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Characteristics of Asphalt Mixed Using Mountain Stone

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Abstract

Aggregate is the main thing in asphalt mixtures with a percentage of about 70% to 80%. The aggregate used should meet the Indonesian National Standard (SNI) before being used in the asphalt mixture. East Kalimantan Province is one of the provinces in Indonesia which always brings in aggregates from outside the region for road construction. This study aims to analyze the modulus of stiffness of the AC-WC mixture using local aggregate of East Kalimantan Province and petroleum bitumen grade 60/70 as a binder due to water immersion. This research is experimental in the laboratory. The variation of the petroleum bitumen content used was 4.5, 5.0, 5.5, 6.0 and 6.5%. Water immersion was carried out at the age of 3, 5 and 7 days. The results showed that at 3 days of immersion, the resilient modulus values obtained at petroleum bitumen content of 4.5, 5.0, 5.5, 6.0 and 6.5% were 421.0, 506.0, 872.5, 747.0 and 648.5 MPa, respectively. At 5 days immersion, the resilient modulus values obtained were 383.5, 386.0, 915.5, 561.0 and 555.5 MPa, respectively. Whereas for the 7 days immersion, the resilient modulus were 290.5, 425.5, 1369.0, 547.5 and 525.0 MPa, respectively. It can be seen that water immersion greatly affects the stiffness modulus of the asphalt mixture. This stiffness will cause the asphalt mixture to be easily damaged or cracked. This can be caused by the influence of the sub-standard aggregates used, namely Senoni stone and Mahakam sand.

Keywords: Characteristics; Asphalt Mixed; Local Aggregate; Senoni, East Kalimantan; Stiffness.

1. Introduction

East Kalimantan Province is one of the provinces with a very large area in Indonesia, where according to data from the Regional Development Planning Agency (BAPPEDA) of East Kalimantan Province in 2018, East Kalimantan Province has a land area of 127,267.52 km^2 and a sea management area of 25,656 km^2. In addition, according to BAPPEDA data in 2013, East Kalimantan Province has 3,300,517 people spread across 10 districts and cities [1].

According to data from the Central Statistics Agency (BPS) in 2015, East Kalimantan Province has a length of State Road, namely, 1,493.68 km consisting of 1,357.25 km of paved roads, 63.27 km of roads with rigid pavements and 73.16 km of aggregated roads or land. This data, of course, continues to increase and does not include roads managed by districts and cities [2].

Regions that have a lot of aggregate reserves, but the quality of the aggregate does not meet the standard, then the improvement of the aggregate will be more economical than bringing the aggregate away from the outside [3, 4]. Substandard aggregates are aggregates that do not meet the properties required in the road specifications, including

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specific gravity, plasticity value, absorption and abrasion which will affect the level of adhesion of the aggregate to asphalt in the asphalt mixture [5]. The problem that can arise due to the use of sub-standard aggregate is the release of asphalt aggregate (stripping) which will result in premature damage and reduced road function [6].

The construction of pavement construction generally uses standard materials derived from natural materials such as stone and sand [7]. This material is used as a material for road foundation layers without or with binder or for asphalt mixtures [8]. In order for construction costs to be minimized, other than that the use of local or local materials needs to be considered and thought out carefully. However, it is necessary to make efforts to optimize the use and utilization of this substandard material [9].

In addition, the increasing demand for road materials cannot be matched by the availability of material sources, especially aggregates [10, 11]. To meet the aggregate needs in an area by bringing in the aggregate from other places which of course will increase the unit price of road construction costs [12, 13]. To overcome this, it is necessary to carry out technical engineering in the use of materials so that local substandard materials or industrial waste materials can be optimized for use on road pavements, both in asphalt mixtures and for road foundation layers [14, 15].

The hot asphalt mixture that is often used for road surface layers in Indonesia is Asphalt Concrete (Laston) or Asphalt Concrete (AC), which is a mixture of bitumen or asphalt material with coarse aggregate and fine aggregate which is processed at very high temperatures [16-18]. Laston has three kinds of mixtures, namely Asphalt Concrete Wearing Course (AC-WC) as a wear layer, Asphalt Concrete Binder Course (AC-BC) as an intermediate layer and Asphalt Concrete Base (AC-Base) as a foundation layer [19, 20].

A road pavement surface layer has the ability to act as a wear layer and also when there is no change in shape that remains in its service life. One of the causes of damage or not reaching the service life of these roads is the increase in the level of traffic congestion. According to Tayfur et al. (2005) and Birgisson et al. (2007) [21, 22], repetition of traffic loads as a result of traffic density causes the accumulation of permanent deformation in the asphalt concrete mixture so that it has decreased road performance in its service life. To solve this problem, one way is to use additives to the mixture.

The stress conditions that occur due to wheel loads on the pavement layer can be tested in the laboratory but by simplifying many factors [23, 24]. In actual conditions the pressure or load is applied in three dimensions [25, 26]. Therefore, a number of simplified tests were introduced to be able to test certain aspects of in-situ behavior. The test is divided into three groups [27, 28]. The first test group is the basic test of the repeated load triaxial test, the unconfined static uniaxial creep compression test, the repeated load indirect tensile test, the dynamic stiffness and fatigue test. Stiffness and fatigue tests). The second group of tests is simulative laboratory testing: the wheel-tracking test and the third testing group is the empirical test using the Marshall tests [29, 30]. Basically, East Kalimantan Province has abundant local aggregate reserves, but so far it is considered as non-standard (sub-standard) aggregate to be used as road pavement material. To overcome this, it is necessary to carry out technical engineering in the use of materials so that local materials which are substandard or industrial waste materials can be optimized for use for road pavement, both for asphalt mixtures and for road foundation layers. The objective of this study was to reveal the characteristics of coarse aggregate, fine aggregate (Mahakam sand) and filler, combined aggregate gradation, and Resilient Modulus of asphalt mixed (horizontal deformation of 3, 5 and 7 days due to water immersion). This study aims to analyze the modulus of stiffness of the AC-WC mixture using local aggregate of East Kalimantan Province and petroleum bitumen grade 60/70 as a binder.

