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The Characteristics of Asphalt Concrete Binder Course (AC-BC) Mixture with Bottom Ash as Aggregate Substitute

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Abstract: Highways serve nearly 80-90% of the population mobility and flow of goods. Utilization of bottom ash, a waste from coal combustion, in highway construction is one of the alternatives to reduce environmental pollution and support Clean Development Mechanism Program of Kyoto Protocol. The aim of this study is to analyze the characteristics of AC-BC mixture that uses bottom ash as partial substitute of fine aggregate and comparing with a standard mixture. Laboratory tests are performed on two different types of mixtures. The tests show that optimum asphalt content for $\text{AC-BC}_{\text{Standard}}$ mixture is 5.20% while $\text{AC-BC}_{\text{Bottom Ash}}$ mixture is 5.25%. Bottom ash has higher porosity along with a little break field and has round shape so that the asphalt absorption is bigger than the crushed stone. Bottom ash can be used as an alternative aggregate to increase the value of flow of the AC-BC mixture, thus converting waste to valuable material.

Keywords: Aggregate replacement; asphalt concrete-binder course; bottom ash.

Introduction

Highways are important transportation infrastructures that influence economy, society, culture, and defense and security. Highways serve nearly 80-90% population mobility and flow of goods, so that the development of road transport infrastructure is a priority. It is reflected by the amount of national budget absorbed for the construction of new road or maintenance of roads [1]. In the 2014 Indonesian national budget (*APBN*), the Ministry of Public Works allocated funds amounting to Rp 84.1 trillion [2]. The impact of this activity is increasing need for both asphalt and natural coarse and fine aggregate. The asphalt is imported as many as 600,000 tonnes per annum. It results in reducing availability of foreign exchange and also diminishing aggregates [3].

The increasing demand for transportation infrastructures, particularly roads, requires appropriate technologies for saving natural resources. Utilization of coal combustion bottom ash waste is one of the alternatives for reducing environmental pollution and supporting Clean Development Mechanism (CDM) program. CDM is regarded as one of the most important internationally implemented market-based mechanisms to reduce carbon emissions [4]. Created under the Kyoto Protocol, the CDM was designed to help developed nations meet domestic Green-house Gas (GHG) reduction commitments by investing in low-cost emission reduction projects in developing countries [4,5]. The coal ash can be utilized as building materials such as fly ash cement, mixture of brick, embankment materials, and road pavement material [6]. Fly ash from coal combustion can be used for construstion materials such as embankment, plant roads, reinforced flyover, etc. The usage of fly ash in road works is able to reduce construction cost about 10 to 20 percent [7]. Santosa, *et al.* [8] evaluated the effect of replacing 10% to 100% fine aggregate with bottom ash. The best result was obtained by replacing the fine aggregate by 10% bottom ash. This replacement could fulfill all requirements except air void. To improve the air void, an additive (chemcrete) should be added. The use of chemcrete increases the stability and improves the air void of asphalt concrete. On the other hand, the growing coal combustion causes problems, especially in the disposal process because it can lead to environmental pollution. It requires efforts and strategies to utilize the coal combustion waste: fly ash or bottom ash for road construction materials to produce high value products and efficient things. One of the strategies is the utilization of bottom ash as an alternative of fine aggregate material in Asphalt Concrete-Binder Course (AC-BC) mixture.

The aim of this study is to determine the optimum bitumen content of AC-BC mixture with crushed

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stone aggregate (AC-BC$_{standard}$), and AC-BC mixture with bottom ash as aggregate substitute (AC-BC$_{Bottom\ ash}$) by 20% and compare the characteristics of AC-BC$_{standard}$ and AC-BC$_{Bottom\ ash}$.

Literature

Asphalt concrete is a construction layer consisting of mixture of asphalt and continously graded aggregate, mixed, spread, and compacted at a specific temperature. Layers of asphalt concrete consists of mixture of three types namely Asphalt Concrete-Wearing Course (AC-WC), Asphalt Concrete-Binder Course (AC-BC), and Asphalt Concrete Base (AC-Base) with maximum aggregate size of 19, 25.4, and 37.5 mm respectively [9].

Bottom ash is waste material from coal combustion in power plants with larger size and heavier than fly ash. Bottom ash will fall down onto the bottom of the furnace combustion (boiler). It is collected in dust collector (ash hopper) and then removed from the furnace for specific purposes [10].

