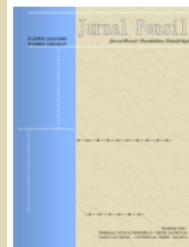


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## COMPARATIVE EFFECTS OF CORN COB ASH AND SIWALAN FRUIT SHELL ASH AS FILLER ON MARSHALL STABILITY AND FLOW OF POROUS ASPHALT MIXTURES

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### Abstract

The application of porous asphalt mixtures has increased because of their ability to improve surface drainage and traffic safety. However, their open-graded structure often reduces mechanical stability, making filler selection important for mixture performance. This study compares corn cob ash and siwalan fruit shell ash as agricultural waste-based fillers on Marshall stability, flow, volumetric characteristics, Cantabro Loss, Asphalt Flow Down, and optimum asphalt content (OAC) of porous asphalt mixtures. Both waste materials were processed into fine ash passing the No. 200 sieve and used at a fixed filler content of 1%. Laboratory testing included material characterization, mixture design, Marshall testing, Cantabro Loss, and Asphalt Flow Down. The OAC was determined using the Australian Asphalt Pavement Association (AAPA, 2004) procedure based on Voids in Mix, Cantabro Loss, and Asphalt Flow Down criteria. The results showed that both mixtures achieved the highest Marshall stability at 4% asphalt content, with 1334 kg for the siwalan fruit shell ash mixture and 1330 kg for the corn cob ash mixture. Flow values ranged from 2 mm to 3 mm, indicating acceptable deformation behavior. The final OAC was 5.00% for the siwalan fruit shell ash mixture and 4.59% for the corn cob ash mixture. These findings indicate that corn cob ash requires lower asphalt binder demand, while siwalan fruit shell ash remains feasible but requires higher binder content. The novelty of this study lies in the direct comparative evaluation of two locally available agricultural waste ashes as sustainable filler materials in porous asphalt mixtures.

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**Keywords:** Porous Asphalt, Corn Cob Ash, Palmyra (Siwalan) Shell Ash, Marshall Stability, Optimum Asphalt Content (OAC)

## **Introduction**

Transportation infrastructure is increasingly required to respond to sustainability challenges involving economic, environmental, and social dimensions (Ashraf & Idrisi, 2024; Elassy et al., 2024; Sassaron et al., 2025). In road construction, pavement sustainability has become an important issue because pavement materials, construction processes, and maintenance activities consume large quantities of natural resources and energy (Michael et al., 2022; Rosario, 2023). Therefore, the development of pavement materials must not only focus on structural performance, but also consider environmental efficiency, material availability, and long-term durability (Akbar et al., 2025; Galambos et al., 2024). This perspective is consistent with the growing emphasis on sustainable road infrastructure, life-cycle-based pavement assessment, and sustainable civil infrastructure development (Akbar et al., 2025; Rosario, 2023).

These sustainability challenges are further intensified by climate change, particularly through the increasing frequency of extreme rainfall and flooding events that directly affect transportation infrastructure performance (Markolf et al., 2019; Rebally et al., 2021; Touloumidis et al., 2025). Flooding can reduce pavement serviceability, disrupt traffic flow, increase travel delays, and accelerate infrastructure deterioration (Blackwood et al., 2022; Lang et al., 2024; Liu et al., 2026). Previous studies have also shown that flood-related disruptions may reduce accessibility, affect commuter mobility, and generate wider economic and operational losses in urban transportation systems (K. He et al., 2026; Y. He, 2020; Yao et al., 2024). Therefore, road pavement systems require design strategies that can improve surface drainage while maintaining sufficient mechanical performance under wet conditions (J. Chen & Yang, 2020; Zhang et al., 2020).

Porous asphalt has become one of the pavement alternatives that supports sustainable drainage because its open-graded structure allows water to infiltrate through interconnected air voids and reduces water accumulation on the road surface (Chen & Yang, 2020; Zhang et al., 2020). This mixture can improve tire–pavement contact during wet conditions, reduce splash and spray, enhance driving safety, and contribute to traffic noise reduction (J. Chen & Yang, 2020; Nejem & Akhtar, 2025). However, porous asphalt also has several technical limitations. Its high air void content and coarse aggregate-dominated gradation may reduce aggregate interlocking and weaken the bond between asphalt binder and aggregate particles (Melati et al., 2023; Zhang et al., 2020). As a result, porous asphalt mixtures are more susceptible to raveling, stripping, rutting, and durability loss when the mixture design is not properly optimized (Ali et al., 2020; Shukry et al., 2018).

Filler plays an important role in improving the performance of porous asphalt mixtures because it contributes to the formation of asphalt mastic, fills micro-voids between aggregate particles, and strengthens the adhesion between asphalt binder and aggregate (Alyousify et al., 2022; Mondal & Ransinchung, 2022). The physical characteristics of filler, including particle size, specific gravity, texture, and absorption capacity, can influence binder stiffness, mixture cohesion, air void structure, and load-bearing capacity (Du et al., 2021; Wang et al., 2026). In porous asphalt mixtures, appropriate filler selection is particularly important because high air void content may reduce aggregate interlocking and increase the risk of raveling or moisture-related damage (Ali et al., 2020; Zhang et al., 2020). Therefore, filler selection must consider not only material availability, but also its effect on Marshall stability, flow, Cantabro Loss, Asphalt Flow Down, and optimum asphalt content (Andrés-Valeri et al., 2023; Shukry et al., 2018).

From a broader sustainability perspective, the use of agricultural waste as alternative filler material may provide macro-level benefits for pavement construction by reducing waste accumulation, minimizing dependence on conventional mineral filler, and supporting circular economy practices in road infrastructure development (Iqbal et al., 2025; Jwaida et al., 2024; Mashaan et al., 2025). Corn cob ash and siwalan fruit shell ash are agricultural by-products that can be processed into fine ash and reused as value-added construction materials, particularly when their physical characteristics satisfy the requirements for asphalt mixture filler (Andrés-Valeri et al., 2023; Mondal & Ransinchung, 2022). In this study, corn cob ash had a specific gravity of 2.52 and

90.15% passing the No. 200 sieve, while siwalan fruit shell ash had a specific gravity of 2.62 and 90.05% passing the No. 200 sieve, indicating that both materials met the fineness requirement for filler in porous asphalt mixtures. These differences in specific gravity and particle characteristics may affect asphalt binder demand, internal void structure, Marshall stability, flow, Cantabro Loss, and Asphalt Flow Down because filler properties influence the interaction between binder and aggregate in asphalt mastic (Alyousify et al., 2022; Wang et al., 2026).

