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The Effect of Fly Ash Filler Substitution and the Addition of Styrofoam Waste on the Marshall Characteristics of AC-WC Asphalt Concrete Mixtures

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Abstract— *This study aims to analyze the effect of fly ash filler substitution, the addition of waste styrofoam, and the combination of both on the Marshall characteristics of Asphalt Concrete-Wearing Course (AC-WC) mixtures, as well as to determine the optimum content that meets the 2024 General Specifications of the Directorate General of Highways. The study employed a laboratory experimental method consisting of determining the Optimum Asphalt Content (OAC), followed by fly ash filler substitution at 0%, 25%, 50%, 75%, and 100% of the conventional filler weight. The optimum fly ash content was then used as the basis for adding waste styrofoam at 0%, 2%, 4%, and 6% by weight of asphalt. Marshall testing was conducted to evaluate Bulk Density, stability, flow, Marshall Quotient (MQ), Void in the Mix (VIM), Void in Mineral Aggregate (VMA), and Void Filled with Asphalt (VFA). The results showed that the Optimum Asphalt Content was 5.53%. The optimum fly ash content was 25%, with a stability of 1,290 kg, flow of 3.50 mm, MQ of 360 kg/mm, Bulk Density of 2.39 g/cm³, VIM of 4.30%, VMA of 15.80%, and VFA of 73.00%. The optimum waste styrofoam content was 1.5%, with a stability of 1,510 kg, flow of 3.62 mm, MQ of 414 kg/mm, Bulk Density of 2.40 g/cm³, VIM of 3.76%, VMA of 15.39%, and VFA of 75.20%. Based on these results, the combination of 5.53% optimum asphalt content, 25% fly ash substitution, and 1.5% waste styrofoam addition produced Marshall characteristics that satisfied the 2024 General Specifications of the Directorate General of Highways.*

Keywords— *AC-WC; fly ash; Marshall characteristics; optimum asphalt content; waste styrofoam.*

I. Introduction

Asphalt Concrete-Wearing Course (AC-WC) is the surface layer of flexible pavement that directly receives traffic loads and is exposed to environmental conditions. The performance of AC-WC mixtures is influenced by the properties and proportions of asphalt, aggregate, and filler. Therefore, the selection of appropriate materials is important to obtain a mixture with adequate stability, durability, and resistance to deformation.

The use of industrial and household waste as alternative materials in asphalt mixtures has received increasing attention as an effort to reduce waste and improve pavement performance. Fly ash, a by-product of coal combustion, has fine particles and can potentially be used as a filler material in asphalt mixtures. In addition, waste styrofoam can be utilized as a modifier in asphalt mixtures because its polymeric properties can affect the characteristics of the asphalt binder and mixture. (Asaryanti, 2016; Delani & Patriotika, 2023).

Previous studies have investigated the use of fly ash as a filler substitute and styrofoam as an additive in AC-WC mixtures. The results indicate that both materials can affect Marshall characteristics, including stability, flow, and volumetric properties. However, the use of fly ash as filler substitution combined with waste styrofoam addition in the same AC-WC mixture has received less attention. Therefore, further investigation is needed to evaluate the effect of the combination of these materials on the Marshall characteristics of AC-WC mixtures.

This study aims to analyze the effect of fly ash substitution as a filler and waste styrofoam addition on the Marshall characteristics of AC-WC mixtures. The study also aims to determine the optimum fly ash and styrofoam contents that produce suitable Marshall characteristics and comply with the 2024 General Specifications of the Directorate General of Highways**.**

II. Literature Review

A. Asphalt Concrete-Wearing Course (AC-WC)

Asphalt Concrete-Wearing Course (AC-WC) is the surface layer of flexible pavement that directly receives traffic loads and is exposed to environmental conditions. The AC-WC mixture consists of coarse aggregate, fine aggregate, filler, and asphalt binder. The properties and gradation of these materials influence the strength, density, void structure, and deformation characteristics of the asphalt mixture.

B. Fly Ash as Filler

Fly ash is a fine residue produced from coal combustion in power plants. Due to its fine particle size, fly ash can be used as an alternative filler material in asphalt mixtures. Its use as a filler substitute can affect the density, volumetric properties, and Marshall characteristics of the mixture. The resulting effect depends on the physical and chemical properties of fly ash and the proportion used in the mixture. (Huang et al., 2005; Hanggara et al., 2022; Huldayani & Syarif, 2023).

Previous research by Huldayani and Syarif investigated the use of Fly Ash and Bottom Ash (FABA) as a substitute for filler in AC-WC mixtures. The study used FABA variations of 25%, 50%, 75%, and 100% and demonstrated that FABA substitution affected the Marshall characteristics of the asphalt mixture.

