Marshall Stability of Porous Asphalt with Oyster Shell Ash Filler Substitution and High Density Polyethylene

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DOI: http://dx.doi.org/10.29103/tj.v13i1.855

(Received: November 2022 / Revised: February 2023 / Accepted: February 2023)

Abstrak

Aspal porus merupakan campuran beraspal yang memiliki rongga udara yang besar yang menyebabkan aspal porus memiliki nilai stabilitas yang rendah. Untuk meningkatkan nilai stabilitas diperlukan bahan tambah lain yang memiliki potensi seperti limbah Abu Cangkang Tiram (OSA) dan limbah *High Density Polyethylene* (HDPE). OSA mempunyai sifat kimia yang mengandung kapur dan silika yang berfungsi untuk keawetan dan mengunci antar agregat pada perkerasan jalan. Sedangkan HDPE memiliki kekuatan yang tinggi dan kaku serta perilaku untuk mengikat sehingga dapat memperkuat ikatan antara agregat dan OSA dan menambah perkuatan terhadap campuran aspal porus. Tujuan penelitian ini adalah untuk menentukan Kadar Aspal Optimum (OAC) pada campuran aspal porus, dan menganalisis variasi persentase terbaik OSA dan limbah HDPE sebagai substitusi aspal pen 60/70. Pengujian yang dilakukan adalah pemeriksaan terhadap parameter *Marshall*. Hasil penelitian menunjukkan bahwa variasi filler 50% OSA : 50% PC dengan 4%, 6% HDPE dapat meningkatkan nilai stabilitas Marshall pada campuran aspal porus serta memenuhi spesifikasi Australian Asphalt Pavement Association (AAPA).

Kata kunci: *Aspal porus, marshall, abu cangkang tiram, HDPE*

Abstract

Porous Asphalt is the asphalt mix containing large air void resulting low stability of porous asphalt. The improvement of stability requires another potential additive material as Oyster Shell Ash (OSA) and High Density Polyethylene (HDPE) waste. OSA contains of chemical characteristics consisting of calcium and silica for durability and locking the aggregate and road pavement. While HDPE is rigid, high strength, and binder that it can strengthen the bond of aggregate and OSA as well as strengthen porous asphalt mix. The research aims to determine OAC to porous asphalt mix, and analyze the best percentage variation of OSA filler substitution and HDPE waste as asphalt pen 60/70 substitution. The test was carried out was Marshall Parameter investigation. The output explained that the variation of 50% OSA filler: 50% PC using 4%, 6% HDPE can improve the Marshall stability on porous asphalt mix and meet specification of Australian Asphalt Pavement Association (AAPA).

Keywords: *Porous asphalt, marshall, oyster shell ash, HDPE*

1. Introduction

Porous asphalt is general used in the developed countries including Netherland, Spain, Belgium, England, Australia, the United State as well as Japan, Singapore, Germany, French, and Malaysia (Corté, 2021), while in Indonesia has not been widely used especially in Aceh Province, Meanwhile, Indonesia requires this material for Indonesia has high rainfall intensity so the porous asphalt can be one of the solution. Porous asphalt is the mixture of open graded hot asphalt with high coarse aggregate percentage and low fine aggregate percentage resulting large air void expected to pass the rainfall so the water does not inundate the road surface (Widhianto et al., 2013). The large void result the porous asphalt has high permeability rate but low stability (Rusyda et al., 2018).

The stability improvement requires another potential additive material as oyster shell ash and High Density Polyethylene (HDPE) waste as asphalt pen 60/70 substitution. Oyster shell waste is the waste produced from oyster aquaculture containing of chemical characteristics consisting of 67.072% calcium and 8.252% silica (Idral, 2016). The calcium is useful for the road pavement durability, while the silica is important to lock aggregates. The oyster shell ash in this research will be substituted to Portland cement as filler.

The problem of this research is how to use waste material in porous asphalt mixture and what is the best variation percentage of OSA filler substitution and HDPE. The research aims to determine OAC to porous asphalt mix, and analyze the best percentage variation of OSA filler substitution and HDPE waste as asphalt pen 60/70 substitution. Gradation used is porous asphalt mix gradation based on Australian Asphalt Pavement Association (AAPA) 2004 Method.

