DURABILITY OF ROAD PAVEMENT AGAINST TIDAL INUNDATION

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ABSTRACT

Semarang, as one of cities located on the North Coast of Java Island, experienced tidal inundation for years. The presence of inundation has adverse effect on road infrastructure, especially on coastal arterial roads, which most of them made of mixture with conventional asphalt. To overcome this problem, it was proposed to use polymer modified asphalt (PMA) for the mixture. This study was carried out to evaluate the durability of the mixture with PMA that continuously immersed in the tidal water, to simulate the occurrence of some road infrastructure in Semarang which was inundated after tidal events. For this purpose, five immersion periods and three kinds of tidal inundation were selected. To evaluate the durability of the mixtures after immersion, two durability indices were used. The results showed that the water pressure (during immersion) could be one of the main causes of strength loss of the mixtures; however, if the water consists of certain chemical compound at sufficient amount, it could also contribute in reducing greatly the durability of the mixture.

Keywords: polymer modified asphalt, durability indices, water pressure, chemical compounds

1. INTRODUCTION

Tidal inundation is a phenomenon of overflow of inland (called as *rob* by locals), that inundates land including roads due to poor drainage system. It is commonly occurred at the time of high tide which coincides with the occurrence of the new and the full moon. This phenomenon becomes widespread due to several cities on the North Coast of Java Island, such as Jakarta or Semarang (Central Java Province), experiencing land subsidence. According to Bakti (2010), the land subsidence in Semarang city can even reach up 3 to 15 cm per year.

In Semarang, several roads that suffered tidal inundation are arterial roads with high heavy traffic since the position of these roads as a connector of the main traffic between Jakarta – Surabaya, two metropolitans of Indonesia. Most of the roads are flexible pavements that using conventional asphalt as their binder, and as a result, they are easily damage under high load and require intensive maintenance. In addition, the presence of tidal inundation worsens the condition of the road pavement. This is due to the tidal water, which contains levels of acidity, levels of Sulfate ($SO_4^{=}$) and Chloride (Cl^-), and high levels of Alkalinity, weaken the cohesion and adhesion between asphalt and aggregate, causing the stripping and/or raveling and trigger other damages, such as holes (Prabowo, 2004).

To solve the problem of the increasing load, there is currently a wide range of asphalt modification that can be used, one of which was made with the addition of polymers (known as polymer modified asphalt or PMA). However, further research needs to be conducted about the tidal inundation influence on the pavement using PMA. For this purpose, this study was carried out to provide evidence that the asphalt mixtures with PMA have sufficient resistance to tidal inundation influences. The tidal water used in this study is from three different locations in the city of Semarang, the PRPP areas, Tanjung Emas and Terboyo (as shown in Figure 1). For durability evaluation process, this study used the modified durability testing procedures which initially developed by Crause et al. (1981).

