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The Improvement of Asphalt Mixture Durability Using Portland Cement Filler and Rice Husk Ash

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Abstract The use of fillers in asphalt mixtures can potentially increase durability and their ability to resist water. This research was conducted to analyze how fillers improve the durability of the mixture. This research uses rice husk ash (RHA) and Portland cement (PC) as fillers in the mixture of asphalt concrete wearing course. The mixing process was carried out by the hot mix method, with the optimum asphalt content being 5.5% and the optimum filler content being 4%. The parameters analyzed were: sieve size, porosity, texture, penetration, aggregate blending, and mixing order. Based on the smaller filler sieve size (#400), it has the potential for a higher level of durability, while for strength, #200 has a higher potency. RHA porosity value #400 is 1.6 times greater than #200, and 5.53 times greater on PC. Asphalt with a smaller filler size has a better level of homogeneity, as seen from the smaller standard deviation of penetration. The results of aggregate blending show that the addition of filler causes aggregate gradations that do not meet the specifications required by Bina Marga. The filler should preferably be used as a substitute for the aggregate in the sieve analysis. Based on the IRMS (Index of Retained Marshall Stability) value, it can be concluded that the dry mixing process gives less value than wet mixing. This shows that wet blends last longer than dry blends.

Keywords Rice Husk Ash, Portland Cement, Durability, Asphalt Mixture

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1. Introduction

One type of flexible pavement layer that can be used to serve heavy traffic loads is Asphalt Concrete (AC). DGoH [1] classifies this layer into 3, namely the wear layer (AC-Wearing Course), the intermediate layer (AC-Binder Course), and the foundation layer (AC-Base). Flexible pavement consists of aggregate (coarse, fine, and filler) and asphalt as a binding material, it was widely used in road construction [2, 3]. The use of fillers in asphalt mixtures needs to be done to produce a mixture that is durable, and resistant to water [4]. Lee [5] stated that filler increases the viscosity and plasticity of asphalt mixtures, and reduces susceptibility to temperature. Commonly used fillers are cement, sand, lime, and rice husk ash [6].

The use of rice husk ash (RHA) as a filler in the AC-WC mixture can increase durability and stability [6–8]. Even so, this study has not been able to show how the performance of RHA increases the durability of the AC-WC mixture. So far, this filler is often used as fuel for making bricks or tiles. Therefore, the use of rice husks for other things, such as in the asphalt mixture, can be a solution for rice waste. This husk has a passing sieve percentage of #200, which is 57-62% and is non-plastic, according to Lubis and Zuliyanto [6]. According to Folleto, et al [9], the composition of rice husk ash contains 94.40% SiO_2, 0.61% Al_2O_3, 0.03% Fe_2O_3, 0.83% CaO, 1.21% MgO, 1.06% K_2O, and 0.77% Na_2O. This filler, an abundant waste, especially in the country agriculture, was one of the largest sources of silica [10] around 87%-97% of its dry weight after complete combustion [11]. Portland cement (PC) as a filler can also increase the durability of the mixture [12]. Moreover, the result of this study shows that PC used as additive to hot mix asphalt creates better stability and decreases flow, leading to less rutting and improving the overall strength of the final mix.

Based on the foregoing, research to find out how rice husk ash and PC improve the durability of this AC-WC mixture needs to be done. Portland cement may be used as a filler or additive to improve many properties of asphalt binder and hot mix asphalt [13,14]. The chemical composition of PC is, i.e., 23.7% SiO_2, 6.58% Al_2O_3, 4% Fe_2O_3, 64.95% CaO, and 0.32% MgO [15]. Some of the aspects examined are grain size, texture, porosity, surface area, mixture homogeneity, and mixing order. The hypothesis underlying the grain size aspect is that the smaller the size, the more it contributes to filling the very small void that larger aggregates cannot enter. Regarding the texture, the coarser causes the interlocking between the grains to be stronger. These two aspects cannot be separated from porosity and surface area. Porosity is one of the features that affect the durability attribute of the mixture [16]. The integrity of the aggregate determines the amount of liquid that can be absorbed by the aggregate, the greater the porosity of the aggregate, the greater the absorption [17,18]. The larger surface area of the grains, the more asphalt is needed to cover the surface. The quality of the mixture must be supported not only by the granular elements, but also by its technical aspects, in this case the mixing process, which includes homogeneity and order. Asphalt mixture is a complex material composed of multiphase mediums, including aggregates, air voids, and mastic, which generate a complicated interaction between each component of the mixture [19].

