Utilization of 4% HDPE as Asphalt Substitution in Porous Asphalt Mixtures with Coconut Shell Ash Variations

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Abstract: Several studies have demonstrated that High-Density Polyethylene (HDPE) can be utilized as an additive in porous asphalt mixtures. The application of plastic waste is expected to mitigate the negative environmental impacts caused by plastic waste. Porous asphalt is a mixture of open-graded aggregates with a predominance of coarse aggregates, which creates voids enabling water to permeate through the mixture; however, this mixture has a relatively low stability value. This study aims to investigate the effect of using HDPE plastic as a substitution for asphalt and variations in coconut shell ash as a filler substitution in porous asphalt mixtures. The HDPE content used was 4% by weight of the optimum asphalt content, complemented with coconut shell ash (CSA) as a filler substitution at variations of 40%, 50%, and 60%. The results reveal that the porous asphalt mixture with 4% HDPE substituting asphalt without CSA yielded the highest stability value of 815 kg. The addition of CSA reduced the average stability value to 665 kg. Furthermore, the permeability value increased from an initial 0.294 cm/sec to 0.426 cm/sec at 60% CSA content.

Keywords: Porous Asphalt, High-Density Polyethylene (HDPE), Coconut Shell Ash.

1. INTRODUCTION

Along with the increasing demand for sustainable infrastructure in recent years, researchers and practitioners in the field of Civil Engineering have been compelled to explore innovative materials that can enhance the performance of composite materials while minimizing environmental impact. One such approach is the utilization of recycled materials like High-Density Polyethylene (HDPE) to improve the mechanical properties of asphalt mixtures. Additionally, the use of natural materials such as Coconut Shell Ash (CSA) can also enhance the characteristic values of asphalt mixtures. Syammaun (2020) employed CSA to improve the permeability value of porous asphalt mixtures.

According to World Atlas, as cited in Harian Wartakota (2018), Indonesia ranks as the fourth largest consumer of plastic bottles worldwide. The consumption of plastic bottles in Indonesia reaches 4.82 billion bottles per year. Plastic takes between 450 and 1000 years to decompose according to the Health Crisis Center of the Indonesian Ministry of Health.

Meanwhile, asphalt is a derivative product of petroleum or can be obtained naturally.

Asphalt from petroleum or natural sources is a non-renewable material whose supply continues to decrease in line with its demand in road construction. Both asphalt and plastic exhibit thermoplastic properties they soften when heated and harden when cooled, albeit at different melting points; thus, HDPE plastic has potential to be utilized as a substitution material for asphalt in asphalt mixtures.

One of the major challenges facing asphalt pavement mixtures is water infiltration. Samarinda city is highly prone to flooding due to its lower surface elevation relative to the Mahakam River water level during the rainy season. Designing porous asphalt mixtures with high stability values is critically needed in cities like Samarinda.

Research conducted by Gultom, Triwijaya, Joewono, Nathania, and Budiman (2025) demonstrated that porous asphalt mixtures with 4% HDPE as asphalt substitution yielded the best stability value of 815 kg.

This study aims to investigate the effect of using HDPE plastic as a substitute for asphalt and CSA as a filler replacement on the characteristics of porous asphalt mixtures. The study will present Marshall parameters obtained from the Laboratory of Civil Engineering, Universitas Mulawarman, thereby providing empirical data applicable to road construction in Samarinda city.

2. LITERATURE REVIEW

2.1 Porous Asphalt Mixture

Porous asphalt mixture consists of coarse aggregates, fine aggregates, and modified asphalt as its binder. Porous asphalt employs an open-graded aggregate gradation with interconnected voids, thus enhancing the surface's water drainage capability. In porous asphalt mixtures, the proportion of coarse aggregates ranges between 70% and 85%. A higher proportion of coarse aggregates results in lower mixture stability compared to conventional pavements (Djumari, 2009). Elsa's study in 2019 used HDPE to increase the stability value, which improved from 540 kg to 879 kg at 4% HDPE content. Syammaun in 2020 used coconut shell ash to increase permeability, from an initial 0.199 cm/s to 0.25 cm/s.

Porous asphalt is designed to provide air spaces within the mixture that facilitate water flow from the surface downward, thereby preventing water ponding on the surface.