C. Waste Styrofoam

Styrofoam is a polymeric material that can be utilized as an additive in asphalt mixtures. Its addition can modify the properties of the asphalt binder and affect the strength and deformation characteristics of the mixture (Asaryanti, 2016; Delani & Patriotika, 2023; Rahmawati et al., 2021). Research by Windi Dewi Asaryanti et al. investigated the addition of waste styrofoam at 0%, 2%, 4%, and 6% in AC-WC mixtures. The results showed that the addition of styrofoam affected the Marshall characteristics of the mixture, indicating its potential as a modifying material in asphalt mixtures.

D. Marshall Characteristics

The Marshall method is used to evaluate the characteristics of asphalt mixtures through several parameters, including stability, flow, Marshall Quotient (MQ), Bulk Density, Void in the Mix (VIM), Void in Mineral Aggregate (VMA), and Void Filled with Asphalt (VFA) (Asphalt Institute, 2014; ASTM International, 2020a). Stability indicates the ability of the mixture to withstand loads, while flow represents the deformation occurring at the maximum load. MQ represents the relationship between stability and flow. Meanwhile, VIM, VMA, and VFA describe the volumetric characteristics of the compacted asphalt mixture.

In this study, the Marshall characteristics of the AC-WC mixture were evaluated based on the 2024 General Specifications of the Directorate General of Highways. These requirements were used as the basis for evaluating the suitability of the mixtures produced in this research.

III. RESEARCH METHODOLOGY

A. Research Materials

The materials used in this study consisted of 1–2 aggregate, Coarse Aggregate (Chipping), Palu sand, stone dust, cement, fly ash, PEN 60/70 asphalt, and waste styrofoam.

B. Mixture Design

The AC-WC mixture was designed based on the combined aggregate gradation in accordance with the 2024 General Specifications of the Directorate General of Highways. The Optimum Asphalt Content (OAC) was determined using five asphalt content variations, namely 4.5%, 5.0%, 5.5%, 6.0%, and 6.5%. After obtaining the OAC, fly ash was used as a substitute for conventional filler at 0%, 25%, 50%, 75%, and 100%. The optimum fly ash content was subsequently used as the basis for the addition of waste styrofoam.

C. Specimen Preparation

The specimens were prepared according to the predetermined mixture proportions. The research stages consisted of preparing OAC specimens, Marshall testing, preparing fly ash variation specimens, Marshall testing, preparing waste styrofoam variation specimens, and Marshall testing. Waste styrofoam was added using the dry process, in which the prepared styrofoam was mixed with the heated aggregate before the asphalt binder was added. The mixing and compaction procedures were kept consistent for all variations.

D. Marshall Testing and Data Analysis

The Marshall test was conducted to determine stability, flow, Marshall Quotient (MQ), Bulk Density, VIM, VMA, and VFA. The results were analyzed by comparing each variation with the requirements of the 2024 General Specifications of the Directorate General of Highways to determine the optimum mixture composition.

IV. RESEARCH RESULTS AND EXPLANATION

A. Asphalt Test

The results of the PEN 60/70 asphalt properties testing are presented in Table 1.

TABLE 1. PEN 60/70 Asphalt Test Results

No	Test Type	Unit	Specifications	Result	Compliance
1	Specific Gravity	-	≥ 1.00	1,01	Complies
2	Penetration	Mm	60-70	66,60	Complies
3	Softening Point	°C	≥ 48	55,5	Complies
4	Ductility	cm	≥ 100	116	Complies

Source: Laboratory Test Results, 2026.

Based on the test results presented in Table 1, the PEN 60/70 asphalt fulfilled all requirements specified in the 2024 General Specifications of Bina Marga. The specific gravity was 1.01, penetration was 66.60 mm, softening point was 55.5 °C, and ductility was 116 cm. Therefore, the asphalt was considered suitable for use as a binder in the AC-WC mixture.

B. Aggregate Test

The results of the aggregate properties testing for 1–2 aggregate, chipping, Palu sand, and stone dust are presented in Table 2.

TABLE 2. Aggregate Test Results

Test Type	Specification	Result	Compliance
1-2 Aggregate			
Bulk Specific Gravity	2,5%	2,76%	Complies
SSD Specific Gravity	2,5%	2,79%	Complies
Apparent Specific Gravity	2,5%	2,85%	Complies
Water Absorption	≤ 3%	1,21%	Complies
Abration	≤ 40%	25,12%	Complies
Coarse Aggregate (Chipping)			
Bulk Specific Gravity	2,5%	2,66%	Complies
SSD Specific Gravity	2,5%	2,68%	Complies
Apparent Specific Gravity	2,5%	2,71%	Complies
Water Absorption	≤ 3%	0,75%	Complies
Abration	≤ 40%	16,94%	Complies
Fine Aggregate (Palu Sand)			
Bulk Specific Gravity	2,5%	2,55%	Complies
Saturated Surface Dry (SSD)	2,5%	2,60%	Complies
Apparent Specific Gravity	2,5%	2,67%	Complies
Water Absorption (%)	≤ 3%	1,84%	Complies
Fine Aggregate (Stone Dust)			
Bulk Specific Gravity	2,5%	2,61%	Complies
Saturated Surface Dry (SSD)	2,5%	2,66%	Complies
Apparent Specific Gravity	2,5%	2,73%	Complies
Water Absorption (%)	≤ 3%	1,63%	Complies

