The Durability of AC-WC and HRS-Base Pavement with Styrofoam Addition

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The Durability Of AC-WC And HRS-Base Pavement With Styrofoam Addition

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Abstract: AC-WC and HRS Base pavement mixture are the type of pavement used as surface and base respectively. Durability of pavement will reduce after service due to the environmental effects. Hence, additives such as Styrofoam is added to enhance the stability and durability. This research investigate the durability of the pavement at the surface and base course. Marshall specimen containing 1.5% Styrofoam was prepared and immersed for 0, 1, 3, 7 and 14 days in order to determine the Residual Strength Index, First durability Index and Second Durability Index. These indexes represent the durability of the pavement. From this study, it was found out that the Residual Strength Index value decreased with the increment of immersion duration for both layers. The IDP and IDK with Styrofoam of AC-WC were higher than the specimens without Styrofoam which were 0.377% and 7.752% respectively. Similar trends were observed for HRS Base. This implies that the use of Styrofoam in the pavement is advantageous because it has the potential to improve the durability of mixture.

Keywords: Styrofoam, Durability, HRS-Base, AC-WC, RSI

1. INTRODUCTION

Durability refers to the ability of the materials in the asphalt pavement structure to withstand the effects of environmental conditions such as water, ageing and temperature variations for long period without any significant deterioration while considering a given amount of traffic loading [1]. Damage of pavement due to moisture is one of the major concerns in bituminous pavements, and can be considered as a degradation of the mechanical properties of the asphalt due to the action of moisture or water, causing serious distresses. Moisture susceptibility is normally associated to the loss of adhesion between asphalt binder and aggregate and/or loss of cohesion within the binder mainly due to the presence of water [2]. These failures might also occur due to the combined effects of moisture and vehicle tires pressure. Hence, selection of materials, aggregate and bitumen is crucial as it is a major contributing factor on the stripping potential of an asphalt mixture which subsequently affect the pavement durability. Effort has been made to enhance pavement strength and durability through the use of additives from local materials such Styrofoam, Gondorukem, recycled plastic, crumb rubber etc. Past studies indicated that these materials enhance the strength and durability of pavement. Gondorukem and HDPE plastic have also been used to strengthen the pavement such as in strengthening Porous Asphalt [3], [4]. Crumb rubber was used to improve the properties of AC-WC when specimen subjected to moisture [5]. Styrofoam has been used to strengthen the AC-WC and HRS-Base[6], [7]. Styrofoam or polystyrene is a type of thermoplastic plastic. This type of plastic can be softened repeatedly by heating it. Styrofoam has very mild properties, thermo-plastic, which is soft when heated and hardens again after being cold. Styrofoam can dissolve in aromatic hydrocarbons and can be a good adhesive. Styrofoam is also very stable and not easily broken down for a long time. So, by using this Styrofoam can be expected to increase the stability of the pavement, as well as its durability or resistance to changes in weather, and temperature. Studies shows that 1.5% replacement of Styrofoam in the binder produced highest stability in AC-WC and HRS-Base which equivalent to Marshall of Stability 1140 kg and 1500 kg, respectively [6], [7]. The presence of water in an asphalt pavement is unavoidable. Water can infiltrate the pavement from the surface via cracks in the surface of the pavement, via the interconnectivity of the air-void system or cracks, from the bottom due to an increase in the ground water level, or from the sides. The moisture conditioning is used to evaluate the effects of water saturation of compacted bituminous mixtures in the laboratory. Yet almost all of the studies aimed at a comparative measure of moisture damage, either via visual observations from field data or laboratory tests or via wet-versus-dry mechanical tests to give a so called moisture damage index parameter [8]. One method used in evaluating the effect of water on the asphalt pavement mixture is the Marshall Immersion method in which the stability of the test specimen is determined after one day immersion in water at a temperature of 60 °C [9]. A numerical index of reduced compressive strength is obtained by comparing the compressive strength of test specimens that have been immersed in water for 24 hours at temperature 60 ± 1°C and 30 minutes in water at 25 ± 1°C under the specified conditions. The Department of Settlement and Regional Infrastructure specification for evaluating the durability of a mixture is a Marshall immersion test in water at 60°C for 24 hours [10]. Comparison of stability immersed with standard stability, expressed as a percent and is called the Retained Strength Index (RSI). The durability of a flexible pavement is a measure of its resistance to weathering (water and temperature) and the abrasive action of traffic within its design life. Depending on the parameter of interest, it can be measured using the thin-film oven test, rolling thin film oven test, pressure ageing vessel method, the concept of durability index from the Marshal test or any other suitable method. In the Marshall test using durability index concept, specimen was subjected to water to the effects of water and temperature by immersing the specimen at 60°C. The durability, or the stripping resistance of the mixture, was characterized by the mechanical response under long exposure to water and temperature. This was expressed by durability curves that reflect the variation of retained strength with the hot immersion time. Usually, pavement mixture was immersed in a 60°C water bath and were tested for strength (Marshall Stability, Resilient Modulus, diametrical split tests, and so forth) after 0, 1, 3, 7, and 14 days of continuous hot immersion [11]. The durability curves can be analyzed based on trend and shape and by a durability index developed to characterize the entire durability curve in a single parameter [11]. The durability index is defined as the average strength loss area enclosed between the durability curve and the line