Previous studies have investigated various waste-based filler materials in asphalt mixtures and porous asphalt applications. Shukry et al. (2018) examined the use of diatomite as filler in porous asphalt mixtures, while Andrés-Valeri et al. (2023) evaluated cellulose ash and combustion soot as filler replacement in porous asphalt. Elmagarhe et al. (2024) studied porous asphalt mixtures containing recycled concrete aggregate and fly ash (Elmagarhe et al., 2024), whereas Rhoma Putra et al. (2024) investigated palm fruit ash as filler in asphalt concrete mixtures (Rhoma Putra et al., 2024). Other studies have also examined marble waste, fly ash, rice husk ash, and human scalp hair in asphalt mixture applications, showing that waste-derived materials can influence Marshall characteristics, durability, permeability, and mixture performance (M. Sa'dillah et al., 2025; TAmelia et al., 2024; Youssef & Fahmy, 2023). However, most previous studies focused on different waste materials, different asphalt mixture types, or single-material evaluation. Therefore, direct comparative evidence on the use of corn cob ash and siwalan fruit shell ash as alternative filler materials in porous asphalt mixtures remains limited.

Recent studies have also shown that alternative ash-based fillers can influence the performance of porous asphalt mixtures. Firmansyah et al. (2026) evaluated cotton cloth ash as filler in porous asphalt mixtures and reported that the material affected optimum asphalt content, Marshall characteristics, Cantabro Loss, Asphalt Flow Down, and permeability behavior. Rani et al. (2023) also investigated oyster shell ash filler substitution combined with HDPE in porous asphalt mixtures and found that the variation influenced Marshall stability and met the Australian Asphalt Pavement Association specification. Therefore, these studies strengthen the importance of evaluating waste-derived ash fillers based on mechanical, volumetric, durability, and binder demand parameters. (Firmansyah et al., 2026; Rani et al., 2023)

Based on the identified research gap, this study aims to compare the effects of corn cob ash and siwalan fruit shell ash as agricultural waste-based filler materials on the performance of porous asphalt mixtures. The evaluation focuses on Marshall stability, flow, volumetric characteristics, Cantabro Loss, Asphalt Flow Down, and Optimum Asphalt Content based on the AAPA 2004 porous asphalt mixture design procedure. The novelty of this study lies in the direct comparison of two locally available agricultural waste ashes as alternative filler materials in porous asphalt mixtures. Unlike previous studies that generally examined waste filler materials separately or used different waste materials, such as diatomite, cellulose ash, combustion soot, fly ash, palm fruit ash, marble waste, rice husk ash, and human scalp hair, this study provides empirical evidence on how corn cob ash and siwalan fruit shell ash influence binder demand, mixture stability, flow behavior, and porous asphalt performance (Shukry et al., 2018; Andrés-Valeri et al., 2023; Elmagarhe et al., 2024; Rhoma Putra et al., 2024; M. Sa'dillah et al., 2025; TAmelia et al., 2024; Youssef & Fahmy, 2023). Therefore, the findings are expected to support the development of more sustainable porous asphalt mixtures through the utilization of agricultural waste materials.

## **Research Methods**

This study employed a laboratory experimental method with a comparative quantitative approach. The research was conducted to evaluate and compare the effects of two agricultural waste-based filler materials, namely corn cob ash powder and siwalan fruit shell ash powder, on the performance of porous asphalt mixtures. The main performance parameters evaluated in this study were Marshall stability, flow, Voids in Mix (VIM), Voids in Mineral Aggregate (VMA), Voids Filled with Bitumen (VFB), Cantabro Loss, Asphalt Flow Down, and Optimum Asphalt Content

(OAC). The research stages consisted of literature review, material preparation, material characterization, mixture design, specimen preparation, laboratory testing, data analysis, and conclusion formulation.

The materials used in this study consisted of coarse aggregate, fine aggregate, asphalt binder, corn cob ash powder filler, and siwalan fruit shell ash powder filler. The coarse aggregate consisted of two fractions, namely 10–15 mm and 5–10 mm, while the fine aggregate consisted of the 0–5 mm fraction. The coarse aggregate and fine aggregate were obtained from PT. Tripalindo Trans Mix. The asphalt binder used in this study was PG 70 asphalt obtained from PT. Aspindo Mutual Surabaya. Corn cob waste was collected from Kecamatan Diwek, Kabupaten Jombang, while siwalan fruit shell waste was collected from Kecamatan Menganti, Kabupaten Gresik. Both agricultural waste materials were processed into fine ash powder and sieved until passing the No. 200 sieve before being used as filler.

Material characterization was conducted before mixture preparation to ensure that all materials satisfied the required technical specifications. Coarse aggregate testing included sieve analysis, bulk specific gravity, saturated surface dry specific gravity, apparent specific gravity, water absorption, and aggregate abrasion. Fine aggregate testing included sieve analysis, specific gravity, and water absorption. Filler testing included sieve analysis and specific gravity. Asphalt binder testing included penetration, specific gravity, flash point, and softening point. These tests were carried out using the relevant SNI test methods and evaluated with reference to the applicable technical requirements and the General Specifications of Bina Marga for Road and Bridge Construction, namely *Spesifikasi Umum Bina Marga 2018 untuk Pekerjaan Konstruksi Jalan dan Jembatan Revisi 2 No. 16.1/SE/Db/2020*.

