The Effect of Aggregate Degradation Level on Durability of Reclaimed Asphalt Pavement

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Abstract. The study you've described focuses on the use of reclaimed asphalt pavement (RAP) as a substitute material in asphalt mixtures with varying percentages of RAP content (25%, 50%, and 75%). The main objectives of the study are to assess the degradation of aggregate components (coarse, fine, and filler fractions) of RAP and to evaluate its impact on the durability of the resulting asphalt mixtures, specifically by measuring the Remaining Strength Index (IRS). In summary, the study highlights the trade-off between using higher percentages of RAP to recycle old pavement materials and maintaining the durability of the resulting asphalt mixture. It demonstrates that as the RAP content increases, the degree of degradation in the asphalt mixture also increases, leading to a decrease in durability as measured by the IRS. However, it's important to note that even with higher RAP content, the asphalt mixture may still meet certain durability requirements, albeit with a slightly reduced IRS value. The findings can help inform decisions in asphalt pavement recycling and mix design for sustainable and cost-effective road construction.

Keywords: RAP, degradation of aggregate, durability

1 Introduction

The Roads have a vital role to play in an economic and social movement. In 2019, the length of Indonesia's asphalt roads reached 325 606 km by Statistics Indonesia, 2017-2019 [1]. However, in reality road damage in Indonesia generally occurs before reaching the design life of the road. Poor drainage system, poor properties of pavement construction materials, unpredictable weather changes, unstable soil conditions, thin

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pavement planning, pavement construction work processes that are not in accordance with specifications, and lack of road maintenance are factors. factors that cause road damage by Yudaningrum *et al.*, 2017 [2]. In addition, the overload of traffic received by the road also results in reduced road strength and durability.

Durability is the ability of asphalt to accept repetitive traffic loads such as friction between vehicle wheels and road surface, vehicle weight, and withstand wear due to weather and climate effects. The old pavement asphalt can be recycled completely for the new pavement [4,5]. in detail, the EN 13108-8 standard defines the RAP as the processed material in the form of milled or the ripped up slabs from existing bituminous road layers and the asphalt mixtures from surplus, rejected or failed productions [20]. RAP function As well as being a new material, it is also a way to reduce construction costs incurred [6,7]. In addition, the main benefit of using RAP in asphalt mixtures is to reduce bulk waste while reducing the use of refined mining materials which are usually used as aggregates [18]. Zaumanis *et al*, 2019 said that The emphasis now is on increasing the percentage of RAP material in the asphalt mix to maximize the benefits of using RAP. There have been several attempts to show that blends containing even up to 100% RA material can work with or better than conventional hot mix pavement [19]. However, during the process of implementing aggregate grading, there will always be changes in the composition of the aggregate. Gradation changes in the mixture are caused by the type of aggregate, grading, compaction process, and asphalt binder [8]. Aggregate degradation can result in gradation and failure of VMA in asphalt mixtures by Sasana, 2003 [9].

Therefore, it is necessary to do research on the effect of the level of degradation on the durability value of the reclaimed asphalt pavement (RAP) based asphalt mixture.

2 Methodology

In this study, there are several steps taken to obtain the desired results including the following:

2.1 Material Testing

Material testing is carried out to determine the characteristics and properties of the material to be used as a pavement material so that it is in accordance with the required standards / specifications, namely:

Aggregates. Testing coarse aggregate, fine aggregate, and filler is needed as an aggregate gradation composition for asphalt mixture materials that meet existing specifications by conducting sieve analysis tests, specific gravity, absorption, filler, aggregate impact value (AIV), aggregate crushing value (ACV), Los angeles abrasion test (LA) . The results of the aggregate test can be seen in Table 1 as follows.

Table 1. Aggregate Testing Results.

No	Type of Testing	Parameters	Value
1	Coarse Aggregate (SNI 03-1969-1990)		
	Bulk density (gr/cm^3)	≥2.5	2.571
	SSD specific gravity (gr/cm^3)	≥2.5	2.618
	Artificial density (gr/cm^3)	≥2.5	.697
	Absorption (%)	<3	1.821
2	Middle Grain Aggregate (SNI 03-1969-1990)		
	Bulk density (gr/cm^3)	≥2.5	2.576
	SSD specific gravity (gr/cm^3)	≥2.5	2.639
	Artificial density (gr/cm^3)	≥2.5	2.749
	Absorption (%)	<3	1.687
3	Rock ash (SNI 03-1969-1990)		
	Bulk density (gr/cm^3)	≥2.5	2.542
	SSD specific gravity (gr/cm^3)	≥2.5	2.612
	Artificial density (gr/cm^3)	≥2.5	2.689
	Absorption (%)	<3	1.675
4	Aggregate crushing value (%) (SNI 03-2417:2008)	Max 30	2.73
5	Aggregate impact value (%) (BS 812:part 3 : 1975)	Max 30	5.28
6	Los angeles abrasion test (%) (BS 812:part 3 : 1975)	Max 40	12.89

Asphalt testing. The testing was carried out for asphalt penetration of 60/70. The tests carried out include penetration, specific gravity, softening point, oil weight loss, and ductility. The results of the 60/70 penetration asphalt test can be seen in Table 2 as follows.