2.2 Porous Asphalt Characteristics

Characteristics refer to the properties of asphalt pavement used in the production of porous asphalt mixtures through Marshall and permeability testing. Some characteristics of porous asphalt include stability, flow, Void in Mix (VIM), Marshall Quotient (MQ), and permeability.

Table 1. Design Criteria for Porous Asphalt (AAPA, 2004)

Criteria	Value
Stability (*kg*)	Min. 500
Flow (*mm*)	2 – 6
Void In Mix (*VIM %)*	18 – 25
Marshall Quotient (*kg/mm*)	Max. 400
Permeability (*cm/s*)	0.1 – 0.5

The design criteria are essential as a reference for evaluating test results. According to Table 1, the stability value of porous asphalt is a minimum of 500 kg; if it is to be used as a wearing course, a minimum stability value of 800 kg is required (General Specifications of Bina Marga 2018). Elsa (2019) produced porous asphalt mixtures with HDPE plastic, achieving the highest stability value of 870 kg; however, the resulting Void in Mix (VIM) was only 16.17%, which is below the AAPA 2004 specification. Syammaun (2020) made porous asphalt mixtures by adding coconut shell ash and HDPE plastic and obtained a stability value of 556 kg with a VIM value still meeting the requirements at 22.95%.

2.3 High Density Polyethylene (HDPE)

HDPE is a type of thermoplastic polymer made from long-chain polyethylene with high density, resulting in a plastic material that is hard, strong, and durable. HDPE is commonly used in various applications requiring plastic that resists pressure, abrasion, extreme temperatures, and chemicals.

HDPE has a melting point ranging from 200°C to 280°C, becoming liquid when heated and easy to mold. It possesses a tensile strength between 3100 and 5500 Psi, thus exhibiting material properties that are among the hardest, strongest, opaque, and more resistant to higher temperatures (Hardiman, 2018).

The use of HDPE plastic as an additive can enhance the characteristics of porous asphalt mixtures, where the material strength heavily depends on the binder to adhere the aggregates. HDPE can improve the mixture's resistance to water and weather, as well as provide economic value by utilizing plastic waste.

2.4 Coconut Shell Ash

Coconut shell ash is a waste product obtained from burning coconut shells. The shells are burned until ash remains and then passed through a No. 200 sieve.

The chemical content in coconut shell ash can be beneficial in various uses such as organic fertilizer, soil amendment, absorbent material, and as a filler in porous asphalt mixtures.

Coconut shell ash typically has a texture ranging from coarse to fine, with a color ranging from black to gray. The ash particles vary in size and shape, which affect their behavior in the mixture. Coconut shell ash has a specific gravity of 1.3 g/cm³, which is lower than that of stone ash with a specific gravity of 2.23 g/cm³.

(a) Drying process of coconut shells (b) Burning process of coconut shells (c) Process of burning into ash

Figure 1. Burning Process of Coconut Shell Ash

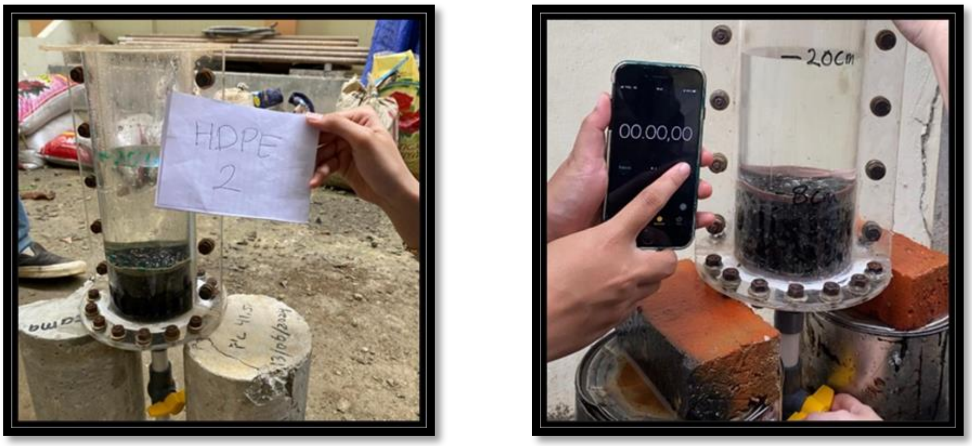
2.5 Permeability

Permeability is the ability of a porous medium to allow the flow of fluids. Any material with void spaces between particles is considered porous, and when these voids are interconnected, the material exhibits permeability (Bowles, 1986). The formula for permeability is expressed as follows:

$$K = 2{,}3\,\frac{aL}{At}\,x\,\left(log\,\frac{h1}{h2}\right) \tag{1}$$

Dimana:

