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THE DURABILITY OF STONE MATRIX ASPHALT (SMA) MIXTURES DESIGNED USING RECLAIMED ASPHALT PAVEMENT (RAP) AGGREGATES AGAINST FLOODWATER IMMERSION

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ABSTRACT
The durability of asphalt mixtures against floodwater immersion can serve as a reference to anticipate potential road damage. Moreover, Reclaimed Asphalt Pavement (RAP) materials have been discovered as a substitute for aggregate materials in road pavement due to their environmental friendliness and cost-effectiveness. Therefore, this research aimed to assess the durability of asphalt mixtures produced using RAP aggregate materials against floodwater immersion for 1, 2, 4, and 8 days. The process involved using Stone Matrix Asphalt (SMA) mixtures with a proportion of 33% RAP aggregate as test specimens. The Marshall test conducted on the asphalt mixture produced an optimum asphalt content (OAC) value of 6.1%. Moreover, the durability of the mixture reduced up to the 8th day of immersion with a residual strength value of 86.29%. It was also discovered that the reduction in the durability value of the mixture produced using 33% RAP aggregate was almost similar to the application of 100% new aggregate (non-RAP). This means RAP aggregate materials are feasible as an environmentally friendly substitute in the mixture of road pavement.
Keywords: *Stone Matrix Asphalt, RAP Aggregates, Floodwater immersion, Durability*

1. Introduction

Flexible pavement is one of the most common and widely used types of road pavement in Indonesia and worldwide (Rahman, 2021). It was named based on the application of flexible asphalt as its binding material. It has also been observed that the most commonly used flexible pavement in Indonesia is Asphalt Concrete (AC) and Hot Rolled Sheet (HRS) (Putri et al., 2018). The problem often encountered with the AC type is cracking (Awuah & Garcia-Hernández, 2022) while HRS pavement has issues with surface deformation, specifically in heavy-traffic areas (Al-Hdabi et al., 2013). This led to the introduction of the Stone Matrix Asphalt (SMA) to address these problems. The SMA was standardized in Indonesia in 2015 through Indonesian National Standard 8129:2015 and is now included in the General Specification for Road Construction 2018 at the Directorate General of Highways.

The methods applied in constructing roads have been expanded to include the utilization of recycled materials (Zaumanis & Mallick, 2015). An example of this is recycling cold milling materials excavated from damaged road pavement into the new pavement through the concept of Reclaimed Asphalt Pavement (RAP). According to Widayanti et al. (2018), the use of RAP in asphalt mixtures has the ability to save costs by 14% - 20%. This means it is economically valuable in addition to being environmentally friendly (Devulapalli & Kothandaraman, 2019). However, its application needs to be reviewed because the material has been previously used for a long time. This led Adiman et al. (2023) to study the inclusion of AC-WC RAP aggregates in SMA mixtures and recommended the addition of up to 33% of this material into the mixture.

The durability of asphalt mixtures in road pavements is greatly influenced by environmental impact, especially climate change (Liu et al., 2022; Qiao et al., 2020). Indonesia is a country that has a relatively high rainfall with a long duration, thereby often causing water puddles or flooding on the road surface (Setiawan et al., 2019). The phenomenon has been identified to be the main trigger for the decrease in the durability of asphalt mixtures and ultimately road damage (Adiman, 2017). This was further confirmed by Adiman and Suparma (2022) that floods or water puddles have the ability to weaken the cohesion bond of the asphalt as well as the adhesive bond between the asphalt and its aggregate, thereby damaging the road and this is often aggravated by the duration of the floodwater. Therefore, it is very important to test the durability of asphalt mixtures against floodwater in order to mitigate damage to the road (Yu-Shan & Shakiba, 2021). This background information led to the conduct of this research on the durability of SMA mixtures produced using RAP aggregate material against floodwater immersion as well as to determine Marshall stability value.

2. Theoretical Context

Stone Matrix Asphalt

SMA is a hot mix asphalt consisting of a coarse aggregate skeleton, a fine aggregate mixture, filler, and a relatively high content of asphalt binder (AASHTO M 325-08, 2012). It is usually arranged in such a way that the coarse aggregate (stone) has the largest proportion and is bound together by mastic including a mixture of fine aggregate, filler, additives, and asphalt in a large proportion. This means there is a direct contact between the coarse aggregate particles and this creates an efficient rock or stone-on-stone skeleton contact. The characteristic and important component of this type of mixture is the stabilizer additive which prevents asphalt drainage (Blazejowski, 2016).

The use of SMA mixtures is becoming more widespread due to their ability to resist deformation or rutting and several advantages for road users such as high skid resistance and noise reduction. Moreover, the nearly uniform aggregate gradation of SMA mixtures is suitable for heavy vehicle traffic (Nejad et al., 2010).

