Analysis of moisture susceptibility of hot mix asphalt with waterproofing additives

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Abstract. Having a good infrastructure system, especially the road networks, is important in supporting the country growth, and hence, it is necessary to ensure that the pavement does not deteriorate earlier than its designed lifetime. The most commonly pavement failures found are potholes and stripping, which are related to water intrusion to the hot mix asphalt (HMA). This research aims to provide an analysis on the moisture susceptibility of HMA with the addition of waterproofing additives, namely the Wetfix-BE, Wetbond-SP, and hydrated lime. The Marshall, Cantabro Loss, and Indirect Tensile Ratio tests were undertaken to assess the performance of the prepared samples. It was found that the specimens that were prepared using hydrated lime, as an alternative and low-cost waterproofing additive, perform reasonably well compared to the specimens that were prepared using the other additives.

1. Introduction
The most common pavement failures that can be found in Indonesia is potholes and other distresses that related to water intrusion [1]. Water intrusion in asphaltic mixture could lead to reduction in strength and durability of the samples as the adhesion bond between the asphalt and the aggregate is being interfered by water and the cohesive bond in the binder or bitumen could be lost [2]. There are some factors that could affect the susceptibility of asphaltic surfaces to water, including the aggregates properties (minerals, source of aggregate, angularity, dust, and moisture content), the asphalt binder properties (stiffness, chemical composition, and refining process) [2], [3].

A number of research projects have been undertaken to study the effect of water or moisture on asphaltic mixture [3]–[7]. This research aims to analyse the effect on adding additives onto the prepared asphaltic samples, which were constructed by using local aggregates. This research also compares the effect of adding three different additives, which consists of two chemical additives (Wetfix-BE and Wetbond-SP) and one natural additive (hydrated lime).

2. Experimental Design
2.1. Aggregates
The aggregate used for this research project was a natural aggregate sourced from a local quarry. The aggregates were crushed and then sieved into four sizes, as seen in Table 1. Table 2 lists the test results to ensure the aggregates were suitable to be used in the asphaltic mixture. The standards were issued by
Standar Nasional Indonesia (SNI) It was found that some of the results did not meet the requirements, but these aggregates were used as they have been used for road constructions previously.

Table 1. Aggregates gradation.

| 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)       |

Table 2. Aggregate tests results.

| Tests                          | Standards                        | Results | Requirements |
|--------------------------------|----------------------------------|---------|--------------|
| Bulk Specific Gravity          | SNI 1969:2008 and SNI 1970:2008  | I 2.33  | II 2.37      | III 2.42     | IV 2.42 | ≥ 2.5 gr/cc |
| SSD Specific Gravity           | SNI 2417:2008                    | 2.45    | 2.45         | 2.96         | 3.07    |
| Apparent Specific Gravity      | 1970:2008                        | 2.64    | 2.64         | 2.80         | 2.88    |
| Absorption (%)                 |                                  | 5.04    | 4.26         | 5.61         | 6.56    | ≤ 3          |
| Los Angeles Abrasion (%)       | SNI 2417:2008                    | 11%     |              |              |        | ≤ 40         |

2.2. Asphalt

Asphalt with penetration value of 60/70 was used for this research project. Similar to the aggregate, the asphalt underwent a series of tests to ensure that the asphalt satisfies the requirements. It can be seen from Table 3 that the asphalt has passed all the requirements stated in the standards.

Table 3. Asphalt test results.

| Tests                          | Standards                        | Unit   | Result | Requirements |
|--------------------------------|----------------------------------|--------|--------|--------------|
| Penetration Test at 25°C       | SNI 06-2456-1991                 | 0,1 mm | 62     | 60-70        |
| Specific Gravity               | SNI 2434-2011                    | gr/cc  | 1.167  | ≥ 1.0        |
| Ductility at 25°C              | SNI 2441-2011                    | cm     | 111    | ≥ 100        |
| Softening Point Test           | SNI 2432-2011                    | °C     | 55     | ≥ 48         |
| Flash Point Test               | SNI 06-2433-1991                 | °C     | 364    | ≥ 232        |
| Fire Point Test                | SNI 06-2433-1991                 | °C     | 336    | ≥ 288        |

2.3. Additives

In this research project, there were three additives used, which consist of two chemical additives and one natural additive. The chemical additives were the Wetfix-BE and Wetbond-SP and the natural additive was hydrated lime. Both Wetfix-BE and Wetbond-SP are categorized as anti-stripping agent and adding them into asphaltic mixture could help in improving the bond between the aggregates and the bitumen, and hence, the asphaltic mixture is hoped to be more resistant to moisture.

