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Reversible moisture damage in asphalt mixture

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Abstract. A moisture damage has been one of the major concerns for HMA pavement by loss of adhesion between bitumen and aggregate surface or loss of the cohesion within asphalt binder due to action of water. Water is the one of major contributor towards the damage of asphalt pavement. The aim of this research is to evaluate the effects of Moisture Damage (MD) towards the performance of asphalt mixture under different conditions (dry, wet and dry back). For this research laboratory fabricated specimens were conditioned in accordance to ASTM D4867 to achieve desire saturation level up to 80% and then immersed in water for different soaking period to simulate flooding scenario. Indirect Tensile strength (ITS) and Resilient Modulus (RM) tests were performed on moisture conditioned specimens at regular interval (1,3 and 5 days). After 5 days testing specimens were stored at room temperature for another 5 days to dry and were tested again to determine the recoverability of moisture damage. The results from this study indicated that tensile strength and modulus gradually decreased with the increasing of conditioning period, and upon drying at certain period specimens recovered 82% and 76% of initial ITS and RM respectively. The results suggested that moisture damage in asphalt mixture tested is reversible.

1. Introduction

Roads are one of the most essential modes of transportation in the world and it plays vital role in economic and social development of a country [1]. Most of the pavements across the globe are being and has been constructed since a long time using a product called asphalt. Asphalt mixture is being used in the whole world for construction of roads, highways and transportation infrastructure as it is cheaper than concrete. Similar to other artificial construction, it is deteriorated with the passage of time by the natural forces like rain, snow etc. [2]. Bitumen and aggregates are the main constituents of an asphalt mixture. Moisture damage is induced by the loss of adhesion between aggregates and bitumen or a loss of cohesion within the asphalt binder itself, resulting in reduction in asphalt mix stiffness [2-3]. Moisture damage (MD) has found to be one of greatest causes of distress in pavements [4-5]. To overcome the effect of moisture damage, a huge amount of money has been spent by Malaysian local authorities in order to maintain the pavements and prolongation of their life. Although moisture is not responsible for impairment of the pavements directly, but to an extent, it enhances the speed and intensity of existing distresses e.g. cracking, raveling, rutting, potholes etc. [6]. It also has been reported that moisture is responsible for deterioration of mechanical properties of asphalt mixture i.e. failure of stiffness and mechanical strength which finally could be a cause of breakdown of the road structure [7]. It is claimed by various researchers that moisture damage is a root cause of overuse failure of pavement and thus results in enhancement in rehabilitation works and conservation costs [2].

It is imperative to recognize materials and blends that are prone to damage driven by moisture. To determine the effect of moisture damage in mixture, there are many tests have been introduced but they don't indicate great connection between the outcomes got in the lab and the field execution of the mixtures [8]. In the majority of these tests the moisture damage is simply identified with the mechanical properties of the asphalt mixture. The major drawback of these tests is that these tests haven't consider physical and chemical properties of bitumen and aggregate. These properties are most important to addressed because failure of bond between aggregate and bitumen is highly connected with individual properties of mixture constituents [2]. Bonding properties of materials is totally depending on surface characteristics of materials [9]. Surface characteristics of materials represent by surface energy concept and used as a tool for selection of moisture prone materials [10]

In many countries, the asphalt pavement is constantly exposed to wet condition and high volume of water runoff due to heavy rainfall throughout the year. The prolonged exposure to water and moisture may expose the pavement to deterioration. According to Lu and Harvey [11], air voids, pavement structure, rainfall intensity and pavement age have the highest influence on moisture damage while repeated loading and cumulative truck traffic have a marginal effect.

A pavement shows an unexpected change in road condition after a disaster such as flooding. Currently in Malaysia, flood becomes one of the problem that leads pavements to early maintenance and rehabilitation. In 2014, the worst flood was occurred in Kelantan due to heavy rain. As a result, higher pavement deterioration was observed. According Tam et al. [12], flood has cause huge economic losses in which the average annual flood damage in Malaysia is as high as RM 100 million (US $33million). Several studies have recognized that moisture interruption decreased the modulus of resilience (Mr) of granular and sub-grade layers [13]. Other studies, Monismith [14] found an increase in pavement deflection due to a lower Mr, as a result reduction in pavement service life. Therefore, asphalt pavement that was still fresh and new in terms of materials (aggregate and bitumen) and was badly damaged due to flood but still intact as a structure, will create concern on whether can it performed as it used to be. To what extend the flood has changed asphalt mixture properties and its internal structure. With poor foundations, the tensile stress on asphalt layer will becomes higher and it will reflect the capability of the asphalt layer to cater the load from the traffic. The strength and capability of future performance of flooded asphalt pavement will become an issue and need to be justify. Therefore, this study has looked into the performance of asphalt pavement that has been simulate as a flooded condition.