The test is carried out to investigate aggregate physical characteristics, asphalt physical characteristics, filler test, object test construction, Marshall test, OAC determination, and permeability test. Based on AAPA standard, this research consists of several asphalt content variations were 4.5%, 5.0%, 5.5%, 6.0% and 6.5%. and to determine OAC is substituted to Portland Cement (PC) as filler using the percentage of 0% OSA: 100% PC, 50% OSA: 50% PC and 100% OSA: 0% PC to the filler total weight, and the HDPE waste is substituted to the asphalt pen 60/70 using the percentage of 2%, 4% and 6% to the asphalt total weight.

OSA waste used in this research is taken from oyster aquaculture located in Alue Naga Village, Syiah Kuala Sub District, Banda Aceh. HDPE waste is taken from the landfill, plastic waste recycle of Induk Sadar Mandiri Aceh Waste Bank, located in Gampong Jawa Village, Banda Aceh. The binder used is Asphalt pen 60/70 produced by Pertamina. The aggregate is obtained from stone crusher machine located in Indrapuri, Aceh Besar

2. Research Method

2.1 Porous Asphalt

The porous asphalt mix was first known as open graded friction courses mixture used since 1950 in the United State to improve the roughness of asphalt pavement (Corté, 2021). The similar researches also had been carried out by (Widhianto et al., 2013), (Rusyda et al., 2018), (Idral, 2016), (Syammaun et al., 2019), (Syammaun, Meillyta, et al., 2020), (Syammaun, Rani, et al., 2020), explained that porous asphalt is asphalt mix containing low fine aggregate proportion producing high air void so the water can be fast flowed through the void to the road channel.

2.2 Porous Asphalt Mix Ingredient

The ingredient of porous asphalt consists of aggregates (fine and coarse aggregate), asphalt, filler, OSA, and HDPE waste. Aggregate is crushed stone, gravel, sand, or other mineral compositions from processing output (filtering, breaking) as main materials of road pavement construction. Aggregate takes 90-95% of the mixture weight or 75-85% mixture volume (Indra et al., 2017). For the reason, it is required the good quality of aggregate used by focusing on the aggregate characteristics such as gradation and grain size, cleanness, surface shape and texture, strength, and porosity carried out by the research (Syammaun et al., 2019).

Asphalt is the material configured in the room temperature and having solid shape and thermoplastic characteristic. Asphalt will melt if heated to a certain temperature, and freeze if the temperature drops (Indra et al., 2017).

The asphalt used in the road pavement has function as binder and provides the strong bond between asphalt and aggregate or asphalt itself (Sugiri & Aschuri, 2010).

Filler is the collection of mineral aggregate passing the sieve No. 200. The filler function in the asphalt and aggregate mixture is filling the voids between coarse aggregate resulting smaller air void and higher mass density, by using the fine graded filler will produce higher grain surface area. It affects the higher contact area between the grains resulted by the higher resistance to shear forces and finally will improve the shear stability (Syammaun et al., 2019), (Syammaun, Meillyta, et al., 2020), (Abidin et al., 2021).

Oyster is the group of shellfish having calcareous and relatively flat shell. Oyster is the animal found in the coastal area which habitat is attaching to substrates such as rocks, roots, mangrove stems and other hard substrates. OSA contains chemical characteristics consisting of 67.072% calcium and 8.252% silica. The calcium is useful for the road pavement durability, while the silica is important to lock aggregates (Abidin et al., 2021).

HDPE waste is one of the plastic type produced by petroleum and can be recycle. It has cone number 2 in the recycle symbol. The study of asphalt pen rheology characteristics both low and high modified by plastic waste (HDPE) mentioned that the asphalt quality modified by plastic produces better characteristics compared to pure asphalt (Sugiri & Aschuri, 2010).

The additional of HDPE on the porous asphalt can improve the stability rate, the stability is related to road damage due to vehicles excessive loads (Indra et al., 2017).

2.3 Porous Asphalt Mix Characteristic

The characteristics required by porous asphalt mix are density, stability, flow, Marshall Quotient (MQ), permeability and durability. Porous asphalt is related to the behavior characteristic of asphalt mix using aggregate gradation of rough fraction as ± 85% to the mixture total weight resulting more open and void structure (Syammaun et al., 2019).

