JMPM: Journal of Materials and Manufacturing Processes
Vol. 8, No. 2, p127-137, Desember 2024
DOI: https//doi.org/10.18196/jmpm.v8i2.23832

Analysis Index of Retained Strenght on AC-WC Asphalt Mixture with the Addition of Cigarette Filter Waste as an Alternative for Asphalt Modification

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Keywords:

AC-WC; Cigarette Filter Waste; Index of Retained Strength; Marshall

ABSTRACT

In order to provide an alternative asphalt mixture that is more durable, various efforts have been made to improve the quality of asphalt, therefore research is needed on polymer modified asphalt by replacing some of the asphalt with cigarette filter waste. In this study, cigarette filter waste was substituted into asphalt with proportions of 2%, 5%, and 8%. The purpose of this study was to determine the percentage of cigarette filter waste that affects the AC-WC mixture based on marshall characteristics and residual stability. The optimum asphalt content (KAO) used was 5.1%, with the results showing that the addition of cigarette filter waste affected the marshall characteristic values, namely the specific gravity value, Voids Filled with Asphalt (VFA), and the highest stability was at a variation of 2%, while the Voids in Mix (VIM), Void in Mineral Aggregate (VMA), and the highest flow. were at a variation of 8%. The residual stability index test showed that water affected the durability of the AC-WC mixture, as evidenced by the highest value in the 24-hour immersion variation with a cigarette filter content of 2% which decreased with increasing immersion time. The addition of cigarette filter waste into the AC-WC mixture has met the Bina Marga Specifications in the Marshall characteristic test, but the change in the residual stability index was only at a soaking time of 24 hours, while for other periods it did not comply with the Bina Marga specifications.

1. INTRODUCTION

Highways with asphalt pavement are the majority of transportation infrastructure in Indonesia. Roads are the main land transportation media consisting of several materials such as coarse aggregate, fine aggregate, filler, bitumen and also additional materials with a certain percentage [1]. Laston Wearing Layer AC-WC (Asphalt Concreate-Wearing Course) is the topmost pavement layer that functions as a wear layer. This layer can increase the resistance of the pavement structure to decreased pavement quality and can increase the life of the pavement. The minimum thickness of this layer is 4 cm with a thickness tolerance of -3.0 cm [2]. The surface layer of the road pavement is a layer that directly interacts with traffic loads and the environment. Waterlogging on the road surface causes the loss of bonds between asphalt and aggregate [3]. The effect of water on pavement damage is complex and related to thermodynamic, chemical, physical, and mechanical processes [4]. Therefore, the asphalt mixture requires reinforcement with additional materials as a modification to support strength, plastic flexibility, number of air cavities, resistance to external forces, and weather. One way to improve the performance of asphalt is by modifying the asphalt by adding a polymer material [5]. Improving the quality of asphalt road pavement can be done by modifying the physical and chemical properties of asphalt pavement forming materials with various additives to obtain better quality, minimize spending on road infrastructure, and provide comfort for the community and the country [6]. Cigarette filters are made of thousands of cellulose acetate polymer chains, after being disposed of into the environment, cigarette filters create a major problem for environmental impacts. The content in cigarette filter waste is cellulose acetate polymer which has thermoplastic properties, binds to plasticizers, is resistant to heat and pressure [7]. However, cigarette filter waste takes 10 years to decompose and every year 1.2 million tons of cigarette waste are produced worldwide [8], [9], becoming one of the major problems that will impact the environment if the increase in smokers continues to increase while responsibility for cigarette waste is ignored [10].

On the other hand, during the rainy season, Indonesia has very high rainfall, resulting in puddles on the road surface which can reduce the durability of the road. Innovation in road pavement design needs to be continuously carried out in order to obtain pavement quality that can withstand extreme weather [11]. Damage to road pavement construction is caused by water that can come from rainwater, poor road drainage systems and rising water due to capillarity. Rainwater that soaks the road section can cause the road pavement, especially the asphalt binding capacity to decrease because the asphalt is continuously submerged in water [12]. AC-WC is a surface layer that in its planning must be waterproof. This layer must be waterproof, so that rainwater that falls on it does not seep into the layers below and weaken these layers [13].