Source: Laboratory Test Results, 2026

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Based on the test results presented in Table 2, the aggregate materials were evaluated according to the requirements of the 2024 General Specifications of Bina Marga. The test results were used to determine the suitability of the aggregates for use in the AC-WC mixture.

C. Filler Test

The filler materials used in this study consisted of cement and fly ash. The results of the filler properties testing are presented in Table 3.

TABLE 3. Cement and Fly Ash Filler Test Results

No	Filler Material	Density (g/cm³)	Specific Gravity (g/cm³)
1	Cement	3,11	3,11
2	Fly ash	2,32	2,32

Source: Laboratory Test Results, 2026

Based on the test results presented in Table 3, the density and specific gravity of cement and fly ash were determined as part of the material characterization. The specific gravity values were subsequently used in the mixture composition calculations and in determining the proportion of fly ash as a substitute for conventional filler.

D. Combined Aggregate Gradation

The combined aggregate gradation was determined based on the proportions of 1–2 aggregate, chipping, Palu sand, and stone dust. The proportions used in the combined gradation were 25%, 26%, 35%, and 10%, respectively, with 4% cement filler. The results of the combined aggregate gradation analysis are presented in Table 4.

TABLE 4. Combined Aggregate Gradation of Normal AC-WC

Sieve Size	Sieve Opening (mm)	1-2 Aggregate	Chipping	Stone dust	Palu sand	Filler	Combined Gradation (%)	Lower Limit (%)	Upper Limit (%)
		25%	26%	35%	10%	4%			
1"	25.4	0.00	0.00	0.00	0.00	0,00	100.00	100	100
3/4"	19.1	21.05	26.00	35.00	10.00	4.00	100.00	100	100
1/2"	12.5	9.65	26.00	35.00	10.00	4.00	96.70	90	100
3/8"	9.6	4.11	25.71	35.00	10.00	4.00	87.10	77	90
No.4	4.75	0.22	7.32	35.00	10.00	4.00	62.58	53	69
No.8	2.36	0.13	0.91	27.03	9.77	4.00	41.83	33	53
No.16	1.18	0.13	0.39	15.32	9.53	4.00	29.37	21	40
No.30	0.60	0.10	0.27	9.18	8.82	4.00	23.45	14	30
No.50	0.30	0.09	0.16	5.30	0.90	4.00	16.21	9	22
No.100	0.15	0.08	0.06	2.12	0.43	4.00	11.50	6	15
No.200	0.075	0.03	0.06	0.39	0.04	4.00	4.50	4	9
Pan	—	0.00	0.00	0.00	0.00	0.00	0.00	—	—

Source: Laboratory Test Results, 2026.

Based on Table 4, the combined aggregate gradation was within the specified limits for the AC-WC mixture. Therefore, the selected aggregate proportions were used for the preparation of the OAC specimens. The combined aggregate gradation results presented in Table 4 are illustrated graphically in Figure 1.

E. Mix Design

After obtaining the aggregate proportions from the combined aggregate gradation analysis and confirming that the gradation met the specified requirements, the reference asphalt content was determined based on the proportions of coarse aggregate (CA), fine aggregate (FA), and filler fraction (FF). The calculation was carried out as follows:

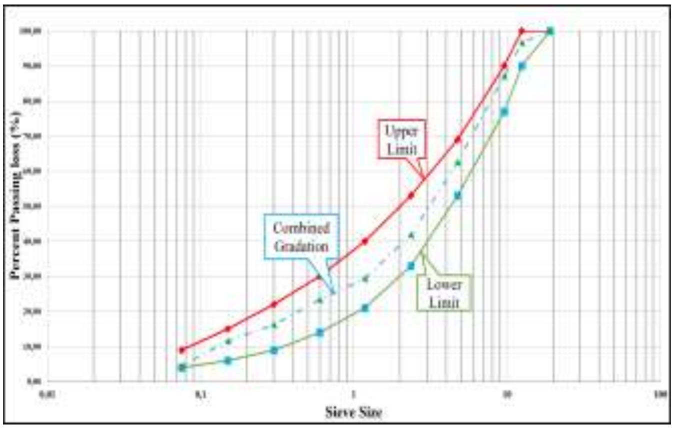

Figure 1. Combined Aggregate Gradation Curve of AC-WC

Coarse Aggregate (CA)

