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Effect of Moisture on Indirect Tensile Strength of Asphalt Concrete

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Abstract: Asphalt concrete is the most widely used in flexible pavement construction and other purposes in this worldwide. Including Malaysia, other countries also prefer to construct the road by using asphalt concrete and still learning about its mechanical and physical properties. In this study, problem of the asphalt concrete properties such as moisture effect to the asphalt concrete was discussed. It was to obtain the knowledge of moisture that presence in asphalt concrete. Basically, the effect of moisture to the asphalt concrete is resulting to the distress regarding to the adhesion and cohesion mechanisms in asphalt concrete itself. Losing of adhesion contributed by the presence of moisture getting into bitumen and aggregates resulting stripping damage to the asphalt pavement. The other mechanism which is losing of cohesion within the bitumen itself that resulting in a reduction in asphalt mix stiffness. The percentage of air void in compacted asphalt concrete sample and its effect to the asphalt concrete behaviour was distinctly discussed. The effect of moisture in asphalt concrete to Indirect Tensile Strength was also determined and discussed in this study. ITS test was conducted in this study to determine the Indirect Tensile Strength value and Tensile Strength Ratio to access the moisture susceptibility of asphalt concrete.

Keywords: Asphalt Concrete, Indirect Tensile Strength (ITS), Moisture

1. Introduction

Asphalt pavement type is widely use at this present in the worldwide. Many developing country prefer asphalt pavement to various application such as transportation roads, parking lots, recreational parks, landfill construction sites and industrial floors. Asphalt pavement is used in urban to a rural area as it is more convenient compare to any other type of pavement like concrete pavement. Asphalt concrete is a mixture of bitumen and different sized aggregates in certain proportions used as the top-most layer in flexible pavement [1]

Moisture in asphalt concrete is the presence of water or other liquid in a small quantity in asphalt concrete. There are various ways of water can intrude into the asphalt concrete. Three different mode which water can reach the asphalt concrete are infiltration of surface water due to permeability in mixture, permeation or diffusion of water vapour and capillary rise of subsurface water [2]. The

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infiltration of water from the soil into the asphalt concrete is one of the major methods of transporting moisture from asphalt pavements. Depending on the permeability, the type of mix used and other environmental factors such as the amount of precipitation, humidity, temperature and the amount of moisture that intrudes into the pavement [1]. The permeability of the mixture depends primarily on the composition of the air void in the mixture. Various functions have been formulated to characterize the permeability of the mixture. Complete voids in the climate properties such as void structure distribution used to model the porosity of air voids. The distribution of air voids in laboratory samples can be entirely distinct from the distribution of air voids in the field. Rise in water level due to surface forces between liquid and solid is known as capillary rise that is important modes of moisture intruding inside the asphalt concrete. Capillary rise in asphalt concrete can transport a big amount of moisture into the mixture. Generally, capillary rise does occur in asphalt mixtures when water comes in contact with the mastics. Capillary rise is not expected to occur if water is in contact with the neat binder caused by hydrophobic nature of the binder. Another important mode of moisture transportation in asphalt concrete is vapour diffusion. Factors of vapour diffusion are stated as diffusion coefficient, relative humidity and storage rate and capacity. The amount of water vapour and rate which it accumulates in asphalt concrete is depending on the factors stated [2].

Four different factors were believed as the main occasions that lead asphalt concrete to the moisture damage. Firstly, the characteristic of asphalt concrete. Form of mixture which a dense-graded mixtures is said more easily to cause a moisture damage compare to open graded mixtures. The cohesive or adhesive type failures chance is minimized if moisture or water is not allowed to stay in the mixture other than the characteristic of aggregate used in mixture that caused to stripping that include the surface texture, porosity, mineralogy, surface moisture and surface coating and also the viscosity of bitumen [3][4]. Secondly, moisture damage is highly occur if the weather condition is wet and cool during the construction. It can highly occur by the loose aggregate on the pavement surface which is frequently pushed into windshields [5]. Thirdly, pavement subsurface drainage with improper maintenance and services lead to the presence of the moisture in the pavement. Lastly, environmental effect after construction that affect the stripping where wet-dry cycles, temperature fluctuations and freeze thaw cycles will allow moisture in asphalt pavement that contribute to stripping. Pore pressure build up and hydraulic scouring are the mechanisms that resulted from traffic loading and relates to the damage of pavement [3].