Stability is one of the characteristics of asphalt mixtures whose strength must meet the specification requirements in order to obtain an effective and strong mixture. In [14], stability is the ability of the mixture to resist deformation or changes in shape caused by traffic that must be borne. Residual Stability is a comparison of the stability of the mixture soaked for 24 hours, the longer the duration of soaking, the lower the residual stability value, the decrease in this stability value is caused by damage due to the influence of water. This damage is caused by the water temperature being too high which affects the pavement which will make the briquette/test object soften along with the duration of soaking [15].

The purpose of this study was to determine the Residual Stability Index (RSI) in the Asphalt Concrete – Wearing Course (AC-WC) mixture using cigarette filter waste (Cellulose Acetate) as a partial replacement of asphalt in a dense gradation hot mixture when the mixture is soaked for 24 hours, 48 hours, and 72 hours. The variations of cigarette filters used were 2%, 5%, and 8% of the volume of asphalt used in 1 mole of test specimen.

2. METHODS

The research was conducted using an experimental research method, namely a method carried out through experimental activities to obtain information. The data was processed to obtain comparative results with existing conditions [16], by making a mixture of asphalt concrete-wearing course (AC-WC) materials according to the 2018 Bina Marga specifications revision 2 and adding cigarette filter waste with a percentage of 2%, 5%, 8% of the total weight of the optimum asphalt content (KAO), as well as variations in the duration of immersion in a water bath to determine the strength of the test object's resistance to the effects of water.

This research was conducted at the Civil Engineering Laboratory of Veteran Bangun Nusantara University. The materials used were coarse aggregates in the form of 1-2 and 0-5 materials and fine aggregates in the form of stone ash obtained from PT. Wira Bhakti Mulia Boyolali. The innovation material used cigarette filter waste obtained in the campus area. The research steps are explained in the form of a flow chart in Figure 1.