The main aim of this study to evaluate of reversible moisture damage towards asphalt mixture performance using different parameters such as Indirect Tensile Strength (ITS) and Resilient Modulus (RM) tests. In order to achieve the aim of study, following objectives have been put forward:

- To evaluate the effects of different moisture conditioning period towards the asphalt mixture performance.
- To evaluate reversable moisture damage in asphalt mixture at certain drying period.

By reviewing literature related to moisture damage, it is quickly understood that there are multiple factors at work when evaluating pavement deterioration caused by moisture. There are several theories and mechanisms contributing to moisture damage are discussed. These theories were developed in order to gain a better understanding of the problem and attempt to address the issue at the most fundamental levels [5].

Water is the worst enemy of asphalt pavements. The presence of water (or moisture) often leads pavements to premature failure in the form of stripping caused by loss of adhesion between bitumen film from the aggregate surface. It is a well-known fact to everyone who has a slight knowledge of pavement engineering that how much animosity water has with the asphalt pavements. Premature failure always happens because of failure of the bond between bitumen film from the surface of the aggregate in form of the isolated distress or it may happen due to premature rutting or fatigue cracks developed in the asphalt mix which reduces its strength [11]. No one can deny the importance of the moisture sensitivity as an important mix design parameter. Francis Hveem realized the importance of water resistance and recognized its critical nature as an engineering property of the mix that should be determined in the selection of the quality material for pavement construction [16].

The physical and chemical characteristics of aggregate and the thickness of asphalt film are two major factors that influence on moisture induced damage in asphalt pavements. Pavements with rough aggregate surface and thicker bitumen film are less prone to damage caused by moisture [14].

In some cases, when the pavement is unloaded, moisture may just weaken the strength or stiffness of asphalt mixture without removing bitumen film from aggregate surface. The resulting loss of strength is recoverable when mixture is re-dried. But moisture induced damage may become irreversible when pavement is loaded during weakened condition [16]. It is described by Caro et al. [17] that MD is one of the main cause that lead pavements to early rehabilitation. They also stated that thermodynamic, chemical, physical, and mechanical processes are likely involved in this action.

Stiffness decreased with conditioning time and degradation process may include various stages with different degradation rates. The beginning stage with short conditioning time is identified with rapid loss of stiffness and in the middle phase of moisture conditioning has moderate degradation rate but it also highly depends on mixtures and last stage of conditioning involved in rapid degradation rate of stiffness. Stiffness degradation in asphalt mixture due to moisture damage is reversible when mixture is re-dried [18].

2. Methodology

In this study, PEN 60-70 bitumen were used as the base binder. All procedures referred to standard specification for Road Works (JKR/SPJ/2008-S4), AASHTO and ASTM.

2.1. Marshall Mix Design Method

Marshall mixture design method was employed in accordance with ASTM 1559 [19] to find OBC that was required for a given blending and grading of aggregates. Moreover, size limits for AC 14 were used according to JKR standard specification [20]. Specimens were fabricated as shown in Figure 1, using specific method of heating, mixing and compacting to asphalt mix aggregate. Marshall stability and flow test were performed as can be seen in Figure 2 on compacted specimen to determine the relative density and mix volumetric (density, Voids Total Mix, Voids fill with Asphalt) to calculate optimum binder content.

Figure 1. Specimens for Marshall Stability.

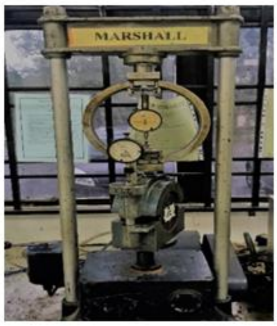

Figure 2. Stability and Flow Test.

2.2. Moisture Conditioning Specimens

To design the asphalt mixture, a standard marshal mix design method was used and 5.2% OBC was determined. The maximum size of aggregate used in mixture was 14mm with 5.2% binder content that had been compacted with Marshall compactor. Overall, 30 specimens (100mm by 65mm) were prepared for conditioning and laboratory testing (Indirect Tensile Strength and Resilient Modulus) to check the mixture performance at various stages (dry, wet and dry back). To evaluate the tensile properties and modulus value of mixture, 6 specimens were put into tests in dry state, whereas the remaining 24 specimens were conditioned as shown in Figure 3 in accordance with ASTM D4867 to examine the impact of moisture saturation of mixture, by immersing the specimens in water under vacuum pressure for 5 to 10 minutes to achieve saturation level up to 80% [21]. Afterward, specimens were immersed in water bath as can be seen in Figure 4 at various moisture conditioning period of 1, 3 and 5 days. At the end of each moisture conditioning period, specimens were taken out of water for the purpose of testing. After 5 days testing, specimens were kept at normal temperature for further 5 days to dry up for testing them again to determine recoverability of moisture damage.