2. Materials and Research Methodology

2.1. Aggregate

Tables 1 to 3 shows the characteristics of coarse aggregate, fine aggregate (sand) and filler, respectively that have been carried out. Based on the test results, the characteristics of coarse aggregate, sand, and filler are shown to meet the Directorate General of Bina Marga, Ministry of Public Works 3rd Revision, 2010 [26].

Table 1. Physical properties of coarse aggregate

No.	Characteristics	Results	Specification		Unit
			Min	Max	
1	Water absorption				
	Crushed stone 5 – 10 mm	2.26	-	3.0	%
	Crushed stone 10 - 20 mm	2.28	-	3.0	%
2	Specific gravity				
	Crushed stone 5 - 10 mm				

	Bulk specific gravity	2.67	2.5	-	-
	Saturated surface dry specific gravity	2.69	2.5	-	-
	Apparent specific gravity	2.80	2.5	-	-
	Crushed stone 1 - 2 cm				
	Bulk specific gravity	2.67	2.5	-	-
	Saturated surface dry specific gravity	2.69	2.5	-	-
	Apparent specific gravity	2.80	2.5	-	-
	Flakiness index				
3	**Crushed stone 5 – 10 mm**	22.10	-	25	%
	Crushed stone 10 - 20 mm	11.38	-	25	%
	Abrasion aggregate				
4	**Crushed stone 5 – 10 mm**	20.92	-	40	%
	Crushed stone 10 - 20 mm	18.56	-	40	%

Table 2. Physical properties of fine aggregate (Mahakam sand)

No.	Characteristics	Results	Specification		Unit
			Min	Max	
1	Water absorption	2.87	-	3.0	%
	Bulk specific gravity	2.48	2.5	-	-
2	Saturated surface dry specific gravity	2.56	2.5	-	-
	Apparent specific gravity	2.66	2.5	-	-
3	Sand Equivalent	90.63	50	-	%

Table 3. Physical properties of filler

No.	Characteristics	Results	Specification		Unit
			Min	Max	
1	Water absorption	2.48	-	3.0	%
	Bulk specific gravity	2.64	2.5	-	-
2	Saturated surface dry specific gravity	2.70	2.5	-	-
	Apparent specific gravity	2.79	2.5	-	-
3	Sand Equivalent	79.59	50	-	%

2.2. Petroleum Bitumen Pen. 60/70

Table 4 shows the results of the petroleum bitumen pen. 60/70 that has been carried out.

Table 4. Physical properties of petroleum bitumen pen. 60/70

No	Characteristics	Results	Specification	
			Min	Max
1	Penetration before weight loss (mm)	77.3	60	79
2	Softening point (°C)	56	48	58
3	Ductility in 25°C, 5cm/minute (cm)	119	100	-
4	Flash point (°C)	310	200	-
5	Specific gravity	1.14	1	-
6	Weight loss (%)	0.2	-	0.8
7	Penetration after weight loss (mm)	89	54	-

The results of the examination of the characteristics of the 60/70 penetration oil asphalt shown in Table 4 show that the asphalt used in this study has met the specifications required by Directorate General of Bina Marga, Ministry of Public Works 3rd Revision, 2010 [26].

2.3. Research Design

To facilitate the research to be carried out, it is necessary to plan the stages that will be the guidelines for this research, the stages of the process are shown in Figure 1. This study used petroleum bitumen content of 4.5, 5.0, 5.5, 6.0 and 6.5%. Indirect Stiffness modulus (ITSM) testing is carried out after the specimen has been immersed in water for 3, 5 and 7 days.