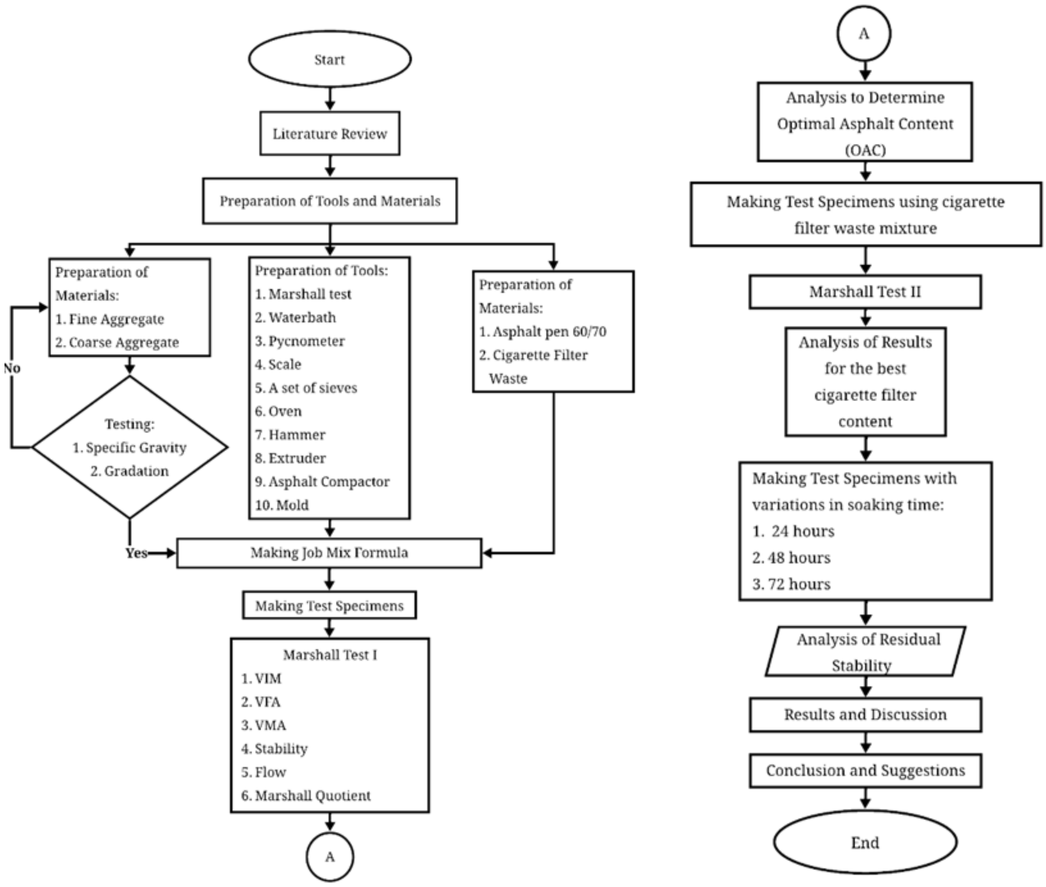

Figure 1. Research Diagram

2.1 Cigarette Filter Waste Mixing

Figure 2. Cigarette Filter Waste Mixing

The mixing of cigarette filter waste into the asphalt mixture uses the dry method, i.e. cigarette filter waste is incorporated into the mixture after the aggregate has been heated. Figure number 1 shows the cut cigarette filter so that when mixing with asphalt it can be covered optimally. Figure number 2 shows the cut cigarette filter that has been weighed according to the asphalt content that is replaced with variations of 2%, 5%, and 8%. Figure number 3 shows the mixing of cigarette filter waste and filler into aggregate that has been heated to 160°C. Figure number 4 shows the cigarette filter waste and filler are stirred evenly and then liquid asphalt at 16°0C is added while being weighed, then heated again while stirring evenly with a temperature of 160 ° C. After evenly mixing the mixture is put into the mole and pounded as much as 75 mash.

2.2 Specific Gravity and Absorption Testing

Specific Gravity and Absorption Testing is a test to determine the value of bulk specific gravity, saturated dry surface specific gravity, apparent specific gravity and absorption of fine aggregate and coarse aggregate [17]. Testing is based on SNI 03-1969-2008 for coarse aggregate, and SNI 03-1970-2008 for fine aggregate.

2.2 Marshall Testing

Marshall Test is a test to determine the performance of asphalt concrete, which was first developed by Bruce Marshall and continued by the US Corps Engineer and standardized by ASTM or AASHTO through several modifications, namely ASTM D 1559-76 or AASHTO T-245-97 [18] [19]. In its implementation, the Marshall test tool is equipped with a watch to read the results of stability and fatigue measurements. The results of stability and fatigue measurements must be multiplied by the calibration factor, in this study the calibration factor value was 19.54 kg. According to [20] the characteristics of Marshall in general can be explained as follows:

1. VIM is the ratio (percentage) of void volume to the total volume of solid mixture or a value that indicates the number of voids in a mixture. VIM is expressed as a percentage of the volume of asphalt mixture. The volume of air voids in the mixture can be determined by the following formula:

$$VIM = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100 \quad (1)$$

Where is G_{mm} is the maximum specific gravity of the mixture after compaction (gr/cc), G_{mb} is the bulk specific gravity of the mixture after compaction (gr/cc), VIM is the air cavity in the mixture (%)

2. VMA is the percentage of void value contained in the aggregate. The value of VMA according to the 2018 Bina Marga Specifications is at least 14% which can be calculated using the following formula:

$$VMA = 100 - \frac{G_{mb} \cdot P_s}{G_{sb}} \quad (2)$$

Where VMA is the air voids in the mineral aggregate (%), G_{mb}. is the bulk density of the mixture after compaction *(gr/cc), G_{sb} is the bulk density of the total aggregate (gr/cc),P_s is the percentage of aggregate content to the total weight of the mixture (%).

3. VFA is a value that indicates the size of the cavity filled by asphalt expressed in percent (%). The value of VFWA greatly affects the durability of a pavement. The VFA value requirement is 65% which can be determined using the formula:

$$VFA = \frac{(VMA - VIM) \times 100}{VMA} \quad (3)$$

Where VFA is the percentage of voids filled with asphalt (%), VMA is the percentage of voids in the aggregate (%), VIM is the percentage of voids in the asphalt mixture (%).

4. Stability is the ability of the pavement layer to withstand deformation or permanent changes in shape, such as: waves, grooves, bleeding. The stability value is obtained by reading the dial or watch on the Marshall tool multiplied by the Marshall tool calibration, the height correction value of the test object, and the unit conversion from lbs to kg.

$$S = p \times q \quad (4)$$

Where S is the Stability value (kg), p is the reading of the tool x calibration, q is the correction number for the thickness of the test object.