CA = 100%−aggregate fraction retained on No. 8
= 100%−41.83%
= 58.2%

Fine Aggregate (FA)

FA = fraction passing No. 8−fraction passing No. 200
= 41.83%−4.50%
= 37.3%

Filler Fraction (FF)

FF = Fraction passing No. 200
= 4,5%

The coefficient was taken as 1. The reference asphalt content was then calculated using the following equation:

$$Pb = 0.035(CA)+0.045(FA)+0.18(FF)+K$$
$$= 0.035(58.2)+0.045(37.3)+0.18(4.5)+1$$
$$= 5.53\% \approx 5.5\%$$

Thus, the calculated reference asphalt content was 5.53%, which was rounded to 5.5% as the central asphalt content for the preparation of the OAC specimens.

Five asphalt content variations were then prepared with an interval of 0.5%, namely 4.5%, 5.0%, 5.5%, 6.0%, and 6.5%. For each asphalt content variation, three test specimens were prepared, resulting in a total of 15 specimens for the determination of the Optimum Asphalt Content (OAC).

F. Marshall Test for Optimum Asphalt Content

The prepared AC-WC specimens were subjected to Marshall testing to evaluate their characteristics, including stability, flow, Marshall Quotient (MQ), Bulk Density, VIM, VMA, and VFA. The Marshall test results for each asphalt content variation are presented in Table 5.

TABLE 5. Marshall Test Results for OAC Determination

Asphalt Content (%)	Bulk Density (g/cm³)	VIM (%)	VMA (%)	VFA (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)
4,5	2,40	4,84	14,04	65,52	1144,70	2,67	431,53
5,0	2,39	4,72	15,04	68,65	1241,32	2,40	521,81
5,5	2,38	4,35	15,81	72,51	1113,85	2,93	379,77
6,0	2,38	3,72	16,35	77,31	1214,92	3,07	400,97
6,5	2,36	3,65	17,36	79,03	1108,96	3,10	358,22

Source: Laboratory Test Results, 2026.

The Marshall test results for each asphalt content variation are presented in Table 5. The relationship between asphalt content and the Marshall characteristics is illustrated in Figure 2.

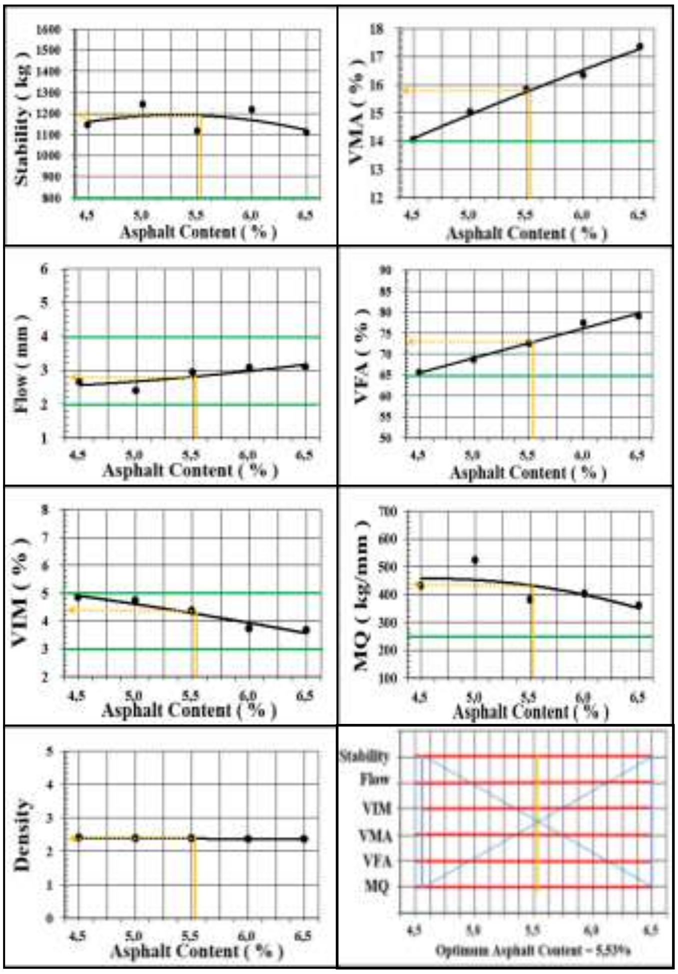

Figure 2. Marshall Characteristics at Various Asphalt Contents

The interpolated Marshall characteristics at the Optimum Asphalt Content (OAC) are presented in Table 6.