The porous asphalt mixture was designed using two alternative filler materials, namely corn cob ash powder and siwalan fruit shell ash powder, each applied at a fixed content of 1% of the total mixture weight. The aggregate gradation consisted of 72% aggregate with a size of 10–15 mm, 22% aggregate with a size of 5–10 mm, 5% fine aggregate with a size of 0–5 mm, and 1% filler. The total weight of each briquette specimen was 1200 g. Five asphalt content variations were prepared, namely 4.0%, 4.5%, 5.0%, 5.5%, and 6.0%. The asphalt weights for these variations were 48 g, 54 g, 60 g, 66 g, and 72 g, respectively, while the aggregate weights were 1152 g, 1146 g, 1140 g, 1134 g, and 1128 g, respectively. The filler weights were 11.52 g, 11.46 g, 11.40 g, 11.34 g, and 11.28 g for asphalt contents of 4.0%, 4.5%, 5.0%, 5.5%, and 6.0%, respectively.

The initial design asphalt content (Pb) was calculated based on aggregate gradation and the proportions of coarse aggregate, fine aggregate, and filler in the porous asphalt mixture. The calculated Pb value for the mixture using siwalan fruit shell ash powder filler was 4.849%, while the Pb value for the mixture using corn cob ash powder filler was 4.8507%. Both values were rounded to 5.0% and used as the basis for preparing asphalt content variations and conducting further performance evaluation. The prepared mixtures were then compacted into briquette specimens according to the asphalt content variations and filler types used in the study.

After compaction, the specimens were conditioned at laboratory temperature before testing to ensure stable specimen conditions. The Marshall test was conducted to determine the stability, flow, and volumetric characteristics of the porous asphalt mixtures. VIM was used to evaluate the percentage of air voids within the compacted mixture, VMA was used to evaluate the void spaces between aggregate particles in the compacted mixture, and VFB was used to evaluate the percentage of VMA filled with asphalt binder. Cantabro Loss testing was conducted to evaluate the resistance of porous asphalt mixtures to aggregate loss and abrasion, while Asphalt Flow Down testing was conducted to evaluate the tendency of asphalt binder to drain from the mixture.

The OAC was determined using the Australian Asphalt Pavement Association (AAPA, 2004) porous asphalt mixture design procedure by considering VIM, Cantabro Loss, and Asphalt Flow Down criteria. The data were analyzed descriptively and comparatively. First, the results of material characterization were compared with the relevant technical requirements. Second, the Marshall stability, flow, VIM, VMA, VFB, Cantabro Loss, and Asphalt Flow Down values were

compared between the mixture containing corn cob ash powder filler and the mixture containing siwalan fruit shell ash powder filler. Finally, the OAC values of both mixtures were compared to determine the influence of filler type on asphalt binder demand and porous asphalt mixture performance.

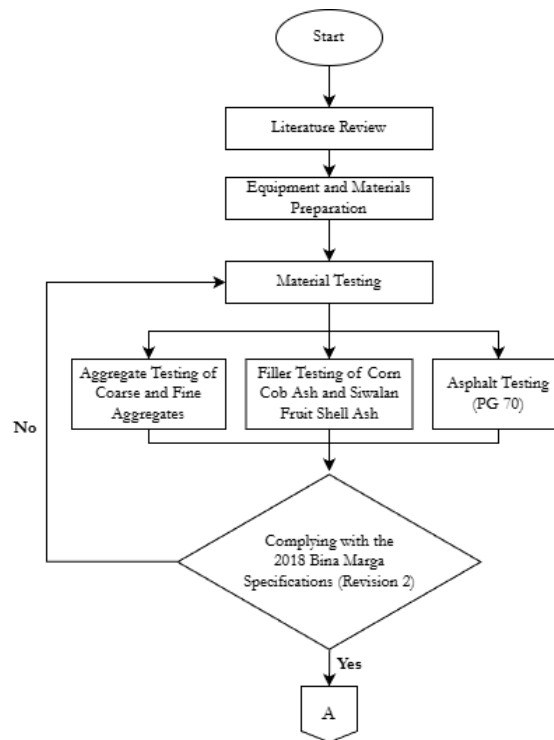


Figure 1. Research Methodology Flowchart for Material Preparation and Characterization

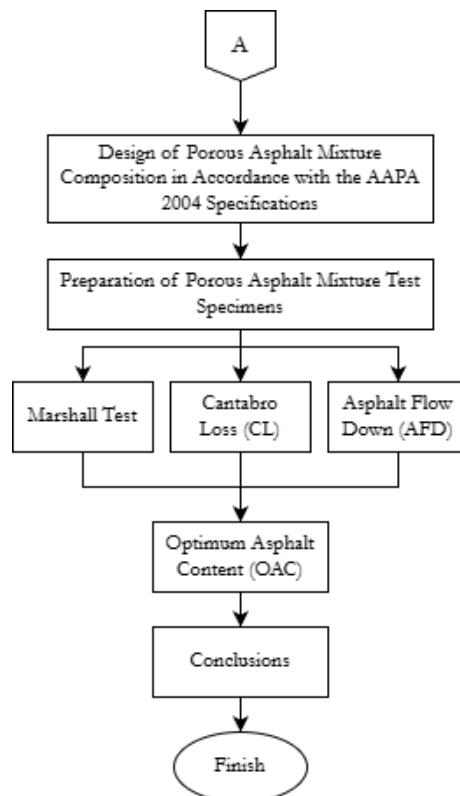


Figure 2. Research Methodology Flowchart for Mixture Design and Performance Evaluation

The overall research procedure is presented in Figure 1 and Figure 2 in sequential order, beginning with material preparation and characterization, followed by mixture design, specimen preparation, and performance evaluation.

### Research Results and Discussion

This section reports and examines the experimental results produced during the laboratory testing program. The analysis focuses on the effect of different waste filler types on the performance of porous asphalt mixtures, particularly in terms of Marshall stability and flow. The results are presented in graphical and tabular forms and are interpreted with reference to relevant specifications and previous studies to provide a comprehensive understanding of the influence of waste-based fillers on the mechanical performance of porous asphalt mixtures.

#### Coarse Aggregate Test Results

The coarse aggregate used in this study was obtained from PT. Tripalindo Trans Mix and consisted of two aggregate fractions, namely 10–15 mm and 5–10 mm. The coarse aggregate test was conducted to evaluate its physical and mechanical properties and to assess its suitability for use in porous asphalt mixtures in accordance with the applicable standards.