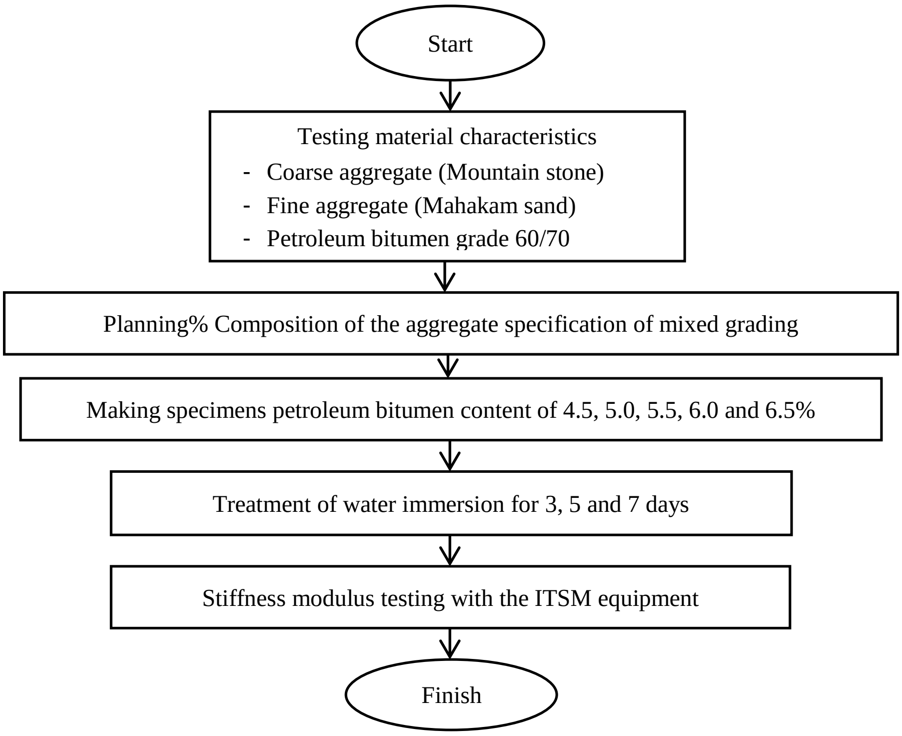

Figure 1. Flowchart of the research methodology

2.4. Indirect Tensile Stiffness Modulus (ITSM) Test

The indirect tensile stress test (ITSM) shown in Figure 1 is used to determine the tensile properties of asphalt concrete which can be further related to cracks that occur in the asphalt mixture, especially the AC-WC mixture. Strain control was used to evaluate the stiffness modulus in which the specimen was subjected to sinusoidal loading axial oscillations in a voltage at a constant amplitude of 5 microstrains. All materials are tested at a temperature of 20˚C, where the sample is subjected to dynamic loads in a certain strain range (linear elastic conditions) with the test configuration. This test is considered a non-destructive test carried out using a Dynapave UTM 30 machine. ITSM testing is calculated by formula and in accordance with the provisions of the British Standard [27].

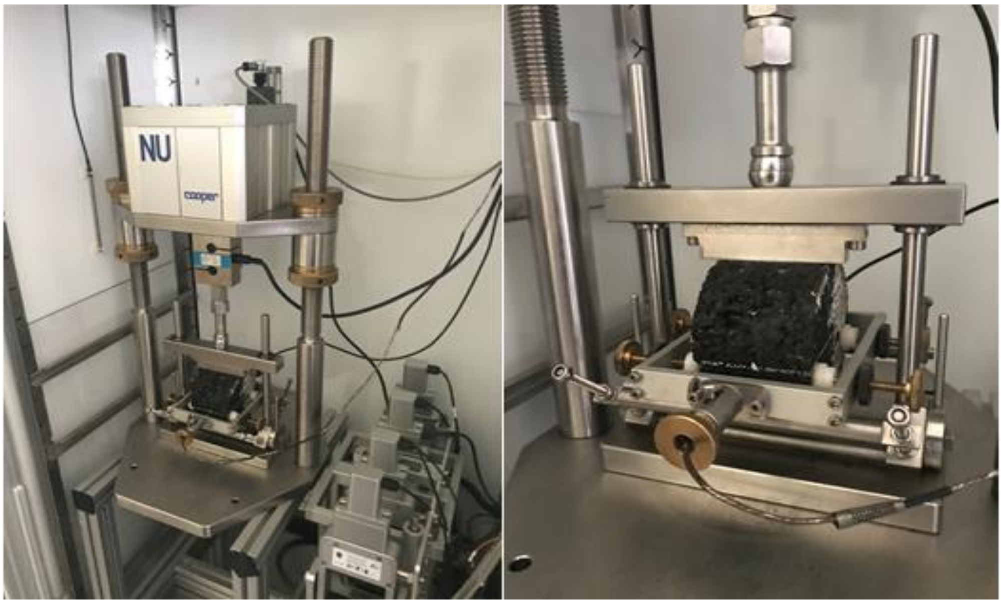

Figure 2. ITSM test

Measurements are made by placing a load on the upper part of the cylindrical specimen, and by recording computerized strain data that is generated in a plane perpendicular to the plane given the load. If you can know the poisson ratio, the size of the test object and the applied load, the modulus of the asphalt mixture. Equation 1 shows the modulus value generated from the ITSM equipment.

$$E = \frac{F(\upsilon + 0{,}27)}{LH} \tag{1}$$

Where:

E = Modulus of elasticity (MPa);

F = The peak value of the applied vertical load;

υ = Poisson ratio (0.35);

L = thickness of specimen (mm);

H = Amplitude of horizontal strain during the applied load cycle (mm).

3. Results and Discussion

3.1. Combined Aggregate Gradation of AC-WC Mixture

Figure 3 shows that the combined aggregate design or the combined aggregate gradation made is within the standard specification interval in Directorate General of Bina Marga, Ministry of Public Works 3rd Revision, 2010 [26].