TABLE 6. Interpolated Marshall Characteristics for OAC Determination

Marshall Characteristic	**Specification**	**Result**	**Compliance**
Stability (kg)	Min. 800	1,190	Complies
Flow (mm)	2–4	2.9	Complies
Marshall Quotient (kg/mm)	Min. 250	440	Complies
VIM (%)	3–5	4.4	Complies
VMA (%)	Min. 15	15.8	Complies
VFA (%)	Min. 65	73.0	Complies
Bulk Density (g/cm³)	—	2.39	Complies
OAC (%)		**5.53**	

Source: Laboratory Test Results, 2026.

Based on the interpolation results, the Optimum Asphalt Content (OAC) was determined to be 5.53%. This value was subsequently used for the fly ash substitution stage.

G. Fly Ash Substitution

The fly ash substitution stage was conducted using the Optimum Asphalt Content (OAC) of 5.53%. Fly ash was used as a substitute for conventional filler at levels of 0%, 25%, 50%, 75%, and 100% of the total filler content.

Five specimens were prepared for each fly ash variation, resulting in a total of 25 specimens. The specimens were then subjected to Marshall testing to evaluate stability, flow, Marshall Quotient (MQ), Bulk Density, VIM, VMA, and VFA. The Marshall test results for each fly ash variation are presented in Table 7.

TABLE 7. Marshall Test Results of Fly Ash Substitution

Fly Ash Content (%)	Bulk Density (g/cm³)	VIM (%)	VMA (%)	VFA (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)
0	2,38	4,07	15,63	74,00	1180,32	2,98	397,15
25	2,37	4,25	15,76	73,06	1293,00	3,41	380,61
50	2,37	4,16	15,65	73,44	1390,36	4,09	340,67
75	2,36	4,12	15,58	73,60	1351,61	4,16	324,86
100	2,36	3,91	15,37	74,59	1386,89	4,22	329,02

Source: Laboratory Test Results, 2026.

The Marshall characteristics at different fly ash substitution levels are illustrated in Figure 3.

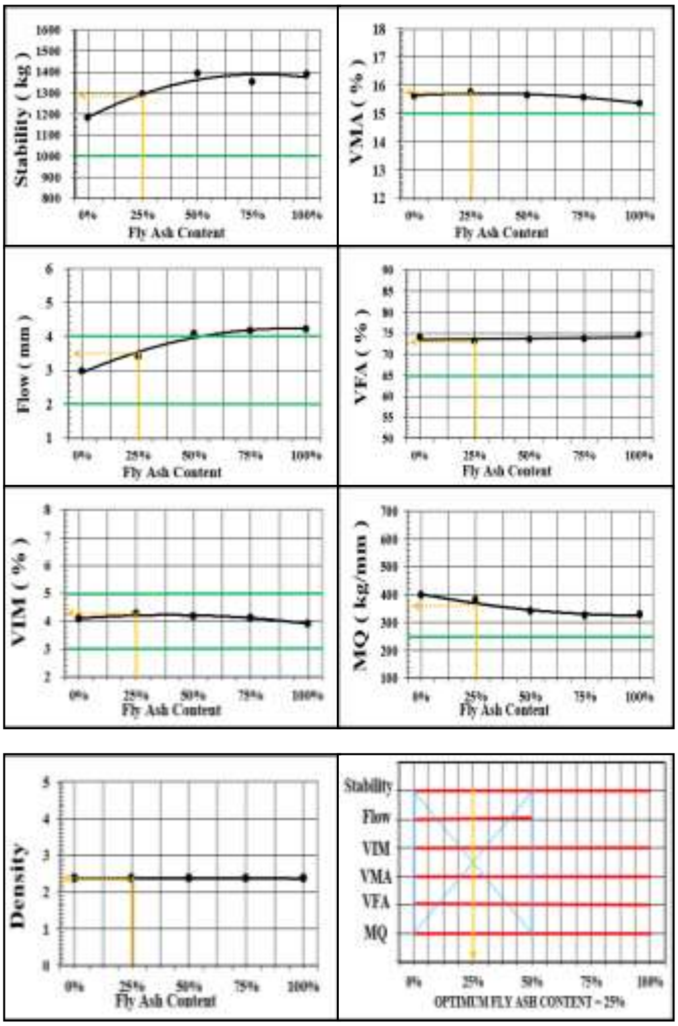

Figure 3. Marshall Characteristics at Various Fly Ash Substitution Levels

The interpolated Marshall characteristics for determining the optimum fly ash content are presented in Table 8.

