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The Effect of Moisture on Hot Mix Asphalt – Case of Indonesian Aggregates

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Abstract: Indonesia is a tropical country and has a monsoon season. It is a common problem in major cities of Indonesia, especially in Jakarta, to have a road pavement being damaged after the rainy or monsoon season, especially when the pavements were flooded. This research aims to study the effect of moisture on asphaltic surfaces as designed according to Indonesian standards in order to determine the characteristic of the asphaltic mixture. The results of this study could help in identifying the issue(s) that cause the susceptibility of the asphaltic mixture, and hence, in the future, these issues could be handled better.The samples were prepared by using two different natural aggregates and two 60/70 asphalt binders that were sourced from different producers. There were four sample combinations prepared, which were then tested for Marshall, Cantabro Loss, and Indirect Tensile Strength (ITS) tests. The Marshall test was used to determine the stability and the flow of aggregates, while the other tests were used to determine the impact of water or moisture on the prepared samples. It was found that the samples that were prepared using Aggregate 2 had a higher stability and were more resistant to abrasion load after the samples being immersed in the water for one hour (based on the Cantabro Loss test results) than the samples that were prepared using Aggregate 1. However, from the ITS test results, it was found that the samples that were prepared using Aggregate 2 became "weaker" after being immersed in the water for 24 hours compared to the samples that were prepared using Aggregate 1. This could be due to the fact that Aggregate 2 had a higher percentage of water absorption value, which will place in effect after a long period of time. It did not seem to matter when the samples were being immersed for only one hour. It was also found that the Cantabro Loss and ITS test results had an inverse relationship, which could be due to the difference in the immersion time of both tests.

Index Terms: hot mix asphalt, Cantabro Loss, Indirect Tensile Strength, moisture

I. INTRODUCTION

Indonesia has been undergoing a massive development on its infrastructure, especially on its highway and road networks. Flexible pavement, specifically hot mix asphalt (HMA), is the still the most commonly used pavement type in Indonesia, despite the fact that the percentage of heavy commercial vehicles are continuously increasing due to the economic growth [1]. Therefore, it is important to ensure that the pavements are reliable and durable. However, a common problem found in many road sections in major cities of Indonesia, such as Jakarta, is a growing number of potholes, cracks, and other pavement distresses after the rainy or monsoon season, especially when the pavements were flooded [2] .

It is a well-known issue that when the presence of water in asphalt mixture could lead to loss of strength and durability of the pavement as the water intrudes the adhesion bond between the binder and the aggregate [3]. The most commonly found pavement distresses in flexible pavement (with asphaltic road surface) due to the presence of water are stripping, potholes, and rutting [4]. There are a number of factors that could affect the susceptibility of asphalt mixture to moisture or water, including the aggregate properties (mineralogy, source of aggregate, and moisture content) and the binder properties (stiffness, chemical composition, and refining process) [5], [6].

Usually the pavement distresses that are caused by the presence of water or moisture starts at the bottom of the asphaltic surface or at the interface between asphalt layers and then continues to become a localized pothole, which eventually leads to a crack [7], [8].The combination between continuous water intrusion, existing pavement distress, and traffic loading will damage the pavement layers even further [8].

There are a number of research projects that have been undertaken worldwide to study the effect of moisture in asphaltic surfaces [9], [10]. This research aims to study the effect of moisture in asphaltic surfaces made of local aggregates and asphalt as designed according to Indonesian standard.

II. RESEARCH DESIGN

The steps followed for this study was presented in the flowchart, as seen in Figure 1.

A. Materials

HMA consists of aggregates, binder (asphalt), and filler (optional). In this research, two types of natural aggregates were used, namely Aggregate 1 and Aggregate 2, as shown in Figure 2 and Figure 3, respectively. These aggregates were crushed into four sizes, as shown in Table 1. The coarsest aggregates are denoted as Aggregate I and the finest aggregates are denoted as Aggregate IV.