K = coefficient of water permeability (cm/s)
a = cross-sectional area of the tube (cm²)
L = thickness of the specimen (cm)
A = cross-sectional area of the specimen (cm²)
t = time required for water to flow from height h1to h2(s)
h_1 = height of the water level at the top boundary of the tube (cm)
h_2 = height of the water level at the bottom boundary of the tube (cm)



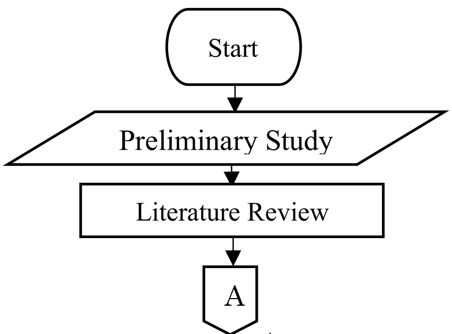
(a) Permeability test (b) Method of recording time

Figure 2. Permeability Test

3. METHODOLOGY

The method employed in this study was conducted at the Civil Engineering Laboratory of Mulawarman University, Samarinda. The flow diagram can be seen in Figure 3.

3.1 Flowchart



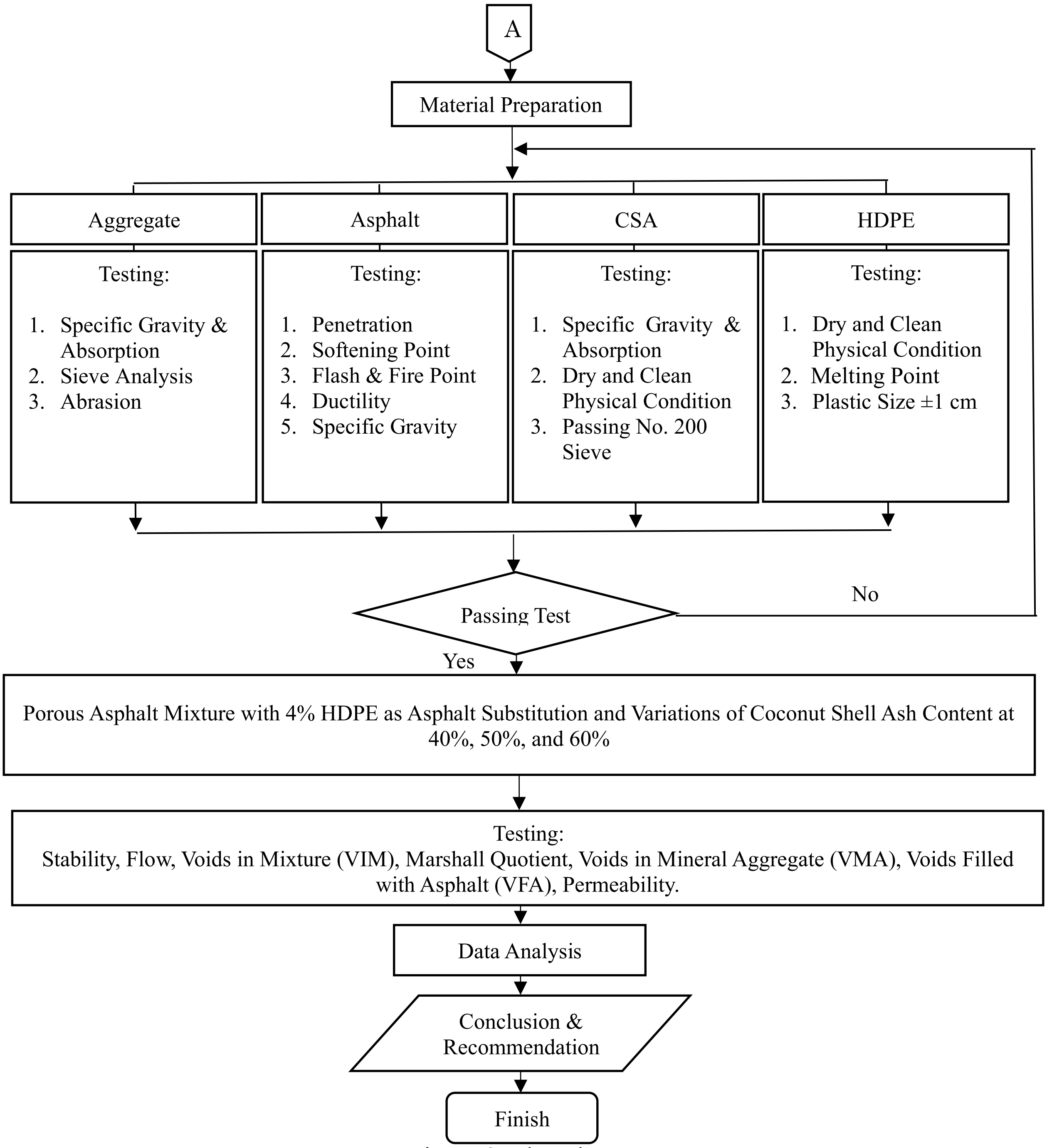


Figure 3. Flowchart

The optimum asphalt content (OAC) used was 4.6%, and the mixture with substitution variations of HDPE plastic content obtained an optimum plastic content of 4%. Therefore, in this study, 4% HDPE was used based on an OAC of 4.6%, then variations of coconut shell ash (CSA) at 40%, 50%, and 60% were added as filler substitutions.

The total number of porous asphalt mixture samples prepared was 18, as outlined in Table 2. This study used the ideal gradation based on the OGA 14 specifications (AAPA, 2004), which is shown in Figure 4.

Table 2. Sample Requirements for Porous Asphalt Mixtures

Marshall Testing	
Testing Specimens	Testing Specimen Requirements
Porous Asphalt Mixture with 4% HDPE as Asphalt Substitution and Variations of Coconut Shell Ash at 40%, 50%, and 60%	9 Units
Permeability Testing	
Testing Specimens	Testing Specimen Requirements