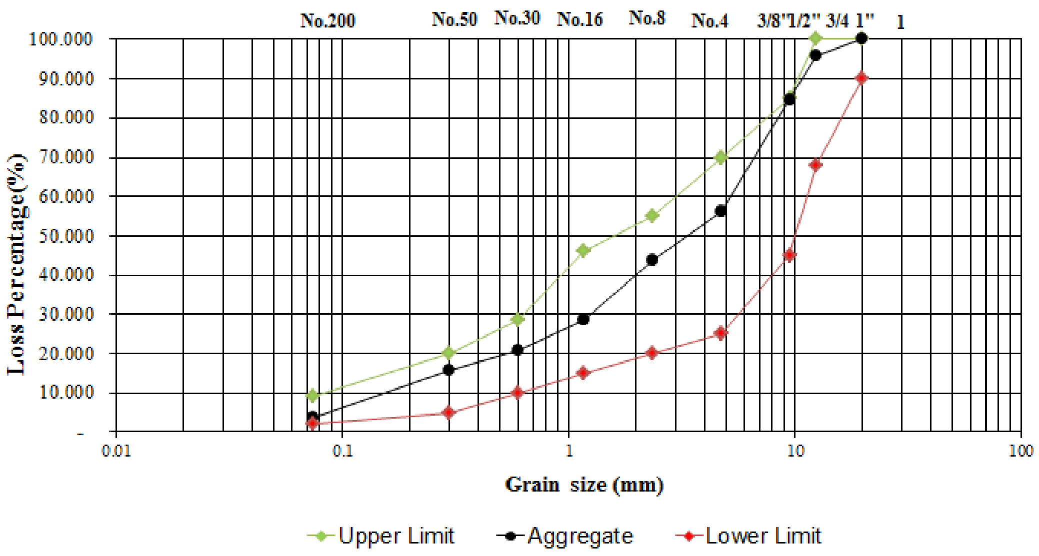

Figure 3. Combined aggregates gradation

3.2. Mixtures Design of AC-WC Mixture

Based on the previous results that analyzed the optimum asphalt content was 5.10%, a mix design was designed to make the test object with various levels of oil asphalt content, namely 4.5%, 5.0%, 5.5% , 6.0% and 6.5% by weight of the mixture. Table 5 shows the composition of the material by weight obtained from the proportion of the aggregate based on the results of the sieve analysis.

Table 5. Material composition in weight for 1200 grams of specimen (D mold = 10 cm)

Asphalt content (%)	Aggregate (gram)				Petroleum bitumen (gram)	Weight (gram)
	Crushed stone 1-2 cm	Crushed stone 0.5-1 cm	Mahakam sand	Stone dust		
4.5	343.8	458.4	229.2	114.6	54	1200
5.0	342.0	456.0	228.0	114.0	60	1200
5.5	340.2	453.6	226.8	113.4	66	1200
6.0	338.4	451.2	225.6	112.8	72	1200
6.5	336.6	448.8	224.4	112.2	78	1200

3.3. Indirect Tensile Stiffness Modulus (ITSM) Results

Table 6 shows the resilient modulus value of the asphalt mixture with water immersion time for 3, 5 and 7 days. It can be seen that the resilient modulus value increases along with the increase in asphalt content until it reaches the optimal value then decreases after getting the optimal value. In this study, it increased to 5.5% asphalt content both at 3, 5 and 7 days immersion.

At the 3-day immersion, the resilient modulus values obtained at the asphalt content of 4.5, 5.0, 5.5, 6.0 and 6.5% were respectively 421.0, 506.0, 872.5, 747.0 and 648.5 MPa. At 5 days immersion, the resilient modulus values obtained were 383.5, 386.0, 915.5, 561.0 and 555.5 MPa, respectively. Whereas for the 7-day immersion specimen, the resulting resilient modulus values were 290.5, 425.5, 1369.0, 547.5 and 525.0 MPa, respectively.

It can be seen that water immersion greatly affects the stiffness modulus of the asphalt mixture. This stiffness will cause the asphalt mixture to be easily damaged or cracked. This can be caused by the influence of the sub-standard aggregates used, namely Senoni stone and Mahakam sand.

Table 6. Resilient modulus of asphalt mixture to immersion time

Immersion time (Days)	Asphalt content (%)	Stiffness modulus mean A (MPa)	Stiffness modulus mean B (MPa)	Average (MPa)
3	4.5	475	367	421.0
	5.0	629	383	506.0
	5.5	997	748	872.5
	6.0	989	505	747.0
	6.5	77	1220	648.5
5	4.5	345	422	383.5
	5.0	295	477	386.0
	5.5	1067	764	915.5
	6.0	568	554	561.0
	6.5	496	614	555.0
7	4.5	332	249	290.5
	5.0	513	338	425.5
	5.5	2549	189	1369.0
	6.0	534	561	547.5
	6.5	515	535	525.0

Based on the test results, the chemical characteristics of Senoni stone and Mahakam sand contain predominantly calcium, followed by silica and alumina or magnesium or ferrous content. Thus electrostatically, these aggregates have a positive electric charge. This shows that the aggregate should be able to stick tightly to the asphalt because the asphalt is negatively charged. But in reality the aggregate adhesion to asphalt is less than 95%. There are two things that can cause it, namely the lack of positive ions from the aggregate or because the absorption is too small so that the asphalt is difficult to stick to.

Time Relationship with Horizontal Deformation of Immersion in 3 Days

Figure 4 shows the relationship between the time domain of the test and the horizontal deformation of the AC-WC mixture with water immersion for 3 days using Senoni rock aggregate and Mahakam sand. It can be seen that in all variations of asphalt content, maximum horizontal deformation occurs in about 0.4 seconds. At asphalt content 4.5% horizontal the maximum deformation that occurs is 20.15 mm, at asphalt content is 5.0% horizontal the maximum deformation that occurs is 35.70 mm, at asphalt content is 5.5% horizontal maximum deformation occurs namely 53.10 mm, the maximum horizontal deformation at asphalt content is 6.0%, 17.35 mm and at 6.5% asphalt content, the maximum horizontal deformation is 31.94 mm.