s_0 *100 percent. Based on Figure 1, this index is expressed as follows:

$$a = \frac{1}{t_n}\sum_{i=1}^{n} a_i = \frac{1}{2t_n}\sum_{i=0}^{n-1}(s_i - s_{i+1})[2t_n - (t_i + t_{i+1})] \quad (1)$$

where all the parameters are defined in the figure

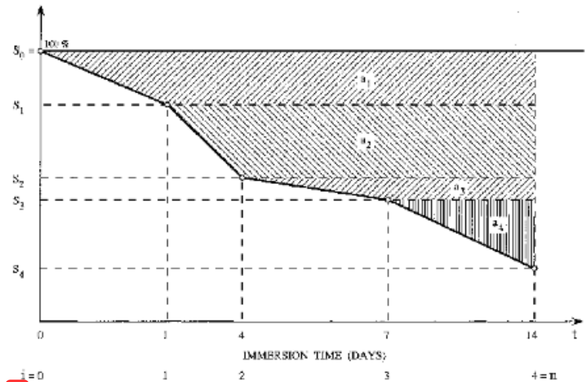

Figure 1: *Durability Curves with parameters defining durability indexes [11]*

The durability index also expresses an equivalent 1-day strength loss. Positive values of (a) indicate strength loss, negative ones a strength gain. Under its definition, a < 100. Consequently, it is possible to express the percentage 1-day equivalent retained strength (s_a) as follows:

$$S_a = (100 - a) \quad (2)$$

The Retained Strength Index (RSI) based on Marshall Stability is determined using Equation (3):

$$RSI = \frac{S_i}{S_o} \times 100 \quad (3)$$

Where;
RSI = retained strength index
S_i = stability after immersion at time t_i or stability of conditioned specimen
S_0 = stability before immersion or stability of unconditioned specimen

For the Durability Index it is divided into two parts which are first durability index and second durability index.
a) First Durability Index (FDI) is defined as the sum of the slopes of the consecutive sections of the durability curves [12] and obtained as presented in equation (4).

$$FDI = \sum_{i=0}^{n-1} \frac{S_i - S_{i+1}}{t_{i+1} - t_i} \quad (4)$$

Where;
Si+1 = percent retained strength at time ti+1
S_i = percent retained strength at time ti
ti, ti+1 = immersion times

b) Second Durability Index (SDI) is formulated as in equation (5).

$$SDI = \frac{1}{t_n}\sum_{i=o}^{n-1} A_i = \frac{i}{2t_n}\sum_{i=0}^{n-1}(S_i - S_{i+1}) \times [2t_n - (t_{i+1} - t)] \quad (5)$$

Where
S_{i+1} = percent retained strength at time ti+1
S_i = percent retained strength at time ti
t_i, t_{i+1} = immersion times (calculated from beginning of test)

Based on the literature review, there is growing concern to improve the durability of pavement in terms of materials used. Styrofoam showed potential improvement of durability based on tested strength. Hence there is a need to further test the materials on the effects of moisture since moisture damage is crucial at tropical region due to the heavy annual rainfall. This research investigates durability of HRS-Base and AC-WC pavement with 1.5% Styrofoam.