Durability of asphalt mixtures depends on two main factors: resistance to age hardening and resistance to moisture damage [6]. Damage in asphalt due to moisture have been studied to characterized and understand the factors and impact of it. The common phenomena observed in asphalt pavements due to the moisture damage are stripping which is separation of bitumen and aggregate, raveling which is dislodgement of aggregate particles in asphalt mixture from the surface, and hydraulic scour, a process that occurs on a saturated surface by which the pavement material is eroded due to dynamic action of tires in the presence of water. Excessive of stripping damage due to repeated traffic loading resulting in pavement failure and deformation occurrence [3]. Stripping failure main factor is the loss of adhesion in bitumen after excessive interaction with moisture [7]. Serious pavement deformation and failure can occur as a result of repeated loading if stripping within the pavement becomes excessive. Stripping failure can take the form of pavement potholes, cracking or surface raveling [1]. Figure 1 below shows the pavement distress due to moisture damage in asphalt pavement which are resulted from stripping.

Figure 1: Pavement Distress Subjected to Moisture [11]

2. Assessment of Moisture Susceptibility in Asphalt Concrete

Moisture susceptibility is the loss of strength in asphalt concrete mixtures due to the effects of moisture and can result in rutting and fatigue cracking distresses developing [8]. Moisture susceptibility of asphalt concrete can be access by Indirect Tensile Strength (ITS) test conducted in the laboratory. The Indirect Tensile Strength is the maximum tensile stress which was calculated from the peak load applied at sample failed and the dimensions of the sample. It is to determine the Tensile Strength Ratio (TSR) after the acquirement of ITS value. The test was carried out to assess if the materials were subject to stripping in the asphalt concrete sample.

3. Materials and Methods

The method used in this study was experiment on materials which asphalt concrete in the laboratory. The experimental works were carried out based on the Standard Specification for Road Work by Malaysian Public Work Department. The first stage was the preparation of materials for the test. Once the samples were prepared, the test were carried out accordance to the objectives.

3.1 Materials

The first stage of this study after the problem identification and literature reviews was the selection and preparation of materials. The specifications and properties of materials, equipment, and other resources used in this study was described as below:

- Fine and coarse aggregates from Batu Pahat quarry. Sieve analysis test for gradation of aggregates using wearing coarse AC 14 mix designation from the Standard Specification for Road Work by Malaysian Public Work Department [12].
- Bitumen penetration grade 60/70 with Optimum Bitumen Content (OBC) 5.82% in mixture [9].
- 20 Hot Mix Asphalt samples for ITS test using Marshall method divided by two group which are conditioned (wet) and unconditioned (dry).

3.2 Methods

Indirect Tensile Strength (ITS) test was conducted after the samples preparation process. An approximate of 1200 g of aggregates was heated to a temperature at 175°C to 190°C. Bitumen was heated with a temperature of 121°C to 125°C. Then, aggregates and bitumen heated were mixed thoroughly at a temperature of 154°C- 160°C by using Thermostatic Asphalt Planetary Mixer. The mixing process was set up for 120 seconds and ready mixture was placed in a preheat mould. Mixture in the mould was compacted by a rammer with 75 blows on each side at temperature of 138°C to 149°C using Automatic Marshall Compactor. After the completion of compaction process, the compacted sample was extruded from the mould by using sample extractor and stored in room temperature.