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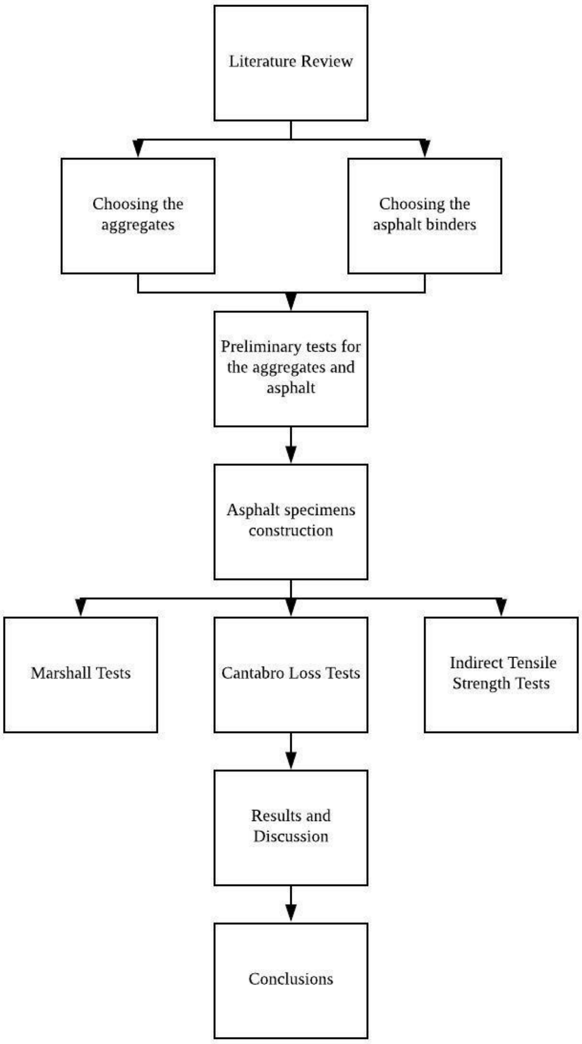

Fig. 1 Research Flowchart

Fig. 2 Aggregate 1

Fig. 2 Aggregate 2

Table 1 Aggregates Grading

Aggregate	Passed Sieve No.	Retained by Sieve No.
I	¾” (19.1 mm)	3/8” (9.6 mm)
II	3/8” (9.6 mm)	#8 (2.4 mm)
III	#8 (2.4 mm)	#16 (1.2 mm)
IV	#16 (1.2 mm)	#200 (0.075 mm)

There were two types of binder used in this research. Both binders were asphalt with 60/70 penetration (as stated in the product specifications) but they were sourced from different producers. There was no filler or additive used in this research. The asphalt samples were prepared with 5.5% asphalt content and the composition of each sample is shown in Table 2 as designed according to [11].

Table 2 Composition of HMA Design

Asphalt Content		Weight of Aggregate (gr)			
%	**gr**	**I**	**II**	**III**	**IV**
5.5	66	242	193	181	476

B. Sample Preparation

Before the asphalt samples being made, both aggregates and binders were assessed for their suitability to be used. There were a series of tests conducted according to the Indonesian National Standard (SNI), as listed in Table 3 and Table 4. From the results, it could be seen that both aggregates passed the requirements. The specific gravity values for aggregate grading I were slightly lower than the requirement, but the aggregates were still used for this research as both aggregates were the common aggregates to be used infield.