2. MATERIAL AND METHOD

The materials used in this study were aggregate, bitumen and Styrofoam. Granite aggregate graded in accordance to AC-WC and HRS-Base gradation for Indonesia and properties is shown in Table 1. The properties of bitumen with penetration grade of 60/70 is shown in Table 2.

Table 1 *Properties of Aggregate*

Properties	Value	Standard
Specific gravity of course aggregate (%)	2.600	BS 812-2
Specific gravity fine aggregate (%)	2.474	BS 812-2

Aggregate crushing value (%)	8.04	BS 812-110

***Table 2** Properties of Bitumen*

No	Properties	Value	Unit	Standard	Value of Standard
1	Ductility	100	cm	SNI 06-2432-1991	≥100
	Ductility (T-FOT)	68.5	cm	ASTM D 1754	≥50
2	Penetration	66.5	0.01mm	SNI 06-2456-1991	60-70
	Penetration (T-FOT)	54.2	0.01mm	ASTM D 1754	≥54
3	Specific Gravity	1.0452		SNI 06-2441-1991	≥1.00
4	Flash Point	273	°C	SNI 06-2433-1991	≥232
5	Burning Point	354	°C	SNI 06-2433-1991	≥232
6	Softening Point	55.5	°C	SNI 06-2434-1991	≥48
7	Average Loss Weight	0.031	%	SNI 06-2440-1991	≤0.8

Styrofoam or polystyrene is a type of thermoplastic plastic and used as replacement of bitumen at 1.5% by the weight of bitumen and the value was based on the optimum value suggested by previous researcher [6], [7]. Figure 2 shows the Styrofoam used in this research.

***Fig 2:** Styrofoam*

Shredded Styrofoam was pre-blended with bitumen at 90°C and stirred for 5 minutes until it was completely mixed. At the same time, aggregate also was heated at the mixing temperature. Mixture of Styrofoam, bitumen and aggregate were produced once all materials reached the mixing temperature and then compacted 75 blows at each side. The 75 blows represent the high traffic. The optimum bitumen content (OBC) were 6.75% for AC-WC and 6.85% HRS-Base determined by Marshall method and investigated in previous research [6], [7]. The optimum bitumen content was used for the specimen with and without Styrofoam. For consistency of data, three specimens were tested for each test. Prior to testing, all specimen were conditioned through immersion at 60°C with an immersion time variation of 0, 1, 3, 7 and 14 days at 60 °C. Temperature selection and procedure of testing in accordance ASTM D1075-07 (procedure for measuring losses from the results of a compressive strength due to the action of water in compaction of asphalt mixtures which is obtained) (2000). The result from Marshall stability tests were analysed based Retained Strength Index (RSI), First Durability Index (FDI) and Second Durability Index (SDI). All equations used in the analysis are shown in Equation (3), (4) and (5).

3. RESULTS AND DISCUSSIONS

Durability of pavement at various immersion duration will be analysed based on Durability Index parameters which are Retained Stability Index (RSI), First Durability Index (IDP) and Second Durability Index (IDK). Retained Stability Index (RSI) of Pavement Mixture To see the extent of pavement durability, Retained Stability Index (RSI) can be used as an indicator. Table 3 and 4 present the RSI of specimen with and without Styrofoam at various immersion duration for AC-WC and HRS-Base. For analysis, 0.5 hours of immersion was taken as the original value of Marshall Stability. Equation 3 was used to calculate the RSI of the specimen as presented in Table 3 and 4. Figure 3 and 4 exhibit the trends of RSI for specimen with and without Styrofoam.