Mixing of filler and asphalt is used to see whether the increase in the mixture's durability comes from the contribution of the filler in affecting the properties of the asphalt or if it is more pure as filler. If it works as pure filler, the properties of the asphalt will not change and only affect the results of the aggregate blending in the fine fraction. Mixing order is used to compare the better value of durability between fillers that are mixed with aggregate first or with asphalt [20].

Based on these aspects, it is aimed that it can be used as reinforcement to find out the property map of RHA and PC when improving the value of the mixture's durability. This study used an Asphalt Concrete Wearing Course (AC-WC) mixture designed based on the Bina Marga specification [1]. This mixture was prepared with optimum asphalt content (OAC) of 5.5% and optimum filler content (OFC) of 4% each using the hot mix asphalt method.

2. Materials and Methods

This research was conducted in Surakarta, Indonesia. The materials used are aggregate from Asphalt Mixing Plant (AMP) Panca Darma Ngasem, asphalt from Pertamina Cilacap, husk ash from Wonogiri, and Portland cement Type 1.

The parameters that will be used in the analysis are: grain size (pass sieve #200 and #400), porosity (absorption test), texture (unit weight test), and homogeneity of filler with asphalt (penetration test), blending (sieve analysis test) and mixing orders (dry process and wet process). The dry method is to mix the filler into the heated aggregate, then add hot asphalt, and stir at avarage speed until it is homogeneous [21]. In contrast, the wet method is to add the filler to hot asphalt and stir at high speed until it is homogeneous, then mix it with the heated aggregate [22]. Furthermore, to obtain the Index of Retained Marshall Stability (IRMS) of the mixture of specimens soaked in fresh water at room temperature for 24 hours, immersed in a water bath at 60^o C for 30 minutes and 24 hours [23]. The IRMS (in %) value can be calculated using Equation 1 [24].

$$\text{IRMS} = {}^{S2}/_{S1} \times 100\% \qquad (1)$$

Where, S_1 is Standard Marshall Stability (kg), and S_2 is Marshall Stability after 24 h (kg).

3. Result and Discussion

3.1. Physical Properties of Filler

The physical properties of fillers have been investigated using unit weight, surface area, absorption, and pore size tests. Filler test specimens are prepared in two sizes, namely #200 and #400 pass sizes. The results of unit weight test can be seen in Table 1.

Table 1. Unit Weight of Filler Portland Cement and Rice Husk Ash

Filler type	**Unit weight values (gram / cm^3)**			
	#200		#400	
	Free fall height (cm)			
	5	35	5	35
Portland cement (PC)	0.85	0.83	0.89	0.89
Rice husk ash (RHA)	0.39	0.42	0.46	0.46

Table 1 shows that both fillers size pass #400 have a slightly higher unit weight value than the filler size pass #200. This means that there is an indication that the smaller the filler size, the easier it will be to compact. Based on Table 1, it can also be seen that the unit weight of PC is higher than RHA. This also indicates that the density of the asphalt mixture using cement is potentially denser than that using rice husk ash. The test data in Table 1 also shows that the free fall height does not affect the unit weight values for fillers with a pass size of #400, but it does affect fillers with a pass size of #200. This can be interpreted that the compaction energy (analogous to free fall height) has a diminishing effect on the density of the mixture using more minor fillers.

Based on the discussion above, the unit weight value of PC is much higher than rice husk ash, so it is much more compact. In addition, the type of filler material gives a much different result compared to the difference in size and compaction energy (height of free fall).