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TABLE 8. Interpolated Marshall Characteristics for Optimum Fly Ash Determination

Marshall Characteristic	Specification	Result	Compliance
Stability (kg)	Min 1000	1290	Complies
Flow (mm)	2 – 4 mm	3,5	Complies
Marshall Quotient (kg/mm)	Min 250 kg/mm	360	Complies
VIM (%)	3 – 5 %	4,3	Complies
VMA (%)	Min 15 %	15,8	Complies
VFA (%)	Min 65 %	73	Complies
Bulk Density (g/cm³)	-	2,39	Complies
Optimum Fly Ash Content (%)		**25**	

Source: Laboratory Test Results, 2026.

Based on the interpolation results, the optimum fly ash content was determined to be 25%. This content was subsequently used as the basis for the addition of styrofoam waste.

H. Styrofoam Addition

After determining the optimum fly ash content, styrofoam waste was added to the AC-WC mixture using the optimum fly ash content of 25% and the OAC of 5.53%. The styrofoam content was varied at 0%, 2%, 4%, and 6% by weight of asphalt.

Three specimens were prepared for each styrofoam variation, resulting in a total of 12 specimens. The specimens were then subjected to Marshall testing to evaluate stability, flow, Marshall Quotient (MQ), Bulk Density, VIM, VMA, and VFA. The Marshall test results for each styrofoam variation are presented in Table 9.

TABLE 9. Marshall Test Results of Styrofoam Addition

Styrofoam Content (%)	Bulk Density (g/cm³)	VIM (%)	VMA (%)	VFA (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)
0	2,37	4,19	15,71	73,33	1321,40	3,46	382,60
2	2,38	3,82	15,38	75,19	1577,08	3,70	425,15
4	2,40	2,94	14,61	79,86	1625,22	3,89	417,99
6	2,40	2,88	14,56	80,19	1562,10	3,98	392,33

Source: Laboratory Test Results, 2026.

The Marshall test results presented in Table 9 show the changes in the Marshall characteristics of the AC-WC mixture with different styrofoam contents. The results indicate variations in stability, flow, Marshall Quotient (MQ), Bulk Density, VIM, VMA, and VFA as the styrofoam content increases. These results were further evaluated through Marshall characteristic curves to determine the optimum styrofoam content. The relationship between styrofoam content and the Marshall characteristics is illustrated in Figure 4.

The Marshall characteristic curves were used to determine the optimum styrofoam content based on the specified requirements. The interpolated Marshall characteristics corresponding to the optimum content are presented in Table 10.

Based on the interpolation results, the optimum styrofoam content was determined to be 1.5%. This content produced Marshall characteristics that met all specified requirements and was selected as the optimum content for the modified AC-WC mixture.

I. Effect of the Combination of Fly Ash and Styrofoam on Marshall Characteristics

A comparison of the Marshall characteristics of the conventional, optimum fly ash, and optimum styrofoam mixtures is presented in Table 11.

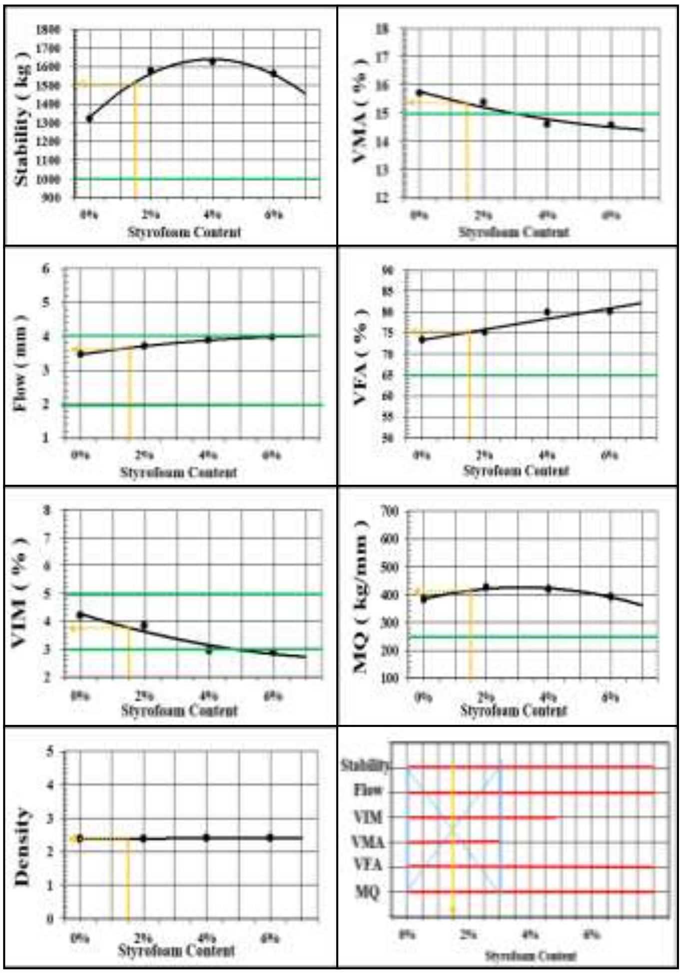

Figure 4. Marshall Characteristics at Various Styrofoam Contents

TABLE 10. Interpolated Marshall Characteristics for Optimum Styrofoam Determination