Theoretical maximum specific gravity (G_{mm}) according to AASHTO T209-12 [13], the bulk specific gravity (Gmb) in accordance with AASHTO T 166-13 [14] and lastly the thickness (t) and diameter (D) were determined to obtain the percentage of air void in the compacted samples before the wet samples were conditioned. The samples were placed in water bath at 60 ± 1°C temperature for 24 ± 1 hours by 25 mm of water above their surface. The method of conditioning the samples was directly immersed in the water bath without saturation vacuum. This method was used to simulate the real situation at site which heavy rain and mainstream weather occur in the areas that received the most rainfall that caused mainstream surface runoff and flood that allows the asphalt pavement immersed in a long period of time in water. Then, the samples were removed from the water bath for the preparation of ITS test.

Sample was positioned on its side between the bearing plates of the test machine. The steel loading strips was placed between the sample and the bearing plates. By pressing the bearing plates together at a constant rate of 50 mm per minute, a load was applied to the sample. The maximum load was recorded, and the load continued until the sample cracked. The machine was stopped and the sample broke apart at the crack for observation.

3.3 Equations

Percentage of air void was calculated by using the Equation 1 below:

$$Air\ void\ percentage\ (\%) = \frac{Gmm - Gmb}{Gmm} \times 100\ Eq.1$$

Where Gmm is the theoretical maximum specific gravity and Gmb is the bulk specific gravity. Indirect Tensile Strength value in kPa was determined by calculating the Equation 2 below:

$$ITS = \frac{2P}{\pi tD} Eq.2$$

Where P is the maximum tensile load in kN, t is the thickness and D is the diameter of the samples in mm. Then, Tensile Strength Ratio (TSR) was calculated by the Equation 3 below:

$$TSR = \frac{ITS_{Wet}}{ITS_{Dry}} \times 100\ Eq.3$$

Where ITS_{Wet} is the average tensile strength of the conditioned subset in kPa and ITS_{Dry} is the average tensile strength of the dry subset in kPa.

4. Results and Discussion

This section described the data and analysis from the experiment conducted in this study. The results obtained were analyzed according to the tabulated data and graphical illustration as shown below.

4.1 Results

Indirect Tensile Strength (ITS) value was calculated by using Equation 2 where the peak load from the ITS test was recorded for each sample. The percentage of air void was also calculated by Equation 1. The results from this tests were shown in Table 1 below:

Table 1: Air void and ITS value

Sample	Sample/ Condition	Indirect Tensile Strength, ITS (kPa)	Air Void Percentage (%)
1	Dry	782	5.25
	Wet	589	4.54
2	Dry	851	4.77
	Wet	489	4.35
3	Dry	855	4.72
	Wet	459	4.62
4	Dry	792	4.77
	Wet	429	4.68
5	Dry	715	6.33
	Wet	397	4.74