Table 2 shows that the absorption and surface area of RHA with a pass size of #400 is higher than that of #200. The surface area most likely influences the absorption value. The surface area value of this filler type with pass size #400 is known to be 1.9 times size #200. This trend is linear with the RHA absorption filler value of pass size #400, which is 1.6 times size #200.

Table 2. Absorption value and surface area of RHA

RHA sieve pass	Absorption (%)	Surface area per gram (cm^2/gram)
#200	21.951	761.07
# 400	35.135	1447.40
#400 Vs #200	1.6 times	1.9 times

Table 3. Pore Size and Pore Volume of PC

PC sieve pass	Pore diameter (nm)	*cumulative pore volume* (cc/g)
#200	4.887	0.00702
#400	27.04	0.00731
#400 Vs #200	5.53 times	1.04 times

In contrast to RHA, for Portland cement, the porosity value was taken from previous studies, as presented in Table 3. The value of the filler surface area was taken from the ratio of weight and volume compacted compared to the value of one PC grain. The results of the analysis obtained that the PC pass sieve #200 has 524 cm^2/gram of surface area, while those who pass #400 are 1028 cm^2/gram. This condition allows PC 400 to be more homogeneous in mixing with asphalt and aggregate, because it has more coverage. However, in terms of the thickness of the asphalt film, the wider the surface area of the PC grain, the thinner the asphalt covering will be.

Based on Table 3, it can be seen that the porosity of the Portland cement filler is smaller (passing sieve #400), and is much greater than #200. This is clearly seen from the diameter ratio of 5.53 times, although the ratio of the pore volume is not very different. This phenomenon resulted in more PC 400 asphalt absorption than PC 200, so the required asphalt content would be greater. More asphalt absorption causes the asphalt mixture to be more durable, but high porosity when receiving repeated loads tends to be weak.

3.2. Asphalt Mastic Properties and Aggregate Blending

The analysis of the properties of the asphalt mastic in this study was viewed from the value of penetration, density, surface area (SA) and bitumen film thickness (BFT). Penetration test is carried out by adding filler to the asphalt. Asphalt mastic with Portland cement (PC) was prepared with a ratio of 42.1: 57.9 which was based on the optimum asphalt content and cement content, while the composition of RHA with asphalt was 4% and 5.5%. The results of the penetration test for the two fillers which are then compared with the previous test can be seen in Table 4.

Table 4 shows that the penetration value of asphalt added with filler is much smaller than without. This condition applies to both sieve sizes (#200 and #400) for both types of filler. Asphalt added with PC and RHA becomes harder so that the value of the depth of the needle penetration is lower. This is in line with Lee [5] who proved that the penetration value decreased uniformly when mixed with fillers.

Table 4 also shows that asphalt with a smaller PC (#400) gives a greater change. This can be seen from the percentage of difference in the value without filler of #400 is more than 50%, while #200 is less than 40%. The homogeneity of the 400 filler is also better; this can be seen from the standard deviation value. The statistical value used to determine the distribution of data in a sample, and how close individual data points are to the mean. The results of the calculation of the standard deviation of the asphalt added with filler are shown in Table 5.

Table 4. The average penetration value of each filler

Filler	Asphalt penetration plus filler (0.1 mm)		Percentage of difference without filler (%)		Asphalt penetration without Filler (0.1 mm) [25]
	#200	#400	#200	#400	
PC	47	31.4	28.68	52.35	65.9
RHA	42	32.8	36.27	50.23	

Table 5. The standard deviation value of asphalt penetration plus filler

Filler sieve pass	Standard deviation of penetration of bitumen with filler	
	PC	RHA
#200	4.472	2.91
#400	1.673	1.30

Table 5 shows that the deviation of the two types of filler pass sieve #400 is smaller than #200. This states that the value obtained is closer to the average value. This is in line with Wahono et al. [26] which stated that lime grains pass sieve #400 is influenced by nanometer particles which are softer and finer so that the mixing is better and more homogeneous.

After asphalt penetration, the next property to be analyzed is specific gravity. Theoretically, the value of the specific gravity of asphalt will also change when mixed with filler. The analysis was carried out based on the theoretical maximum density formula, whose results can be seen in Table 6.