5. Flow is the amount of deformation that occurs in a pavement layer due to withstanding the load received. The amount of deformation value in the pavement layer is influenced by the VIM, VFWA, and stability values. The flow value is obtained by reading the dial or watch on the Marshall tool. The flow value is expressed in mm.
6. *Marshall Quotient*is the result of dividing the stability value by the flow value, which is used as an approximation to the stiffness level of the mixture. The MQ value is expressed in kg/mm. The Marshall properties can be calculated using the following formula:

$$MQ = \frac{S}{F} \tag{5}$$

Where MQ is the Marshall Quotient value (kg/mm), S is the Stability value (kg), F is the Fatigue value (Flow)

3. RESULTS AND DISCUSSION

3.1 Material Characteristics Test Results

This test aims to determine the characteristics of the aggregate that will be used to determine the percentage of aggregate fractions. The results of the specific gravity and absorption tests based on SNI 03-1969-2008 are shown in tables 1 - 3.

Table 1. Specific Gravity and Absorption of Coarse Aggregate

Filter	Magnitude	Specification	Reference
Bulk Specific Gravity	2.68	Min 2.5 gr/cm3	SNI 1969 : 2008
Saturated surface dry specific gravity (SSD)	2.71	Min 2.5 gr/cm3	
Apparent specific gravity	2.75	Min 2.5 gr/cm3	
Absorption	0.95	Max 3%	

Table 2. Specific Gravity and Absorption of Medium Aggregate

Filter	Magnitude	Specification	Reference
Bulk Specific Gravity	2.71	Min 2.5 gr/cm3	SNI 1969 : 2008
Saturated surface dry specific gravity (SSD)	2.74	Min 2.5 gr/cm3	
Apparent specific gravity	2.81	Min 2.5 gr/cm3	
Absorption	1.35	Max 3%	

Table 3. Specific Gravity and Absorption of Fine Aggregate

Filter	Magnitude	Specification	Reference
Bulk Specific Gravity	2.64	Min 2.5 gr/cm3	SNI 1970 : 2008
Saturated surface dry specific gravity (SSD)	2.72	Min 2.5 gr/cm3	
Apparent specific gravity	2.86	Min 2.5 gr/cm3	
Absorption	2.92	Max 3%	

Aggregate sieve analysis testing based on SNI ASTM C136:2012 produces an analysis of the percentage distribution of aggregate grains which can be seen in Table 4. Combined Gradation is the sum of the percentages of each sieve in each fraction.

Table 4. Combined Gradation

No Filter	Sieve Size (mm)	Original Gradation				Combined Gradation	Specification		Information
		A Stone Ash	B Max Stone ½"	C Max Stone ¾"	D Filler		Min.	Mom.	
1"	25	100.00	100.00	100.00	100.00	100.00	100	100	Fulfil
3/4"	19	100.00	100.00	100.00	100.00	100.00	100	100	Fulfil
1/2"	12.7	100.00	100.00	90.65	100.00	98.13	90	100	Fulfil
3/8"	9.5	100.00	99.59	5.52	100.00	80.96	77	90	Fulfil
#4	4.75	96.14	39.33	0.86	100.00	57.24	53	69	Fulfil
#8	2.36	75.78	9.33	0.33	100.00	37.67	33	53	Fulfil
#16	1.18	56.68	5.55	0.29	100.00	27.94	21	40	Fulfil
#30	0.6	40.72	3.74	0.28	100.00	20.28	14	30	Fulfil
#50	0.3	29.50	3.02	0.26	100.00	15.09	9	22	Fulfil
#100	0.15	18.10	1.95	0.22	100.00	9.69	6	15	Fulfil
#200	0.075	10.56	1.41	0.13	97.00	6.14	4	9	Fulfil

Next, aggregate combined gradation analysis is performed. Aggregate gradation is one of the parameters that affect the strength of a pavement layer [21]. Combined gradation is obtained by adding the percentage of each sieve in each fraction. The method used to find the percentage of combined aggregate is trial and error. If the calculation results do not meet the specifications, a re-sieve analysis test will be carried out. The results of the gradation analysis are presented in Figure 3.