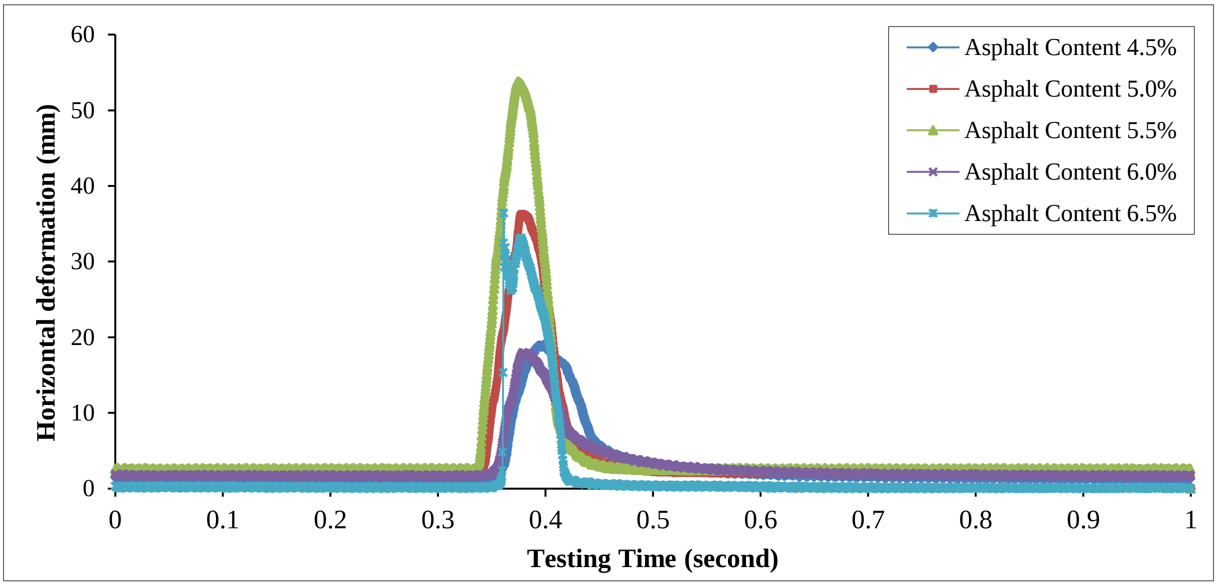

Figure 4. The relationship between the time domain of the test and the horizontal deformation of the AC-WC mixture for 3 days immersion

Time Relationship with Horizontal Deformation of Immersion in 5 Days

Figure 5 shows the relationship between the test time domain and the horizontal deformation of the AC-WC mixture with water immersion for 5 days using Senoni stone aggregate and Mahakam sand. It can be seen that in all variations of asphalt content, maximum horizontal deformation occurs in about 0.4 seconds.

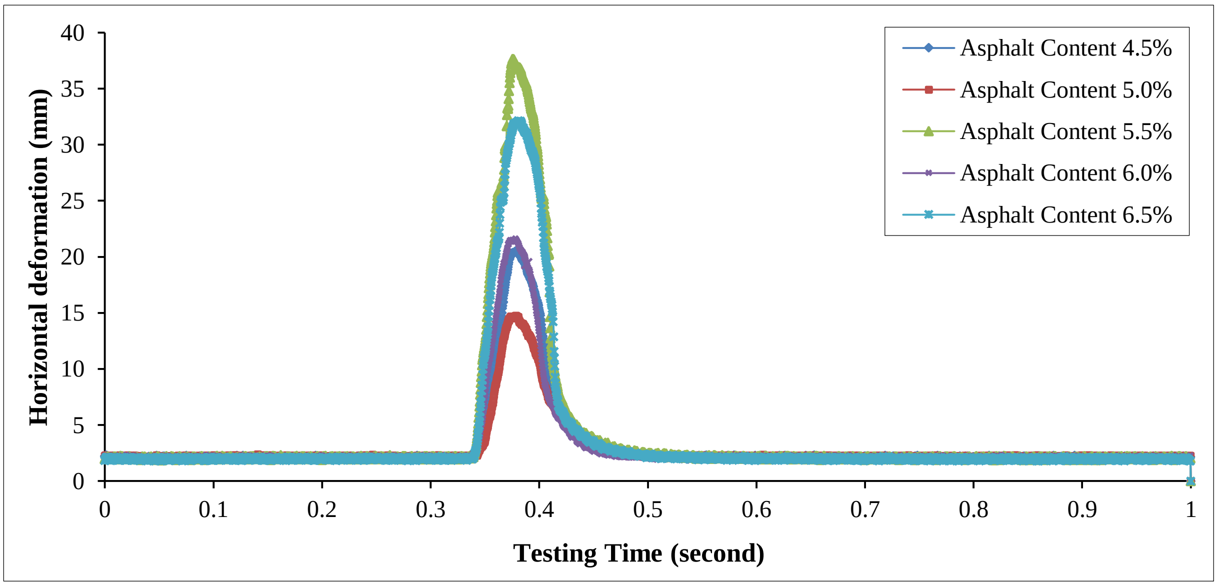

Figure 5. The relationship between the time domain of the test and the horizontal deformation of the AC-WC mixture for 5 days immersion

At asphalt content 4.5% horizontal the maximum deformation that occurs is 20.19 mm, at asphalt content is 5.0% horizontal the maximum deformation that occurs is 14.54 mm, at asphalt content is 5.5% horizontal maximum deformation occurs that is, 37.37 mm, the maximum horizontal deformation at 6.0% asphalt content was 21.46 mm and at 6.5% horizontal asphalt content, the maximum deformation occurred was 31.86 mm.

Time Relationship with Horizontal Deformation of Immersion in 7 Days

Figure 6 shows the relationship between the time domain of the test and the horizontal deformation of the AC-WC mixture with water immersion for 7 days using Senoni rock aggregate and Mahakam sand. It can be seen that in all variations of asphalt content, maximum horizontal deformation occurs in about 0.4 seconds. At asphalt content 4.5% horizontal the maximum deformation that occurs is 20.19 mm, at asphalt content is 5.0% horizontal the maximum deformation that occurs is 14.54 mm, at asphalt content is 5.5% horizontal maximum deformation occurs that is, 37.37 mm, the maximum horizontal deformation at 6.0% asphalt content was 21.46 mm and at 6.5% horizontal asphalt content, the maximum deformation occurred was 31.86 mm.

