3 Aggregate gradation

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Upper of restriction zone</th>
<th>Lower of restriction zone</th>
<th>Requirement with restriction zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 mm</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>19</td>
<td>95</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>12.5</td>
<td>85</td>
<td>85</td>
<td>90-100</td>
</tr>
<tr>
<td>9.5</td>
<td>60</td>
<td>60</td>
<td>Maks 90</td>
</tr>
<tr>
<td>No 4</td>
<td></td>
<td></td>
<td>---</td>
</tr>
<tr>
<td>No 8</td>
<td>45</td>
<td>33</td>
<td>28-58</td>
</tr>
<tr>
<td>No 16</td>
<td>36</td>
<td>21</td>
<td>25,6-31,6</td>
</tr>
<tr>
<td>No 30</td>
<td>29</td>
<td>15</td>
<td>19,1-23,1</td>
</tr>
<tr>
<td>No 50</td>
<td>20</td>
<td>11</td>
<td>15,5</td>
</tr>
<tr>
<td>No 100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No 200</td>
<td>10</td>
<td>8</td>
<td>4-10</td>
</tr>
</tbody>
</table>

The red color is restriction zone

4.3 Stability and Flow Test

Marshall Testing is done by destruct the test samples to determine the characteristics of hot mix asphalt concrete, as expressed in stability, flow and Voids in Mineral Aggregate (VMA), Voids Filled with Binder (VFB) and Voids In Mixture (VIM). Trial and error asphalt percentage is determined based on the aggregate percentage in order to get the optimum amount of asphalt in a particular grade of asphalt concrete mixture. From the preliminary testing of the upper and lower gradation restriction zone the best Marshall stability and flow based on upper limit of gradation with 6.4% of asphalt is acquired as shown on Table 4.

Table 4. Marshall test tabulation

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void in Mineral Aggregate, VMA</td>
<td>15,96%</td>
<td>Min 15 %</td>
</tr>
<tr>
<td>Void In Mixture, VIM</td>
<td>5,19%</td>
<td>3,5 – 5,5 %</td>
</tr>
<tr>
<td>Void Filled with Binder, VFB</td>
<td>67,51%</td>
<td>Min 65 %</td>
</tr>
<tr>
<td>Stability</td>
<td>873 kg</td>
<td>Min 800 kg</td>
</tr>
<tr>
<td>Flow</td>
<td>4,04 mm</td>
<td>Min 3,0 mm</td>
</tr>
<tr>
<td>Marshall Quation</td>
<td>234 kg/mm</td>
<td>Min 250 kg/mm</td>
</tr>
</tbody>
</table>

The test results show greater VMA than required. Since VIM follows accordance, it means that there is quite a lot of asphalt in the void, which is stated in the value of VFB that meets the requirements. The value of Marshall Quotation decreases as the flow value increases.

4.4 Resilient Modulus Test

Resilient modulus test is measured by indirect tensile strength in repeated loads using UMATTA which generate data of tensile strain, tensile stress and resilient modulus on variations of the chosen temperatures, loads, and load frequencies. The test is performed without damaging the specimen (non-destructive test); assumed to be at the time of asphalt concrete is in the elastic phase. Some parameters were obtained directly by the automatic computer calculation, e.g. resilient modulus, rise time peak, time of loading, tensile stress, peak
force and total recoverable strain (Siswosoebrotho et al, 2005). The temperature of test was selected 25, 37.5, and 50 °C, load varies from 187.5 to 2000 N and loading frequency 1 and 0.3 Hz. Discussion of the data in terms of strain, stress and resilient modulus.

4.5. Tensile strain

Tensile strain occurs simultaneously with the tensile stress when the load with 5 pulses is applied on the sample test. Figure 1 describe the amount of tensile strain that occurs in the temperature variation of 25, 37.5, and 50°C. It can be seen that the strain increases as the temperature increases.

![Figure 1 Strain vs temperature](image)

Figure 1 Strain vs temperature

Figure 2 shows the relationship between tensile strain to load variation from 187.5 to 2000 N at 0.3 and 1 Hz load frequency. Strain value increases with load increases. Strain value of temperature changes and loading on the 0.3 hz load frequency showed a similar pattern but greater than 1 hz.
4.6. Tensile stress

Figure 3 shows the relationship between stress and temperature variations of 25, 37.5, and 50°C. The higher the temperature the mixture capability received loading became lower. This is not apart from nature viscoelastic asphalt which changes from solid to elastic when the temperature increases which causes the loosening of bonds (interlocking) between aggregates and asphalt. Just as the relationship between strain and temperature in Figure 1, the stress on the load frequency 0.3 Hz is greater than load frequency 1 Hz at the same temperature changes.

Figure 4 shows the relationship between stress and loading variations of 187.5 to 2000 N. The greater load given the stress that occurs will be higher and proportional. Because the tests are carried out in elastic mixture phase then the value increase of stress has not shown a turning point, in the other word that stress is increase inline with the load is increase.
4.7. Resilient modulus

Figure 5 shows resilient modulus and temperature relationship. Resilient modulus decrease is inline with temperature increase. As strain and stress under temperature relationship, this phenomenon related with asphalt viscoelastic behavior under temperature effect.

Figure 6 shows resilient modulus and load relationship. Resilient modulus increase is inline with load increase. As strain and stress load relationship in the mixture elastic phase, the resilient modulus has not show turning point yet. Resilient modulus value at 1hz indicate same pattern with 0,3 hz, but larger.
5. CONCLUSIONS

The relationship between parameters and test results are stated as follows:
1. Temperature as the test’s parameter has major effect and inversely proportional to the amount of tensile strain, tensile stress and resilient modulus. The higher the testing temperature, the smaller the resilient modulus, tensile stress with the higher the tensile strain. A drastic reduction in resilient modulus and tensile stress about 85% and tensile strain increase about 80%, has been observed for temperature increase from 25 to 50º C.
2. Load as the test’s parameter is directly proportional to the tensile strain, tensile stress and resilient modulus. The higher the load, the tensile strain, tensile stress and resilient modulus will keep increasing.
3. Load frequency 1 and 0.3 Hz as the test’s parameter has minor effect to the strain, stress, resilient modulus temperature and load relationship. Perhaps if the load frequencies were significantly different will give significant result also.

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