Table 6. The density of asphalt plus filler

Filler sieve pass	Specific gravity			Bitumen density with filler	
	Asphalt [25]	PC	RHA	PC	RHA
#200	1.14	3.110	2.22	1.558	1.43
#400	1.14	3.122	2.28	1.559	1.47
Average	1.14	3.116	2.25	1.5585	1.45
% Difference		49.98	35.56	36.71	7.19

Table 6 shows that the specific gravity (SG) of asphalt added with filler has increased for both types of filler used and grain sizes. The SG value of asphalt mixed with PC is greater than RHA. The percentage of difference in value is 36.71% mixed with PC and 27.19% mixed with RHA. However, the essensial density of the filler material decreases after being mixed in the asphalt. The percentage decrease in cement is almost 50%, while ash is around 36%.

Based on the surface area analysis (see Table 2), it can be seen that the difference in surface area values will affect the thickness of the asphalt film covering the two fillers. In addition, when it is mixed with aggregate, it will also affect the BFT value of the aggregate. The thinner the asphalt film results in the lower the adhesion of the asphalt to the aggregate. The results of BFT calculations can be seen in Table 7.

Table 7. BFT value of asphalt mixed with filler

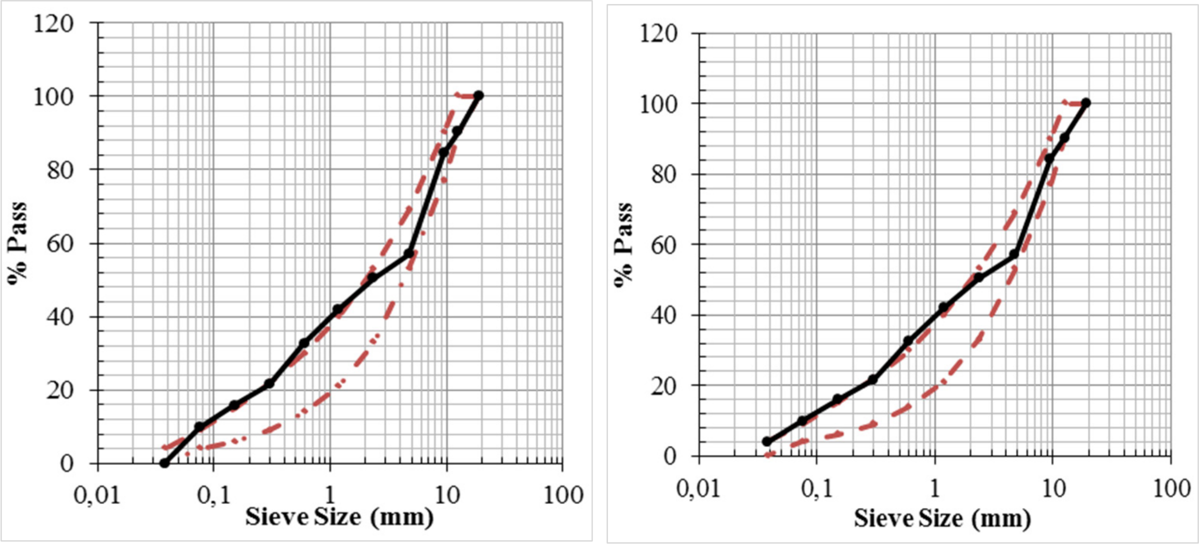
Filler sieve pass	BFT Value (μm)	
	RHA	PC
#200	15.81	23.019
#400	8.31	11.735
Difference	7.5	11.284
% Difference	47.44	49.02

Table 7 shows that the smaller the filler size, the thicker the asphalt film covering it is. This condition occurs both for PC and RHA. The difference in BFT value of cement (11.284 μm) is greater than rice husk ash (7.5 μm). However, when viewed from the percentage of difference, the two fillers are not too different, which is close to 50%. The BFT value greatly affects the durability of the mixture, the thinner the asphalt film makes it easier for a mixture to be penetrated by water and is very reactive to changes in temperature that occur. Therefore, these conditions can reduce the adhesion or adhesion force of asphalt with aggregate.