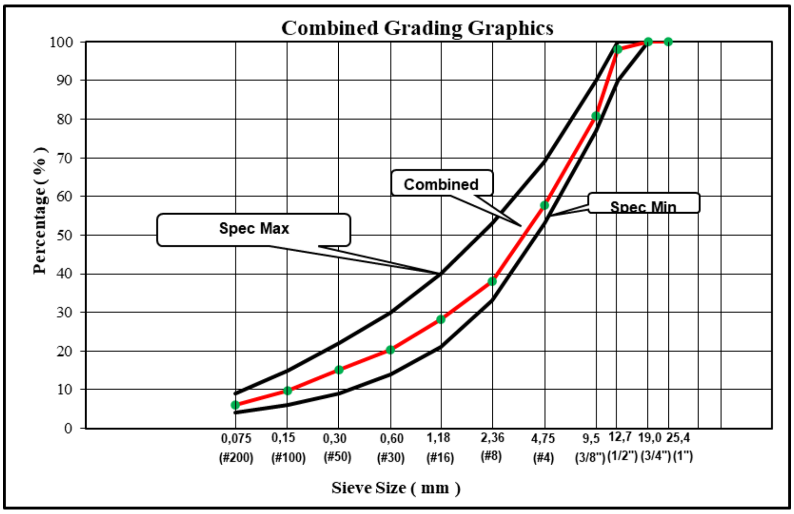

Figure 3. Combined Grading Graphics

The results of the calculations in the form of percentages of coarse aggregate, medium aggregate, fine aggregate and filler are used as constants in calculating the estimated KAO, the calculations to determine the estimated KAO using the Pb formula are shown in the following calculations [22]:

Pb = (0.035 x CA) + (0.045 x FA) + (0.180 x FF) + K
= (0.035 x 62.33) + (0.045 x 31.54) + (0.180 x 6.14) + 0.989
= 2.181 + 1.419 + 1.105 + 0.989
= 5.69% ≈ 5.7%

K = Constant (0.5-1.0 for AC)

So the result of the calculation using the Pb formula, the estimated KAO required is 5.69% rounded to 5.7%. Based on the Bina Marga regulation where the AC-WC constant is 0.5-1.0, so that five variations of asphalt content are made, with two asphalt content above and two asphalt content below the estimated KAO value with an increase and decrease of 0.5%.

3.2 Test ResultsMarshall Test Object

Next, the test specimens were made with each variation consisting of 3 briquettes to obtain KAO which will be used in the innovation asphalt mixture. The test results can be seen in table 5.

Table 5.Results of asphalt content testing variations

% Asphalt Content	BJ Max Mixture (gr/cc)	BJ. Bulk Mixture (gr/cc)	% VIM	% VMA	% VFA	Stability (Kg)	Flow	MQ
4.7	2,480	2,371	4.38	15.76	72.21	1569.71	2.70	628.52
5.2	2,462	2,361	4.10	16.57	75.25	1765.11	2.08	872.96
5.7	2,444	2,393	2.09	15.89	86.87	1719.52	2.25	878.89
6.2	2,426	2,377	2.04	16.90	87.98	1869.33	1.97	955.13
6.7	2,406	2,361	2.00	17.90	88.81	1706.49	2.22	782.91
LIMITATION			*3.0-5.0*	*Min 15*	*Min 65*	*Min 800*	*2.0-4.0*	*Min 250*

From the research and calculation of briquettes with 5 variations of asphalt content, it can be seen that the VIM of the mixture with asphalt content of 5.7%, 6.2%, and 6.7% is still below the specification limit and for the others it is in accordance with the 2018 Bina Marga Specifications, Revised Edition 2, which can be seen in Table 5.

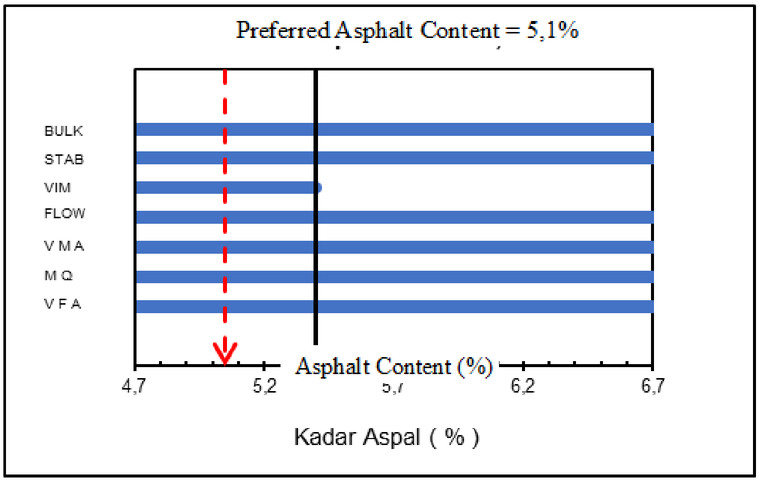

Figure 4. Graph of asphalt content determination

Figure 4 shows the results of Marshall characteristic testing with five variations of asphalt content, each variation made three test objects. The KAO obtained was 5.05% which was rounded to 5.1%.