Table 2. Asphalt Penetration Test Results 60/70.

No	Type Test	Unit	Specifications	Value
1	Penetration	0,1 mm	60-70	65.33
2	Specific Gravity	gr/cm^3	≥ 1	1.04
3	Soft Point	^{o}C	≥48	51
4	Weight Loss	%	≤0.8	0.75
5	Ductility	Cm	≥100	132

2.2 Determining Asphalt Mixed Composition

Determining asphalt mixed gradation. In calculating the AC-WC gradation composition, a sieve analysis test is first carried out to determine the proportion of aggregate contained in the RAP material, which is divided into aggregate fraction 1 – 2, sieve fraction 0.5 – 1, and fine fraction. The addition of fresh aggregate is necessary so that the aggregate composition in the asphalt mixture gradation meets the upper and lower limits according to the 2018 General Bina Marga Specifications. The proportion of fresh aggregate added is designed based on the percentage of RAP material content that will be used in the asphalt mixture, namely 25, 50, and 75 percent. The results of the combination of gradation of fresh aggregate and RAP material are then divided into three components, namely the coarse aggregate (CA), fine aggregate (FA) and filler (FF) fractions, which can be seen in Table 3, and the RAP-based asphalt mixture gradation can be seen in Fig. 1. as follows.

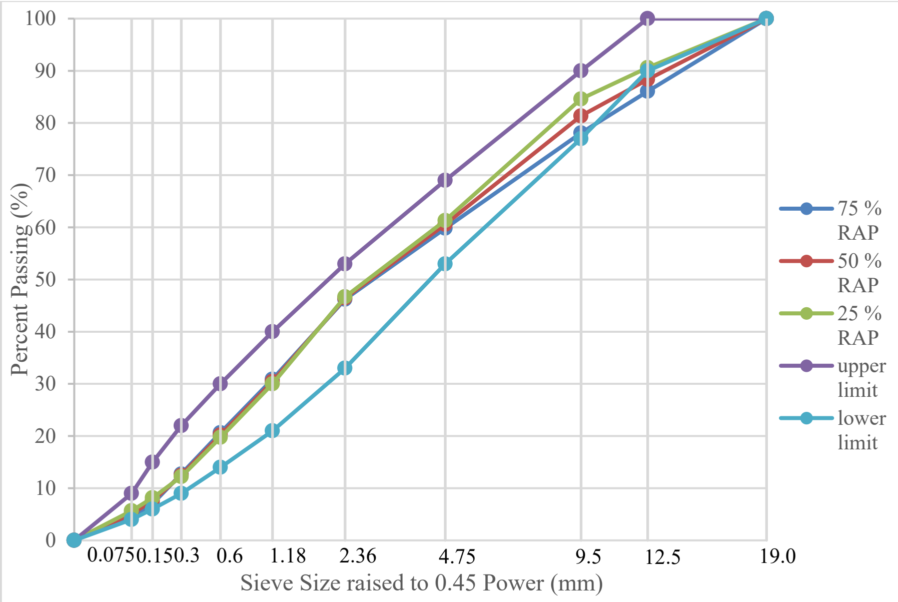

Fig. 1. RAP-based asphalt mixture gradation graph.

Table 3. Composition of fresh aggregate and RAP material in RAP-based asphalt mixtures.

% RAP	RAP Aggregate Proportion (gram)			New Aggregate Proportion (gram)			Amount (gram)
	CA	**FA**	**FF**	**CA**	**FA**	**FF**	
25%	102.3	137.9	9.8	277.1	420.2	52.7	1000
50%	204.6	275.7	19.7	174.8	282.3	42.9	1000
75%	306.9	413.6	29.5	72.5	144.5	33.0	1000

Determining optimum asphalt content. The asphalt contained in RAP material has undergone an aging process during its service life, so that the asphalt becomes hard and less applicable to asphalt mixtures [10]. Therefore, when using RAP, fresh additional bitumen is needed to restore the asphalt content to its optimum state [11]. It is recommended that the RAP mix for binder results from reducing the base binder by the amount of residual asphalt content [17]. In determining the optimum asphalt content, this research begins with making RAP-based asphalt mixture test specimens with asphalt content of 4.5%, 5.0%, 5.5%, 6.0% and 6.5%. Marshall testing is then carried out to assess the characteristics and strength of the asphalt mixture. Based on consideration of the VIM, VMA, VFA, flow and stability parameters of the asphalt mixture, the optimum asphalt content of the RAP-based asphalt mixture can be determined [12] which can be seen in Table 4 as follows.