Figure 3. ASTM D4867

Figure 4. Specimens Moisture Conditioning

2.3. Indirect tensile strength test

ITS test was applied in light of ASTM D 6931 [22] using Universal Compression Machine with Indirect tensile loading fixture as shown in Figure 5 on the (100mm diameter by 65mm thick) specimen under subsequent conditions. Additionally, there were three sets of specimens categorised for different conditioning phases such as dry (control), wet and dry back. They comprised of dry specimens that were kept at normal temperature for 10 days; moisture conditioned specimens that were immersed in water for various conditioning time (1, 3 and 5 days) and dry back specimens that were stored at normal temperature for drying them back for 5 days after initial moisture conditioning to represent the dry back phase. The ITS test was employed at 25 Celsius using loading rate of 50mm/min. The ITS (σ) of mixtures were calculated using equation (1).

$$S = \frac{2000P}{\pi t D} \tag{1}$$

Where:
P = Peak load (N)
D = Specimen's Diameter (mm)
T = Specimen's Thickness. (mm)

Figure 5. Universal Compression Machine.

2.4. Resilient Modulus Test

RM test was performed following ASTM D 7369-11 [23] under the repeated load using Universal Testing Machine as shown in Figure 6 at 25 Celsius on cylindrical specimens (100mm by 65mm) under different phase (control, wet and dry back). Specifically, specimens were tested in dry condition and as well as tested on 1, 3 and 5 days of water conditioning to check the effect of moisture conditioning period towards asphalt mixture performance. After 5 days testing specimens were stored at room temperature for another 5 days for dry back period and then tested to determine the recoverability of MD in mixture at certain drying period.

Figure 6. Universal Testing Machine.

3. Results and Discussion

3.1. Moisture Conditioning

To evaluate the effects of water saturation of compacted bituminous mixture, all the specimens that have been represent to different conditioning regimes were conditioned according to ASTM D4867 [21]. For the result all conditioned specimens achieved degree of saturation between 55 and 70% which is within the range 55-80% as required by ASTM D4867.

3.2. Indirect Tensile Strength

ITS test is used to determine the tensile properties of asphalt concrete which can be further relate to the cracking properties of pavement.

Figure 7 presents the indirect tensile strength of specimens at different condition (dry, wet and dry back). Specimens with maximum conditioning period (5 days) give the lowest value of tensile strength with 945 kPa while the unconditioned specimens shown highest value of ITS with 1273 kPa. A clear trend of decreasing the tensile strength with increasing conditioning period can be seen in Figure 7. Asphalt mixture total lost up to 26% of initial ITS at the end of 5 days conditioning, but intensity of decreasing the strength is higher at early period of conditioning with 14% loss of initial strength after 1-day conditioning while in others 4 days just lost up to 12% of initial strength.

Figure 7 also shows the result of tensile strength for dry back condition of mixture after drying period. Specimens recover 82% of initial strength which is evidence in the support of recoverability of moisture induces damage in asphalt mixture.