3.3 Test ResultsMarshall Innovation Test Object

After the KAO value was determined, asphalt mixture test specimens were made with the innovation of adding 2%, 5%, and 8% cigarette filter waste as many as 3 briquettes for each variation, the results can be seen in table 6.

Table 6. Results of the Marshall test of cigarette filter innovations

% Cigarette Filter Level	BJ Max Mixture (gr/cc)	BJ. Bulk Mixture (gr/cc)	% VIM	% VMA	% VFA	Stability (Kg)	Flow	MQ
2	2,467	2,384	3.38	88.42	96.18	1765.11	3.03	593.70
5	2,467	2,349	4.77	88.58	94.61	1719.53	2.22	859.00
8	2,467	2,331	5.50	88.67	93.79	1713.01	1.68	1111.33
LIMITATION			*3.0-5.0*	*Min 15*	*Min 65*	*Min 800*	*2.0-4.0*	*Min 250*

From table 6, the results of the Marshall test with variations in the addition of cigarette filter waste of 2%, 5%, and 8% are obtained, it can be seen that the highest stability is at a content of 2% with a value of 1765.11 Kg and the only flow that meets the standard is at a content of 2% with a value of 3.03. So from the results of the Marshall test, the innovation of 2% cigarette filter content was chosen as the preferred content in the manufacture of residual stability test objects.

3.4 Cost Analysis Calculation Results

Based on the cost analysis carried out to determine the amount of bitumen asphalt saved from modification using cigarette filter waste, the calculation is obtained with the following formula:

Asphalt mixture volume = Road Length x Road Width x Asphalt Thickness x AC-WC Asphalt Specific Weight

= 100 meters x 6 meters x 0.04 meters x 2.25 tons/m^3

= 54 tons

AC-WC bitumen volume = % x AC-WC Mix Volume

= 5.1% x 54 tons

= 2.75 tons = 2750 kg

So when using a variation of cigarette filter waste with a level of 2%, then 2750 kg - 2% = 55 kg. So every AC-WC paving with a road length of 100 meters and a thickness of 4 cm will save 55 kg of asphalt.

3.5 Residual Stability Test Result Index

Marshall stability is the maximum load that the mixture can support before collapsing. The immersion index (IP) value depends on the type and quality of the pavement assuming adequate condition of the pavement. The immersion index (IP) value is also called the Residual Stability Index. A large Residual Stability Index value indicates high pavement durability and vice versa [23].

The residual stability index is a comparison of the immersion of the test object in water at a temperature of 60°C for 24 hours with standard stability, expressed as a percentage, which aims to determine the resistance and durability of the asphalt mixture to the effects of water. The duration of the immersion time span of 24 hours, 48 hours, and 72 hours has been in accordance with the specification limits for a maximum immersion of 24 hours for normal immersion, with an innovation of 2% cigarette filter content of 3 briquettes in each immersion variation. The results of the manufacture of test objects can be seen in table 7.

Table 7. Marshall test results for immersion variations

Immersion Variations (O'clock)	BJ Max Mixture (gr/cc)	BJ. Bulk Mixture (gr/cc)	% VIM	% VMA	% VFA	Stability (Kg)	Flow	MQ
24	2,467	2,351	4.73	88.58	94.67	1628.33	3.37	484.78
48	2,467	2,345	4.96	88.61	94.40	1498.07	3.43	438.37
72	2,467	2,339	5.18	88.63	94.15	1335.23	3.70	367.78
LIMITATION			*3.0-5.0*	*Min 15*	*Min 65*	*Min 800*	*2.0-4.0*	*Min 250*

The calculation of immersion variation in table 7 shows that the VIM, VMA, and Flow values increase with increasing immersion time, while the VFA and Stability values decrease. The stability value obtained will be used to calculate the residual stability using the IRS formula.