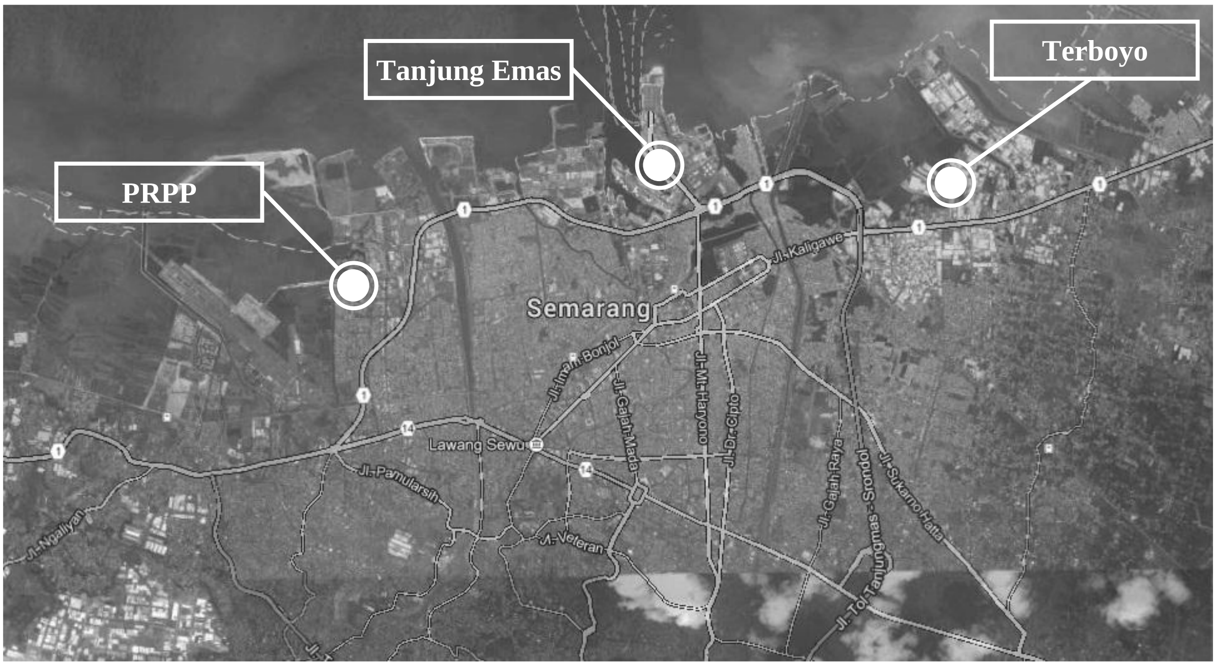

Figure 1: Locations of Tidal Inundation Sampling

2. DURABILITY OF PAVEMENT

Crause et al. (1981) stated that in the service condition, most mixtures deteriorated rapidly after being immersed for a long period although they passed the standard Marshall Immersion criterion (75% retained strength after 24-hour immersion on 60° C). In order to understand the durability potential of the mixtures over the immersion period, two indices, namely the first and second durability indices, were identified and adopted for the analysis of the durability test data. Both indices were formulated based on the following durability curve.

As seen in Figure 2, the abscissa of the chart shows the logarithmic scale of immersion period (usually in days) and the ordinate shows percentage of retained Marshall Stability (or in this research represents retained tensile strength ratio).

The first index (r, in %) is defined as the sum of the slopes of consecutive sections of the durability curve (see Figure 2), and expressed as:

$$r = \sum_{i-0}^{n-1} \frac{S_i - S_{i+1}}{t_{i+1} - t_i} \quad (1)$$

in which:

S_{i+1} = percent retained strength at time t_{i+1}

S_i = percent retained strength at time t_i
t_i and t_{i+1} = immersion periods (from beginning of test)