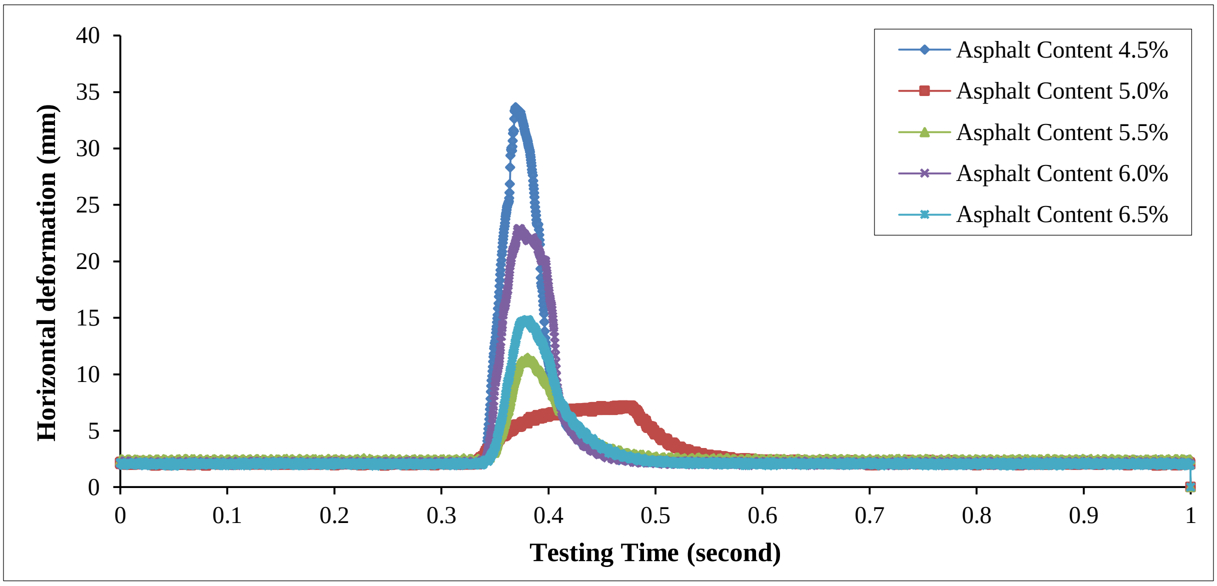

Figure 6. The relationship between the time domain of the test and the horizontal deformation of the AC-WC mixture for 7 days immersion

The amount of horizontal deformation is directly proportional to the magnitude of the resilient modulus value. The greater the resilient modulus value that occurs, the greater the horizontal deformation value. In this study, the AC-WC mixture using sub-standard aggregates had small resilient modulus values compared to the resilient modulus values of AC-WC mixtures using standard aggregates. The resulting AC-WC mixture is strong enough but does not have good resistance to water. This is caused by the adhesion of the aggregate to the asphalt which is less than 95% and does not meet the General Specifications 2010 Revision 3 of Bina Marga. In addition, the high absorption capacity of the aggregate which is also accompanied by a large asphalt surface tension which reduces the wetting effect of the asphalt also causes this to occur. To change the ionic charge of bitumen also has to do with laboratory engineering.

The stiffness of the asphalt mixture is closely related to the stability and flow values. Asphalt mixtures, especially AC-WC have high stability with a small flow value, this makes the mixture stiffer, especially for the test object that has an accelerated aging process both in the field and in the laboratory. As previously explained, the high stability is due to the low penetration of petroleum bitumen. This can also be explained by considering that the VIM value of the asphalt mixture that does not undergo an accelerated aging laboratory process is smaller than that of the asphalt mixture that has undergone an accelerated immersion in the laboratory. The small VIM value indicates that the mixture is denser and the mixture is stiffer which is indicated by the Marshall Quotient (MQ) value on the Marshall characteristics. A high MQ value indicates that the asphalt mixture has higher stiffness [18-30].

4. Conclusion

Aggregates used in Based on the test results of the characteristics of coarse aggregate (crushed stone), rock ash, and rock ash filler shown, it can be seen that the aggregate used meets the general specifications in 2010 of Bina Marga for the required road materials. However, coarse aggregate (Senoni stone) is based on the results of the adhesion test of the aggregate to asphalt where the result is <95% so it is classified as non-standard (sub standard) aggregate. However, considering the unfulfilled properties are not natural properties of the aggregate, efforts to improve these properties by engineering the materials in the laboratory can be carried out.

Aggregates from Samarinda, East Kalimantan in the form of Senoni stone and Mahakam sand are very good for use as class A foundation layers but should not be used as aggregates for asphalt mixtures because they have poor adhesion to asphalt and cannot withstand water immersion. At the 3-day immersion, the resilient modulus values obtained at the asphalt content of 4.5, 5.0, 5.5, 6.0 and 6.5% were respectively 421.0, 506.0. 872.5, 747.0 and 648.5 MPa. At 5 days immersion, the resilient modulus values obtained were 383.5, 386.0, 915.5, 561.0 and 555.5 MPa, respectively. Whereas for the 7-day immersion specimen, the resulting resilient modulus values were 290.5, 425.5, 1369.0, 547.5 and 525.0 MPa, respectively. Asphalt mixture using mountain rock aggregates in Senoni, East Kalimantan and asphalt content of 5.5% is resistant to water immersion until the age of 7 days with the largest resilient modulus (stiffness modulus), which is 1369.0 MPa.

Laboratory engineering carried out to optimize the use of substandard aggregate from Senoni rock and Mahakam sand as a material for asphalt mixtures has not been proven on a project scale. For that, a pilot project needs to be carried out and observed for two seasons for further proof.