Table 4. Optimum Asphalt Content.

Information	% RAP		
	25%	**50%**	**75%**
Optimum Asphalt Content	5.8%	5.6%	5.4%

2.3 Specimen Preparation

The RAP-based asphalt mixture specimen was compacted on both sides of the specimen 75 times each. Then the specimens were soaked at a temperature of 60°C with varying soaking times of 0.5-hour, 1 day, 7 days, 14 days and 28 days as shown in Table 5 as follows.

Table 5. Making of Durability RAP Material Test Objects.

Soaking Time	Optimum Asphalt Content			Number of Test Specimens
	RAP 25% 5.80%	RAP 50% 5.60%	RAP 75% 5.40%	
0.5 Hour	3 pieces	3 pieces	3 pieces	9
1 X 24 Hour	3 pieces	3 pieces	3 pieces	9
7 X 24 Hour	3 pieces	3 pieces	3 pieces	9
14 X 24 Hour	3 pieces	3 pieces	3 pieces	9
28 X 24 Hour	3 pieces	3 pieces	3 pieces	9
Amount				45

2.4 Specimens Testing

Tests carried out on specimens include:

Marshall Testing. Marshall testing is carried out with the aim of obtaining an asphalt mixture that meets the requirements specified in the planning criteria. This test includes stability and VIM measurements. The reference used in this test is SNI-06-2489-1991 regarding how to test asphalt mixtures.

Sieve Analysis. Aggregate sieve analysis is the determination of the percentage by weight of aggregate that passes from a filter set then the percentage figures are depicted on the grain distribution graph. This test refers to SNI 03-1968-1990 concerning the analysis method of coarse and fine aggregate sieve and SNI 03-6822-2002 concerning the method of analysis of the extracted aggregate sieve. However, before the sieve analysis is carried out to get the gradation after mixing (the final gradation) it is necessary to carry out the extraction process with the method used is centrifugal extraction with gasoline as a solvent to separate the aggregate and asphalt contained.

2.5 Data Analysis

Calculating the durability of the asphalt mixture using the Index Residual Strength (IRS) parameter, this value will show the resistance of the mixture to damage caused by the influence of temperature and water. In addition, it is also seen from the Marshall parameters, namely stability and VIM.

3 Result and Discussion

In this study, there are several steps taken to obtain the desired results including the following:

3.1 Marshall Testing

Marshall testing is carried out with the aim of obtaining an asphalt mixture that meets the requirements specified in the planning criteria. This test includes stability and VIM measurements. The reference used in this test is SNI-06-2489-1991 regarding how to test asphalt mixtures.

Marshall testing is used to determine the performance of the asphalt mixture in terms of several characteristics, namely stability and voids in mixture (VIM). In addition, measurements were made of the size and weight of the test object. The following is Fig. 2. Testing Marshall.

Fig. 2. Marshall Testing Process.

The results of Marshall testing for stability can be seen in Table 6 and VIM in Table 7 as follows.

Table 6. Results of Immersion Testing for Stability.

% RAP	Stability (Kg)	
	0.5 hours	24 hours
RAP 25%	1,876.3	1,813.0
RAP 50%	1,805.7	1,658.0
RAP 75%	1,792.2	1,565.1