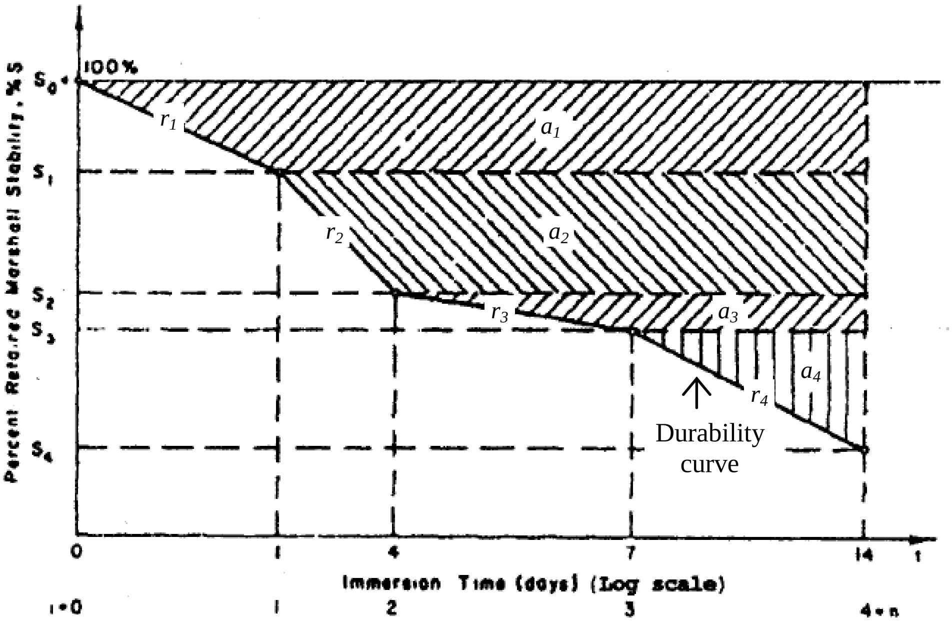

Figure 2: Schematic Description of Durability Curve
(Crause et al., 1981)

Practically, the first durability index expresses the percentages loss in strength as weighted for one day. This could produce two probability values of *r*, that is, negative values of *r* indicate strength gain and positive one a strength loss. In case of specimens were disintegrated and failed after immersion of less than one day, values of *r* can be greater than 100% (Siswosoebrotho et al., 2003). While, the absolute value of r, called as R, can be wrote as follows.

$$R = \frac{r}{100} S_0 \qquad (2)$$

The second durability index (a, in %) is defined as the average strength loss area enclosed between the durability curve and the line S_0 = 100%. Based on Figure 2, this index may be expressed as follows:

$$a = \frac{1}{t_n}\sum_{i=1}^{n} a_i = \frac{1}{2t_n}\sum_{i=0}^{n-1}(S_i - S_{i+1})[2t_n - (t_i + t_{i+1})] \qquad (3)$$

where all terms are defined in the Figure 2 and in equation (1).

It should be noted that the areas of increment (stated as a_i in Figure 2) are defined as an area partitioned horizontally by the line S_i and S_{i+1}, since they express the relative contribution of the immersion period increments to the total loss in strength. In this respect, the relative weight of the early time increments is much higher than the later ones (Siswosoebrotho et al., 2003). The second durability index also expresses an equivalent one-day strength loss. Again, negative values of *a* indicate strength gain and negative ones a strength loss.

Based on its definition, the value of *a* should be less than 100. Consequently, it is possible to express the percentage of one-day equivalent retained strength S_a (in %) as follows :

$$S_a = (100 - a) \qquad (4)$$

Other formulas to define the second durability index in terms of the absolute values of the equivalent loss or retained strength (A and S_a, respectively, in kPa) are as follows:

$$A = \frac{a}{100} S_0 \tag{5}$$

$$S_a = S_0 - A \tag{6}$$

3. DETERMINATION OF DURABILITY INDICES

In this research, the type of mixture used was fine-graded asphaltic concrete – wearing course (AC-WC). It is a blend of aggregate from Kali Kuto, Batang (Central Java Province) quarry and polymer modified asphalt Starbit E–55 (manufactured by Bintang Djaja, PT., 2009). Before preparing the mixtures, the materials were tested and should fulfill the requirements issued by Directorate General of Highways (2010). The results of the tests are depicted in Tables 1 and 2 for aggregate and asphalt materials, respectively.

Table 1: Results of Aggregate Tests

No	Properties	Unit	Specification		Results
			Min.	Max.	
Course Aggregate					
1.	Water absorption	%	-	3.00	1.57
2.	Specific gravity	-	2.50	-	2.61
3.	Abrasion	%	-	40.00	21.95
4.	Flakiness and elongation indices	%	-	10.00	6.99
5.	Affinity for asphalt	%	95.00	-	98.00
6.	*Soundness*	%	-	12.00	3.08
Fine Aggregate					
1.	Water absorption	%	-	3.00	1.63
2.	Specific gravity	-	2.50	-	2.63
3.	Sand Equivalent	%	60.00	-	88.52

Table 2: Results of Asphalt Tests

No	Properties	Unit	Specification		Results
			Min.	Max.	
1.	Penetration	0.1 mm	40	-	57
2.	Softening point	° C	54	-	57
3.	Flash point	° C	232	-	321
4.	Solubility of asphalt	%	99	-	99.33
5.	Ductility	cm	100	-	109
6.	Specific gravity	-	1.00	-	1.05

Using the materials above, asphalt mixtures were prepared and optimum asphalt content (OAC) was determined. In this research, OAC selected was 5.7% and the average tensile strength (measured using Indirect Tensile Strength or ITS test) at OAC was 1,284.08 kPa. This value was S_0 in this research.