Table 1. Results of Coarse Aggregate Testing

Test	Test Method	Requirement	Result	Remark
Sieve Analysis (10–15 mm)	SNI ASTM C136-2012	<1%	0.97%	Meets requirements
Sieve Analysis (5–10 mm)	SNI ASTM C136-2013	<1%	0.97%	Meets requirements
Bulk Specific Gravity		>2.5	4.28	Meets requirements
Saturated Surface Dry (SSD) Specific Gravity	SNI 1969-2016	>2.5	4.34	Meets requirements
Apparent Specific Gravity		>2.5	4.59	Meets requirements
Water Absorption		<3%	1.45	Meets requirements
Aggregate Abrasion	SNI 2417-2008	<40%	36.06	Meets requirements

(Source: Author’s Processed Results, 2026)

The results in Table 1 indicate that the coarse aggregate satisfies all specified technical requirements and is appropriate for porous asphalt mixtures. The sieve analysis for both 10–15 mm and 5–10 mm fractions show values below 1%, complying with the limits set by SNI ASTM C136, indicating proper gradation. Furthermore, the measured bulk, SSD, and apparent specific gravity values exceed the minimum requirement of 2.5, reflecting good aggregate density and quality. The water absorption value of 1.45% is below the maximum allowable limit of 3%, indicating low porosity and adequate durability. In addition, the aggregate abrasion value of 36.06% is within the permissible limit of 40%, demonstrating sufficient resistance to wear. Overall, these results confirm that the coarse aggregate meets the relevant standards and is appropriate for application in porous asphalt mixtures.

#### Fine Aggregate Test Results

Table 2. Fine Aggregate Test Results

Test	Test Method	Requirement	Result	Remark
Sieve Analysis	SNI ASTM C136-2012	< 10%	5.31%	Meets requirements
Bulk Specific Gravity	SNI 1970-2016	> 2.5	2.59	Meets requirements

Test	Test Method	Requirement	Result	Remark
Saturated Surface Dry (SSD) Specific Gravity		> 2.5	2.62	Meets requirements
Apparent Specific Gravity		> 2.5	2.67	Meets requirements
Water Absorption		< 3	1.06	Meets requirements

(Source: Author’s Processed Results, 2026)

The fine aggregate used in this study was obtained from PT. Tripalindo Trans Mix and consisted of the 0–5 mm aggregate fraction. As illustrated in Table 2, the fine aggregate conforms to the established criteria for porous asphalt mixtures. Compliance with SNI ASTM C136-2012 is demonstrated by the sieve analysis value of 5.31%, which is well below the maximum permissible limit of 10%. Furthermore, testing in accordance with SNI 1970-2016 shows that the bulk, SSD, and apparent specific gravity values all exceed the minimum requirement of 2.5, reflecting satisfactory aggregate quality. The measured water absorption of 1.06%, which is significantly lower than the 3% limit, further indicates good durability. Based on these findings, the fine aggregate obtained from PT. Tripalindo Trans Mix is considered suitable for use in porous asphalt mixtures.

### Filler Powder Test Results

This subsection presents the test results of corn cob ash powder and siwalan fruit shell ash powder, which were evaluated to assess their physical properties and suitability for use as filler in porous asphalt mixtures, which were evaluated to evaluate their physical properties and suitability for use in porous asphalt mixtures.

Table 3. Corn Cob Ash Powder Filler Test Results

Test	Test Method	Requirement	Result	Remark
Sieve Analysis	SNI ASTM C136-2012	>75%	90.15%	Meets requirements
Specific Gravity	SNI 1970-2016	>2.5 g	2.52 g	Meets requirements

(Source: Author’s Processed Results, 2026)

Table 4. Siwalan Fruit Shell Ash Powder Filler Test Results

Test	Test Method	Requirement	Result	Remark
Sieve Analysis	SNI ASTM C136-2012	>75%	90.05%	Meets requirements
Specific Gravity	SNI 1970-2016	>2.5 g	2.62 g	Meets requirements

(Source: Author’s Processed Results, 2026)

The filler powder test results indicate that both alternative filler materials used in this study meet the specified requirements for porous asphalt mixtures. The sieve analysis results show that the percentage passing the No. 200 sieve exceeded 75%, with corn cob ash powder reaching 90.15% and siwalan fruit shell ash powder reaching 90.05%. The specific gravity values also satisfied the minimum requirement of 2.5, with corn cob ash powder showing a value of 2.52 and siwalan fruit shell ash powder showing a value of 2.62. These results confirm that both agricultural waste-based filler materials are suitable for use in porous asphalt mixtures. The difference in specific gravity may also contribute to differences in asphalt binder demand and mixture performance.

### Asphalt Binder Test Results

This subsection presents the asphalt binder test results, which were undertaken to examine the physical properties of the binder and to ensure its compliance with the specified requirements for use in porous asphalt mixtures.

Table 5. Asphalt Binder Test Results

Test	Test Method	Requirement	Result	Remark
Asphalt Penetration	SNI 2456-2011	-	79 mm	-
Asphalt Specific Gravity	SNI 2441-2011	-	1.74	-
Flash Point	SNI 2433-2011	> 230°C	339°C	Meets requirements
Softening Point	SNI 2432-2011	-	49.5°C	-

(Source: Author’s Processed Results, 2026)

The asphalt binder used in this study was PG 70 asphalt obtained from PT. Aspindo Mutual Surabaya. Based on the results shown in Table 5, the asphalt binder exhibits properties that are suitable for use in porous asphalt mixtures. The penetration value of 79 mm indicates an appropriate level of binder consistency, while the specific gravity of 1.74 reflects adequate material density. The flash point of 339°C exceeds the minimum requirement of 230°C specified in SNI 2433-2011, demonstrating good resistance to high-temperature conditions during mixing and compaction. In addition, the softening point value of 49.5°C indicates satisfactory thermal behavior of the asphalt binder. Overall, the test results confirm that the PG 70 asphalt binder obtained from PT. Aspindo Mutual Surabaya meets the relevant performance requirements and is appropriate for application in porous asphalt mixtures.