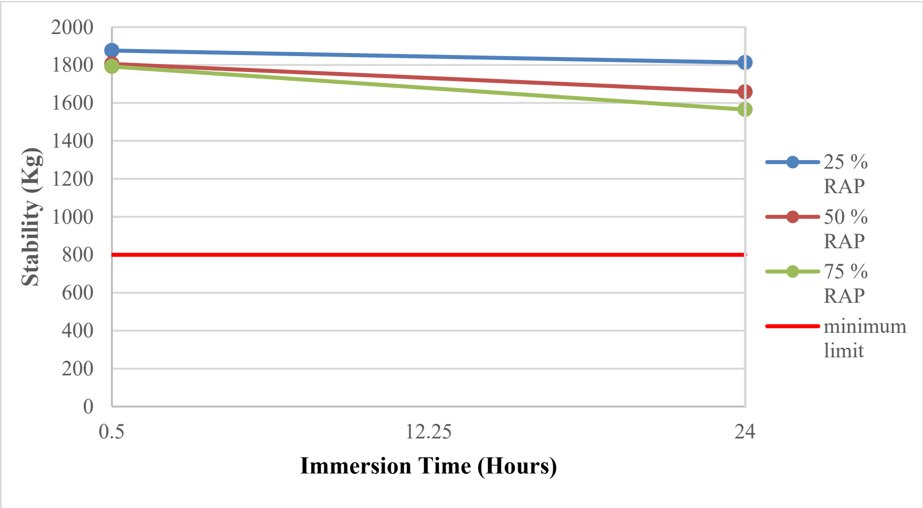

Fig. 3. Comparison of the stability value of the RAP mixture with the immersion time.

It can be seen in Table 6 and Fig. 3. above that the stability value of the three RAP mixtures has decreased with increasing immersion time. This is due to the pressure of water trying to enter the cavities in the mixture. So that it causes the loss of the bond between the aggregate and the asphalt and the stability value decreases.
Judging from the number of RAPs used, the three mixtures of RAP can be seen that the more RAP levels are used, the lower the stability value will be. This is because the asphalt content in the RAP is thought to have been damaged due to the service life of the road. Therefore, the greatest stability value was achieved at RAP 25% followed by 50% and 75%. However, if it is viewed based on the length of immersion, the stability value starts from 7 days onwards, the greatest stability is achieved by RAP 75% and the smallest at RAP 25% This is in line with research [13] which states that the highest stability is achieved at 0% RAP followed by 35 %, 55%, and 60% RAP in the mixture. However, for all uses of RAP for AC-WC pavement, RAP 35% achieved the highest stability value at 1022 kg and the optimum asphalt content was found to be 6.8%.

Table 7. Results of Immersion Testing for VIM.

% RAP	**VIM (%)**	
	0.5 hours	**24 hours**
RAP 25%	4.20	4.92
RAP 50%	4.1	4.86
RAP 75%	3.5	4.53

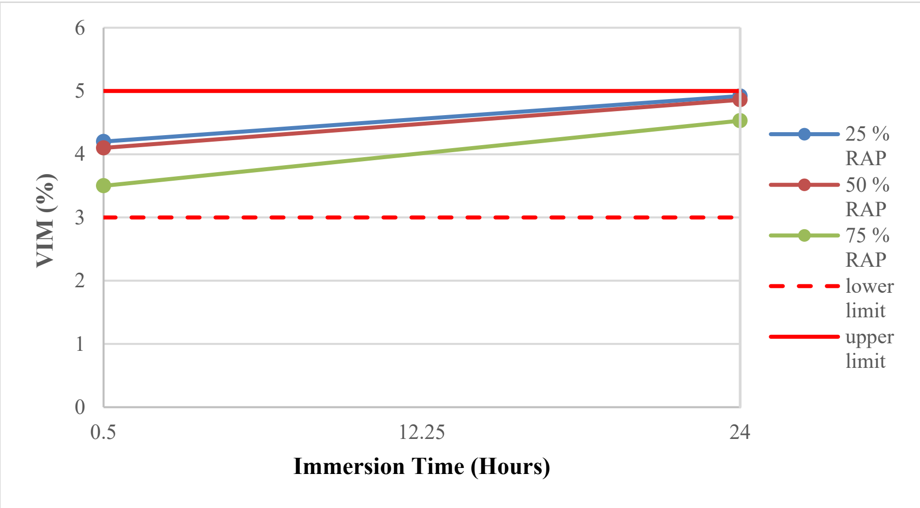

Fig. 4. Comparison of the VIM value of the RAP mixture with the immersion time.

Based on Table 7 and Fig. 4., it is found that the effect of immersion on the VIM value is that the longer the immersion is carried out on the test object, the greater the VIM value. This is because the pressure from the water forces it to enter the cavity of the mixture so that the cavity of the mixture becomes large. In addition, the VIM value is also influenced by the mixture temperature, compaction temperature, and compaction load.
Meanwhile, if viewed from the percentage of RAP used, it can be seen that the more the percentage of RAP used, the greater the VIM value during immersion for up to 1 day. The largest VIM was achieved at 25% RAP with 1 day immersion, namely 4.92% (still meets the 2018 Highways specification standard). This is in line with research [14] which stated that a mixture of 35% RAP, 55% RAP, and 60% RAP resulted in lower VIM values. This shows that RAP can fill the voids in the mixed cavity. The VIM value decreases with increasing asphalt content in the mixture because the more asphalt is used, the more cavities are filled with asphalt so that the total air in the mixture decreases [14].