***Table 3** Retained Stability Index (RSI) for AC-WC*

Duration of Immersion (days)(hours)	Av. Stability (kg)		RSI (%)	
	0% Styrofoam	1.5% Styrofoam	0% Styrofoam	1.5% Styrofoam
0(0.5 hours)	1183.701	1296.828	100	100
1 (24 hours)	1146.058	1260.246	96.820	97.179
3 (72 hours)	1069.743	1215.903	90.373	93.760
7 (168 hours)	945.750	1066.962	79.898	82.275
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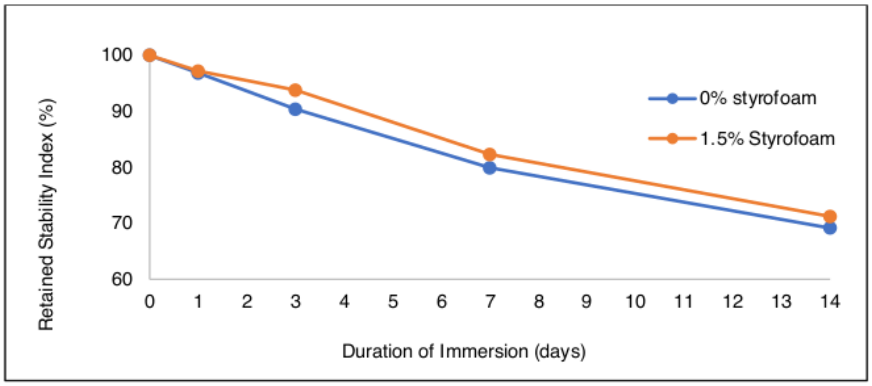

Fig 3. *Retained Stability Index (RSI) for AC-WC*

From Figure 3, in general RSI and duration has inverse linear relationship. Similar trend also observed for RSI of HRS-Base. Both specimens with and without Styrofoam has almost similar RSI which are 97.179% and 96.820, respectively with 1% difference after 24 hours of immersion. Differences of RSI can be seen after 3 days immersion and onwards. Based on general specifications of road and bridge construction works (2018) that the minimum RSI value of asphalt concrete mix is 90% after 24 hours soaking at 60℃. As seen in Table 3, the asphalt mixture still retained good resistance to water damage as the RSI is 96.86% after 24 hours soaking. Up to 96 hours of soaking, the pavement can still retain its strength above 90%. This implies that the asphalt mixture is able to resist pavement damage due to water such as flood. The RSI of the specimen with Styrofoam after 96 hours immersion is about 4% higher than the RSI of the specimen without Styrofoam. Hence, this indicates that Styrofoam can be used to strengthen the pavement as AC-WC particularly at area that prone to flood.

Table 4 *Retained Stability Index for HRS-Base*

Duration of Immersion (days)(hours)	Av. Stability (kg)		RSI (%)	
	0% Styrofoam	1.5% Styrofoam	0% Styrofoam	1.5% Styrofoam
0 (0.5)	1282.004	1393.404	100	100
1 (24)	1228.009	1350.765	95.788	96.940
3 (72)	1134.221	1286.259	88.473	92.311
7 (168)	987.199	1110.903	77.004	79.726
14 (336)	856.241	941.503	66.789	67.569

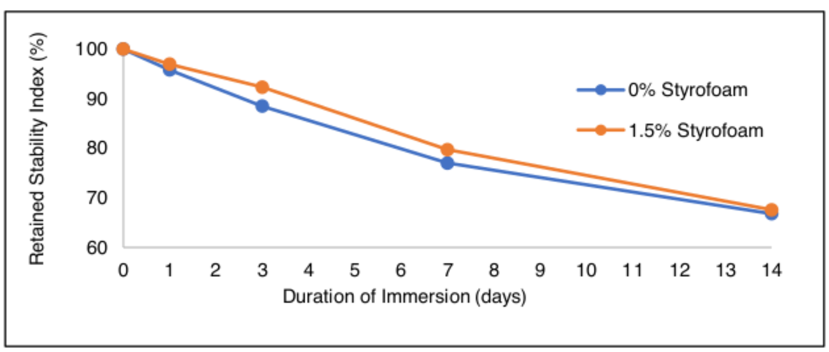

Fig 4*. Retained Stability Index for HRS-Base*

By referring to Table 4 and Figure 4 in general, the RSI of HRS-Base result in similar trend with RSI of AC-WC. However, considerable difference of RSI can be seen after 3 days. The RSI of HRS-Base without Styrofoam did not achieve 90% RSI at 96 hours of immersion. Unlike the specimen without Styrofoam, Styrofoam addition improved the RSI of HRS-Base. At 14 days immersion, the RSI of both types of specimen are almost similar. It can be stated that the

1.5 Styrofoam can increase its durability for all the immersion time. In flexible pavement, the threshold value of RSI is 75%. This limit indicates that asphalt mixture is assumed to be strong enough to hold on damage caused by the influence of water when the RSI value is equals or more than the limit value. From Figure 3 and Figure 4, asphalt mixtures for AC-WC and HRS-Base are able to resist the damage due to water up to 7 days immersion.