For the purposes of evaluating the durability of asphalt mixture by immersion, four types of water as immersion media used in this study. They were fresh water and tidal inundation from three different locations (see Figure 1), i.e. PRPP, Tanjung Emas and Terboyo areas. Before being used to test the mixtures, all types of water should perform chemical tests. The results of the tests can be seen in Table 3.

Table 3: Results of Chemical Testing of Water from Different Sources (Perdana, 2013)

Parameter	Unit	Source of water			
		Fresh water	Tidal indundation at PRPP area	Tidal indundation at Tanjung Emas area	Tidal indundation at Terboyo area
pH	-	6,9	7,8	7,6	7,5
Alkalinity CO_3	mg/L $CaCO_3$	12	40	-	-
Alkalinity H CO_3	mg/L $CaCO_3$	132	154	256	200
Chloride (Cl^-)	mg/L Cl	17,22	16.738,39	5.165,68	7.718,48
Sulfate ($SO_4^=$)	mg/L SO_4	4,19	2.549,99	1.189,99	1.529,99

From Table 3, in terms of chemical compound, the waters used can be sorted as follows (the largest chemical compound in the first place): tidal inundation at PRPP, Terboyo, and Tanjung Mas areas, followed by fresh water. It can also be seen that the tidal inundation at Tanjung Mas and Terboyo areas essentially has chemical compounds that are relatively similar with those of fresh water.

Durability test was performed by immersing the asphalt mixtures at optimum asphalt content for a certain periods. In this research, instead of following the procedure initially developed by Crause et al. (1981), two modifications had been made, i.e. different immersion periods (12 hours or 0.5 days, then 1, 3, 5 and 7 days) and ambient temperature as the temperature of the water when immersion was performed. After being immersed for those periods, asphalt mixture performance is determined by using the ITS test. In order to evaluate the durability of the asphalt mixture, the ratio of the tensile strength of mixtures after immersion to tensile strength of mixture without immersion, expressed in%, used in this study. The plot of this ratio against immersion period can be seen in Figure 3.

From Figure 3, it seems that the overall performance of asphalt mixture that is quite good. It can be seen from the retained tensile strength that was higher than 80% (as a minimum value, according to The Asphalt Institute, 1996), although the retained tensile strength of the mixtures after being immersed for 7 days in a row indicated dropped quite significantly, and all of them were under the requirement of 80%.

In Table 4, it can be seen the details of the durability of the mixtures after immersion process, which is expressed in terms of durability indices. From Figure 3 and Table 4, it appears that the loss of strength of the asphalt mixture occurs twice, i.e. the first period of immersion (for 12 hours), and after immersion for 7 days. According to Siswosoebrotho et al. (2003), it seems that the pattern for both indices at various periods of immersion is similar; however, the second index seems to be more sensitive towards higher values of strength loss. In addition, the second index gives more comprehensive information in defining the values of the equivalent retained strength, by either percentage or the absolute value of the strength parameter.