### Porous Asphalt Mix Design (Pb)

In this study, the porous asphalt mixture was designed using two alternative agricultural waste-based filler materials, namely corn cob ash powder and siwalan fruit shell ash powder, each applied at a fixed content of 1% of the total mixture weight. Corn cob ash was obtained from Kecamatan Diwek, Kabupaten Jombang, while siwalan fruit shell ash was obtained from Kecamatan Menganti, Kabupaten Gresik. Both filler materials were sieved until passing the No. 200 sieve before being used in the porous asphalt mixture.

Table 6. Design Asphalt Content (Pb) for Mixtures with 1% Siwalan Fruit Shell Ash Powder Filler

SIEVE NO		Total Mix Passing (%)	Retained (%)
No	Opening (mm)		
3/4 “	19	100.00	
1/2 “	12.5	96.37	3.63
3/8 “	9.5	65.78	30.59
# 4	4.75	14.28	51.50
# 8	2.36	7.05	7.23
# 16	1.18	6.63	0.42
# 30	0.6	6.14	0.49
# 50	0.3	5.51	0.64
# 100	0.15	3.44	2.07
# 200	0.075	2.06	1.38
	Coarse Aggregate (CA)	Fine Aggregate (FA)	Filler (FF)
	0.035	0.045	0.18
%	92.95	4.985010984	2.064621136

Constant Value	1 - 2	1
Pb	4.849	Rounded Design Binder Content (Pb) : 5

(Source: Author’s Processed Results, 2026)

Table 7. Design Asphalt Content (Pb) for Mixtures with 1% Corn Cob Ash Powder Filler

SIEVE NO		Total Mix Passing (%)	Retained (%)
No	Opening (mm)		
3/4 “	19	100.00	
1/2 “	12.5	96.37	3.63
3/8 “	9.5	65.78	30.59
# 4	4.75	14.27	51.50
# 8	2.36	7.04	7.23
# 16	1.18	6.63	0.42
# 30	0.6	6.15	0.48
# 50	0.3	5.51	0.63
# 100	0.15	3.45	2.06
# 200	0.075	2.08	1.37
	Coarse Aggregate (CA)	Fine Aggregate (FA)	Filler (FF)
	0.035	0.045	0.18
%	92.96	4.97	2.08
Constant Value	1 - 2	1	
Pb	4.8507	Rounded Design Binder Content (Pb) : 5	

(Source: Author’s Processed Results, 2026)

The calculation of the design asphalt content (Pb) was conducted based on the aggregate gradation and the distribution of coarse and fine aggregates, along with filler, in an asphalt mixture that utilizes alternative filler materials. Table 6 and Table 7 present the calculated Pb values for mixtures containing 1% Siwalan fruit shell ash and 1% corn cob ash, respectively. The aggregate gradation of both mixtures shows nearly identical distributions, showing that replacing the filler material did not alter the overall gradation structure. The calculated Pb values were 4.849% for the Siwalan fruit shell ash mixture and 4.8507% for the corn cob ash mixture. The negligible difference between these values suggests that both fillers exhibit comparable effects on the initial asphalt binder demand. Following standard mix design practice, the Pb values were rounded to 5%, which was subsequently adopted as the design asphalt content for further Marshall performance evaluation. These results indicate that both Siwalan fruit shell ash and corn cob ash at a 1% replacement level are feasible alternative fillers without significantly influencing the required asphalt binder content.

Table 8. Briquette Composition and Asphalt Content Variation

Briquette Weight Variation	1200 g				
	I	II	III	IV	V
Asphalt Content	4%	4.5%	5%	5.5%	6%
Asphalt Weight	48 g	54 g	60 g	66 g	72 g
Aggregate Percentage	96%	95.5%	95%	94.5%	94%
Aggregate Weight	1152 g	1146 g	1140 g	1134 g	1128 g

(Source: Author’s Processed Results, 2026)

Table 9. Aggregate Gradation Composition

Aggregate Size	%	I	II	III	IV	V
0 mm - 5 mm	5	57.6 g	57.3 g	57 g	56.7 g	56.4 g
5 mm - 10 mm	22	253.44 g	252.12 g	250.8 g	249.48 g	248.16 g
10 mm - 15 mm	72	829.44 g	825.12 g	820.8 g	816.48 g	812.16 g

(Source: Author’s Processed Results, 2026)

Table 10. Filler Content Variation

Filler Type	%	I	II	III	IV	V
Corn Cob Ash Powder Filler	1	11.52 g	11.46 g	11.4 g	11.34 g	11.28 g
Siwalan Fruit Shell Ash Powder Filler	1	11.52 g	11.46 g	11.4 g	11.34 g	11.28 g

(Source: Author’s Processed Results, 2026)

### Marshall Test Result

The Marshall test was conducted to evaluate the mechanical and volumetric characteristics of the porous asphalt mixtures. The main parameters measured in this test included stability, flow, Voids in Mix (VIM), Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB). Stability indicates the maximum load that the asphalt mixture can withstand before failure, while flow represents the deformation of the specimen under loading. VIM refers to the percentage of air voids within the compacted asphalt mixture. VMA represents the volume of void spaces between aggregate particles in the compacted mixture, including air voids and effective asphalt binder content. VFB indicates the percentage of VMA filled with asphalt binder. These parameters are important for assessing the strength, deformation behavior, internal void structure, and durability potential of porous asphalt mixtures.