3.2 Durability Results

The calculation of durability is carried out using the Index Retained Stability (IRS) parameter. The results of the IRS calculation were obtained through testing the mechanical properties of the test object (stability and flow) which were divided into two groups with a time difference. The IRS score required by Bina Marga is a minimum of 90%. One way to see the potential for durability of a mixture is to look at the Index Retained Stability (IRS) value obtained as a result of the marshal immersion test [15]. Marshall's Index Residual Strength (IRS) using the following equation [16]:

$$\text{IRS} = \frac{S1}{S2} \text{ x } 100\% \quad \geq 90 \tag{1}$$

where:
S1 = the average value of Marshall stability after immersion for T1 (Kg)
S2 = the average value of marshall stability after immersion for T2 (Kg)
IRS = Index Retained Stability (%)

By using the formula above, the calculation of the Index Residual Strength of the three asphalt mixtures includes RAP 25%, RAP 50%, RAP 75%. The results of the calculation of the Index Residual Strength can be seen in Table 8 as follows.

Table 8. Index Residual Strength.

% RAP	**Index Residual Strength (%)**
25%	96.63
50%	91.82
75%	87.33
Specification	≤ 90

Based on the table above, it is obtained that the IRS value of the test object with a mixture of RAP 25% and RAP 50% respectively of 96.63% and 91.82% indicates an IRS value ≥ 90, which means that the test object is sufficiently resistant to damage caused by the influence of temperature and water. Meanwhile, for the percentage of RAP 75%, it was obtained that the IRS value ≤ 90 was 87.33% or did not meet the specifications.

3.3 Degradation of Aggregate Results

In this study, a sieve analysis test was carried out before the mixing process (initial gradation) and after mixing (the final gradation) was carried out to obtain the rate of aggregate degradation in each of the specimens. However, the final grading is obtained from the extraction process using the centrifugal extraction method. The extraction process is carried out on the asphalt mixture after mixing which aims to separate the aggregate and the asphalt contained in the mixture and obtain its final gradation. The solvent used is premium gasoline which functions to separate aggregate and asphalt.
The extraction process carried out by researchers can be seen in Fig. 5. Meanwhile, the rate of aggregate degradation calculated based on sieve analysis test can be seen in Table 9 as follows.

Fig. 5. Centrifugal extraction process.

Table 10. Aggregate degradation rate of each aggregate fraction in The Asphalt mixed.

% RAP	Aggregate degradation rate (%)		
	CA	FA	FF
25%	3.65	2.11	1.54
50%	4.30	2.66	1.64
75%	4.94	2.91	2.03

From Table 10 above, it can be illustrated graphically as follows:

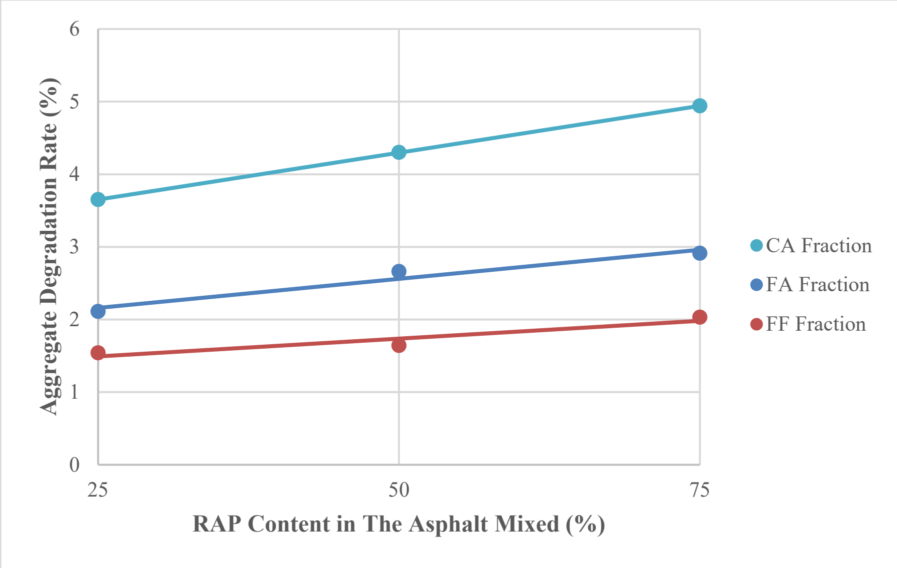

Fig. 6. Comparison of aggregate degradation rates for each aggregate fraction based on the RAP content in the asphalt mixed.