2.4 Optimum Asphalt Content (OAC)

The determination of OAC requires three parameters including VIM (void in mix), cantabro loss (durability to the grain release) and asphalt flow (*AAPA_IG-8_Asphalt_Mix_Design*, 2004). The volume weight is the comparison of test object dry weight and water weight to the volume (Rachman et al., 2019).

Table 1 Specification of Optimum Asphalt Content (OAC) determination (*AAPA_IG-8_Asphalt_Mix_Design*, 2004)

No	Specification	Requirement (%)
1	Cantabro Loss (CL) %	< 35
2	Void In Mix (VIM) %	18-25
3	Asphalt flow down (AFD) %	< 0.3

Stability is the capacity of road pavement in receiving the traffic load without any shape transformation, still have roadway wave or bleeding (Liu et al., 2020). Based on the output of the Marshall tool dial, the stability rate must be multiplied by tool calibration value and the test object correction factor. Australian Asphalt Pavement Association (AAPA) requires the stability rate as ≥ 500 kg (*AAPA_IG-8_Asphalt_Mix_Design*, 2004). Flow is shape transformation of the mixture due to collapse limit load in mm or 0.1 (Dalhat et al., 2022). The flow rate is 2 – 6 mm. Marshall Quotient (MQ) is quotient between Marshal stability and flow (*AAPA_IG-8_Asphalt_Mix_Design*, 2004). The Marshall Stability rate and flow which is high indicate rigid asphalt concrete mixture, so it will not be crack after receiving the load (Khuntia et al., 2014). Permeability is important to determine the capacity of porous asphalt pavement in flowing the water. The object test was soaked to get the saturation condition before the test. Then it was tested the time required by the 5 cm water height to infiltrate down (Sun et al., 2019). Durability is the capacity of asphalt concrete (solid asphalt mix) accepting traffic loads repetition, friction and the worn due to weather and climate. The factors affecting durability I the asphalt mix are thick asphalt cover, small VIM (void in mix) and high VMA (void in mineral aggregate) (Zheng et al., 2021).

2.5 Australian Asphalt Pavement Association Method

Australian Asphalt Pavement Association (AAPA) require cantabro loss as < 35 %. This test is carried out to determine mixture durability to the grain release. The requirement and specification of porous asphalt based on (*AAPA_IG-8_Asphalt_Mix_Design*, 2004) can be detail explained as below table.

Table 2 The requirement and specification of porous asphalt (*AAPA_IG-8_Asphalt_Mix_Design*, 2004)

No	Design Criteria	Value
1	Cantabro loss test (%)	< 35
2	Asphalt flow down test (%)	< 0.3
3	Marshall stability (kg)	≥ 500
4	Plastic melting (mm)	2 – 6
5	Air void rate (%)	18 – 25
6	Marshall quotient (kg/mm)	< 400
7	Amount of impact per area	50

2.6 Material and Equipment Used

The materials prepared to be used in this research are fine and coarse aggregates, asphalt, OSA and HDPE. Asphalt used is Asphalt pen 60/70, coarse aggregate retains the sieve No.4 (4.75 mm), fine aggregate passes the sieve No. 4 (4.75 mm). The Aggregates are taken from Indrapuri Sub District, Aceh Besar District. OSA waste as the filler substitution is found from oyster aquacukture located in Banda Aceh. While HDPE waste is from landfill, scavenger or waste bank, and household waste.

(a) (b)

Figure 1 (a) HDPE waste and (b) HDPE waste after cutting

(a) (b)

Figure 2 (a) Oyster shell waste and (b) Oyster shell ash

The equipments used in the research are the equipments using for the test of asphalt physical characteristics, aggregate physical characteristics, and Marshall parameter test based on AAPA 2004 Method.

3. Result and Discussion

3.1 The output of aggregate physical characteristics test

The output of aggregate physical characteristic test consist specific gravity, absorption, flatness, elongation, abration and impact, it can be shown in the below Table 3.