The recommended dosage for Wetfix-BE is 0.3% and in this research project, this additive was mixed at 0.1%, 0.2%, and 0.3% to see if the amount of additive can be reduced. Wetfix-BE is used to improve the bond and to stabilize the bond between the aggregates and the asphalt, especially during monsoon season [6]. The advantages of using this additive are it can be used as asphalt modifier to strengthen the bond between the aggregates and the bitumen, it can be mixed with any aggregates, it can help reducing maintenance cost, and it can extend the pavement life up to four years [6].
For the other chemical additive, which is Wetbond-SP, the recommended dosage is between 0.3% and 0.5%, and in this research project, this additive was mixed at 0.3%, 0.4%, and 0.5%. Wetbond-SP is also an anti-stripping agent that can be used to improve the bonding between aggregates and the asphalt, and hence, can extend the pavement life [7]. The research study conducted by [7] also compared the performance of Wetfix-BE and Wetbond-SP. It was found that both additives did not have any significant effect on improving the stability of the samples, but were able to reduce the voids in mixture, which represents that the samples became denser.

Hydrated lime is one of the natural additives that can be added into asphaltic mixture or hot mix asphalt (HMA). Several benefits that can be obtained by adding this additive include it can reduce stripping, it can help stiffening the asphalt binder, and it can improve the resistance of HMA to fracture growth [8]. Also, the research project in [8] shows that there is a significant saving in using hydrated lime in HMA and an increase in expected pavement life.

2.4. Laboratory Tests

There were three tests undertaken for the prepared samples, which were the Marshall, Cantabro Loss, and Indirect Tensile Strength tests.

2.4.1. Marshall Test. The Marshall tests were undertaken according to SNI 06-2489-1991. The parameters obtained from this test were the stability and the flow. Other parameters can also be calculated by measuring the weight of the specimens, including Void in Mix (VIM), Void in Mineral Aggregate (VMA), Void Filled with Asphalt (VFA), density, and Marshall Quotient (MQ). Marshall tests were undertaken to determine the optimum moisture content (OMC) of the hot mix asphalt samples, which was found to be at 5.5%. The tests were done three times for each variation to obtain statistically significant results.

2.4.2. Cantabro Loss Test. The Cantabro Loss test is a test used to measure the loss of abrasion of HMA samples as stated [9]. This test measures the breakdown of the prepared HMA specimens with Los Angeles Abrasion machine. The Cantabro Abrasion Loss (CAL) value was determined by finding the difference between initial and final weight of the HMA specimens after the specimen being rotated in Los Angeles machine for 300 revolutions at a speed of 30 revolutions per minute (rpm). The results were presented in percentage and it shows the durability and the quality of the asphalt binder. The tests were done three times for each variation to obtain a statistically significant result.

Due to the equipment limitation, the procedure for this test was slightly modified. The HMA specimens were prepared with a diameter of 10.2 cm and a height of 6.35 cm, which was smaller than the specimen size specified in [10]. However, it does not affect the objective of conducting the Cantabro Loss test because this test determines the percentage lost after the specimens being abraded. Moreover, the prepared samples were immersed in the water bath at 60oC for one hour before being placed into the Los Angeles Abrasion device, to simulate the asphaltic surface being flooded, and thus, the resistance of the specimens to traffic loading after contact with water can be assessed. This procedure is similar to the research project described in [11], where they used 24 hours immersion time instead.

2.4.3. Indirect Tensile Strength (ITS) Test. The ITS test is a test to determine 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. The values obtained from two different test conditions were used to calculate the Tensile Strength Ratio (TSR), which is represented in percentage. The test was done according to AASHTO T-283.