Porous Asphalt Mixture with 4% HDPE as Asphalt Substitution and Variations of Coconut Shell Ash at 40%, 50%, and 60%	9 Units
Total Number of Test Specimens	18 Units

The straight line positioned in the middle of the graph in Figure 4 represents the gradation used in this study.

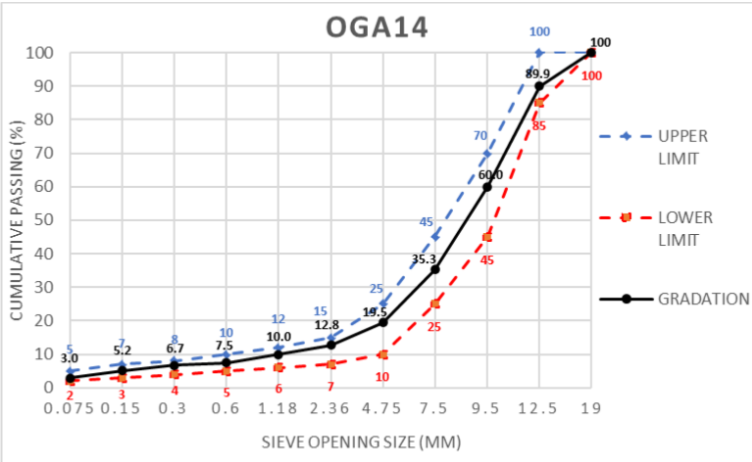


Figure 4. Center Gradation Sieve Analysis Graph

3.2 Mix Design

In this study, the first step before preparing the asphalt mixture was the gradation planning and determination of the optimum asphalt content (OAC). The gradation planning was derived from sieve analysis based on the Open Graded Asphalt (OGA) specifications by AAPA (2004). Meanwhile, the OAC was determined through sieve analysis calculations referring to the Indonesian standard Bina Marga No: 001-03/BM/2006 titled “Penentuan Kadar Aspal Optimum dari Campuran Beraspal Panas Dengan Asbuton Olahan”.
After the gradation planning and OAC were obtained, the modified asphalt mixtures were prepared using 4% HDPE plastic and coconut shell ash (CSA) substitution at 40%, 50%, and 60%. Prior to fabricating the test specimens, the preparation stages were as follows:

1. Shredding the HDPE plastic into pieces approximately 0.5 cm in size.
2. Weighing the coconut shell ash at proportions of 40%, 50%, and 60% based on the filler weight in the mixture.
3. Weighing the aggregates according to the predetermined gradation, then placing them into trays and drying in an oven at 150°C for 30 minutes to 1 hour. This step was performed to remove moisture and ensure that the aggregate temperature was appropriate for mixing.