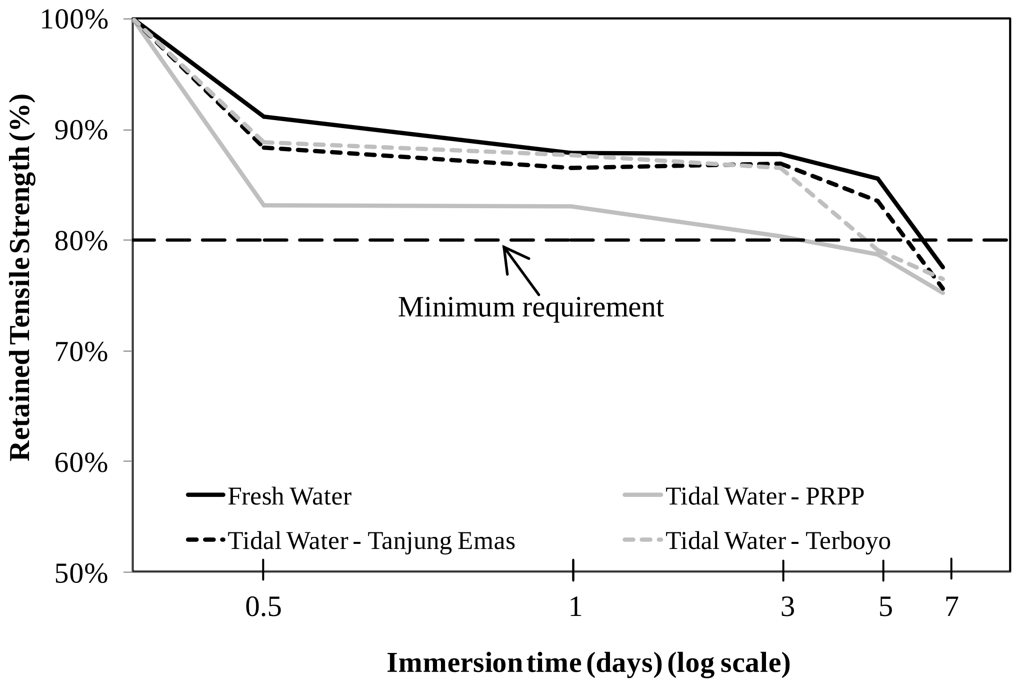

Figure 3: Durability Curves of Samples Immersed under Different Waters

Table 4: Durability Indices of Samples Immersed under Different Waters (Perdana, 2013)

Sources of Water	Immersion Period (days)	First Durability Indices		Second Durability Indices			
		r (%)	R (kPa)	a (%)	Sa (%)	A (kPa)	Sa (kPa)
Fresh Water	0,5	17.609	226.120	8.490	91.510	109.022	1,175.058
	1	24.262	311.540	11.460	88.540	147.156	1,023.864
	3	24.288	311.875	11,497	88.503	147.634	980.675
	5	25.405	326.220	12,455	87.545	159.930	967.710
	7	29.412	377.680	13.600	86.400	174.633	924.317
Tidal inundation at PRPP area	0,5	33.647	432.060	16.223	83.777	208.315	1,075.765
	1	33.922	435.580	16.345	83.655	209.886	858.164
	3	35.287	453.110	18,300	81.704	234.929	831.361
	5	36.112	463.705	19.002	80.997	244.010	787.220
	7	37.805	485.445	19.486	80.514	250.222	759.818
Tidal inundation at Tanjung Emas area	0,5	23.296	299.140	11.232	88.768	144.228	1,139.852
	1	26,958	346.160	12.867	87.133	165.219	969.291
	3	26.787	343.970	12.623	87.377	162.091	948.909
	5	28.449	365.310	14.048	85.952	180.382	934.998
	7	32.426	416.370	15.184	84.816	194.971	877.729
Tidal inundation at Terboyo area	0,5	22.248	285.680	10.727	89.273	137.739	1,146.341
	1	19.974	316.040	11.782	88.218	151.292	989.948
	3	24.827	323.295	12.589	87.411	161.656	964.404
	5	28.009	371.075	15.779	84.221	202.611	908.939
	7	26.730	388.085	16.157	83.843	207.471	808.519

Remarks: tensile strength of the mixture without immersion (S_0) = 1,284.08 kPa

4. ANALYSIS

As seen in Figure 3, the durability of all samples follows the following pattern: drop significantly in the first period, reduce slightly afterwards; and again much drop on the last period. This trend does not always behave like this, sometimes declining trend in the durability occurred in the first period, then increased in the second or third period, after that, it declined again in the last period (Siswosoebrotho et al., 2003; Ali, 2013).