Bottom ash and boiler slag have been used with considerable success as fine aggregates in asphalt paving mixtures for at least the past 25 years in different states of the United States. The American Coal Ash Association reported that during 1996 more than 75,000 metric tons (83,000 tons) of boiler slag and nearly 14,400 metric tons (16,000 tons) of bottom ash were used in asphalt paving [11]. A 1994 survey of all 50 state transportation agencies indicated that five states have made some recent use of bottom ash and/or boiler slag as aggregate in asphalt paving on state roadways. These five states are Arkansas, Missouri, Texas, West Virginia, and Wyoming [12]. Dry bottom ash is more commonly used in emulsion cold mix asphalt, hot mix asphalt on the road foundation, rigid pavement or on construction of road shoulders [13].

In West Virginia, United States, the usage of dry bottom ash on flexible pavement on a cold mix asphalt emulsion by 6%-7% of the mass of asphalt emulsion on a secondary road with moderate traffic volumes shows satisfactory results throughout the 1970's until the 1980's [11]. There have been periodic indications of problems with paving mixtures in West Virginia containing bottom ash, in which pyrite contamination in the bottom ash had not been considered. Pyrite particles will weather in service, despite being coated with asphalt cement, causing popouts, and deep red stains in the pavement surface [11].

In the United Stated, wet bottom ash (boiler slag) is more commonly used for surface layer of asphalt pavement as it is proven to increase roughness (skid resistance). Boiler slag has adhesive (affinity) better to asphalt and it has a dust-free surface. Thereby, it increases the aggregate-asphalt adhesion and resistance to flaking asphalt of aggregates (stripping). Moreover, boiler slag is so black that can not be faded so easily due to sunlight or weather as to reduce the reflection of sunlight and accelerate the melting of snow [13]. For example in West Virginia, USA, it was found that the use of 50% wet bottom ash, 39% river sand, 3% fly ash, and 8% asphalt for the surface layer with a thickness of 12.7 to 50.8 mm used as a resurface on the surface layer of asphalt pavement are able to meet the design life of 10 years, with little change in the road surface although it is traversed by heavy vehicular traffic [11]. While in South Texas, the use of wet bottom ash as much as 75% of fine aggregate mass mixed with 25% limestone and with bitumen content of 6%-7% to recoat the pavement leads road surfaces to remain in good condition without any shoving, ravelling, and retains roads to be black and rough even they are traversed by heavy vehicles [13]. The other research on the use of bottom ash as construction materials for highway embankments resulted in an economic alternative to the use of traditional materials and test results indicated that ash mixtures compared favorably with conventional granular materials [14].

Materials and Methods

Materials

Materials used in this study consist of coarse aggregate, fine aggregate, bottom ash, crushed stone-filler, and bitumen penetration 60/70. The materials used in this study, are shown in Figures 1.a through e.