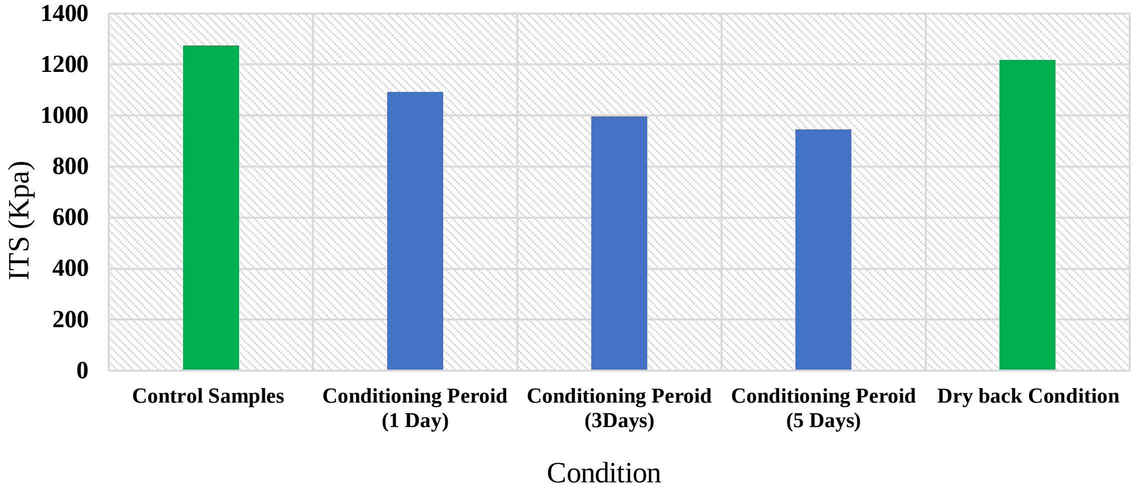

Figure 7. Indirect Tensile Strength.

3.3. Resilient Modulus

RM test is a performance test used to evaluate the relative quality of materials and asphalt mixture as well as to generate input for pavement evaluation and analysis.

Figure 8 shows the values of resilient modulus for all three stages (dry, wet and dry back) at temperature 25ºC with the pulse repetition period of 1000 ms. As shown in Figure 8, control (unconditional) specimens give the highest resilient modulus with 3239 Mpa while conditioned specimens shows lowest modulus with 1806 Mpa. Resilient modulus gradually decreases with increasing conditioning period. Asphalt mixture lost up to 44% of initial modulus at the end of 5 days conditioning. Initially, moisture susceptibility of mixture was observed slightly higher. After 24 hours of moisture conditioning mixture lost up to 14% of initial modulus. In the case of recoverability dried specimens recover 76% of initial modulus which slightly lower than then recoverability in the form of tensile strength.

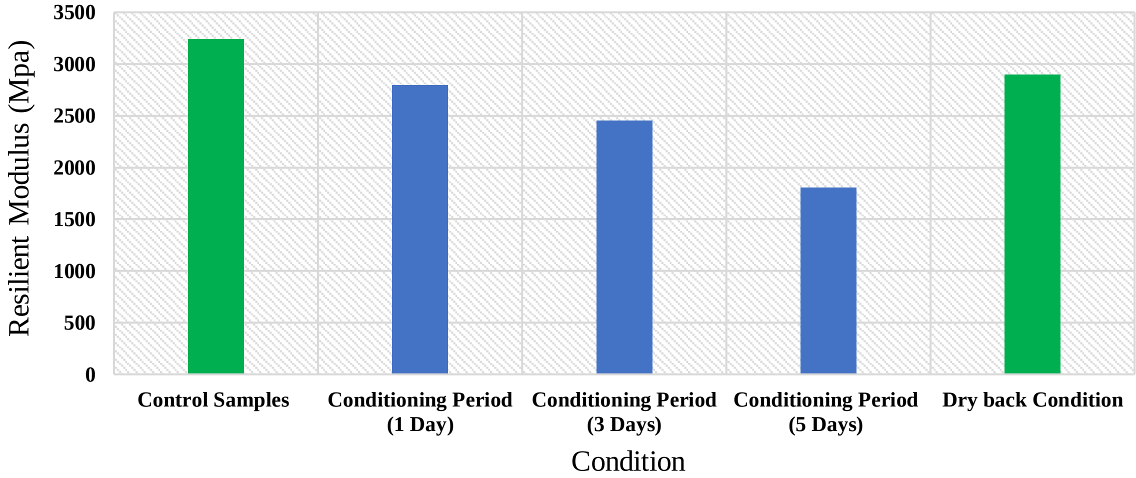

Figure 8. Resilient Modulus.

4. Conclusions

An experimental study has been conducted to evaluate the reversible moisture damage in hot mix asphalt mixture using ITS and RM tests. Based on the results obtained from laboratory experiments and analysis, the following conclusion were reached:

- A clear trend of gradually decreasing tensile strength and resilient modulus with increasing conditioning period. Mixture with maximum conditioning period (5 days) shows the less susceptible to fatigue cracking because of lower value M_R.
- Based on the result, initial conditioning period was reduced higher percentage of both Indirect Tensile Strength and Resilient modulus as compared to others interval.
- Upon drying at certain period mixture recovered 82% and 76% of the initial ITS and M_R. Recoverability of Indirect tensile strength found slightly higher then resilient modulus.
- It can be concluded that Indirect tensile strength of the mixture subjected to certain moisture conditioning regimes are recoverable upon drying. The results suggested Moisture damage in asphalt mixture tested is reversible.

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