(a) HDPE plastic was first added to the asphalt

(b) The aggregate was added into the mixture of asphalt and HDPE plastic.

Figure 3. Process of Mixing Plastic and Coconut Shell Ash

The initial step in the creation of the porous asphalt mixture involved heating the asphalt in a pan. Subsequently, 4% HDPE plastic was added to the heated asphalt and stirred continuously until a homogeneous blend was achieved. Then, the oven-dried aggregate was incorporated into the pan containing the asphalt-plastic mixture and stirred thoroughly to ensure that the asphalt adequately coated the entire aggregate surface. Throughout the mixing process, the temperature of the mixture was monitored using a metal thermometer and maintained at approximately 150°C to ensure optimal mixing conditions.

Next, the asphalt mixture was molded into test specimens using molds placed on a compaction plate and secured with a mold holder. Circular paper cut to the mold diameter was placed inside the mold to prevent sticking and facilitate demolding. The asphalt mixture was then poured into the mold, leveled with a spatula, and poked 15 times on the edges and 10 times in the center to promote uniform distribution and eliminate large air voids. Additional circular paper was placed on top of the mold once filled.

The compaction stage followed, where the mixture was compacted by vertical tamping 50 times with a tamping hammer dropped from a height of 45.7 cm, in accordance with the Open Graded Asphalt (OGA) 2004 specifications. To ensure uniform compaction, the mold was then flipped, and tamping was repeated 50 times on the opposite side with the same drop height. During the entire tamping process, it was essential to keep the tamping hammer's axis perpendicular to the mold base to achieve consistent compaction density.

In the final stage, the mold was carefully detached from the compaction plate and placed onto a specimen extractor or jack. Each specimen was labeled according to the percentage of coconut shell ash used for identification purposes. The specimens were then allowed to rest at room temperature for 24 hours to enable the mixture to cure and stabilize before characterization testing was conducted.

3.3 Material and Mixture Testing Standards

Aggregate testing was conducted following the Indonesian National Standard (SNI) as specified in the General Specifications of Bina Marga 2018 Division 6, and the standards from the Australian Asphalt Pavement Association (AAPA) 2004, including:

1. Sieve analysis of coarse and fine aggregates based on Open Graded Asphalt, AAPA 2004.
2. Specific gravity and absorption of coarse aggregate referring to SNI 03-1969-2008.
3. Specific gravity and absorption of fine aggregate referring to SNI 03-1970-2008.
4. Aggregate abrasion test (Los Angeles abrasion) according to SNI 03-2417-2008.

Asphalt testing was carried out based on the Indonesian National Standard (SNI) specified in the General Specifications of Bina Marga 2010 Revision 3 for hard asphalt. Five asphalt test methods were applied as follows:

1. Asphalt specific gravity test based on SNI-2441-2011.
2. Penetration test according to SNI 2456-2011.
3. Softening point test according to SNI 2434-2011.
4. Flash point and fire point test according to SNI 2433-2011.
5. Asphalt ductility test based on SNI 2432-2011.

Marshall characteristic testing was conducted on the porous asphalt mixture to obtain results that meet the design parameters of porous asphalt. In this study, the Marshall test was performed following RSNI M-01-2003 “Metode Pengujian Campuran Beraspal Panas dengan Alat Marshall”.

4. RESULTS AND DISCUSSION

4.1 Aggregate and Asphalt Materials

The examination results of materials, including tests on coarse aggregate, fine aggregate, filler, normal asphalt, and HDPE plastic-modified asphalt with variations of 2%, 4%, and 6% by weight of the asphalt material, are presented. All test results can be found in Table 3, Table 4, and Table 5.