Siswosoebrotho et al. (2003) stated that the trend of the durability curve may describe two processes, that is, the process when the mixture attained its optimum strength after compaction; and the process of water infiltration into the mixture until the occurrence of stripping. Both of these processes were not running in a linear manner and may not occur at the same time. The first process generally started from the end of the compaction process. The end of this process was not clearly defined, but it was appeared at the time when the value of the retained strength was relatively constant. The process can be influenced by the waiting time (or curing time) before the specimen is immersed in an immersion bath. In this study, the curing time was in the range of 3-7 days.

The curing time between the end of compaction and early immersion was not the same for all specimens. Generally, the curing time was greater in specimens that have a longer period of immersion. If the concept of optimum strength obtained before immersion was true, then the sample with longer immersion period will have a higher initial strength. If the specimen was immersed before achieving optimum strength, the strength will directly decrease once it was immersed, such as occured in the case of specimens with the shortest period of immersion.

The second process started at the beginning of the period of immersion and cannot be inspected visually, but the effect could be known when the value of the remaining strength began to decline. The asphalt stripping process also may not be inspected visually on the surface of the specimen in a short period of immersion, but it can be clearly seen after immersing for a day or longer. The second process will reduce the strength of the specimen significantly, especially after a long period of immersion.

Figure 3 shows that the decrease of the strength is not occurred only on samples immersed in various sea waters, but also on samples immersed in fresh water. This lead to a hypothesis that the reduce in the strength is mainly caused by the immersion of the samples in any kind of water, although the effect of chemical compound in the water also plays an important role. In order to evaluate this hypothesis, a statistical test using the Student's t test (Montgomery and Runger, 2003) on pair-wise difference was employed. Two following cases were evaluated at 95% confidence level:

(a) Case 1: there is no difference of tensile strength of samples tested in two successive immersion periods.
(b) Case 2: there is no difference of tensile strength of samples obtained from different water sources.

The results of the statistical tests are shown in Tables 5 and 6 for case 1 and 2, respectively.

According to Tables 5 and 6, the following observations may be made:

(a) At a significance level of 0.05 (i.e. 95% level of significance), the hypothesis that there is no difference between tensile strength of samples immersed at mid-periods was accepted, while at the same significance level, the hypothesis that there is no difference between tensile strengths of samples immersed at early- and end-periods were rejected. The reduction of tensile strength due to the significant influence of water showed that at the beginning of immersion was likely that the optimum strength of the asphalt mixture had not been reached, so that the presence of water pressure in asphalt mixture initiated preliminary stripping. This stripping may contribute on the reduce in tensile strength of the mixtures. This fact did not only occur on mixtures immersed in tidal water, but also occur on mixtures immersed in fresh water whose chemical compounds are low. The large decrease of tensile strength was observed again at 5-day immersion period, and became more significant at 7-day immersion period. The decrease is due to the continuous weakening by water pressure to the adhesion of asphalt - aggregate, and also in part due to the chemicals contained in the water used as media. The detail explanation of the effect of chemicals on the mixtures delivered in the following part.