Reclaimed Asphalt Pavement (RAP)

RAP is a material obtained from milling or full-depth removal of the road pavement layer using a Cold Milling Machine (TRB, 2011). It can also be defined as the recycled asphalt obtained from the excavation of damaged road pavement material. According to NAPA (1996), RAP material contains high-quality aggregate when peeled and sieved properly but tends to have certain weaknesses because it is old and previously used. Therefore, there is a need for a proper mixing design with new materials before it can be reused in order to produce a mixture that meets the specification requirements (Yu et al., 2014).

Damage to Asphalt Mixture Due to Flooding

According to Hicks (1991), the asphalt mix pavement damaged by immersion is usually due to two mechanisms (Omar et al., 2020):

1. Loss of adhesion caused by water entering the space between the asphalt and aggregate and which peels off the thin layer of the asphalt film.
2. Loss of cohesion caused by water softening the asphalt cement, thereby weakening the bond between the asphalt concrete and the aggregate.

Wibawa (2016) and Farret (2016) stated that floodwater immersion has a lower durability value compared to laboratory water. This is due to the higher content of dissolved particles such as mud in floodwater compared to laboratory water. The mastic layer in the asphalt mixture becomes easily eroded by the mud contained in floodwater through the advective transport process. This mud content allows the erosion of the mastic layer to damage the bond between the asphalt and aggregate

3. Research Methods

Research Location and Time

This research was conducted at the Transportation Engineering Laboratory of the Civil Engineering Department, Faculty of Engineering, University of Riau, Pekanbaru. The process involved preparing materials and equipment as well as conducting the tests from June to September 2022.

Research Material

The materials used to prepare Marshall test specimens and water immersion tests include:

1. RAP aggregates obtained by milling pavement layers on Garuda Sakti Street, Pekanbaru City, Riau Province using Cold Milling Machine.

2. New aggregates from the Pangkalan area, Lima Puluh Kota Regency, West Sumatra Province.
3. Pertamina Pen 60/70 asphalt.
4. Floodwater accumulated on Garuda Sakti Street, Pekanbaru City, Riau Province, for immersion.

Marshall Specimens Test for the SMA Mixture

Marshall test specimens used were produced based on SNI 06-2489-1991. The process involved conducting physical tests on the constituent materials of the mixture such as aggregates and asphalt according to the standard requirements stated in the General Specification for Road Construction 2018 Revision 2 (Directorate General of Highways, 2020) before producing the specimens.

The SMA test specimens used for the durability test were discovered to have satisfied the Marshall characteristics stated in Indonesian National Standard 8129:2015 presented in Table 1. The test was conducted by comparing the results of the stability values of the test specimens without immersion with those immersed in floodwater for 1, 2, 4, and 8 days.

Table 1 - Requirements for Stone Matrix Asphalt (SMA) Mixture

No	Mixture Characteristics	Requirements
1	Asphalt content, %	6,0 -7,0
2	The number of collisions per field	50
3	Void In the Mix (VIM), %	4,0 – 5,0
4	Void in Mineral Aggregate (VMA), %	> 17
5	Marshall stability, kg	> 600
6	Marshall flow, mm	2,0 – 4,5

Source: Indonesian National Standard 8129:2015

4. Results and Discussions

Test Results of the Aggregate, Asphalt, and Flood Water

The results of the laboratory test on the properties of RAP aggregate, new aggregate, and asphalt used as ingredients for the mixture in line with the standard SMA mixture requirements stated in the General Specification for Road Construction 2018 Revision 2 (Directorate General of Highways, 2020) are presented in the following Tables 2 and 3. Moreover, the shape of RAP and the new aggregate is indicated in Figure 1, while the results of the analysis conducted on the flood water content used for the durability test are in Table 4.

Table 2 - Properties of RAP Aggregate and New Aggregate

No	Laboratory test	Standard Requirements	Result	
Coarse Aggregate			RAP Agg	New Agg
1	Soundness test	Max. 12%	2,46%	1,31%
2	Los Angeles Abrasion	Max. 30%	24,05%	21,66%
3	Aggregate adhesiveness to asphalt	Min. 95%	98,00%	95,52%
4	Angularity (%)	100/90	96/91	100/98
5	Flat and elongated	Max. 5%	15,06%	4,91%
6	Absorption	Max. 2%	0,40%	0,47%
7	Specific gravity (g/cc)	-	2,630	2,700
Fine Aggregate				
1	Sand equivalent	Min. 50 %	62,96%	78,02%
2	Angularity	Min. 45	34,00%	49,90%
3	Clay lumps and friable particles in aggregate	Max. 1%	0,44%	0,32%
4	Absorption	Max. 2%	0,13%	0,85%
6	Specific gravity (g/cc)	-	2,270	2,621
Filler				
1	Apparent specific gravity	-	1,44	2,700