Table 3. Results of Aggregate and Filler Materials Test

Testing	Coarse Aggregate	Fine Aggregate	*Filler* (CSA)	Stone Ash
SSD Specific Gravity (*gr/cm³*)	2,79	2,55	1,45	2,30
Bulk Specific Gravity (*gr/cm³*)	2,76	2,49	1,30	2,23
Apparent Specific gravity (*gr/cm³*)	2,85	2,66	1,54	2,40
Absorption (*%*)	1,19	2,57	11,73	3,09
Aggregate Wear	19.68%			

Table 4. Results of Normal Asphalt and Modified Asphalt Test

Testing	Normal Asphalt	Modification Asphalt HDPE 4%	Specifications
Specific Gravity (*gr/cm³*)	1,006	1,009	≥1,0
Penetration (*mm*)	66	66,7	60
Softening Point (°*C*)	49,5	50	≥48
Flash and Fire Point (°*C*)	360	358	≥232
Ductility (*cm*)	127	137	≥100

Table 5. Results of Melting Point Test

Melting Point Test	Temperature
Normal Asphal	60ºC
HDPE	260ºC

4.2 Characteristics of Porous Asphalt Mixture with 4% HDPE as Asphalt Substitution

The characteristic testing produced Marshall parameters including stability, flow, Voids in Mineral Aggregate (VIM), Marshall Quotient, and permeability. This study did not perform raveling and binder drain-off tests. The porous asphalt mixture was prepared using an optimum asphalt content (OAC) of 4.6% with 4% HDPE as substitute for asphalt, and variations in coconut shell ash content at 40%, 50%, and 60%, as presented in Table 6 and Table 7.

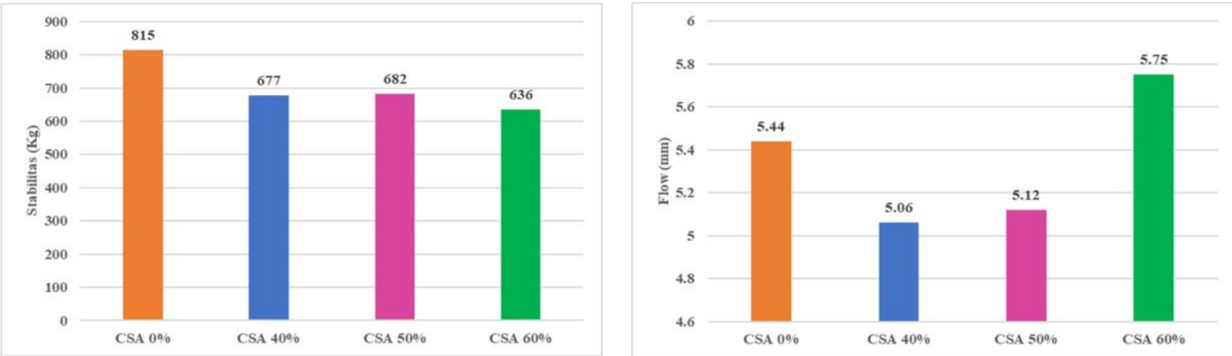
Table 6. Marshall Test Results

Sample	Marshall Characteristics			
	Stability (*kg*)	*Flow* (*mm*)	VIM (*%*)	MQ (*kg/mm*)
HDPE 4% + CSA 40%				
Sample 1	856,08	4,38	20,92	195,45
Sample 2	686,62	5,52	22,17	124,39
Sample 3	489,23	5,28	22,05	92,66
Averages Value	677	5,06	21,72	133,79
HDPE 4% + CSA 50%				
Sample 1	760,69	4,5	21,83	169,04
Sample 2	567,5	5,2	22,64	109,13
Sample 3	718,44	5,65	21,6	127,16
Averages Value	682	5,12	22,03	133,2
HDPE 4% + CSA 60%				
Sample 1	742,08	6,93	21,56	107,08
Sample 2	641,37	4,90	21,72	130,89
Sample 3	525,77	5,42	22,70	97,01
Averages Value	636	5,75	21,99	110,61
Specifications (AAPA,2004)	≥ 500	2 – 6	18 – 25	≤ 400

Table 7. Permeability Test Results

Sample	HDPE 4%	HDPE 4% + CSA		
		40%	50%	60%
1	0,309	0,349	0,417	0,338
2	0,261	0,456	0,364	0,510
3	0,309	0,387	0,424	0,427
Averages Value	0,293	0,398	0,402	0,426
Specifications (AAPA,2004)	0,1 – 0,5 cm/s			

The average values of stability and flow from Table 6 are then presented graphically as shown in Figure 5.