Figure 1a. Coarse Aggregate

Figure 1b. Fine Aggregate

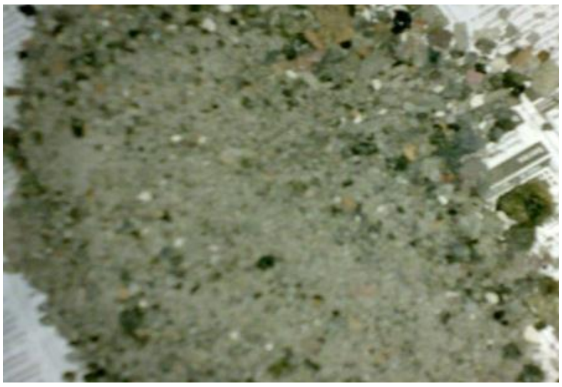

Figure 1c. Bottom Ash

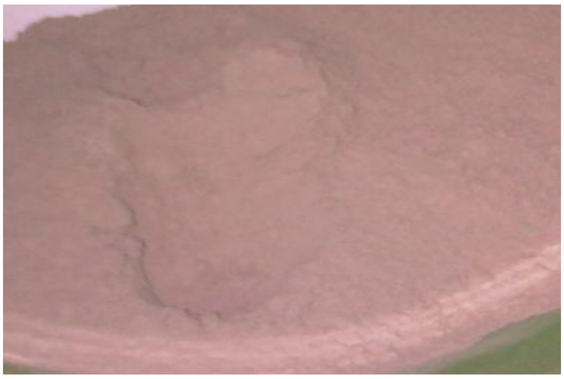

Figure 1d. Stone Ash Filler

Figure 1e. Bitumen Pen 60/70

Methods

The method used in this study is an experimental testing in the laboratory. The standards used, are namely the Standard National of Indonesia (SNI) SNI 1969:2008 [15], SNI 2417:2008 [16], SNI 03-2439-1991 [17], SNI 03-1970-1990 [18], SNI 03-4428-1997 [19], SNI 03-4142-1996 [20], SNI 06-2456-1991 [21], and ASTM Vol. 04.3 [22]. Hot mixed asphalt was designed with absolute density approach in accordance to the design guidelines of Directorate General of Highways, Ministry of Public Works [23]. The aggregate gradation limit specification followed Bina Marga SKBI 2.4-26.1987 [24]. The total number of samples are 102; i.e. 72 for Stage 1 and 30 for Stage 2. Details of tests and samples of Stage 1 are shown in Table 1 and for the Stage 2 are shown in Table 2.

In Table 2, X is optimum asphalt content value for $AC\text{-}BC_{Standard}$ and Y for $AC\text{-}BC_{Bottom\ Ash}$.

Results

Aggregate Testing Results

Aggregate tests were conducted to determine the characteristics of coarse aggregate, fine aggregate, bottom ash, and filler. The bottom ash was obtained from coal combustion of PLTU Suralaya, Indonesia. The combined aggregate gradation chosen was a mixture of Asphalt Concrete Binder Course, in accordance to the Highways specifications. The physical properties of the coarse aggregate, fine aggregate, filler, and bottom ash [25] can be seen in Tables 3 to 5.

Asphalt Test Results

Asphalt test was conducted to determine the characteristics of the material used in the asphalt mixture. Asphalt bitumen was obtained from Pertamina with penetration 60/70. Asphalt test included penetration, softening point, flash and fire point, ductility, specific gravity, and viscosity. Asphalt test results can be seen in Table 6.

Viscosity test was done using Saybolt-Furol with standard test method ASTM E-102 [26]. The data from the viscosity test results, plotted on semi-logarithmic graph (relationship between the kinematic viscosities (cSt) with temperature in °C, are shown in Figure 2). From Figure 2, the mixture temperature in 170 centistokes is 151°C and the compaction temperature in 280 centistokes is 141°C.

Table 1. Tests in Stage 1.

No.	Test	Mixture type	Asphalt content (%)	The number of samples	
				Number	Total
1.	Marshall Test	AC-BC$_{Standard}$	4.0	3	27
			4.5	3	
			5.0	3	
			5.5	3	
			6.0	3	
			6.5	3	
			7.0	3	
			7.5	3	
			8.0	3	
		AC-BC$_{Bottom\ Ash}$	4.0	3	27
			4.5	3	
			5.0	3	
			5.5	3	
			6.0	3	
			6.5	3	
			7.0	3	
			7.5	3	
			8.0	3	
2.	Absolute density	AC-BC$_{Standard}$	P - 0.5%	3	9
			P	3	
			P + 0.5%	3	
		AC-BC$_{Bottom\ Ash}$	Q - 0.5%	3	9
			Q	3	
			Q + 0.5%	3	
		Total number of samples in Stage 1			72

Table 2. Tests in Stage 2.

No.	Test	Mixture type	Asphalt content (%)	The number of samples	
				Number	Total
1.	Absolute density	AC-BC$_{Standard}$	X	3	6
		AC-BC$_{Bottom\ Ash}$	Y	3	
2.	Marshall immersion	AC-BC$_{Standard}$	X (immersion in 30 minutes)	6	12
			X (immersion in 24 hours)	6	
		AC-BC$_{Bottom\ Ash}$	Y (immersion in 30 minutes)	6	12
			Y (immersion in 24 hours)	6	
		Total number of samples in Stage 2			30

Table 3. Physical properties of Coarse Aggregate: Crushed Stone [25].