Based on Fig. 6. It is found that the greater the percentage of RAP levels used, the greater the level of degradation that occurs. This happened because the RAP material used had been damaged due to the planned age/traffic load. Meanwhile, if viewed from the component fractions, it can be seen that the levels of degradation in order from the lowest to the highest levels, namely mineral filler (FF) fraction, fine aggregate (FA) fraction, and coarse aggregate (CA) fraction. The largest aggregate degradation rate was experienced by the CA fraction in the asphalt mixture with a content of 75% RAP which reached 4.94%.

3.4 Aggregate Degradation with Marshall Results

In an asphalt mixture, the aggregate gradation will affect the interlocking between the aggregates [8]. The aggregate gradation in an asphalt mixture has an effect on the level of Marshall characteristics. So, it is necessary to do calculations to determine the effect of the level of aggregate degradation on Marshall characteristics such as VIM and stability in terms of three components, namely CA, FA, and filler as follows.

Relationship between Aggregate Degradation and The Asphalt Mixed Stability. The aggregate gradation affects the stability of an asphalt mixture. So, it is necessary to know the effect of aggregate degradation from the CA fraction, FA fraction, and FF fraction on the stability properties of an asphalt mixture which can be seen in the following graph.

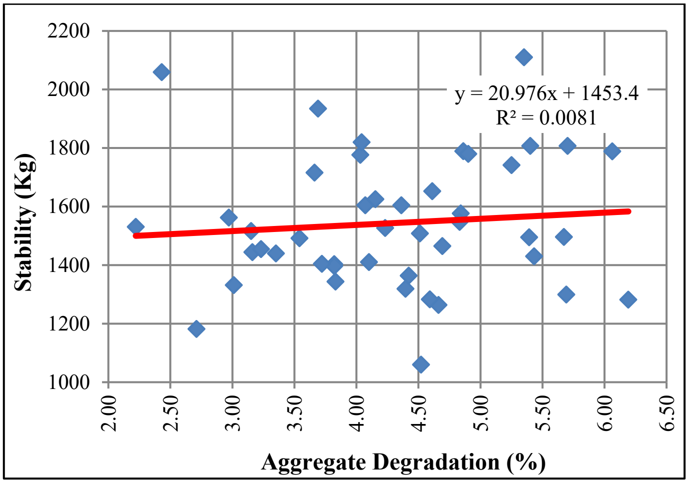

Fig. 7. Relationship between aggregate degradation of the CA fraction and stability.

Based on Fig. 7 above, it can be seen that the greater the level of degradation in the CA fraction, the stability value tends to increase due to the decreasing content of the CA fraction in the asphalt mixture which changes to the FA fraction and also the FF fraction. As a result, the asphalt mixture tends to become denser. The highest degradation in the CA fraction was 6.19% with a stability value of 1282,206 Kg, while the smallest degradation was 2.22% with a stability of 1530,748 Kg (Min. Stability ≥ 800 Kg).

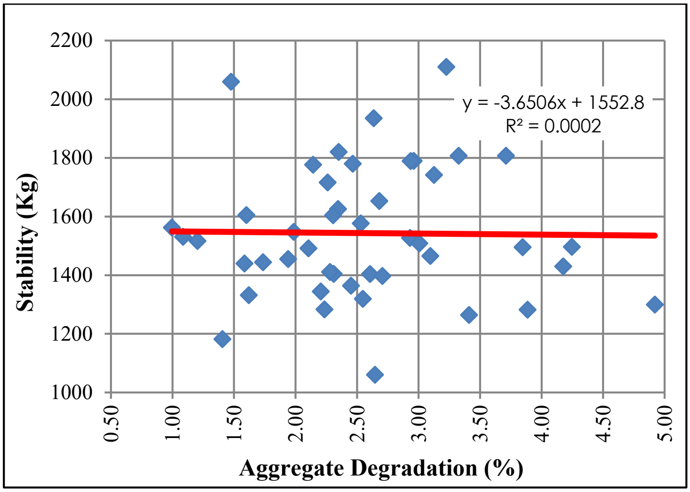

Fig. 8. Relationship between aggregate degradation of the FA fraction and stability.

Based on Fig. 8. above, it is known that the greater the level of degradation in the fine fraction (FA) relatively does not have a significant influence on the stability of the asphalt mixture even though there is a slight tendency to decrease stability. This may be due to the proportion of changes in the FA fraction to the FF fraction being smaller than the proportion of changes in the CA fraction to the FF fraction in the asphalt mixture. As a result, the FA fraction content in the asphalt mixture will increase and the aggregate gradation in the asphalt mixture will tend to become more uniform, thereby reducing the chance of interlocking between aggregates. The highest FA fraction degradation was 4.92% with a stability of 1299.888 Kg, while the lowest FA degradation was 1.00% with a stability of 1562.636 Kg.