(a) Graph of Stability Values (b) Graph of Flow Values

Figure 5. Graph of Stability and Flow Values in Porous Asphalt Mixture with 4% HDPE Asphalt Substitution and CSA Variations

Figure 5 presents a comparison between stability and flow values of porous asphalt mixtures containing 4% HDPE as asphalt substitution, with coconut shell ash (CSA) content variations at 0% (orange), 40% (blue), 50% (pink), and 60% (green). The orange bars represent mixtures with 4% HDPE substitution without CSA, showing a stability value of 815 kg. Mixtures with CSA substitution exhibit lower stability values across all variations.

Considering the porous asphalt criteria in Table 1, CSA can be used as a substitute for stone filler. However, this study has yet to determine the optimum CSA content. Further experiments with a wider range of CSA variations are necessary to identify an optimal mixture.

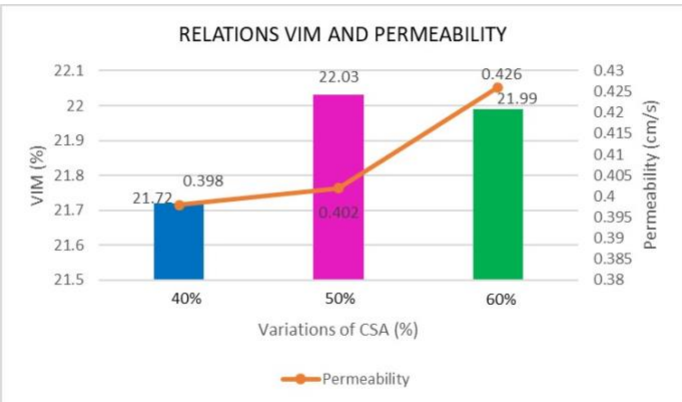


Figure 6. Graph of Voids in Mineral Aggregate (VIM) and Permeability Relationship

Figure 6 shows the relationship between Voids in Mineral Aggregate (VIM) and permeability values in the porous asphalt mixture with 4% HDPE and CSA variations of 40%, 50%, and 60%. Theoretically, VIM is expected to be directly proportional to permeability. However, Figure 6 reveals a contrary trend, where the VIM for the 50% CSA variation is 22.03%, while the 60% CSA variation has a slightly lower VIM of 21.99%, yet the permeability value is higher in the latter. This anomaly is hypothesized to result from the heterogeneous mixing of CSA due to the difference in melting points between HDPE (260°C) and asphalt (60°C). In the porous asphalt mixture with 50% CSA, the voids formed are disconnected, while in the 60% CSA mixture, the voids are more interconnected, facilitating greater permeability.

5. DISCUSSION

High melting point characteristic of HDPE plastic at 260ºC presents challenges during the mixing process. When shredded plastic is added after the asphalt and aggregates have been heated, the plastic tends to integrate better despite not fully melting. This contrasts with the approach of melting the plastic first before mixing it with asphalt and aggregates, which may cause the asphalt to boil due to the significant melting point difference (asphalt melts around 60ºC). Boiling asphalt adversely affects its characteristics, rendering it unsuitable as a mixture component.

For porous asphalt mixtures modified to enhance stability, HDPE plastic substitution is recommended due to its beneficial effect on stability values. Conversely, for the purpose of improving permeability, the use of coconut shell ash (CSA) as a filler is preferable.

Future research is encouraged to explore different plastic types as substitutions, such as PET or LDPE, and alternative fillers like fly ash, to further optimize the properties of porous asphalt mixtures.

6. CONCLUSION

Based on the conducted study examining the effects of substituting HDPE plastic and coconut shell ash as fillers, the conclusions are as follows:

1. HDPE plastic is more advantageous as an asphalt substitute in porous asphalt mixtures compared to mixtures including coconut shell ash (CSA).
2. Porous asphalt mixtures with 4% HDPE substitution yielded a stability value of 815 kg, VIM of 22.99%, flow of 5.44 mm, MQ of 149.82 kg/mm, and permeability of 0.294 cm/sec.
3. Porous asphalt mixtures with 4% HDPE substitution plus 50% CSA had a stability value of 682 kg, flow of 5.12 mm, VIM of 22.03%, MQ of 133.2 kg/mm, and permeability of 0.402 cm/sec.
4. Coconut shell ash did not improve the stability value of the 4% HDPE porous asphalt mixture.

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