Table 11. Marshall Test Results

Marshall Parameter	Asphalt Content									
	With Siwalan Fruit Shell Ash Powder Filler					With Corn Cob Ash Powder Filler				
	4%	4.5%	5%	5.5%	6%	4%	4.5%	5%	5.5%	6%
Stability (kg)	1334	1137	1122	876	752	1330	1117	1146	856	780
Flow (mm)	2	2	2	3	3	2	3	2	3	3
VIM (%)	21	18	16	14	12	21	18	15	9	8
VMA (%)	28.9	26.6	23.6	17.8	17	28.6	27.4	24.0	13.4	11.4
VFB (%)	26.4	31.8	31.5	23.6	26.2	27.2	33.3	35.7	31.1	32.8

(Source: Author’s Processed Results, 2026)

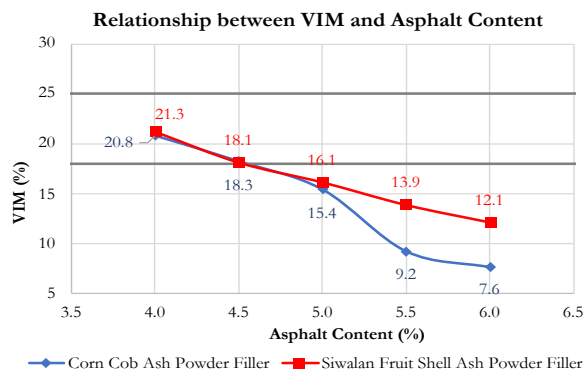


Figure 3. Relationship Between VIM & Asphalt Content Graphic

The VIM values for both mixtures decreased gradually as asphalt content increased, indicating that additional binder filled the void spaces between aggregate particles more effectively. For the mixture with siwalan fruit shell ash filler, the VIM decreased from 21% at 4% asphalt content to 12% at 6%. A more significant reduction was observed in the mixture incorporating corn cob ash filler, where the VIM decreased from 21% to 8% over the same asphalt content range. This trend is consistent with previous studies explaining that porous asphalt is designed with high air void content, and changes in binder content can influence the internal void structure and mixture performance (J. Chen & Yang, 2020). In addition, filler type and filler characteristics affect asphalt mixture properties, asphalt mastic behavior, and binder–filler interaction, which may explain the different VIM responses between the two waste-based filler materials (Alyousify et al., 2022; Mondal & Ransinchung, 2022; Wang et al., 2026). Therefore, the lower VIM values observed in the corn cob ash mixture suggest a stronger void-filling and densification effect compared with the siwalan fruit shell ash mixture within the tested asphalt content range.

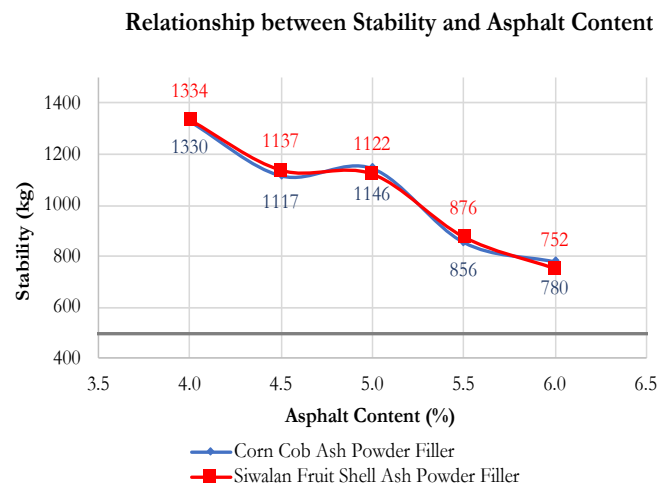


Figure 4. Relationship Between Stability & Asphalt Content Graphic

The Marshall stability results indicate that both porous asphalt mixtures exhibited the highest stability at lower asphalt contents. For the mixture with siwalan fruit shell ash filler, the maximum stability value of 1334 kg was achieved at an asphalt content of 4%, after which stability progressively decreased with increasing asphalt content. A similar trend was observed for the mixture containing corn cob ash filler, with a peak stability value of 1330 kg at 4% asphalt content. This trend is consistent with previous findings that Marshall stability is strongly influenced by the balance between asphalt binder content, aggregate interlocking, and internal void structure. At an appropriate asphalt content, the binder improves aggregate adhesion and mixture cohesion; however, when the binder content exceeds the optimum range, excess asphalt may occupy internal voids, reduce the effectiveness of the aggregate skeleton, and decrease structural efficiency (Chen & Yang, 2020; Sa’dillah et al., 2025). A technical pavement guideline also explains that excessive binder can fill the pores and make the binder–aggregate matrix unstable, which may reduce deformation resistance under repeated loading (Transport Infrastructure Ireland, 2017). Therefore, the reduction in stability at higher asphalt contents in this study can be attributed to excess binder weakening aggregate interlocking and reducing the load-bearing capacity of the porous asphalt mixture.

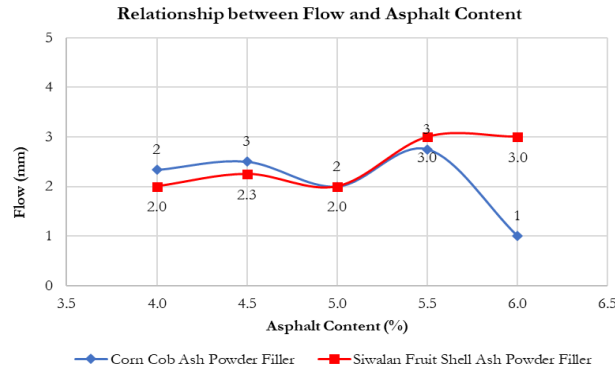


Figure 5. Relationship Between Flow & Asphalt Content Graphic

The Marshall flow results show a gradual increase in flow values with increasing asphalt content for both mixtures. For the porous asphalt mixture with siwalan fruit shell ash filler, the flow value increased from 2 mm at lower asphalt contents of 4–5% to 3 mm at higher asphalt contents of 5.5–6%. A similar trend was observed in the mixture incorporating corn cob ash filler, where the flow value increased from 2 mm to 3 mm as the asphalt content increased. This behavior indicates that higher asphalt binder content increases mixture flexibility and deformation capacity under loading. This finding is consistent with previous porous asphalt studies showing that asphalt content influences Marshall flow because additional binder can improve aggregate coating and reduce internal friction, resulting in a more deformable mixture (Chen & Yang, 2020; Sa’dillah et al., 2025). However, excessive flow may indicate that the mixture becomes too plastic and less resistant to deformation; therefore, flow values must be interpreted together with stability, VIM, Cantabro Loss, and Asphalt Flow Down to determine the optimum asphalt content (Transport Infrastructure Ireland, 2017; Sa’dillah et al., 2025). In this study, the flow values of both mixtures remained within 2–3 mm, indicating that the mixtures still maintained acceptable deformation behavior within the tested asphalt content range.