The stability index testing procedure follows the reference of SNI M-58-1990. The following is the formula for calculating residual stability:

$$IRS=[\frac{MSi}{MSs}]\times 100\%$$

Where IRS is the Residual Stability Index, Msi is the 24-hour Immersion Marshall Stability (innovation), MSs is the 30-minute Immersion Marshall Stability (normal).
The following is the calculation of the residual stability index:

IRS24 hours = $[\frac{MSi}{MSs}]\times 100\%$
=[1628.33 / 1765.11] × 100%
= 92.25%

IRS72 Hours = $[\frac{MSi}{MSs}]\times 100\%$
=[1335.23 / 1765.11] × 100%
= 75.65%

IRS48 Hours= $[\frac{MSi}{MSs}]\times 100\%$
=[1498.07 / 1765.11] × 100%
= 84.87%

From the calculation results above, the residual stability index data is obtained, which is presented in Figure 5.

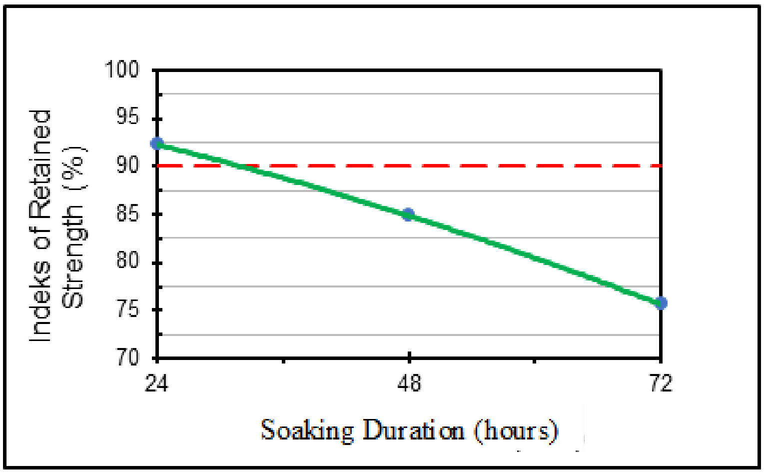

Figure 5. Residual Stability Index Graph

Figure 4 shows the results of the calculation of residual stability using the IRS formula, with the results of 24-hour immersion at 60°C of 92.25%, 48 hours of 84.87%, and 72 hours of 72.65%, where according to SNI M-58-1990 the minimum limit of residual stability is 90%. So from the results of the calculation that meets the specifications only the 24-hour immersion.

4. CONCLUSION

Based on the results of the analysis of Marshall characteristics that have been carried out using 2%, 5% and 8% variations of cigarette filter waste, it can be concluded that the addition of cigarette filter waste affects the value of Marshall characteristics.

The decrease in performance in the 5% and 8% variations is due to the increasing levels of cigarette filter waste in the AC-WC mixture which can reduce the specific gravity value of the mixture. The decrease in the specific gravity of the mixture due to the reduced percentage of asphalt content in the mixture results in many aggregate surfaces that are not covered by asphalt, so that the binding between the aggregate and the asphalt is not optimal.

Based on the statistical analysis of normal asphalt mixtures and variations of cigarette filter waste, it shows that at levels of 2%, 5%, and 8% there is a decrease in the value of Stability, Flow and VFA. The VMA, VIM, and MQ values increased gradually. It can be concluded that the more levels of variation used, the less in accordance with Bina Marga specifications. Only at 2% variation level that all Marshall characteristic values meet the specifications.

Based on the environmental impact analysis, cigarette filter waste poses a serious environmental threat due to its biodegradability, toxic chemical content, and impact on the ecosystem. Solutions such as recycling, processing, or innovative utilization such as the addition of cigarette filter waste into asphalt mixtures can reduce the amount of cigarette filter waste.

Based on the results of the Marshall characteristic analysis of normal asphalt mixtures and cigarette filter waste innovations against the immersion time range with immersion variations of 24 hours, 48 hours, and 72 hours, it can be concluded that the immersion time range can affect the Marshall characteristic value, because the longer the immersion time can reduce the residual stability value. In accordance with SNI M-58-1990, the minimum limit of residual stability is 90%. At 24-hour immersion it is 92.25%, 48 hours it is 84.87%, and 72 hours it is 72.65%, so only the 24-hour immersion meets the specifications.

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