No.	Tests	unit	Weight retained in sieve					Average	Specification		Standard
			3/4	1/2	3/8	No. 4	No. 8		Min.	Max.	
1.	Specific gravity coarse aggregate										SNI 1969: 2008
	a. Bulk specific gravity	gr/cc	2.718	2.708	2.629	2.673	2.678	2.681	2.50	-	
	b. Saturated Surface Dry (SSD) specific gravity	gr/cc	2.746	2.734	2.684	2.713	2.724	2.720	2.50	-	
	c. Apparent specific gravity	gr/cc	2.795	2.782	2.781	2.784	2.806	2.790	2.50	-	
	d. Effective specific gravity	gr/cc	2.757	2.745	2.705	2.729	2.742	2.735	2.50	-	
2.	Absorption of water	%	1.02	0.99	2.08	1.48	1.70	1.45	-	3.0	
3.	Abbration with Los Angeles Machine	%						20.13	-	40.0	SNI 2417: 2008
4.	Adhesive of aggregate and asphalt	%						99	95	-	SNI 03-2439-1991
5.	Index of thinness	%						8.61	-	10.0	ASTM D-4791

Table 4. Physical Properties of Fine Aggregate and Stone Ash-filler [25].

No.	Tests	unit	Weight retained in sieve					Ave-rage	Specification		Standard
			No. 16	No. 30	No. 50	No.100	No.200		Min.	Max.	
1.	Specific gravity fine aggregate										
a.	Bulk specific gravity	gr/cc	2.809	2.725	2.733	2.737	2.726	2.746	2.50	-	
b.	Saturated Surface Dry (SSD) specific gravity	gr/cc	2.816	2.746	2.811	2.815	2.804	2.798	2.50	-	SNI 03-1970-1990
c.	Apparent specific gravity	gr/cc	2.831	2.783	2.964	2.968	2.957	2.901	2.50	-	
d.	Effective specific gravity	gr/cc	2.820	2.754	2.849	2.853	2.842	2.823	2.50	-	
2.	Absorption of water	%	0.28	0.77	2.86	2.84	2.86	1.92	-	3.0	
3.	Equivalent sand value	%						45.36	-	50.0	SNI 03-4428-199
4.	Material through sieve No. 200	%						7.66	-	8.00	SNI 03-4142-1996
5.	Specific gravity of filler	%						2.73	-	-	SNI 15-2531-1991

Table 5. Physical Properties of Bottom Ash [25].

No.	Tests	unit	Weight retained in sieve					Ave-rage	Specification		Standard
			No. 16	No. 30	No. 50	No.100	No.200		Min.	Max.	
1.	Specific gravity of bottom ash										
a.	Bulk specific gravity	gr/cc	2.091	1.725	2.145	2.068	1.744	1.955	2.50	-	
b.	Saturated Surface Dry (SSD) specific gravity	gr/cc	2.259	2.110	2.349	2.319	2.229	2.253	2.50	-	SNI 03-1970-1990
c.	Apparent specific gravity	gr/cc	2.512	2.829	2.692	2.758	3.382	2.835	2.50	-	
d.	Effective specific gravity	gr/cc	2.306	2.277	2.419	2.413	2.563	2.396	2.50	-	
2.	Absorption of water	%	8.02	22.38	9.47	12.13	27.78	15.96	-	3.00	

Table 6. Asphalt Test Results [25].

No.	Tests	unit	Specification		Result	Standard
			Min.	Max.		
1.	Penetration,25°C,100gr, 5sec.	0.1 mm	60	79	65	SNI 06-2456-1991
2.	Softening point of asphalt	°C	48	58	49.50	SNI 06-2434-1991
3.	Flash point of asphalt	°C	200	-	285	SNI 06-2433-1991
4.	Fire point of asphalt	°C	-	-	292.50	SNI 06-2433-1991
5.	Ductility, 25°C	cm	100	-	>100	SNI 06-2432-1991
6.	Spesific gravity of asphalt	gr/cc	1	-	1.038	SNI 06-2441-1991
7.	Viscosity test in 120°C	cSt	Time: 434 seconds		904	
	Viscosity test in 140°C	cSt	Time: 135 seconds		283.6	ASTM E 102-93
	Viscosity test in 160°C	cSt	Time: 52 seconds		108	

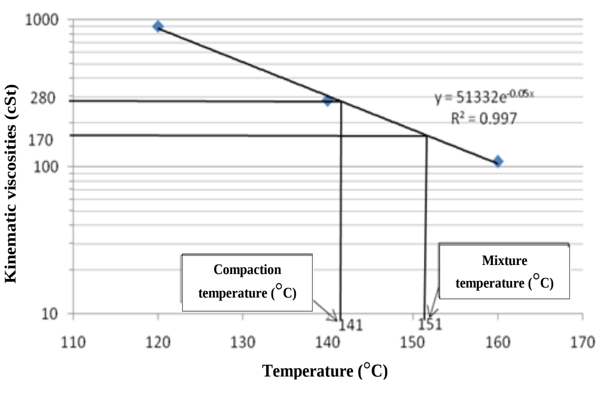

Figure 2. Relationship between the Kinematic Viscosities (cSt) with Temperature (°C).