Table 3 Assessment Test Results for Aggregate 1

Tests	Aggregate				Requirement
	I	**II**	**III**	**IV**	
Bulk Specific Gravity	2.4	2.5	3.11	4.51	≥ 2.5 gr/cc
SSD Specific Gravity	2.41	2.55	3.44	4.61	
Apparent Specific Gravity	2.44	2.66	3.36	4.53	
Absorption (%)	0.96	2.76	2.4	2	≤ 3%
Los Angeles Abrasion	16.75%				≤ 40%

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Table 4 Assessment Test Results for Aggregate 2

Tests	Aggregate				Requir ement
	I	II	III	IV	
Bulk Specific Gravity	2.39	2.51	3.11	3.42	≥ 2.5 gr/cc
SSD Specific Gravity	2.42	2.59	3.44	3.96	
Apparent Specific Gravity	2.48	2.73	3.36	3.84	
Absorption (%)	1.56	3.28	2.4	3.22	≤ 3%
Los Angeles Abrasion	14.18%				≤ 40%

The binders were also tested for their suitability to be used according to SNI. For confidentiality purposes, the binders were named as "Asphalt P" and "Asphalt S". Based on the data presented in Table 5, it can be seen that both binders satisfy all the requirements stated in the SNI.

Table 5 Assessment Test Results for the Binders

Tests	Standard	Asphalt P	Asphalt S	Requirement
Penetration at 25°C	SNI 06-2456-1991	64 mm	69 mm	60-70 mm
Specific Gravity	SNI 2441-2011	1.074 gr/cc	1.114 gr/cc	Min. 1.0 gr/cc
Ductility at 25°C	SNI 2432-2011	126 cm	160 cm	Min. 100 cm
Softening Point	SNI 2434-2011	50°C	50°C	Min. 48°C
Flash Point	SNI 06-2433-1991	365°C	306°C	Min. 232°C
Fire Point	SNI 06-2433-1992	368°C	338°C	Min. 288°C

C. Sample Construction

From the two aggregates and the two binders used in this research, there were four asphalt mixture combinations prepared, as seen in Table 6. For each combination, there were 12 samples constructed, which were used for Marshall, Cantabro Loss, and Indirect Tensile Strength (ITS) tests (4 samples for each test).

Table 6 Research Matrix

	Asphalt P	Asphalt S
Aggregate 1	Combination 1	Combination 2
Aggregate 2	Combination 3	Combination 4

D. HMA Tests

As stated in 2.3, there were three tests conducted for the asphalt samples and the tests were conducted according to certain specifications as listed in Table 7.

Table 7 Test Specifications

Tests	Specifications
Marshall	SNI 06-2489
Cantabro Loss	Tex-245-F
ITS	AASHTO T-283

The Marshall tests were conducted for the prepared asphalt samples according to *Standar Nasional Indonesia* (SNI) 06-2489-1991 [12] to determine the characteristics of the asphalt mixture samples. The test results will generate several parameters, including stability, flow, Void in Mix (VIM), Void in Mineral Aggregate (VMA), Void Filled with Asphalt (VFA), and density.

The Cantabro Loss test is a test that could be used to determine the loss of abrasion of compacted HMA samples as stated in [13]. This test measures the breakdown of the prepared asphalt samples with Los Angeles Abrasion device. The Cantabro Abrasion Loss (CAL) was determined by calculating the percentage difference the between initial and final weight of the samples after they were being rotated in Los Angeles machine for 300 revolutions at a speed of 30 revolutions per minute (rpm).

For this research, due to the equipment limitation, the procedure for this test was slightly modified. The samples were prepared with a diameter of 10 cm. This is smaller than the specimen size specified in [13], but it does not hinder in accomplishing the objective of this test as this test is looking at the percentage lost after the specimens being abraded. Moreover, the prepared specimen was immersed in water bath at 60°C for one hour to simulate the HMA surfaces being flooded, and hence, the ability of the specimen to resist disintegration action after contact with water can be assessed. This procedure is similar to the research project described in [14], although they immersed the specimen for 24 hours in the water at 60°C.

The ITS test is a test to determine the ratio of the stability or the strength of a sample when the sample is dry (sample is denoted as "Dry") to the stability or the strength of a sample when the sample has been immersed in the water bath for 24 hours at 60°C (sample is denoted as "Sat").

III. RESULTS AND DISCUSSION

A. Marshall Test Results

Table 8 shows the average Marshall test results and some other parameters for all four combinations. It could be seen that asphalt variations that satisfied the requirement are combination 3 and combination 4.