Table 5: Test on Hypothesis that There is No Difference between Tensile Strength of Samples Immersed under Different Periods

Paired of Immersion Period (in days)	Results of Hyphotesis Test	
0 to 0.5	t_0	6.958
	$t_{0.05,n-1}$	$\pm$ 2.201
	Conclusion	Reject
0.5 to 1	t_0	0.879
	$t_{0.05,n-1}$	$\pm$ 2.201
	Conclusion	Accept
1 to 3	t_0	0.941
	$t_{0.05,n-1}$	$\pm$ 2.201
	Conclusion	Accept
3 to 5	t_0	2.130
	$t_{0.05,n-1}$	$\pm$ 2.201
	Conclusion	Accept
5 to 7	t_0	2.978
	$t_{0.05,n-1}$	$\pm$ 2.201
	Conclusion	Reject

Table 6: Test on Hypothesis that There is No Difference between Tensile Strength of Samples Immersed under Different Sources of Water

Paired of Different Water Sources	Results of Hyphotesis Test	
Fresh Water and Tidal Inundation (PRPP)	t_0	3.637
	$t_{0.05,n-1}$	$\pm$ 2.145
	Conclusion	Reject
Fresh Water and Tidal Inundation (Tanjung Emas)	t_0	1.870
	$t_{0.05,n-1}$	$\pm$ 2.145
	Conclusion	Accept
Fresh Water and Tidal Inundation (Terboyo)	t_0	1.346
	$t_{0.05,n-1}$	$\pm$ 2.145
	Conclusion	Accept

Paired of Different Water Sources	Results of Hyphotesis Test	
Tidal Inundation (PRPP and Tanjung Emas)	t_0	-2.716
	$t_{0.05,n-1}$	$\pm$ 2.145
	Conclusion	Reject
Tidal Inundation (PRPP and Terboyo)	t_0	-4.192
	$t_{0.05,n-1}$	$\pm$ 2.145
	Conclusion	Reject
Tidal Inundation (Tanjung Emas and Terboyo)	t_0	-0.260
	$t_{0.05,n-1}$	$\pm$ 2.145
	Conclusion	Accept

(b) There was an interesting finding regarding with the results of statistical tests on whether the tensile strength of the asphalt mixtures had different values when they immersed in different waters. It is showed in Table 6 that the strength of the mixtures immersed in fresh water is similar with that of mixtures immersed in tidal water from Terboyo and Tanjung Emas areas. This suggested that if the water has chloride (Cl^-) of between 5.000 to 8.000 mg and Sulfate ($SO_4^=$) of between 1.000 to 1.500 mg in 1 liter of water, the decrease in tensile strength of the mixture immersed in water was marginal. However, if the amount of Chloride and Sulfate in tidal water twice these values, the potential for tidal water to damage the mixtures became 2-8 times larger.

(c) It can be summarized that water pressure had a significant influence on the stripping process when the mixture had not attained its optimal strength and when the mixture immersed in the water for a long time. However, the water pressure is not the only the major cause of the reduce in durability of asphalt mixture, because if the water contained a sufficient amount of certain chemicals, like Chloride and Sulfate, then the combination of the water pressure together with chemical compounds will accelerate the deterioration of the pavement structure. And the use of polymer modified asphalt in the mixture could only withstand against water pressure and high-amount of chemicals in tidal water not more than 3 days. It realized that each chemical compound has different effect on the durability of the mixture. Therefore, a research that simulating the effect of each chemical compound on the durability of the mixture is currently underway.

5. CONCLUSIONS

a. This paper has evaluated the effect of tidal inundation on the durability of pavement structure. For this purpose, different tidal water from three locations in Semarang (Central Java – Indonesia) was employed as media for immersion test, with fresh water was used as basis of comparison. Five different immersion periods were selected to simulate the effect of period length on the durability of asphalt mixture. The results showed that water pressure could be one of the main causes of strength loss of the mixtures; however, if the water consists of certain chemical compound at sufficient amount, it could contribute in reducing the durability of the mixture.

b. A continuous and long- immersion period (in this case, 5 – 7 days) of pavement structure should be avoided. This is because the percentage of pavement that occurring stripping is large enough and this lead to the pavement structure failure.

c. Another finding in this research was sufficient curing time of the mixture to attain its optimal strength after compaction might assist the mixtures against the bad effect of environment. This curing time might be difficult to be measured, but it could be determined by using structural capacity measurement, such as by using Falling-weight deflectometer (FWD) or other similar devices.

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