5. Declarations

5.1. Data Availability Statement

The data presented in this study are available in article.

5.2. Funding and Acknowledgements

This work was not supported by the Indonesian Scholarship Program but it's personal expenses. Most of the research works were conducted in the Eco Material and Concrete Laboratory, Transportation Systems Engineering Laboratory and Road and Asphalt Laboratory, Civil Engineering Department, Hasanuddin University, Makassar-Indonesia.

5.3. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] PSDG-ESDM-RI. Report on Updating Data and Balance of Mineral Resources, (2013) (in Indonesia).

[2] Eswan, S A Adisasmita, M I Ramli, and S Rauf. "The Effect of Water Immersion on Compressive Strength of Senoni Stone, East Kalimantan." IOP Conference Series: Earth and Environmental Science 419 (February 8, 2020): 012103. doi:10.1088/1755-1315/419/1/012103.

[3] H. R. Anwar Yamin. "Utilization of Fak Fak Crystalline Rocks for Asphalt Mixtures." Road and Bridge Research and Development Center (2011) (in Indonesian).

[4] Haghshenas, Hamzeh F., and Robert C. Rea. "In-Place Density of Asphalt Pavements: Case Study during Cold Weather Paving." Journal of Transportation Engineering, Part B: Pavements 145, no. 4 (December 2019): 05019003. doi:10.1061/jpeodx.0000135.

[5] Liu, Jenny, Sheng Zhao, Peng Li, and Steve Saboundjian. "Variability of Composition, Volumetric, and Mechanic Properties of Hot Mix Asphalt for Quality Assurance." Journal of Materials in Civil Engineering 29, no. 3 (March 2017). doi:10.1061/(asce)mt.1943-5533.0001481.

[6] Tjaronge, M. Wihardi, and Rita Irmawaty. "Influence of Water Immersion on Physical Properties of Porous Asphalt Containing Liquid Asbuton as Bituminous Asphalt Binder." In Proceedings of 3rd International conference and Sustainable Construction Material and Technologies-SCTM, , Kyoto, Japan, vol. 153, (2013): M4-1.

[7] Mohammad, Louay N., Mostafa Elseifi, Samuel B. Cooper, and Amar Raghavendra. "Levels of Variability in Volumetric and Mechanical Properties of Asphalt Mixtures." Journal of Materials in Civil Engineering 25, no. 10 (October 2013): 1424–1431. doi:10.1061/(asce)mt.1943-5533.0000545.

[8] Mohammad, Louay N., Zhong Wu, Chenggang Zhang, Mohammad J. Khattak, and Chris Abadie. "Variability of Air Voids and Mechanistic Properties of Plant-Produced Asphalt Mixtures." Transportation Research Record: Journal of the Transportation Research Board 1891, no. 1 (January 2004): 85–97. doi:10.3141/1891-12.

[9] Tumpu, M, M W Tjaronge, A R Djamaluddin, A A Amiruddin, and La One. "Effect of Limestone and Buton Granular Asphalt (BGA) on Density of Asphalt Concrete Wearing Course (AC-WC) Mixture." IOP Conference Series: Earth and Environmental Science 419 (February 8, 2020): 012029. doi:10.1088/1755-1315/419/1/012029.

[10] Mabui, D S, M W Tjaronge, S A Adisasmita, and M Pasra. "Resistance to Cohesion Loss in Cantabro Test on Specimens of Porous Asphalt Containing Modificated Asbuton." IOP Conference Series: Earth and Environmental Science 419 (February 8, 2020): 012100. doi:10.1088/1755-1315/419/1/012100.

[11] Mabui, D. S., Tjaronge, M. W., Adisasmita, S. A., and Pasra, M. "Performance of Porous Asphalt Containing Modificated Buton Asphalt and Plastic Waste." International Journal of GEOMATE 18, no. 65 (January 1, 2020): 118–123. doi:10.21660/2020.65.67196.

[12] Lapian, F E P, M I Ramli, M Pasra, and A Arsyad. "Opportunity Applying Response Surface Methodology (RSM) for Optimization of Performing Butonic Asphalt Mixture Using Plastic Waste Modifier: a Preliminary Study." IOP Conference Series: Earth and Environmental Science 419 (February 8, 2020): 012032. doi:10.1088/1755-1315/419/1/012032.

[13] Sukrislistarto, M. I. Ramli, M Pasra, and A. A. Amiruddin. "The Sustainable Performance Challenge of Asphalt Mixture Using Polypropylene Due to Environmental Weather." IOP Conference Series: Earth and Environmental Science 419 (February 8, 2020): 012075. doi:10.1088/1755-1315/419/1/012075.

[14] Meraudje, A., M. I. Ramli, M. Pasra, and A. A. Amiruddin. "The Potential Utilization of Polyethylene Terephthalate (PET) Waste as Fine Aggregate Replacement in Asphalt Mixture." IOP Conference Series: Earth and Environmental Science 419 (February 8, 2020): 012036. doi:10.1088/1755-1315/419/1/012036.

[15] Erdawaty, Erdawaty, Tri Harianto, A. B. Muhiddin, and Ardy Arsyad. "Experimental Study on Bearing Capacity of Alkaline Activated Granular Asphalt Concrete Columns on Soft Soils." Civil Engineering Journal 6, no. 12 (November 30, 2020): 2363–2374. doi:10.28991/cej-2020-03091623.

[16] Directorate General of Highways Department of Public Works. Construction and Building Guidelines No: 001-01/BM/2006, Utilization of Buton Asphalt: General, (2006).