The main difference between the combinations 1 and 2 and combinations 3 and 4 is the aggregate used. Aggregate 1 was manually crushed to the required sizes, while Aggregate 2 was obtained from an asphalt mixing plant, and hence, the aggregates would have been crushed into the required sizes by using an automatic crusher. The usage of crusher, not only helped in speeding up the process, but also, ensuring that the aggregates to be angular, which will be useful to achieve a good interlocking motion when being compacted. In this research, all the elongated and flaky aggregates were not used. From the results, it can be seen that none of the combinations could achieve the required density. This could be due to the compaction process, which still used the manual compactor. Moreover, the stability of samples with combination 1 and combination 2 did not achieve the required value, while the samples with combination 3 and combination 4 had a very high value and exceeded the required value, which is good.

Table 8 Marshall Test Results

Parameter	**Combination**				Requirement
	1	**2**	**3**	**4**	
Sample height (cm)	7.68	7.95	7.9	7.9	[redacted]
Dry weight (gr)	1239.15	1238.1	1312.5	1300	[redacted]
SSD weight (gr)	1296.4	1277.35	1347.5	1332.5	[redacted]
Weight in the water (gr)	666.4	666.3	721.2	707	[redacted]
Bulk specific gravity	1.97	2.02913	2.1	2.08	[redacted]
SSD specific gravity	2.0575	2.09	2.12	2.13	[redacted]
Stability (kg)	639.28	516.21	1695.63	1541.8	≥ 800
Flow (mm)	4.725	3.65	4.35	4.99	3-6
Void in Mixture (%)	5.46	4.41	5.01	5.03	3-6
Void Filled with Asphalt (%)	73.46	80.99	75.87	76.46	≥ 65
Density (gr/cm^3)	1.97	2.01	2.145	2.07	≥ 2.2
Void in Mineral Aggregates	20.57	23.76	20.71	21.56	≥ 16

B. Cantabro Test Results

Table 9 shows the average Cantabro Loss tests results and some other parameters for all four sample combinations. Cantabro Abrasion Loss (CAL) is the output generated by the Cantabro Loss test. It measures the percentage of difference between the initial sample weight and final sample weight after the sample being abraded in the Los Angeles abrasion device. The higher the CAL values, the more susceptible the sample will be to the presence of water or moisture. From the data, it can be seen that sample constructed with combination 1 had the highest CAL value of 15%, while the sample constructed with combination 3 had the lowest CAL value (8.9%). Overall, it can be seen that the asphalt samples that were constructed using Aggregate 2 had a lower CAL values compared to the other samples that were constructed using Aggregate 1. From Table 9, it can also be observed that asphalt samples that had higher specific gravity values (both bulk and SSD) had a lower value of CAL. The specific gravity can give an indication on how compact the sample is. Thus, it can be concluded that the more compact a sample, the more resistant the sample will be to the abrasion force caused by the traffic loading when water or moisture is present.

Table 9 Cantabro Loss Test Results

Parameter	**Combination**			
	1	**2**	**3**	**4**
Sample height (cm)	8.3	7.925	8.05	7.9
Initial sample weight (gr)	1260.4	1230	1273.1	1300
Final sample weight after being abraded (gr)	984.475	891.75	1159.6	1148.9
SSD weight (gr)	1280.425	1273.5	1299.85	1332.5
Weight in the water (gr)	647.225	653.1	698.2	723.8
Bulk specific gravity	1.990717	1.982943	2.11618	2.13684
SSD specific gravity	2.022344	2.052813	2.160631	2.190149
CAL	15%	13.65%	8.90%	11.68%

C. ITS Test Results

Table 9 shows the average ITS test results and some other parameters for all four sample combinations. ITS value is the ratio of the stability or the strength of a sample when the sample is dry to the stability or the strength of a sample when the sample has been immersed in the water bath for 24 hours at 60°C.