3. Results and Discussion

3.1. Marshall Test Results

Table 5 shows the results obtained from the Marshall tests for the samples with addition of Wetfix-BE. The values shown are the average of values for three samples. It can be seen that the results met the
requirements for most test parameters. From the test results, it can be seen that adding Wetfix-BE to the samples can help increasing the stability of the specimens, although still cannot reach the requirements. This is most likely due to the quality of the aggregates used. The more Wetfix-BE present on, it can be seen that the flow of the samples reduced and the VIM decreased. This shows that the binder became more rigid and the samples became denser. The addition of Wetfix-BE also lowered the density of the samples.

Table 4. Marshall test results of samples with addition of Wetfix-BE.

| Parameters | Unit | 0   | % Wetfix-BE | Requirements |
|------------|------|-----|-------------|--------------|
|            |      |     | 0.1         | 0.2          | 0.3          |
| Stability  | kg   | 620.71 | 780.90     | 748.73      | 770.71       | > 800 kg     |
| Flow       | mm   | 3.17   | 2.93        | 2.83         | 2.33         | 2-4 mm       |
| VIM        | %    | 11.36  | 5.06        | 4.43         | 4.19         | 3-5 %        |
| VFA        | %    | 44.24  | 67.14       | 71.35        | 72.63        | > 65%        |
| VMA        | %    | 2.00   | 2.03        | 2.03         | 2.04         | > 15%        |
| Density    | mm   | 20.37  | 15.37       | 15.47        | 15.26        |
| MQ         | kg/mm| 197.94 | 266.34      | 266.79       | 335.70       | > 250 kg/mm  |

Table 5 shows the results obtained from Marshall tests for the samples with addition of Wetbond-SP. Similar to Table 4, the values shown are the average results of three tests. It can be seen that the results met all the requirements for most parameters. Adding the Wetbond-SP can increase the stability, similar to the Wetfix-BE. There was no significant change in the flow observed. The addition of Wetbond-SP also lowered the density, but the density did not change as the Wetbond-SP percentage increases.

Table 5. Marshall test results of samples with addition of Wetbond-SP.

| Parameters | Unit  | 0   | %Wetbond-SP | Requirements |
|------------|-------|-----|-------------|--------------|
|            |       |     | 0.3         | 0.4          | 0.5          |
| Stability  | kg    | 620.71 | 771.02     | 774.85      | 786.28       | > 800 kg     |
| Flow       | mm    | 3.17   | 3.17        | 3.33         | 3.17         | 2-4 mm       |
| VIM        | %     | 11.36  | 5.22        | 5.05         | 5.04         | 3-5 %        |
| VFA        | %     | 44.24  | 66.90       | 67.13        | 66.88        | > 65%        |
| VMA        | %     | 2.00   | 2.03        | 2.03         | 2.04         | > 15%        |
| Density    | mm    | 20.37  | 15.77       | 15.36        | 15.22        |
| MQ         | kg/mm | 197.94 | 244.45      | 233.68       | 254.45       | > 250 kg/mm  |

Table 6 shows the results obtained from the Marshall tests for the samples with addition of hydrated lime. The values shown are the average of values for three samples. It can be seen that the results met the requirements for most test parameters. Adding hydrated lime could improve the stability and the samples that were added with 1.5% and 2% of hydrated lime can have stability values more than 800 kg. The samples with hydrated lime had lower flow values compared to the samples that did not have hydrated lime. The density of the samples decreases as the percentage of hydrated lime increases.
Table 6. Marshall test results of samples with addition of Hydrated Lime.

| Parameters | Unit | % Hydrated Lime | Requirements |
|------------|------|-----------------|--------------|
|            |      | 0   | 1.0  | 1.5  | 2.0  | > 800 kg |
| Stability  | kg   | 620.71 | 781.42 | 843.95 | 923.20 | > 800 kg |
| Flow       | mm   | 3.17  | 2.93  | 2.80  | 2.70  | 2-4 mm   |
| VIM        | %    | 11.36 | 6.05  | 5.98  | 5.74  | 3-5 %    |
| VFA        | %    | 44.24 | 70.94 | 63.61 | 64.67 | > 65%    |
| VMA        | %    | 2.00  | 2.01  | 2.01  | 2.01  | > 15%    |
| Density    | mm   | 20.37 | 20.80 | 16.45 | 16.23 |          |
| MQ         | kg/mm| 197.94 | 266.63 | 301.76 | 343.01 | > 250 kg/mm |