First Durability Index

Another way to see the durability of the pavement is to look at the Durability Index based on First Durability Index and Second Durability Index. The calculation analysis of FDI is shown in Equations (4) and (5). Table 5 and Table 6 present the results of FDI for AC-WC and HRS-Base, respectively.

Table 5; *First Durability Index for AC-WC pavement.*

Immersion (hours)	Retained Marshall Stability (%)		S_i-S_{i+1}		t_i+t_{i+1}		r (%)			
			a		b		a/b	cumulative	a/b	cumulative
	0% Styrofoam	1.5% Styrofoam	0% Styrofoam	1.5% Styrofoam	0% Styrofoam	1.5% Styrofoam	0% Styrofoam		1.5% Styrofoam	
0.5	100	100	-	-	-	-	-	-	-	-
24	96.82	97.179	3.18	2.821	23.5	23.5	0.135	0.135	0.12	0.12
72	90.373	93.76	6.447	3.419	48	48	0.134	0.27	0.071	0.191
168	79.898	82.275	10.475	11.485	96	96	0.109	0.379	0.12	0.311
336	69.144	71.196	10.754	11.079	168	168	0.064	0.443	0.066	0.377

Table 6; *First Durability Index for HRS-Base pavement.*

Immersion (hours)	Retained Marshall Stability (%)		S_i-S_{i+1}		t_i+t_{i+1}	r (%)			
			a		b	a/b	cumulative	a/b	cumulative
	0% Styrofoam	1.5% Styrofoam	0% Styrofoam	1.5% Styrofoam		0% Styrofoam		1.5% Styrofoam	
0.5	100	100	-	-	-	-	-	-	-
24	95.788	96.94	4.212	3.06	23.5	0.179	0.179	0.13	0.13
72	88.473	92.311	7.316	4.629	48	0.152	0.332	0.096	0.227
168	77.004	79.726	11.468	12.585	96	0.119	0.451	0.131	0.358
336	66.789	67.569	10.215	12.157	168	0.061	0.512	0.072	0.43

The FDI in Table 5 represented by 'r' and the unit is in percentage. Comparison of results will be based on the longest immersion duration which is 336 hour or 14 days. As shown in Table 5, the value of 'r' cumulative are 0.443 and 0.377 for specimen without Styrofoam and with Styrofoam, respectively. This shows that the FDI of pavement with Styrofoam is lower than the FDI without Styrofoam about 13%. The FDI is related to the average loss of strength in pavement. It means that the loss of pavement strength without Styrofoam is greater than the pavement with Styrofoam. It can be stated that the pavement with Styrofoam is more durable than the pavement without Styrofoam when subjected to water. The First Durability Index for HRS-Base is presented in Table 6. A positive value of "r" in the calculation of the first durability index for both types of specimen indicates a loss of strength. The greater the positive value, the greater will be the decrease in strength. The FDI of HRS-Base asphalt mixture without Styrofoam (r = 0.512) is greater than the first durability index of HRS-Base mixture with Styrofoam (r = 0.430). Thus, HRS-Base mixture without Styrofoam addition experiences a greater loss of strength compared to HRS-Base mixture that uses Styrofoam as an additive. Hence, the HRS-Base mixture with Styrofoam is more durable than the HRS-Base without Styrofoam.

Second Durability Index

The results of the Second Durability Index are presented on Table 7 and Table 8, for AC-WC pavement mixture without and with Styrofoam addition respectively. Meanwhile, for HRS-Base pavement mixture without and with Styrofoam are presented on Table 9 and 10 respectively.

Table 7 *Second Durability Index (SDI) Marshall AC-WC without Styrofoam*

Immersion time (hours)	Retained Marshall Stability (%)	S_i-S_{i+1}	t_i+t_{i+1}	$2t_n$-b	a=[1/2t_n].a.c		Sa
		a	b	c	e	cumulative	100-e
0.5	100	-	-	-	-	-	100
24	96.820	3.180	24.5	23.5	1.557	1.557	98.443
72	90.373	6.447	96	48	2.149	3.706	97.851

168	79.898	10.475	240	72	2.245	5.951	97.755
336	69.144	10.754	168	168	2.689	8.639	97.311
			∑	8.639			