3.3. Aggregate Blending with Filler

The proportion of aggregate in the mixture needs to be determined before making the sample. The composition or grading arrangement of the aggregate grains must comply with the specifications used. This study uses Sugiarso [25] Sieve Analysis Test, which is then added with a filler of rice husk ash or Portland cement. The results of this blending analysis can be seen in Figures 1 and 2.

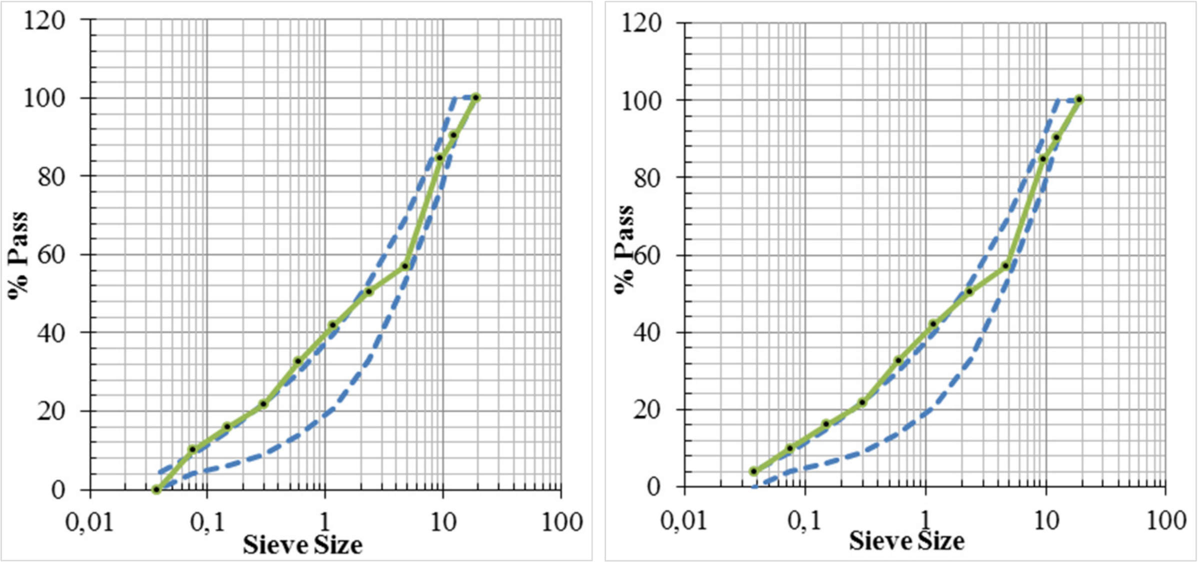
Based on Figures 1 and 2, the gradation pattern of AC-WC with RHA and PC is almost the same. The amount of filler that passes through sieve #200 affects the cumulative percent pass for each filter. The aggregate that passes sieves #16 to #200 do not meet specifications; the percentage value exceeds the upper limit. This condition also occurs in mixtures with filler #400. Based on the results of the modified aggregate mixing experiment above, the filler should partially replace the aggregate, so that the aggregate mixture remains 1200 grams. The proportion of fillers to be replaced is adjusted to the proportion of the aggregates fractions. This is done so as not to affect the aggregate grading graph and still meet the required specifications.



(a) RHA #200

(b) RHA #400

Figure 1. Gradation of (a) RHA #200 and (b) RHA #400



(a) PC #200

(b) PC #400

Figure 2. Gradation of (a) RHA #200 and (b) RHA #400

3.4. The Role of Filler in the Durability of Asphalt Mixtures

The process of making asphalt mixtures can be done in several ways, namely: hot or cold, and dry or wet processes. This study compares the performance of mixtures prepared in two ways, namely wet and dry mixing. Each order uses filler sizes #200 and #400, for rush husk ash plus variations with or without soaking for 24 hours in a water bath at 60°. The results of the above analysis can be seen in Table 8.