[17] Tjaronge, MW, Rita Irmawaty, and Muralia Hustim. "Effect of Buton Granular Asphalt Gradation and Cement as Filler on Performance of Cold Mix Asphalt Using Limestone Aggregate." Journal of Engineering Science and Technology 15, no. 1 (2020): 419-433.

[18] Bulgis, M W Tjaronge, S A Adisasmita, and M Hustim. "Analysis of Stability of Residue Asphalt Emulsion Mixture Containing Buton Granular Asphalt (BGA)." IOP Conference Series: Earth and Environmental Science 419 (February 8, 2020): 012073. doi:10.1088/1755-1315/419/1/012073.

[19] Iroth, M W, M W Tjaronge, and M. Pasra. "Influence of Short Term Oven Aging on Volumetric Properties of Asphalt Concrete Mixture Containing Modified Buton Asphalt and Limestone Powder Filler." IOP Conference Series: Earth and Environmental Science 419 (February 8, 2020): 012072. doi:10.1088/1755-1315/419/1/012072.

[20] Tumpu, M, M W Tjaronge, and A R Djamaluddin. "Prediction of Long-Term Volumetric Parameters of Asphalt Concrete Binder Course Mixture Using Artificial Ageing Test." IOP Conference Series: Earth and Environmental Science 419 (February 8, 2020): 012058. doi:10.1088/1755-1315/419/1/012058.

[21] Tayfur, Süreyya, Halit Ozen, and Atakan Aksoy. "Investigation of Rutting Performance of Asphalt Mixtures Containing Polymer Modifiers." Construction and Building Materials 21, no. 2 (February 2007): 328–337. doi:10.1016/j.conbuildmat.2005.08.014.

[22] Birgisson, B., A. Montepara, E. Romeo, R. Roncella, J.A.L. Napier, and G. Tebaldi. "Determination and Prediction of Crack Patterns in Hot Mix Asphalt (HMA) Mixtures." Engineering Fracture Mechanics 75, no. 3–4 (February 2008): 664–673. doi:10.1016/j.engfracmech.2007.02.003.

[23] Hunter, Robert N., Andy Self, John Read, and Elizabeth Hobson. "The Shell Bitumen Handbook." London, UK: ICE Publishing, (2015).

[24] Mahyuddin, Abrar, M. W. Tjaronge, Nur Ali, and M. Isran Ramli. "Experimental analysis on stability and indirect tensile strength in asphalt emulsion mixture containing Buton granular asphalt." International Journal of Applied Engineering Research 12 (2017): 3162-3169.

[25] Gaus, A., M. W. Tjaronge, N. Ali, and R. Djamaluddin. "Experimental Study on Characteristics of Asphalt Concrete Bearing Coarse (AC BC) Mixture using Buton Granular Asphalt (BGA)." International Journal of Applied Engineering Research 9, no. 22 (2014): 18037-18045.

[26] Gaus, Abdul, Tjaronge M.W., Nur Ali, and Rudy Djamaluddin. "Compressive Strength of Asphalt Concrete Binder Course (AC-BC) Mixture Using Buton Granular Asphalt (BGA)." Procedia Engineering 125 (2015): 657–662. doi:10.1016/j.proeng.2015.11.097.

[27] Budiamin, Tjaronge MW, S. H. Aly, and R. Djamaluddin. "Mechanical characteristics of hotmix cold laid containing buton granular asphalt (BGA) and flux oil as wearing course." ARPN Journal of Engineering and Applied Sciences 10, no. 12 (2015): 5200-5205.

[28] Bulgis, M W Tjaronge, S A Adisasmita, and M Hustim. "Effect of Buton Granular Asphalt (BGA) on Compressive Stress-Strain Behavior of Asphalt Emulsion Mixture." IOP Conference Series: Materials Science and Engineering 271 (November 2017): 012069. doi:10.1088/1757-899x/271/1/012069.

[29] Lapian, Franky E. P., Muhammad Isran Ramli, Mubassirang Pasra, Ardy Arsyad, and Hajriyanti Yatmar. "Application of Surface Response Methodology (RSM) for Improving the Marshall Quotient of AC-WC Mixtures Containing PET Plastic Waste." ICCOEE2020 (2021): 966–975. doi:10.1007/978-981-33-6311-3_109.

[30] Tjaronge, M W, Fakhruddin, M A Caronge, M H Zaifullah, and M F Rahmat. "Preliminary Study on Compressive Strength of Porous Asphalt Containing Modified Buton Asphalt, Waste Plastic and Limestone Powder." IOP Conference Series: Materials Science and Engineering 875 (July 23, 2020): 012032. doi:10.1088/1757-899x/875/1/012032.

[31] Asphalt Institute. "The asphalt handbook." College Park, MD: Asphalt Institute, (2007).

[32] Carbonneau, Xavier, Yves Le Gal, and Pierre Bense. "Evaluation of the indirect tensile stiffness modulus test." In Sixth International RILEM Symposium on Performance Testing and Evaluation of Bituminous Materials, RILEM Publications SARL, (2003): 308-315.

[33] Baskara, Gusti Made Bagus, Ervina Ahyudanari, and I. Nyoman Arya Thanaya. "Analysis of Stiffness Modulus of Asphalt Concrete Mixture by Using Artificial Aggregates." Jurnal Teknik ITS 8, no. 2 (2019): F81-F85.

[34] Directorate General of Bina Marga, Ministry of Public Works 3rd Revision, 2010, Spesifikasi Umum Jalan dan Jembatan, Bina Marga (in Indonesian).

[35] British standards (BS EN 12607-26: 2012). Method for Determination of the indirect tensile stiffness modulus of bituminous mixtures.