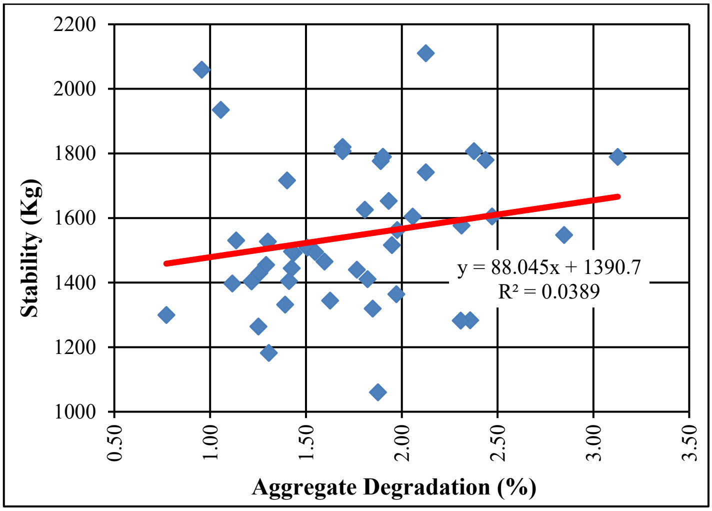

Fig. 9. Relationship between aggregate degradation of the FF fraction and stability.

Based on Fig. 9. above, it is known that the greater the level of degradation in the FF fraction, the stability value tends to increase, although the magnitude of the increase is not very significant. This may be caused by increasing the mineral filler content which can result in an increase in the density of the asphalt mixture. The highest FF fraction degradation was 3.13% with a stability of 1789.130 Kg, while the lowest FA degradation was 0.77% with a stability of 1299.888 Kg.

Relationship between Aggregate Degradation and VIM. The aggregate gradation affects the cavities in the asphalt mixture. The interlocking property between aggregates in the asphalt mixture is important. So, it is necessary to know the effect of aggregate degradation from the CA fraction, FA fraction, and FF fraction on the VIM (void in mixture) properties. The relationship between aggregate degradation and VIM can be seen in the following graph.

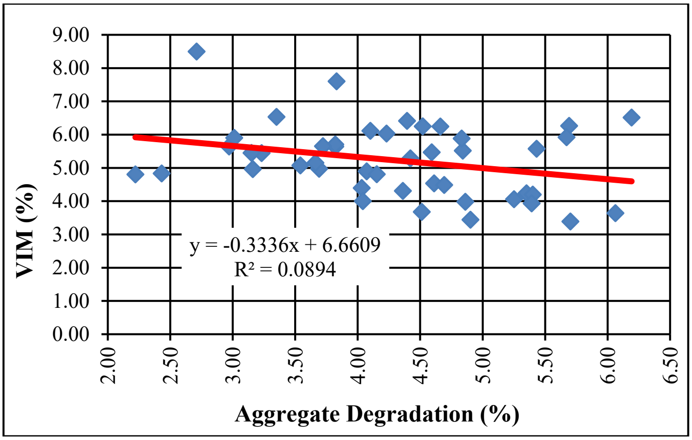

Fig. 10. Relationship between aggregate degradation of the CA fraction and VIM.

Based on Fig. 10. above, it can be seen that the greater the level of degradation in the CA aggregate fraction, it can reduce the VIM value due to the reduction of coarse aggregate to FA fraction and filler so that it can fill the empty voids in the mixture.

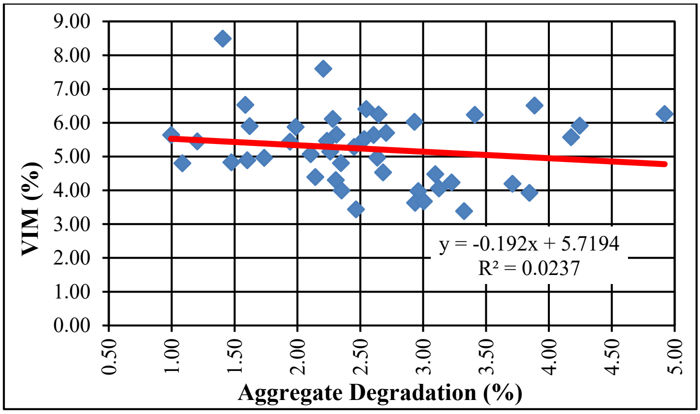

Fig. 11. Relationship between aggregate degradation of the FA fraction and VIM.