### Cantabro Loss & Asphalt Flow Down

Table 12. Cantabro Loss and Asphalt Flow Down Test Results

CL & AFD	Asphalt Content									
	With Siwalan Fruit Shell Ash Powder Filler					With Corn Cob Ash Powder Filler				
	4%	4.5%	5%	5.5%	6%	4%	4.5%	5%	5.5%	6%
CL	35.6	28.92	24.6	20.94	16.7	37.3	29.1	23.6	18.7	14.3
AFD	0.19	0.28	0.38	0.77	1.62	0.15	0.25	0.35	0.67	1.28

(Source: Author’s Processed Results, 2026)

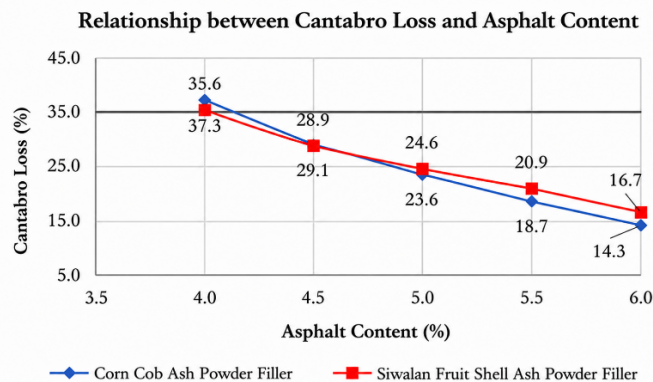


Figure 6. Relationship Between Cantabro Loss & Asphalt Content Graphic

The Cantabro Loss results indicate a clear decreasing trend with increasing asphalt content for both porous asphalt mixtures. For the mixture containing siwalan fruit shell ash filler, CL values decreased from 35.6% at 4% asphalt content to 16.7% at 6%, while the mixture with corn cob ash filler showed a similar reduction from 37.3% to 14.3%. This reduction in Cantabro Loss reflects improved aggregate cohesion and abrasion resistance due to increased binder content, which improves the durability of porous asphalt mixtures.

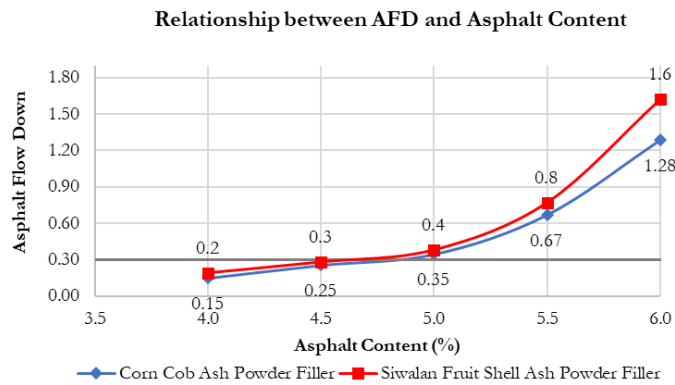


Figure 7. Relationship Between Asphalt Flow Down and Asphalt Content

An increase in asphalt content led to higher Asphalt Flow Down values in both porous asphalt mixtures. The mixture containing siwalan fruit shell ash filler exhibited AFD values rising from 0.19% at 4% asphalt content to 1.62% at 6%, while the corn cob ash filler mixture showed a comparable increase from 0.15% to 1.28%. This trend indicates that higher binder contents increase the potential for binder draindown as a result of thicker binder films and reduced resistance to flow.

### Optimum Asphalt Content (OAC)

In this study, the Optimum Asphalt Content (OAC) was identified with reference to the Australian Asphalt Pavement Association (AAPA, 2004) procedure. Its determination considered three main parameters Voids in Mix (VIM), Cantabro Loss, and Asphalt Flow Down and used the porous asphalt gradation criteria specified in the 2004 AAPA guideline.

1. Asphalt content determination corresponding to a VIM value of 18% (minimum OAC)

$$\text{Minimum OAC} = KA_{maks} + \left( \frac{Bb - V_{max}}{V_{min} - V_{max}} \right) \times (KA_{min} - KA_{maks})$$

Where:

- $KA_{max}$  = Asphalt content at which the VIM value is greater than or equal to the specified limit ( $\geq 18\%$ )
- $KA_{min}$  = Asphalt content at which the VIM value is less than or equal to the specified limit ( $\leq 18\%$ )
- $V_{max}$  = VIM value at  $KA_{max}$
- $V_{min}$  = VIM value at  $KA_{min}$
- $Bb$  = Minimum allowable VIM limit (18%)

2. Determining the asphalt content corresponding to a Cantabro Loss value of 35% (maximum OAC).

$$\text{Maximum OAC} = KA_{maks} + \left( \frac{Ba - CL_{maks}}{CL_{min} - CL_{maks}} \right) \times (KA_{min} - KA_{maks})$$

Where:

- $KA_{max}$  = Asphalt content at which the CL value is greater than or equal to the specified limit ( $\geq 35\%$ )
- $KA_{min}$  = Asphalt content at which the CL value is less than or equal to the specified limit ( $\leq 35\%$ )
- $CL_{max}$  = Contabro Loss value at  $KA_{max}$
- $CL_{min}$  = Contabro Loss value at  $KA_{min}$
- $B_a$  = The maximum allowable Cantabro Loss limit is 35%.

3. Calculating the mean value of the minimum and maximum Optimum Asphalt Content (OAC).

$$Average\ OAC = \frac{(Minimum\ OAC + Maximum\ OAC)}{2}$$

Table 13. Minimum, Maximum, and Average Optimum Asphalt Content (OAC)

OAC	Siwalan Fruit Shell Ash Powder Filler	Corn Cob Ash Powder Filler
<b>Min</b>	4.53%	4.14%
<b>Max</b>	4.76%	4.54%
<b>Avg</b>	4.64%	4.34%

(Source: Author’s Processed Results, 2026)

Table 13 summarizes the minimum, maximum, and average Optimum Asphalt Content (OAC) values for porous asphalt mixtures incorporating siwalan fruit shell ash powder and corn cob ash powder as filler. In the AAPA 2004 procedure, the optimum asphalt content is not determined by a fixed asphalt content value, but by meeting the porous asphalt performance criteria, particularly Voids in Mix (VIM), Cantabro Loss, and Asphalt Flow Down. In this study, the minimum OAC was determined based on the asphalt content corresponding to a VIM value of 18%, while the maximum OAC was determined based on the asphalt content corresponding to the maximum allowable Cantabro Loss value of 35%. Therefore, the OAC values obtained in this study were evaluated against these AAPA 2004 criteria.