It can be seen that the samples that used Aggregate 2, which are the combinations 3 and 4, had higher ITS values compared to the other aggregates. It shows that the samples with combinations 3 and 4 had a lower resistance to moisture compared to the samples with combinations 1 and 2. This could be due to the fact that Aggregate 1 has a lower water absorption level (as seen in Table 3).

Table 10 Indirect Tensile Strength Test Result

Parameter	Combination 1		Combination 2		Combination 3		Combination 4	
	Dry	Sat	Dry	Sat	Dry	Sat	Dry	Sat
Sample height (cm)	7.375	8.3	8	8.1	7.75	7.55	7.8	7.6
Dry weight (gr)	1150	1235	1200	1205	1275	1290	1300	1260
SSD weight (gr)	1165	1250	1235	1245	1305	1320	1330	1290
Weight in the water (gr)	535	575	570	595	600	625	625	625
Stability (kg)	0.31	0.275	0.14	0.21	0.25	0.66	0.25	0.415
Flow (mm)	3.85	2.755	3.22	1.62	2.64	2.44	2.68	2.5
Left flow (mm)	97	80	187.5	87.5	112.5	90.5	125	65
Right flow (mm)	90	62.5	117.5	69.5	80	50	132.5	67
ITS	0.81		1.48		2.73		1.71	

D. Factors Affecting CAL Values

After all the test results have been obtained, further analysis was conducted to study the relationship between the parameters to understand which factors affecting the CAL and ITS values, and eventually, which parameter(s) are contributing to improve the moisture resistance of asphalt mixture. Figure 4 shows the relationship between CAL and the Marshall test parameters, namely the stability, flow, VFA, VMA, VIM, and density for the four sample combinations. It can be observed that there is a strong relationship between the stability and the density of the samples to the CAL values, while there is no relationship that can be found between the CAL and the other parameters. The higher the stability, the lower the CAL values will be and the higher the density, the lower the CAL values will also be. This suggests that the ability of an asphalt mixture to resist traffic loading is strongly related to its ability to bear the abrasion load with the presence of water or mixture. The density parameter, which shows how compact the sample is, is strongly related to the CAL values. The denser or the more compact a sample is, the more susceptible the sample will be to the abrasion load due to traffic loading. This is due to the increasing percentage of air void when the density of a sample decreases.

E. Factors Affecting ITS Values

Figure 4 shows that there is a strong relationship between ITS and CAL values, with the coefficient of determination (R^2) of 0.96. The higher the CAL values, the lower the ITS values will be. This is an interesting finding as what is hoped to be seen is the opposite, which is the higher the CAL values, the higher the ITS values should be. A sample is said to have a higher resistance to moisture when the ITS values are low. However, it is important to note that CAL and ITS tests produced different parameters and the test methods were also different. The relationship observed in Figure 5 could be explained by the immersion duration during both tests. The Cantabro Loss test only immersed the samples for one hour before the samples were put to the Los Angeles Abrasion device, while the ITS test immersed the samples for 24 hours before the samples were placed in the test device.

IV. CONCLUSIONS

From this research, it can be concluded that aggregate is the most influential component in determining the stability and the strength of an asphalt mixture, especially the shape of the aggregate. Having angular aggregates as the ingredients of the asphalt mixture will help the aggregates to have a good interlocking between the aggregates, which will help in improving stability of the asphalt mixture samples. This finding was also observed in Cantabro Loss test results. The samples that were prepared using Aggregate 2 had a higher resistant to moisture than the samples that were prepared using Aggregate 1. However, the opposite was found in the ITS test results. The samples that were prepared using Aggregate 2 was actually had a higher ITS values compared to the samples that were prepared using Aggregate 1, which suggest that the samples are more susceptible to moisture, and hence, after being immersed in the water for 24 hours, the samples become weaker. This could also be due to the fact Aggregate 2 has a higher percentage of water absorption, which will lead to more water being absorbed during the 24 hours immersion time.