Marshall Characteristic	Specification	Result	Compliance
Stability (kg)	Min 1000	1510	Complies
Flow (mm)	2 – 4 mm	3,62	Complies
Marshall Quotient (kg/mm)	Min 250 kg/mm	414	Complies
VIM (%)	3 – 5 %	3,76	Complies
VMA (%)	Min 15 %	15,39	Complies
VFA (%)	Min 65 %	75,2	Complies
Bulk Density (g/cm³)	-	2,4	Complies
Optimum Styrofoam Content (%)		**1,5**	

Source: Laboratory Test Results, 2026.

The comparison shows changes in the Marshall characteristics after the incorporation of fly ash and styrofoam. These changes are illustrated in Figure 5 and further discussed based on each Marshall parameter.

Figure 5 shows the comparison of Marshall characteristics among the OAC mixture, the optimum fly ash mixture, and

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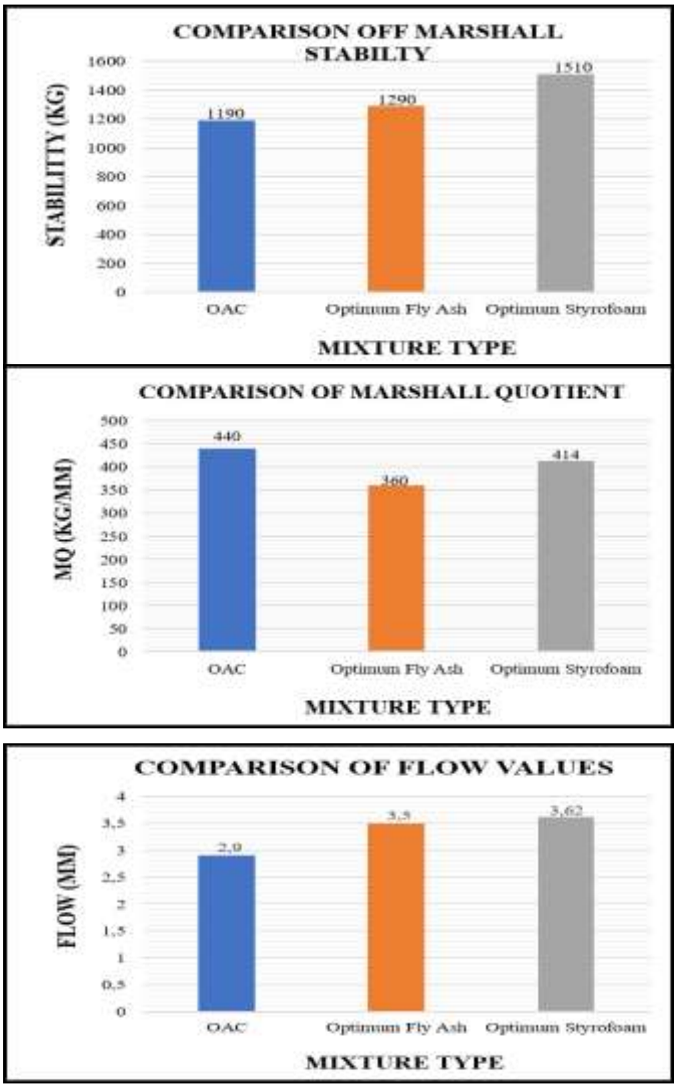
the optimum styrofoam mixture. The results indicate that the incorporation of fly ash and styrofoam affected both the mechanical and volumetric properties of the AC-WC mixture.

TABLE 11. Comparison of Marshall Characteristics

Parameter	Unit	OAC	Optimum Fly Ash	Optimum Styrofoam	Specification	Compliance
Asphalt Content	%	5.53	5.53	5.53	–	–
Fly Ash Content	%	–	25	25	–	–
Styrofoam Content	%	–	–	1.5	–	–
Bulk Density	g/cm³	2.39	2.39	2.40	–	Complies
Stability	kg	1,190	1,290	1,510	Min. 1,000	Complies
Flow	mm	2.90	3.50	3.62	2–4	Complies
Marshall Quotient (MQ)	kg/mm	440	360	414	Min. 250	Complies
VIM	%	4.40	4.30	3.76	3–5	Complies
VMA	%	15.80	15.80	15.39	Min. 15	Complies
VFA	%	73.00	73.00	75.20	Min. 65	Complies

Source: Laboratory Test Results, 2026.