Based on Fig. 11. above, it can be seen that the increasing level of aggregate degradation in the FA fraction can cause a decrease in the VIM value in the mixture. Because the fine aggregate that turns into filler has filled the empty voids in the mixture.

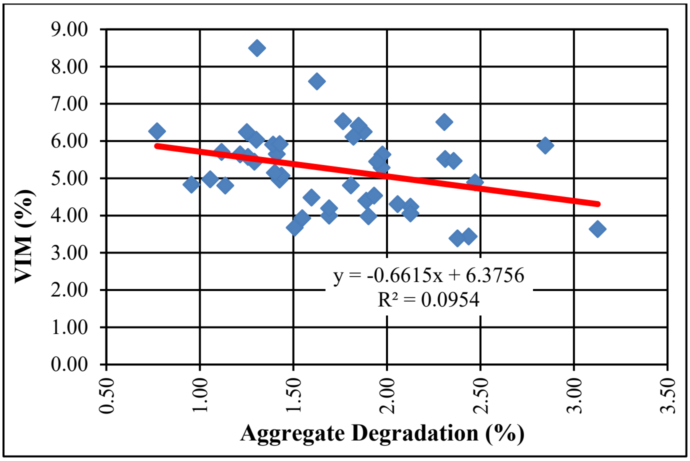

Fig. 12. Cand VIM.

Based on Fig. 12. above, it is found that an increase in the level of aggregate degradation in the FF (filler) fraction can cause the pore size in the reduced mixture or the void in mixture (VIM) value to get smaller.

3.5 The Effects of Aggregate Degradation on The Durability of Asphalt Mixed

Durability (durability) is the ability of the surface layer to accept repetition of traffic loads such as vehicle weight, friction between vehicle wheels and the road surface, and withstand wear due to weather and climate effects such as air, water or temperature changes. One way to see the potential for durability of a mixture is to look at the Index Residual Strength (IRS) value obtained as a result of the marshal immersion test [15]. The relationship of aggregate degradation with IRS can be seen as follows:

Table 11. Aggregate Degradation Relationship with IRS.

% RAP	Degradation of Aggregate (%)			IRS
	CA	FA	*Filler*	
		(%)		(%)
25%	3.99	2.39	1.60	96.63
50%	4.44	2.59	1.85	91.82
75%	4.98	2.75	2.23	87.33

based on Table 11 can be illustrated graphically as follows.

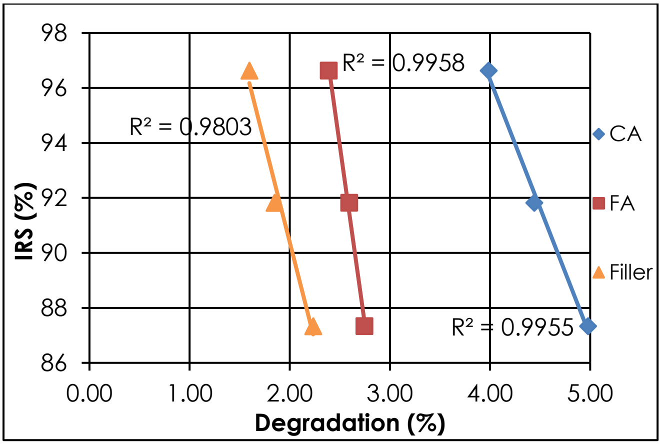

Fig. 13. Graph of the relationship between aggregate degradation and IRS.

Based on Fig. 13, it can be seen that in the CA, FA, and FF fractions the greater the level of degradation, then the value of the Index Residual Strength (IRS) will decrease. In the CA fraction, the level of degradation that occurred was between 3.99% -4.98%. In the FA fraction, the degradation rate ranged from 2.39% -2.75%. While the filler fraction ranged from 1.60% -2.23%. The IRS value in the asphalt mixture with a RAP content of 25% and 50% fulfills the requirements ≥ 90%, meaning that it is quite resistant to damage caused by the influence of temperature and water. However, at the RAP 75% the IRS value <90% (not fulfilling).

4. Conclusion

The conclusion of this study is that as the percentage of RAP used increases, the greater the level of degradation obtained. Whereas in the CA, FA, and FF fractions the greater the level of degradation, then the value of the Index Residual Strength (IRS) will decrease. The IRS value in the asphalt mixture with a RAP content of 25% and 50% fulfills the requirements ≥ 90%, meaning that it is quite resistant to damage caused by the influence of temperature and water. However, at the RAP 75% the IRS value <90% is not fulfilling.

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