The mixture incorporating siwalan fruit shell ash powder exhibited higher minimum, maximum, and average OAC values, namely 4.53%, 4.76%, and 4.64%, respectively, compared with the mixture incorporating corn cob ash powder, which showed OAC values of 4.14%, 4.54%, and 4.34%, respectively. These results indicate that both mixtures satisfied the OAC determination range based on the AAPA 2004 criteria, but the siwalan fruit shell ash mixture required a higher binder content than the corn cob ash mixture. This difference may be associated with the physical characteristics of the filler, particularly particle texture, porosity, and asphalt absorption capacity, which influence binder demand in the porous asphalt mixture (Y. Chen et al., 2022; Diab & Enieb, 2018; Dimulescu & Burlacu, 2021).

Based on the average OAC, the corn cob ash filler mixture, with an average OAC of 4.34%, was projected to the nearest asphalt content of 4.5%, resulting in an Asphalt Flow Down value of 0.25. Meanwhile, the siwalan fruit shell ash filler mixture, with an average OAC of 4.64%, was projected to the nearest asphalt content of 5.0%, resulting in an Asphalt Flow Down value of 0.38. The final OAC was then obtained by adding the average OAC and the corresponding Asphalt Flow Down value in accordance with the AAPA 2004 procedure. As a result, the final OAC was 5.00% for the siwalan fruit shell ash mixture and 4.59% for the corn cob ash mixture. Compared with the initial design binder content/Pb of approximately 5.0%, the siwalan fruit shell ash mixture produced a final OAC equal to the rounded design binder content, while the corn cob ash mixture produced a lower final OAC. This indicates that corn cob ash filler is more efficient in terms of

asphalt binder demand, whereas siwalan fruit shell ash requires a higher asphalt content to satisfy the porous asphalt mixture design criteria.

$$\text{Final OAC of Porous Asphalt Mixtures} = \frac{(\text{Minimum OAC} + \text{Maximum OAC})}{2} + \text{AFD}$$

Table 14. Final Optimum Asphalt Content (OAC) of Porous Asphalt Mixtures

<b>Final OAC</b>	
<b>Siwalan Fruit Shell Ash Powder Filler</b>	<b>Corn Cob Ash Powder Filler</b>
5%	4.59%

(Source: Author’s Processed Results, 2026)

Table 14 presents the final Optimum Asphalt Content (OAC) values for porous asphalt mixtures incorporating siwalan fruit shell ash powder and corn cob ash powder as filler. The final OAC for the mixture containing siwalan fruit shell ash powder filler was 5.00%, while the mixture with corn cob ash powder filler showed a lower final OAC of 4.59%. Based on the AAPA 2004 porous asphalt mixture design procedure, the OAC is not evaluated against a single fixed asphalt content value, but is determined by satisfying the required performance criteria, particularly Voids in Mix (VIM), Cantabro Loss, and Asphalt Flow Down. In this study, the OAC determination used a VIM criterion of 18% as the minimum OAC limit and a Cantabro Loss criterion of 35% as the maximum OAC limit, while Asphalt Flow Down was used to account for binder draindown potential. Therefore, both final OAC values were considered acceptable because they were obtained through the AAPA 2004 criteria-based procedure.

Compared with the rounded design binder content (Pb) of 5.0%, the siwalan fruit shell ash mixture produced a final OAC equal to the design binder content, whereas the corn cob ash mixture produced a lower final OAC of 4.59%. This indicates that corn cob ash powder filler requires less asphalt binder to satisfy the porous asphalt design criteria, making it more efficient in terms of binder demand. In contrast, the siwalan fruit shell ash powder filler requires a higher asphalt binder content, which may be attributed to differences in filler characteristics such as particle texture, porosity, and asphalt absorption capacity. These findings show that filler type influences the final OAC and should be considered in porous asphalt mixture design.

### **Conclusion**

This study demonstrates that corn cob ash powder and siwalan fruit shell ash powder can be used as alternative agricultural waste-based filler materials in porous asphalt mixtures. The Marshall test results showed that both mixtures achieved their highest stability at 4% asphalt content, with the siwalan fruit shell ash mixture reaching 1334 kg and the corn cob ash mixture reaching 1330 kg. The flow values of both mixtures ranged from 2 mm to 3 mm, indicating acceptable deformation behavior within the tested asphalt content range. These results indicate that both waste-based filler materials are capable of producing porous asphalt mixtures with adequate mechanical response.

Based on the Australian Asphalt Pavement Association (AAPA, 2004) porous asphalt mixture design procedure, the final Optimum Asphalt Content (OAC) was determined by considering Voids in Mix, Cantabro Loss, and Asphalt Flow Down criteria. The final OAC of the siwalan fruit shell ash mixture was 5.00%, while the corn cob ash mixture produced a lower final OAC of 4.59%. This finding indicates that corn cob ash powder is more efficient in terms of asphalt binder demand, whereas siwalan fruit shell ash powder requires a higher binder content, possibly due to differences in particle texture, porosity, and asphalt absorption characteristics.

The novelty of this study lies in the direct comparative evaluation of two locally available agricultural waste ashes as filler materials in porous asphalt mixtures. Compared with previous studies that generally examined waste filler materials separately or focused on different types of waste, this study provides empirical evidence that corn cob ash and siwalan fruit shell ash produce different effects on Marshall stability, flow, air void characteristics, Cantabro Loss, Asphalt Flow Down, and OAC. Therefore, the main contribution of this study is the identification of corn cob ash powder as a more binder-efficient filler, while siwalan fruit shell ash powder remains a feasible alternative filler with higher binder demand. These findings support the use of agricultural waste materials in sustainable porous asphalt mixture design and provide a basis for further research on long-term durability, permeability, moisture resistance, and field performance.

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