Table 3 - Asphalt Pen 60/70 Physical Properties Test Results

No	Laboratory test	Unit	Standard Requirements	Result
1	Penetration at 25°C	0,1 mm	60 – 70	60
2	Kinematic viscosity at 135°C (cSt)	cSt	≥ 300	500
3	Softening point	°C	≥ 48	48,4

4	Ductility at 25°C	cm	≥ 100	≥ 150
5	Flash point	°C	≥ 232	352
6	Solubility in TCE (Trichloroethylene)	%	≥ 99	99,94
7	Specific gravity	g/cc	≥ 1,0	1,0372
After loss on heating or TFOT (SNI-06-2440-1991) or RTFOT (SNI-03-6835-2002):				
8	Loss on heating	%	≤ 0,8	0,01
9	Penetration at 25°C	%	≥ 54	93
10	Ductility at 25°C	cm	≥ 50	≥ 100

Fig. 1. Comparison of RAP and New Aggregate (Virgin Aggregate) forms

Table 4. Flood Water Characteristics

No.	Water immersion sample	Parameter		
		pH	TSS (mg/L)	TDS (mg/L)
1	Floodwater at Garuda Sakti Street	6,80	0,14	0,77

Determination of the Optimum Asphalt Content of SMA Mixture

The gradation targeted in preparing the specimen for SMA mixture was the middle value as indicated in the General Specification for Road Construction 2018 Revision 2 (Directorate General of Highways, 2020). The aggregate material used consists of 33% RAP aggregate and 67% new aggregate (Adiman et al., 2023) as indicated in the following Table 5.

Table 5 - Aggregate Composition of SMA Mixture Test Specimens

Filter		Pass Specifications (%)				Fixed Spec	RAP Aggregate Gradation	RAP Aggregate Proportions	New Aggregate Proportions
mm	#	Range			Target	%	% Fixed	%	%
25	1"	100	-	100	100	0	0,0	0,0	0,0
19	3/4"	100	-	100	100	0	1,0	0,0	0,0
12,5	1/2"	90	-	100	95	5	3,9	0,0	5,0
9,5	3/8"	50	-	80	65	30	4,4	0,0	30,0
4,75	No. 4	20	-	35	27,5	37,5	29,4	29,0	8,5
2,36	No. 8	16	-	24	20	7,5	21,3	2,0	5,5
0,075	No. 200	8	-	11	9,5	10,5	38,2	2,0	8,5
< 0,075	Pan					9,5	1,9	0,0	9,5
Total						100,00	100,00	33,00	67,00

Source: Adiman et al. (2023)

The optimum asphalt content (OAC) of SMA mixture was determined by preparing Marshall test specimens at different asphalt content levels in order to evaluate the Marshall characteristics based on Indonesian National Standard 8129:2015. The stabilizing agent used was Viatop[66]. It has been previously applied by Radetyo (2016) to obtain VCAmix/VCAdrc ratio and Draindown test results that met the specification standards. It is also important to note that the Marshall characteristics evaluated include the voids in the mix (VIM), voids in the mineral aggregate (VMA), Marshall stability, and Marshall flow. The asphalt contents used to determine the OAC were varied at 6.0%, 6.5%, and 7.0% as indicated in Table 1. The results of SMA mixture Marshall test are presented in Table 6, while the determination of the OAC is in Figure 2.

Table 6 - Marshall Test of SMA Mixture with 33% RAP Aggregate

Marshall criteria	Mixture requirements	Asphalt content		
		6,0%	6,5%	7,0%
Density (gr/cm^3)	-	2,319	2,340	2,341
VMA (%)	> 17 %	17,7	17,4	17,8
VTM (%)	4 - 5 %	4,6	3,1	2,4
VFA (%)	-	73,8	82,2	86,7
Marshall Stability (kg)	> 600 kg	688	759	689
Marshall Flow (mm)	2 - 4,5 mm	3,8	3,5	4,1
MQ (kg/mm)	-	181	217	168

No	Marshall criteria	Mixture requirements		Asphalt content				
				Interpolation (%)		Bar chart (%)		
		Min.	Max.	Min.	Max.	6,0	6,5	7,0
1	Density (gr/cm^3)	-		6,00	7,00			
2	VMA (%)	17	-	6,00	7,00			
3	VIM (%)	4	5	6,00	6,20			
4	VFA (%)	-		6,00	7,00			
5	Marshall Stability (kg)	600	-	6,00	7,00			
6	Marshall Flow (mm)	2	4,5	6,00	7,00			
7	MQ (kg/mm)	-		6,00	7,00			
8	Asphalt content requirement (%)	6	7	6,00	7,00			
Range of asphalt content						6,00	6,20	
Optimum Asphalt Content (OAC)						6,10		

Fig. 2. Determination of OAC Value for SMA Mixture with 33% RAP Aggregate

The results presented in Table 6 and Figure 2 showed that the 6.10% OAC value recorded for the SMA mixture with 33% RAP aggregate meets the requirements of Indonesian National Standard 8129:2015.