AC-BC$_{Standard}$ Test Results

Marshall test and absolute density for each mixture of AC-BC$_{Standard}$ with bitumen/ asphalt content ranges from 4% to 8%, were measured. There are seven characterictics is Marshall Test: Void in Mineral Aggregate (VMA, % volume), Void in Mixture (VIM, % volume), Voids in Mixture refusal density (VIM$_{RD}$), Voids Filled with Bitumen (VFB, % VMA), stability, flow, and Marshall Quotient (MQ). Marshall Test results for AC-BC$_{Standard}$ and its density can be seen in Table 7.

AC-BC$_{Bottom\ Ash}$ Test Results

Marshall Test results and absolute density for each mixture of AC-BC$_{Bottom\ Ash}$ with bitumen/asphalt content ranges from 4% to 8% can be seen in Table 8.

Results of Testing AC-BC Mixture on Optimum Asphalt Content

The determination of the value of optimum asphalt content for the AC-BC$_{Standard}$ and AC-BC$_{Bottom}$ Ash

Table 7 Marshall Test Results for AC-BC$_{Standard}$ [25].

Characteristic of mixture	Bitumen/asphalt content (%)									Specification
	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	
Density ($^{gr}/_{cc}$)	2.359	2.379	2.399	2.419	2.424	2.429	2.434	2.421	2.417	
VMA (%)	16.04	15.76	15.50	15.24	15.51	15.78	16.08	16.96	17.55	Min. 14%
VIM (%)	8.53	7.03	5.52	4.00	3.12	2.16	1.27	1.06	0.90	3.50-5.50%
VIM$_{RD}$ (%)			4.12	2.25	1.09					Min. 2.50%
VFB (%)	46.77	55.37	64.41	73.73	79.92	86,31	92,12	93,76	94,85	Min. 63%
Stability (kg)	1,039	1,110	1,189	1,280	1,261	1,227	1,201	1,134	1,097	Min. 1,000 kg
Flow (mm)	3.90	4.11	4.28	4.45	4.60	4.62	4.77	4.83	4.92	Min. 3.00 mm
MQ (kg/mm)	266.4	270.2	278.0	287.6	274.4	265.7	251.8	234.9	222.9	Min. 250 kg/mm

Table 8. Marshall Test Results for AC-BC$_{Bottom\ Ash}$

Characteristic of mixture	Bitumen/asphalt content (%)									Specification
	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	
Density ($^{gr}/_{cc}$)	2.346	2.368	2.388	2.408	2.411	2.416	2.420	2.408	2.393	
VMA (%)	15.33	14.97	14.72	14.45	14.80	15.07	15.40	16.27	17.22	Min. 14%
VIM (%)	8.43	6.87	5.40	3.87	3.05	2.10	1.23	1.03	0.89	3.50-5.50%
VIM$_{RD}$ (%)			4.00	2.52	1.06					Min. 2.50%
VFB (%)	45.01	54.12	63.34	73.20	79.37	86.07	91.98	93.65	94.82	Min. 63%
Stability (kg)	1,021	1,082	1,161	1,250	1,235	1,209	1,166	1,104	1,063	Min. 1,000 kg
Flow (mm)	4.00	4.18	4.40	4.62	4.69	4.75	4.85	4.90	4.99	Min. 3.00 mm
MQ (kg/mm)	255.5	258.6	263.7	270.7	263.1	254.5	240.5	225.3	213.0	Min. 250 kg/mm

mixture is shown in Figure 3 and Figure 4, respectively. For the AC-BC$_{Standard}$ mixture, the asphalt content that satisfies the three characterictics of Marshall Test: stability, VMA, and flow value, are between 4% and 8%. The asphalt content that can satisfy all specification of Marshall Test are from 5 to 5.4%. The value of optimum asphalt content of the AC-BC$_{Standard}$ is 5.2% (indicated by the arrow in Figure 3). For the AC-BC$_{Bottom\ Ash}$ mixture, asphalt content that satisfies the seven characterictics of Marshall Test and absolute density is between 5% and 5.5%. The value of optimum asphalt content of the AC-BC$_{Bottom\ Ash}$ is 5.25% (indicated by the arrow in Figure 4).