Figures 1 to Figures 7 show the comparison of Marshall parameter values between the control sample (no additive added), samples mixed with Wetfix-BE, samples mixed with Wetbond-SP, and samples mixed with hydrated lime. For the stability parameter, it can be seen that samples mixed hydrated lime had higher stability values compared the other samples. Looking at the results, the samples mixed with 2% hydrated lime had the highest stability value. For the samples with Wetfix-BE and Wetbond-SP added, the stability values did not differ much and the additives were unable to improve the stability of the samples until they reach the minimum value, which is 800 kg.

Figure 2 shows the values of flow parameter for all sample variations. It can be seen that all samples fall within the requirement, which is between two and four millimetres. However, the flow values of the samples that were mixed with Wetfix-BE and hydrated lime decreased as the percentage of additives increased.

Figure 3, Figure 4, and Figure 5 illustrate the variations of VIM, VFA, and VMA parameters for all sample variations, respectively. It can be seen that adding additives into the samples decreased the VIM percentage significantly, which means that all additives are effective in making the samples denser. Wetfix-BE was the additive that could decrease the VIM by the highest amount and it can be observed that as the percentage of additive increases, the VIM values decreases too. This finding shows that the samples mixed with Wetfix-BE and Wetbond-SP had less void or became denser. However, the samples mixed with hydrated lime exceeded the allowable VIM percentage, but these samples had lower VIM compared to the control sample.

The VMA values for samples mixed with Wetfix-BE increases as the percentage of additive increases, but for samples mixed with Wetbond-SP stays relatively constant as the percentage of additive increases. There was not any clear pattern can be observed in Figure 4, which shows the variation in VFA values and there were not any significant changes can be seen in the VMA values for all sample variations.

Figure 6 shows the changes in density of the samples after the additives were added. For the samples mixed with Wetfix-BE and Wetbond-SP, it can be seen that the density decreased to approximately 15%, while for the samples mixed with hydrated lime, the density of the samples decreased to about 16% only when at least 1.5% of hydrated lime was used.

Lastly, Figure 7 illustrates the variation of MQ parameter for all samples. As the percentage of hydrated lime increases, the MQ parameter increases as well, while there were not any clear trends that could be studied for the other samples mixed with Wetfix-BE and Wetbond-SP.
**Figure 1.** Comparison the stability values for samples mixed with additives.

**Figure 2.** Comparison the flow values for samples mixed with additives.

**Figure 3.** Comparison the VIM values for samples mixed with additives.

**Figure 4.** Comparison the VFA values for samples mixed with additives.

**Figure 5.** Comparison the VMA values for samples mixed with additives.

**Figure 6.** Comparison the density values for samples mixed with additives.

**Figure 7.** Comparison the MQ values for samples mixed with additives.
3.2. Cantabro Test Results
Figure 8 shows the average Cantabro Loss tests results for control sample, sample with Wetfix-BE added, samples with Wetbond-SP added, and samples with hydrated lime added. The higher the Cantabro Abrasion Loss (CAL) values, it shows that the asphaltic mixture would be more susceptible to water. For all additives, it can be seen that as the percentage of additive increases, the CAL values decrease and the CAL values at maximum dosage for each additive were lower than the control sample. This shows that all additives have relatively equal in terms of the effectiveness in improving the resistance to moisture of the asphaltic mixture. Based on the data shown in Figure 8, it can be seen that using Wetbond-SP at 0.5% is the most effective dosage for this asphaltic mixture, which can be seen from the lowest value of CAL. Additionally, the samples mixed with 2% hydrated lime also had similar CAL values than the samples mixed with 0.5% Wetbond-SP.