The durability of SMA Mixture with 33% RAP Aggregate against Floodwater Immersion

The results of the durability test conducted on the SMA mixture with 33% RAP and 100% new aggregates immersed in floodwater for 1, 2, 4, and 8 days are displayed in the following Figure 3. It is important to note that the SMA mixture with 100% new aggregate had an OAC value of 6.23% (Adiman et al., 2023).

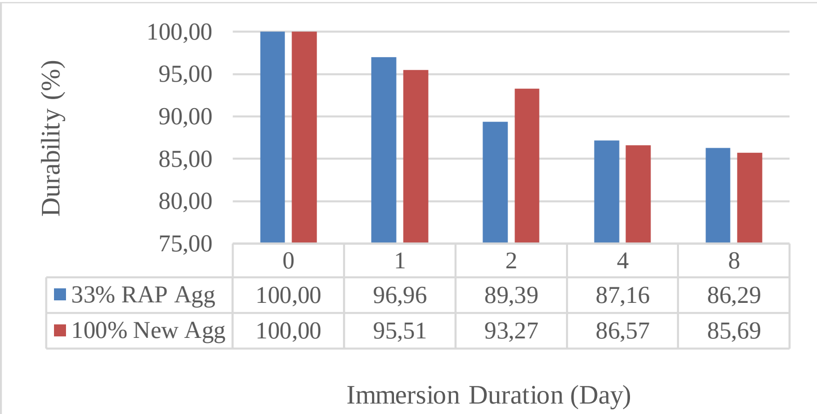

Fig. 3. Comparison of the Durability for The SMA Mixture with 33% RAP Aggregate and 100% New Aggregate against Different Floodwater Immersion Duration

Figure 3 shows that the durability of SMA mixtures with 33% RAP aggregate reduced as the duration of immersion increased. This was associated with the penetration of the asphalt mixture by more floodwater, weakening the bond between the asphalt and the aggregate. In their research, Zou et al. (2023) also concluded that water immersion is one of the main factors causing damage to asphalt mixtures. This is because the water only takes four hours to penetrate a 25 μm thick asphalt layer. On the other hand, the quality of the immersion water content also affects the damage to the asphalt mixture, especially if it comes from acid rainwater (Xiao et al., 2022). So that the decrease in durability in this study is a normal thing because it is related to the duration of immersion and the quality of the water contained in the floodwater.

In Figure 3, it was also discovered that both mixtures (33% RAP aggregate and 100% new aggregate) exhibited a similar trend of a decreased durability value at a longer immersion duration. This was indicated by the almost similar value with a difference of ±1% recorded for immersion durations of 1, 4, and 8 days (although the durability of 33% RAP aggregate is higher than 100% new aggregate). The largest difference between the durability of 33% RAP aggregate and 100% new aggregate was recorded for the immersion duration of 2 days with approximately ±4%, where the durability of 100% new aggregate is higher than 33% RAP aggregate. This happens because the SMA mixtures with 100% new aggregate have a higher asphalt content which can fill more pores in the mixture, thereby increasing the time required for the floodwater to fill the pores. The phenomenon of water immersion damage of the asphalt mixture used so far can only be seen from the test results and cannot be studied in depth due to the complexity of the factors that influence the damage, the lack of satisfactory tools or protocols that can simulate in the laboratory, and the method of theoretical analysis continues (Zhang et al., 2023). However, from the analysis results obtained using 33% RAP aggregate generally performs almost the same as 100% new aggregate up to an immersion duration of 8 days.

5. Conclusion

The results and discussion showed that the SMA mixture produced with 33% RAP aggregate proportion had an OAC value of 6.1% and its durability values against floodwater immersion for 1, 2, 4, and 8 days were recorded to be 96.96%, 89.39%, 87.16%, and 86.29%, respectively. This indicated that the value generally reduced as the immersion period increased. A similar trend was also reported for the SMA mixture with 100% new aggregate (non-RAP). This means RAP aggregate material is a suitable environmentally friendly substitute due to its ability to produce equally good SMA mixture characteristics when compared to the application of 100% new aggregate.

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