Table 3 Recapitulation of aggregate physical characteristic test

Test	Standard	Output	Specification
Specific gravity	SNI 03-1969-1991	2.738 gr/cm^3	Min. 2.5 gr/cm^3
Absorption	SNI 03-1969-1991	1.739	Max. 3%
Flatness	ASTM D-4791	9.83%	Max. 10%
Elongation	ASTM D-4791	9.63%	Max. 10%
Abration	SNI 2417-2008	16.44%	Max. 40%
Impact	SNI 2417-2008	6.49%	Max. 25%

3.2 The output of asphalt physical characteristics test

The output of aggregate physical characteristic test consist specific gravity, penetration, ductility, and melting point, it can be shown in the below Table 4.

Table 4 Recapitulation of asphalt physical characteristic test + HDPE

No.	Asphalt Physical Characteristic	Output					
		Asphalt Penetration 60/70	Asphalt + HDPE 2%	Asphalt + HDPE 4%	Asphalt + HDPE 6%	Requirement of Asphalt Pen. 60/70	Requirement of Modification Asphalt
1.	Specific gravity (gr/cm^3)	1.03	-	-	-	≥1.0	≥1.0
2.	Penetration (mm)	64.50	62	60	58	60 – 70	≥50
3.	Ductility (cm)	130	126	123	120	≥100	≥100
4.	Melting point (°C)	48.5	54	54.5	55	≥48	≥54

3.3 The output of Marshall test without filler substitution and HDPE

The output of Marshall test without filler substitution and HDPE resulted the Marshall parameters including density, stability, flow, VIM and MQ. The output of Marshall test using the asphalt variations as 4.5%, 5.0%, 5.5%, 6.0% and 6.5% using open graded can be explained in below table.

Table 5 The output of Marshall test without filler substitution and HDPE

No	Mixture Characteristic	Asphalt Content (%)					AAPA (2004) Specification
		4.5	5	5.5	6	6.5	
1	Density (gr/cm^3)	2.05	2.08	2.09	2.10	2.14	≥2
2	VIM (%)	22.65	20.86	19.84	18.87	16.50	18-25%
3	Stability (kg)	474.68	546.62	598.65	627.07	429.81	Min. 500 kg
4	Flow (mm)	3.23	3.30	4.13	4.37	4.43	2-6%
5	MQ (kg/mm)	148.03	165.84	145.21	147.07	100.71	Max. 400 kg/mm

3.4 The output of Marshall test using filler substitution and HDPE

The output of Marshall test using filler substitution and HDPE with OAC as 5.8% was used to create the object test using filler substitution as 0% OSA: 100% PC, 50% OSA: 50% PC and 100% OSA: 0% PC, and HDPE substitution as 2%, 4% and 6%. The output of density using filler substitution and HDPE can be detail explained in Table 6 below.

Table 6 The output of density test using OSA substitution and HDPE

No	Characteristic	HDPE Substitution (%)			Requirement (gram/cm^3)
		2	4	6	
1	Density (0% OSA : 100% PC)	2.00	2.11	2.12	≥ 2
2	Density (50% OSA : 50% PC)	2.03	2.11	2.12	
3	Density (100% OSA : 0% PC)	2.04	2.04	2.13	

P-ISSN 2088-0561
E-ISSN 2502-1680

The density test in porous asphalt mix is 2.00 gram/cm^3 - 2.13 gram/cm^3, it explained that OSA substitution and HDPE. The results of the VIM test on the effect of oyster shell ash substitution of with HDPE was 18.16%-22.88% as being mentioned in Table 7.

Table 7 The output of VIM test using OSA substitution and HDPE

No	Characteristic	HDPE Substitution (%)			Requirement (%)
		2	4	6	
1	Void In Mix (0% OSA: 100% PC)	22.88	18.73	18.38	18 – 25
2	Void In Mix (50% OSA: 50% PC)	21.88	18.49	18.16	
3	Void In Mix (100% OSA: 0% PC)	21.49	21.28	17.80	

3.5 The output of stability test by using filler substitution and HDPE

The output of stability test was 466.96 kg - 789.47 kg in which the total stability value meet the requirement, but not for the percentage 50% OSA: 50% PC using 2% HDPE and percentage 100% OSA: 0% PC using 2% and 4% HDPE do not meet the requirement as min. 500 kg as being mentioned in Table 8 below.