![Figure 8. Comparison the CAL values for samples mixed with additives.](image)

3.3. Indirect Tensile Strength (ITS) Test Results
Figure 9 shows the average ITS test results at dry and wet conditions. The stability values of the samples at dry condition were higher than the samples at wet condition for all samples. The samples that were mixed with Wetfix-BE had higher strength values compared to the samples that were mixed with Wetbond-SP and with lime, while the samples that were mixed with Wetbond-SP and with lime were comparable equal.

Moreover, TSR 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. The lower the value, the lower the resistance to moisture the sample has. Figure 10 shows the results for TSR values for all samples and it can be seen that the TSR values vary for all sample variations. However, it can be seen that the samples that were mixed with Wetfix-BE and hydrated lime, there was no clear effect on increasing the percentage of Wetfix-BE, while for the samples that were mixed with Wetbond-SP, it can be seen that the higher the percentage, the higher the TSR value will be. In this case, it can be seen that using Wetbond-SP at 0.5% gives the best result for the TSR and hence, the best dosage and additive to be used for the ITS test. The samples that were mixed with 2% hydrated lime also had the similar TSR value as the one mixed with 0.5% Wetbond-SP.
4. Summary and Conclusions

The aggregates used in this research project did not satisfy all the requirements, and hence, the control sample had a low stability value. However, from the research results, it was found that all additives were able to improve the stability of the prepared samples, especially the hydrated lime. The hydrated lime was able to increase the stability of the prepared samples until it surpassed the minimum requirement. Adding the additives can also reduce the void in asphaltic mixture (VIM), which shows that the prepared specimens became denser. From the Cantabro Loss and Indirect Tensile Strength tests, it was also found that increasing the percentage of additives could help in improving the ability of the asphaltic mixture to bear the effect of moisture. Overall, using Wetbond-SP at 0.5% in the asphaltic mixture gave the best results, although it was also found that the specimens that were prepared using hydrated lime, as an alternative and low-cost waterproofing additive, perform reasonably well compared to the specimens that were prepared using the other additives.
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References
[1] P. S. Kandhal and I. J. Rickards, “Premature Failure Of Asphalt Overlays From Stripping: Case Histories,” 2001.
[2] E. Rmeili and T. Scullion, “Detecting Stripping in Asphalt Concrete Layers Using Ground Penetrating Radar,” Transp. Res. Rec. J. Transp. Res. Board, vol. 1568, no. 1, p. 165, 1997.
[3] K. D. Stuart, “Moisture damage in asphalt mixtures - a state-of-the-art report,” 1990.
[4] N. D. Little and R. D. Jones, “Chemical and Mechanical Processes of Moisture Damage in HotMix Asphalt Pavements. Moisture Sensitivity of Asphalt Pavements,” 2003.
[5] A. D. Nataadmadja, E. Prahara, and O. Setyandito, “Analysis of moisture susceptibility of hot mix asphalt (HMA),” IOP Conf. Ser. Earth Environ. Sci., vol. 195, p. 12021, 2018.
[6] R. S. Akuba, “Pengaruh Pemakaian Aditif Wetfix-Be pada Campuran Asphalt Concrete Binder Course (AC-BC),” Universitas Negeri Gorontalo, 2014.
[7] D. P. Purba, “Studi Penentuan Kadar Optimum AntiStripping Agent Wetbond-SP danWetfix-Be Terhadap Campuran AspalPanas (AC-BC),” Universitas Sumatera Utara, 2018.
[8] D. N. Little, J. A. Epps, and P. E. Sebaaly, “The Benefits of Hydrated Lime in Hot Mix Asphalt,” 2006.
[9] N. P. Khosla, G. B. Birdsall, and S. Kawaguchi, “An In-Depth Evaluation of Moisture Sensitivity of Asphalt Mixtures,” 1999.
[10] TxDOT, “Test Procedure for Cantabro Loss,” 2014.
[11] V. S. Arrieta and J. E. C. Maquilón, “Resistance to Degradation or Cohesion Loss in Cantabro Test on Specimens of Porous Asphalt Friction Courses,” Procedia - Soc. Behav. Sci., vol. 162, p. 290, 2014.