The comparison of optimum bitumen/asphalt content based on the results of Marshall Test, Marshall Immersion Test, and absolute density AC-BC$_{Standard}$ and AC-BC$_{Bottom\ Ash}$ is presented in Table 9.

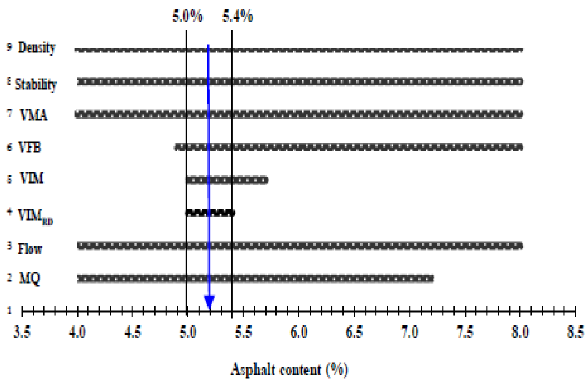

Figure 3. Determination of optimum asphalt content from AC-BC$_{Standard}$.

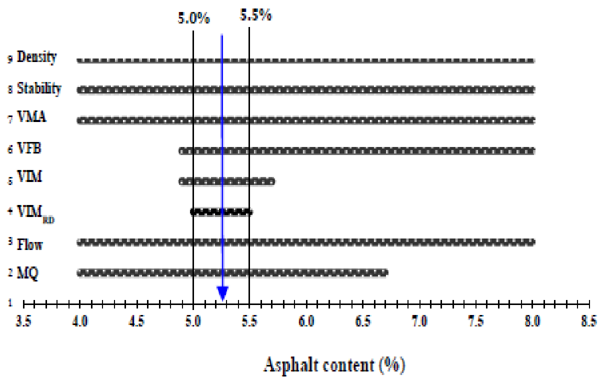

Figure 4. Determination of Optimum Asphalt Content from AC-BC$_{Bottom\ Ash}$.

Discussion

Based on the Marshall Test and absolute density of samples (Table 9) the optimum asphalt contents obtained from this study is as follows: optimum asphalt content of AC-BC$_{Standard}$ mixture is 5.20% and of AC-BC$_{Bottom\ Ash}$ mixture 5.25%. The density at optimum asphalt content for AC-BC$_{Standard}$ is 2.412 gr/cc whereas for AC-BC$_{Bottom\ Ash}$ is 2.397 gr/cc. The larger density values of AC-BC$_{Standard}$ than the AC-BC$_{Bottom\ Ash}$ is due to the fact that the crushed stone aggregates have less porosity and low absorption compared to bottom ash. This result is similar to the one reported by Triawan [27] and Yudhianto [28]. The optimum asphalt content with bottom ash is larger than that of crushed stone. The value of optimum asphalt content for the mixture using bottom ash is 13.272%, whereas optimum asphalt content values

Table 9. Comparison of Optimum Asphalt Content Results $AC\text{-}BC_{Standard}$ and $AC\text{-}BC_{Bottom\ Ash}$

Characteristic of mixture	$AC\text{-}BC_{Standard}$	$AC\text{-}BC_{Bottom\ Ash}$	Specification
Optimum asphalt content (%)	5.20	5.25	
Marshall Test (immersion in 30 minutes)			
Density (gr/cc)	2.412	2.397	
VMA (%)	15.22	14.61	Min. 14%
VIM (%)	4.75	4.68	3.50-5.50%
VFB (%)	68.83	67.96	Min. 63%
Stability (kg)	1,254	1,227	Min. 1,000 kg
Flow (mm)	4.44	4.60	Min. 3 mm
MQ (kg/mm)	282.4	266.7	Min. 250 kg/mm
Marshall Immersion Test (immersion in 24 hours)			
Stability (kg)	1,134	1,041	Min. 1,000 kg
Flow (mm)	4.13	4.10	Min. 3 mm
MQ (kg/mm)	274.5	254.1	Min. 250 kg/mm
IRS (%)	90.42	84.91	Min. 75%
Absolute density			
VIM_{RD} (%)	3.37	3.28	Min. 2.5%

for the mixture using natural stone is 6.363%. Further, the performance of the asphalt concrete mixtures using bottom ash in optimum asphalt content is lower than the asphalt concrete mixtures using natural stone as indicated by Marshall parameters: Marshall Immersion, Indirect Tensile Strength, and Wheel tracking. Generally, bottom ash can be used as partial aggregate substitution of asphalt concrete mixture for road with low traffic [27].