Table 8 *Second Durability Index (SDI) Marshall AC-WC mixture with Styrofoam*

Immersion time (hours)	Retained Marshall Stability (%)	S_i-S_{i+1}	t_i+t_{i+1}	$2t_n$-b	a=[1/$2t_n$].a.c		Sa
		a	b	c	e	cumulative	100-e
0.5	100	-	-	-	-	-	100
24	97.179	2.821	24.5	23.5	1.381	1.381	98.619
72	93.760	3.419	96	48	1.140	2.521	98.860
168	82.275	11.485	264	72	2.461	4.982	97.539
336	71.196	11.079	504	168	2.770	7.752	97.230
				∑ 7.752			

The SDI refers to 'a' in Table 7 and Table 8. As seen from Table 7 and Table 8, the value of 'a', is 8.639 and 7.752 for AC-WC without and with Styrofoam respectively. The positive value of SDI means loss of strength. The higher the value of SDI the higher the loss of strength of the pavement mixture. Thus, it can be stated that the loss of strength in the AC-WC pavement without Styrofoam is greater than the AC-WC pavement with Styrofoam.

Table 9 *Second Durability Index (SDI) Marshall for HRS-Base without Styrofoam*

Immersion time (hours)	Retained Marshall Stability (%)	S_i-S_{i+1}	t_i+t_{i+1}	$2t_n$-b	a=[1/$2t_n$].a.c		Sa
		a	b	c	e	cumulative	100-e
0.5	100	-	-	-	-	-	100
24	95.788	4.212	24.5	23.5	2.062	2.062	97.938
72	88.473	7.316	96	48	2.439	4.501	97.561
168	77.004	11.468	240	96	3.277	7.777	96.723
336	66.789	10.215	168	168	2.554	10.331	97.446
			∑	10.331			

Table 10 *Second Durability Index (SDI) Marshall for HRS-Base with Styrofoam*

Immersion time (hours)	Retained Marshall Stability (%)	S_i-S_{i+1}	t_i+t_{i+1}	$2t_n$-b	a=[1/$2t_n$].a.c		Sa
		a	b	c	e	cumulative	100-e
0.5	100	-	-	-	-	-	100
24	96.94	3.060	24.5	23.5	1.498	1.498	98.502
72	92.311	4.629	96	48	1.543	3.041	98.457
168	79.726	12.585	240	96	3.596	6.637	96.404
336	67.569	12.157	504	168	3.039	9.676	96.961
			∑	9.676			

A large value of SDI indicates the higher value of loss of pavement strength. The second durability index on pavement for HRS-Base with Styrofoam (a = 9,676%) is smaller than the second durability index of pavement without Styrofoam (a = 10,331). Thus, pavement with Styrofoam is more resistant to the effect of water compared to pavement without Styrofoam.

Further comparison of durability between the AC-WC and HRS-Base mixtures shows:

- continuous increment of RSI for all samples that have been strengthening with Styrofoam for all immersion time for both pavement mixtures i.e. AC-WC as well as HRS-Base.
- improvement of durability performance based on FDI for both AC-WC and HRS-Base with addition of Styrofoam. However, more strength loss is observed in HRS-Base.
- increment of durability on AC-WC and HRS-base based on SDI when added with Styrofoam. HRS-base experiences higher magnitude of strength loss compared to AC-WC.

Moreover, after strengthening by Styrofoam, AC-WC shows a better performance in the Marshall Stability than HRS-Base pavement mixture. On the other hand, the addition of Styrofoam additive into pavement mixture result in better resistance to the effects of water damage in pavement.

4. CONCLUSIONS

Based on the research, few conclusions are drawn:

a. the durability of the Asphalt Concrete - Wearing Course (AC-WC) layer with Styrofoam was higher than the asphalt mixture without Styrofoam.

b. durability of Hot Rolled Sheet - Base (HRS-Base) layer with Styrofoam was higher than the asphalt mixture without Styrofoam.
c. for the Asphalt Concrete - Wearing Course (AC-WC) layer, the average stability value of the specimens with the addition of Styrofoam and standard materials still meets specifications up to an immersion for 14 days. And the stability value is still above the standard until soaking for 14 days for the Hot Rolled Sheet - Base (HRS-Base) layer.
d. it can be concluded that the use of Styrofoam as an additive in pavement produced promising results in terms of durability against moisture damage

5. ACKNOWLEDGMENT

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