Table 8 The output of stability test using OSA substitution and HDPE

No	Characteristic	HDPE Substitution (%)			Requirement (kg)
		2	4	6	
1	Stability (0% OSA: 100% PC)	604.92	778.06	789.47	Min. 500
2	Stability (50% OSA: 50% PC)	492.92	761.95	789.25	
3	Stability (100% OSA: 0% PC)	466.96	489.45	581.81	

3.6 The output of flow using filler substitution and HDPE

The output of flow was 2.47% - 4.67% in which the total flow value meets the requirement as 2 - 6 mm as being mentioned in Table 9.

Table 9 The output of flow using OSA substitution and HDPE

No	Characteristic	HDPE Substitution (%)			Requirement (mm)
		2	4	6	
1	Flow (0% OSA: 100% PC)	3.63	3.83	4.30	2-6
2	Flow (50% OSA: 50% PC)	3.43	3.97	4.67	
3	Flow (100% OSA: 0% PC)	2.47	3.03	3.57	

3.7 The output of Marshall Quotient using filler substitution and HDPE

The output of MQ was 146.66 kg/mm – 204.64 kg/mm in which the total MQ value meet the requirement as max. 400 kg/mm as being mentioned in Table 10.

Table 10 The output of MQ using OSA substitution and HDPE

No	Characteristic	HDPE Substitution (%)			Requirement (kg/mm)
		2	4	6	
1	Marshall Quotient (0% OSA: 100% PC)	168.47	204.64	188.78	Max. 400
2	Marshall Quotient (50% OSA: 50% PC)	146.66	193.92	169.60	
3	Marshall Quotient (100% OSA: 0% PC)	195.54	163.73	164.88	

3.8 Correlation stability and flow at variation of 50% OSA: 50% PC

The results of stability test on porous asphalt that the variation of 50% OSA: 50% PC, it is seen that there is an increase in stability. However, from the Figure 3, it can be seen that the stability value began to decrease with the addition of 6% HDPE although the stability value was 789.25 kg.

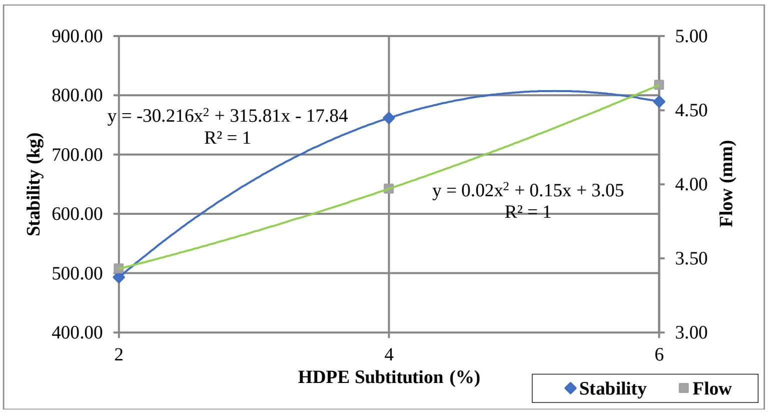

Figure 3 The graph of correlation between stability and flow

Figure 3 above explain that the increase in stability values occurred in variations of 2% and 4% HDPE were 492.92 kg and 761.95 kg. From these conditions it can be concluded that increasing the stability value in the asphalt mixture results in an increase in the correlation between the materials in the mixture. Furthermore, the flow test for the 6% HDPE variation increased from the 2% HDPE variation. Variations in HDPE cause the flow to increase while stability decreases.

4. Conclusion

The output explained that the variations of OSA filler and HDPE waste substitution affect the characteristics of porous asphalt. The test outputs showed that OSA has potency as filler material in porous asphalt mix and HDPE substitution can improve the characteristics of asphalt pen 60/70. The stability will improve if HDPE content increase. Since asphalt and HDPE contents have the same characteristic that is thermoplastic. More HDPE contents affect the porous asphalt become more condensed. More OSA in porous asphalt influence the decrease of stability, for OSA filler has function just as mix filler that is not capable for particle binder in the mix. For this study presented the variation of 50% OSA : 50% PC using 4% and 6% HDPE.

Acknowledgments

The researchers would like to thank the Ministry of Research, Technology and Higher Education Indonesia for funding the publication of this study

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