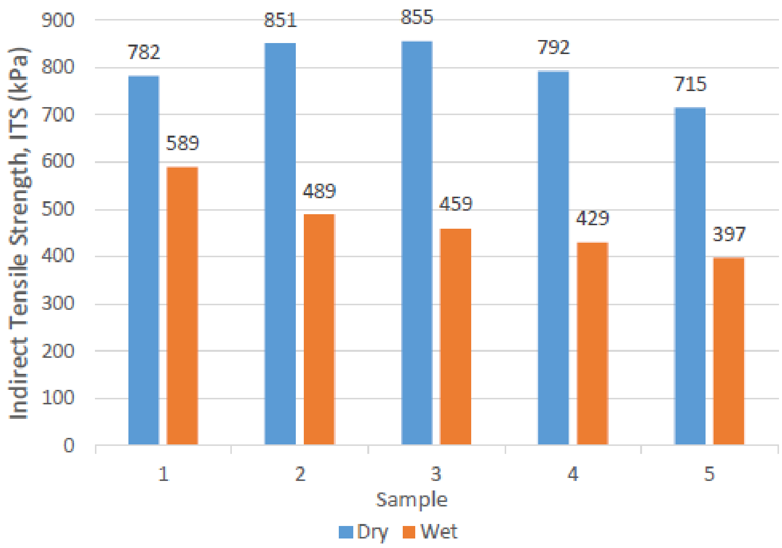

Figure 2: The Indirect Tensile Strength for wet and dry condition

Based on Figure 2, it was observed that the average ITS value of dry sample was 799 kPa, meanwhile average ITS value for wet sample was 473 kPa. The highest value on the graph was 855 kPa which was the ITS value for dry sample 3 whereas the lowest value was 397 kPa. The percentage difference between the highest ITS value and lowest ITS value attained was 53.57%. A significant number of percentage on the difference of strength in asphalt concrete samples proved that the moisture present in the samples gave a significant impact to the strength of asphalt concrete. From the data obtained, ITS value for dry sample is higher compared to ITS value for the wet sample. It was because of the presence of moisture had the effect to the sample's bond between aggregate and bitumen, indirectly reduced its tensile strength. This data showed that the presence of moisture in asphalt concrete gave some impacts to asphalt concrete such as the reduction of strength that lead to damage on road pavement. The mixture that indicates higher ITS value is capable of withstanding larger tensile stress prior to cracking [10]. The percentage of air void is believed to have the relationship with ITS value of asphalt concrete samples. According to Figure 3, the result for air void percentage and ITS value is shown below.

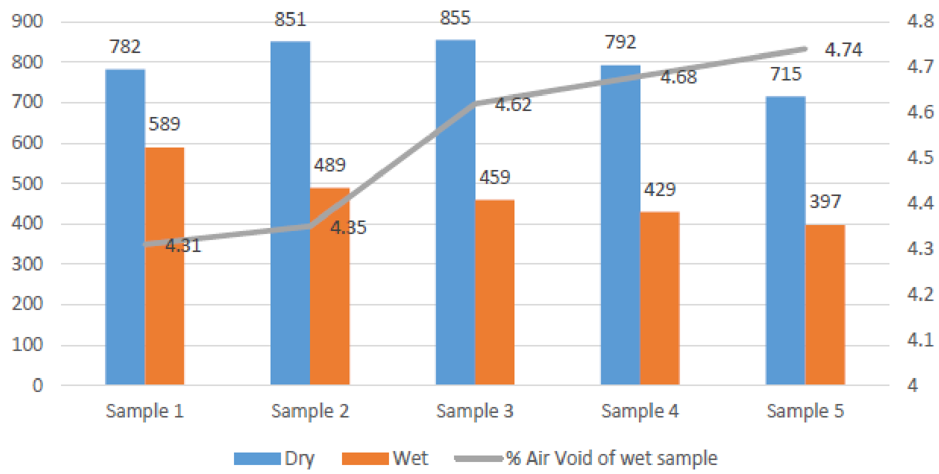

Figure 3: Relationship between ITS value and air void percentage of wet sample

From this result, it can be interpret that ITS value of wet sample improved as the lower percentage of air void in wet samples. The percentage difference between the highest percentage of air void which was 4.74% and the lowest percentage (4.31%) was determined by 9.07% of difference. The difference in percentage was concluded as there were a reduction in indirect tensile strength of asphalt concrete in trend with the percentage of air void. High percentage of air void in sample somehow lead to the excess pathway for moisture to retain in the samples which will caused the moisture damage. However, too low amount of air void percentage resulted in flushing which was when extra bitumen is forced to the surface from the mix. The relationship of indirect tensile strength and the percentage air void in samples existed.

Then, moisture sensitivity in asphalt concrete was determined from the tensile strength ratio (TSR). TSR results were used in evaluating the performance of asphalt concrete in terms of moisture damage. TSR is the ratio of indirect tensile strength of wet sample to indirect tensile strength of dry sample. TSR represented moisture damage of asphalt concrete that caused by the reduction in mixture reliability. According to AASHTO T283, it was stated that minimum TSR was 80% [15]. Table 2 and Figure 4 showed the TSR results for this study.