The optimum asphalt contents for Hot Rolled Sheet (HRS) containing bottom ash and HRS-Standard are 16.2% and 8.4%, respectively. At the optimum asphalt content, the HRS containing bottom ash mixture has lower stability and durability compared to HRS-Standard mixture but it still fullfils the required specification. The performance of HRS containing bottom ash mixture is promising for use as alternative material and should further be developed although based on the economic analysis the utilization of bottom ash for HRS mixture was more costly compared to HRS-Standard [28].

Based on the Marshall test, Voids in Mixture (VIM) value of optimum asphalt content $AC\text{-}BC_{Standard}$ mixture is 4.75%, while for the $AC\text{-}BC_{Bottom\ Ash}$ mixture 4.68%. The differences of VIM value are due to differences in levels of asphalt content and density values. It is very important to maintain the value of VIM. The VIM value required is between 3.5% - 5.5% for AC-BC mixture [9,29]. The mixture in that range or interval is not susceptible to melting, flowing and plastic deformation [29]. The stability value of optimum asphalt content to $AC\text{-}BC_{Standard}$ is 1,254 kg while one of $AC\text{-}BC_{Bottom\ Ash}$ mixture is 1,227 kg. Crushed stone aggregate has abrasion and level of hardness better than those of bottom ash. In addition, the particle shape of bottom ash is round, easily broken, and unfavorable aggregate interlocking making stability of $AC\text{-}BC_{Bottom\ Ash}$ mixture lower than $AC\text{-}BC_{Standard}$. The minimum requirement for stability value of AC-BC mixture is 1,000 kg [9,29] so that both mixtures meet the specified requirements. The Marshall Flow test of $AC\text{-}BC_{Standard}$ optimum asphalt content is 4.44 mm while the $AC\text{-}BC_{Bottom\ Ash}$ is 4.60 mm. Bottom ash is more porous than crushed stone aggregate so that bottom ash absorbs the asphalt stronger than crushed stone aggregate does. Specifications of AC-BC flow value is at minimum 3 mm [9,29]. The Marshall Quotient values for $AC\text{-}BC_{Standard}$ mixture is 282.47 kg/mm and $AC\text{-}BC_{Bottom\ Ash}$ mixture is 267 kg/mm. $AC\text{-}BC_{Standard}$ mixture is more rigid than the $AC\text{-}BC_{Bottom\ Ash}$ mixture, but still fulfill the specification of Marshall Quotient values AC-BC (minimum 250 kg/mm) [23].

Based on the absolute density test, the value of VIM_{RD} of optimum asphalt content for $AC\text{-}BC_{Standard}$ mixture is 3.37% and the value VIM_{RD} $AC\text{-}BC_{Bottom\ Ash}$ mixture is 3.28% because the bottom ash absorbs asphalt more than the crushed stone does and effective volume of asphalt $AC\text{-}BC_{Standard}$ is larger than the $AC\text{-}BC_{Bottom\ Ash}$. The minimum value requirement VIM_{RD} for AC-BC mixture is 2.5% [9,29]. The parameters of the Marshall Immersion test are indicated by Index of Retained Strength (IRS). IRS values for $AC\text{-}BC_{Standard}$ mixture is 90.42%, while for $AC\text{-}BC_{Bottom\ Ash}$ is as much as 84.91%. The index of retained strength shows that both of the mixture is still able to support the weight. In this case, the property of bitumen in the mixture does not change significantly as a result of oxidation and exfoliation (60°C). Bina Marga specification for the index of retained strength is minimum 75% [9], which means that both of the mixture meets the requirements.

Conclusions

Conclusions of this study are as follows:

1. The optimum asphalt content value of AC-$BC_{Bottom\ Ash}$ mixture is 5.25%, larger than the optimum asphalt content AC-$BC_{Standard}$ mixture which is 5.20%.
2. Density, voids in mixture aggregate, voids in mixture, voids filled with bitumen, stability, marshall quotient, voids in mixture refusal density, and index of retained strength of the optimum asphalt content of the mixture of AC-$BC_{Standard}$ are larger than the ones of the mixture of AC-$BC_{Bottom\ Ash}$.
3. Bottom ash can be used as an alternative material to replace fine aggregate to produce larger flow values compared to the AC-$BC_{Standard}$ mixture.

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