Based on Table 8, the value of stability, density, and void in the mix (VIM) has several relationships, namely if the small VIM value causes the density value of the mixture and the stability value to be high. This table shows that the wet process of VIM value is smaller than the dry process. This causes the value of stability and density in wet conditions to be higher. The value of stability, flow, and Marshall Quotient (MQ) has a relationship, namely the value comes from the ratio between stability and flow. The MQ value indicates the stiffness of the asphalt mixture. The stiffness value in the wet process is generally higher than the dry process. In theory, the void mixed aggregate (VMA), VIM, and void filled with asphalt (VFWA) values are interrelated, where the VMA and VIM values are always directly proportional, while the VFWA values are inversely proportional to the other two. Table 8 also shows that in general the VFWA value of the mixture with the wet process is higher than the dry process.

Based on the Marshall characteristic values, then it can be used to analyze the level of durability of the mixture. One of the indicators that can be used is IRMS (Index of Retained Marshall Stability). This index states the percentage of stability strength during the immersion period; the value is obtained from the stability value of the remaining test object after immersion for 1x24 at 60°C. The residual stability specification indicated by Bina Marga 2010 after immersion is greater than 90%. As mentioned above, the IRMS value is influenced by the stability of the mixture, so the factors that affect the stability will also affect this value. The result can be seen in Figures 3 and 4.

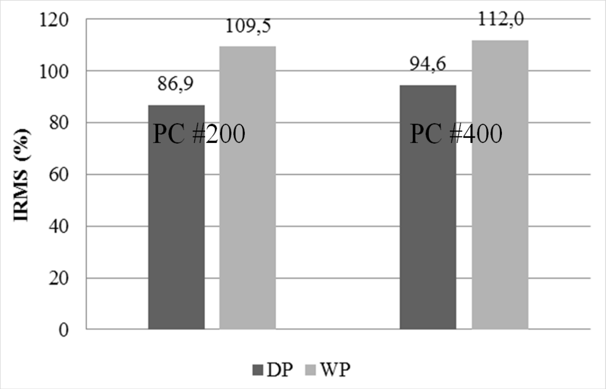


Figure3. IRMS value of mixture with PC on dry process (DP) and wet process (WP)

Figures 3 and 4 illustrate the IRMS value in the dry process (DP) condition which is smaller than in the wet process (WP) condition. This can be seen for all variations used, either #200 and #400, as well as variations in the types of fillers. However, for PC, there was a sharp difference from 86.9% and 94.60% in the DP conditions changing to 109.5% and 112%. In contrast to PC, the changes that occur in RHA are not that large, less than 3%, even for the mixture with filler passing #400, the difference in process orders only gives a change of about 0.34%. Figure 3 also shows that the dry process with PC pass #200, the remaining stability value does not meet the specifications of Bina Marga 2010 (≥ 90%), which is only 86.93%. Therefore it can be said that wet mixing and smaller grain sizes produce asphalt mixtures that are more durable than dry process.

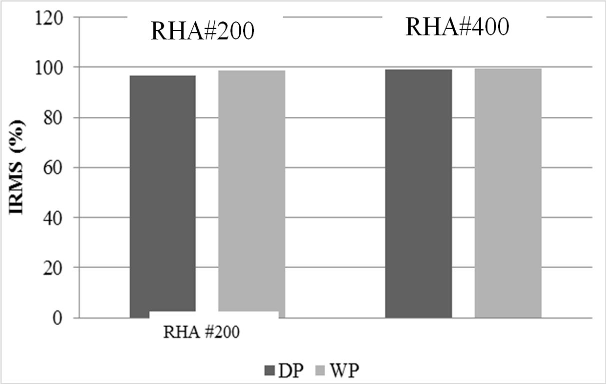


Figure4. IRMS value of mixture with RHA on dry process (DP) and wet process (WP)