Table 2: Tensile Strength Ratio of this study

Sample	Tensile Strength Ratio, TSR (%)
1	75.3
2	57.5
3	53.7
4	54.2
5	55.5

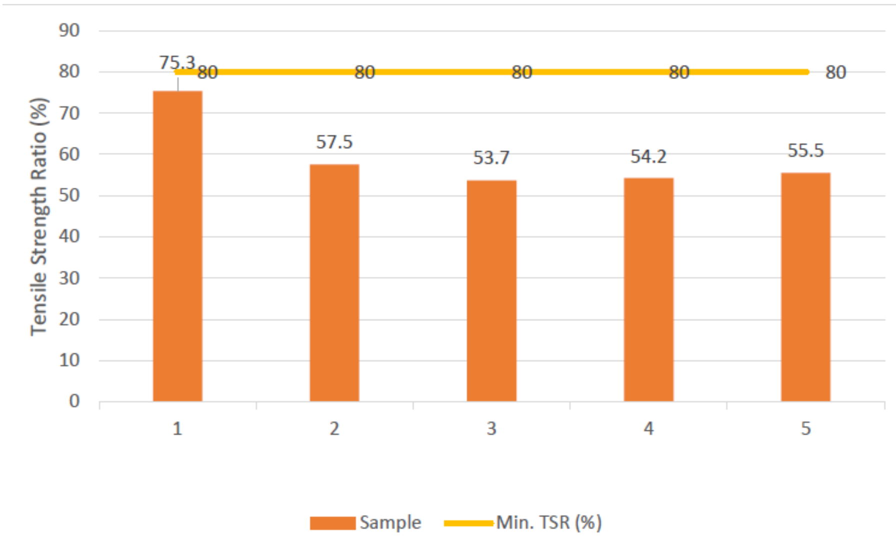

Figure 4: Tensile Strength Ratio bar chart

From the result, it shows that TSR value were obtained for sample 1 (75.3%), sample 2 (57.5%), sample 3 (53.7%), sample 4 (54.2%) and sample 5 (55.5%). From the data gained, it showed that all the samples tested not passed the value of minimum requirement of moisture susceptibility according to AASHTO T283 which indicate that TSR value must exceed 80%. All the samples were indicated as failed as the TSR value for each sample was under 80%.

This is because of the wet samples were immersed and conditioned in the water bath for a long period of time which was 24 hours. The stripping was occur in the asphalt concrete sample as the presence of excessive moisture in the samples. This indicated that the moisture susceptibility of this mixture design will fail if it is apply for the road pavement in areas that often affected by severe flooding.

5. Conclusion

The conclusion that can be made from this study were the presence of moisture in asphalt concrete caused the reduction of asphalt concrete strength as there was a significant difference value of peak load recorded between two samples subsets. Next, Tensile Strength Ratio (TSR) of each sample was obtained. From the data obtained, it showed that all the samples tested not passed the value of minimum requirement of moisture susceptibility according to AASHTO T283 [15] which indicate that TSR value must exceed 80%. All the samples were indicated as failed as the TSR value for each sample was under 80%. The author also can conclude that the failure of each sample in this study to achieve minimum requirement value of TSR indicated that mixture design and OBC used could not probably suitable for the road pavement in areas that recognized often affected by severe flooding. However, the objective of this study was achieved as the moisture susceptibility of asphalt concrete in this study was determined and it was stipulated that there was the effect of moisture to indirect tensile strength in asphalt concrete. Lastly, the author can conclude from this study that the relationship of air void percentage in asphalt concrete sample and ITS value indicated that the influence of air void to the amount of moisture presence in the asphalt concrete affecting the strength of bitumen aggregate bonding.

6. Recommendation

It was recommended as freeze and thaw cycle process in Indirect Tensile Strength (ITS) test can be performed in evaluating moisture resistance in asphalt pavement to represent countries of four seasons by testing on wet or conditioned specimens in another study. Other than that, it also recommended to perform various performance testing of asphalt mixture such as Fatigue test, Boil test, Hamburg test, and others on effect of moisture to obtain other parameters.

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