Additionally, it was also important to pay attention to the asphalt samples compaction method, especially when the samples were compacted manually, as the method will determine the quality of the samples. There is an inverse relationship found between the CAL and the ITS values, which could be due to the difference in the immersion time for the samples before they were placed in the test devices.

In conclusion, it is necessary to ensure that the aggregates used in the asphaltic mixture satisfy all the requirements stated in SNI and have angular shapes. Having an aggregate with high absorption value could lead to reduction in strength and stability of the asphaltic mixture, especially when exposed to moisture or water.

Moreover, there were two asphalt binders used for this study and there was not any significant effect observed between the two.

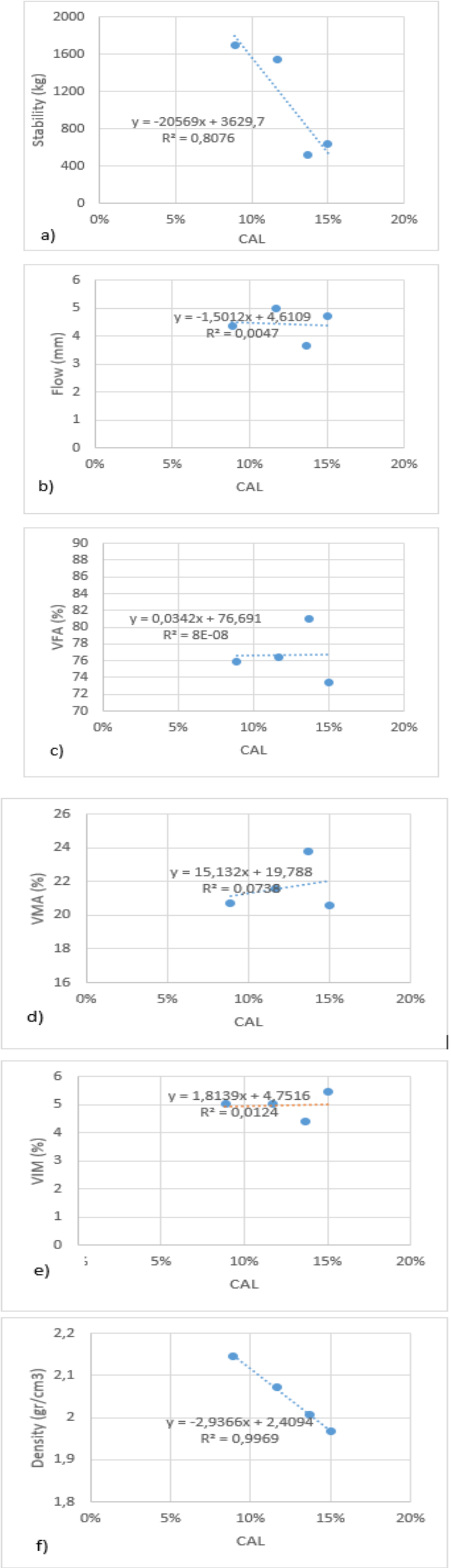

Fig. 4 Relationship between CAL and stability (a), flow (b), VFA (c), VMA (d), VIM (e), and density (f)

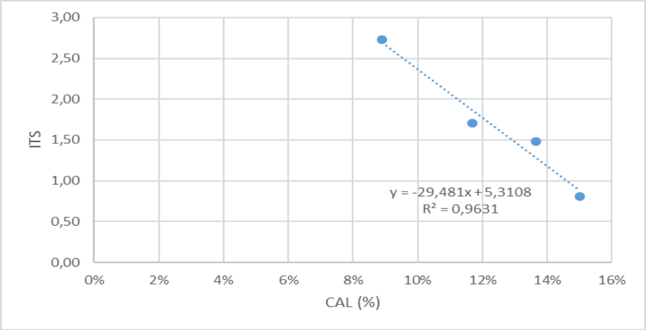

Fig. 5 Relationship between CAL and ITS values

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