Table 8. Average Marshall test results and volumetric analysis

Filler Type	Order	I24/WI	VIM	VMA	VFWA	Stability	Flow	MQ	*Density*
			(%)	(%)	(%)	(kg)	(mm)	(kg/mm)	
PC #200	Dry		3.67	13.94	74.22	1781	3.85	560.89	2.312
	Wet		3.59	16.64	78.93	1832	3.72	562.06	2.314
PC #400	Dry		3.73	14.00	73.91	1326	3.23	418.10	2.311
	Wet		3.64	16.68	78.70	1480	3.01	495.87	2.313
RHA #200	Dry	WI	4.6	15.2	67	1776	3.72	497	2.263
	Wet	WI	3.7	14.9	73	1841	3.13	596	2.285
RHA #200	Dry	I24	4.6	15.2	67	1716	3.6	482	2.262
	Wet	I24	3.7	14.4	71	1821	3.10	619	2.284
RHA #400	Dry	WI	4.5	15.1	68	1729	3.55	505	2.264
	Wet	WI	3.6	14.3	72	1782	2.69	605	2.286
RHA #400	Dry	I24	4.6	15.1	67	1713	3.43	500	2.264
	Wet	I24	3.6	14.3	72	1772	2.82	628	2.285

Notes: WI: without immersion, I24: with immersion 24 hours

Another factor that also affects the durability of the mixture is the asphalt film (see Table 7). It is evident that grain size affects the BFT value. This analysis needs to be done to determine the ratio of BFT when filler is added to the mixture. Based on the Shell Bitumen Handbook [27], the value can be analyzed from the sieve analysis data and surface area factor (SAF). The overall SAF and BFT values obtained can be seen in Table 9.

Table 9 shows that the smaller the grain size (# 400), the overall BFT value has decreased. This trend is the same as the BFT value, as shown in the previous Table 7. Based on the results of the above analysis, it can be said that the effect on increasing the durability of the asphalt mixture is the small grain size, large surface area, high density, homogeneity, and low penetration. This is consistent with Lee [5] who stated that the resistance to the effects of water can be increased by using lower penetration bitumen.

Table 9. SAF and BFT values for each filler

	Portland cement (PC)		**Rice husk ash (RHA)**	
	#200	#400	#200	#400
SAF (m2/kg)	8.999	10.259	8.999	10.259
Whole BFT (µm)	5.67	4.98	5.66	4.97

4. Conclusion

Based on the physical properties, it can be concluded that the smaller filler grain size (#400) has a higher shelf life potential, while the strength size #200 has a higher potential. The porosity value of RHA #400 is 1.6 times greater, while that of PC is 5.53 times. This shows that the filler can absorb more asphalt so that its durability tends to be strong. However, high porosity when subjected to repeated loads, the strength tends to be weak.

Based on the penetration value, it is known that the addition of smaller filler to asphalt gives a greater change in penetration value, as seen from the percentage change of more than 50%. In addition, this mixture has a better level of homogeneity as seen from the smaller penetration standard deviation.

In addition, it can be concluded that the addition of filler causes an aggregate gradation that does not meet the required specifications. Filler should be used instead of aggregate in sieving. Based on the IRMS value, it can be seen that the dry mixing process gives a smaller value than the wet one. This shows that wet mixing is more durable than dry process.

Further research needs to be done with other variations. For example, variations in filler content combined with variations in the treatment process for raw asphalt, mastic and asphalt mixtures. Based on the results obtained, filler should be used as a substitute for aggregate in the sieve analysis. In addition, modifications to the mixing temperature (asphalt or its mixture) can also be made related to the thermoplastic properties of asphalt.

APPENDIX

Notation List Table

Notation	**Explanation**
AC	Asphalt concrete
AC-BC	Asphalt concrete binder course
AC-B	Asphalt concrete based
AC-WC	Asphalt concrete wearing course
RHA	Rice husk ash
PC	Portland cement
OAC	Optimum asphalt content
OFC	Optimum filler content
AMP	Asphalt Mixing Plant
DP	Dry process
WP	Wet process
IRMS	Index of Retained Marshall Stability
SA	Surface area
BFT	Bitumen film thickness
SG	Specific gravity
VIM	Void in the mix
VMA	Void mixed agrgregate
VFWA	Void filled with asphalt
MQ	Marshall Quotient
I24	Immersion 24 hours
WI	Without immersion
SAF	Surface area factor

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