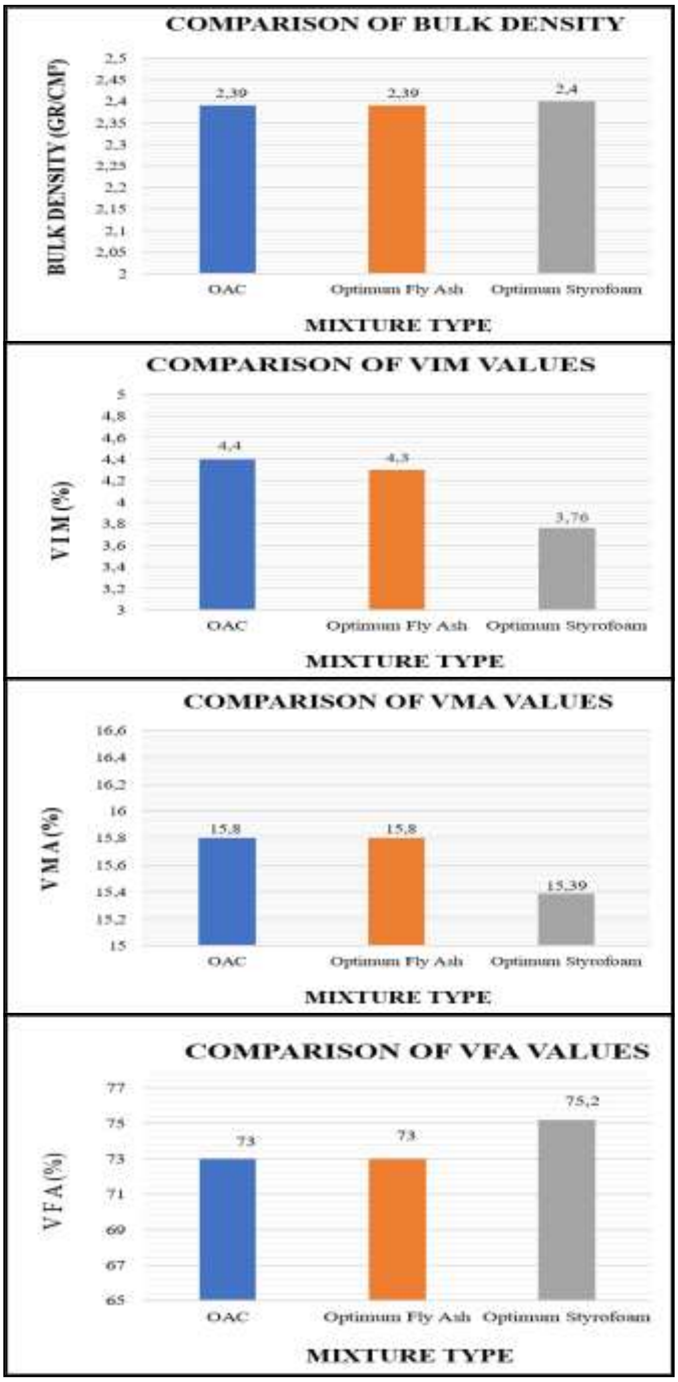


Figure 5. Comparison of Marshall Characteristics of AC-WC Mixtures

The Marshall stability increased from 1,190 kg for the OAC mixture to 1,290 kg after the addition of 25% fly ash and further increased to 1,510 kg with the addition of 1.5% styrofoam. The flow value also increased from 2.90 mm to 3.50 mm and 3.62 mm, respectively. Meanwhile, the Marshall Quotient decreased from 440 kg/mm to 360 kg/mm with the addition of fly ash, but increased to 414 kg/mm after the addition of styrofoam.

The Bulk Density remained relatively stable, increasing slightly from 2.39 g/cm³ in the OAC mixture to 2.40 g/cm³ in the optimum styrofoam mixture. The VIM decreased from

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4.40% to 4.30% and 3.76%, while the VMA remained at 15.80% after fly ash substitution and decreased to 15.39% after styrofoam addition. In contrast, the VFA increased from 73.00% to 75.20% in the optimum styrofoam mixture. Overall, all Marshall characteristics remained within the specified requirements, indicating that the combination of 25% fly ash and 1.5% styrofoam produced an acceptable AC-WC mixture.

V. Conclusion And Recommendations

A. Conclusion

Based on the results and discussion presented above, the following conclusions can be drawn:

1) The optimum asphalt content (OAC) was determined to be 5.53%, while the optimum fly ash content was 25%.
2) The optimum styrofoam content was determined to be 1.5%. The combination of 25% fly ash and 1.5% styrofoam produced Marshall characteristics that met the specified requirements.
3) The optimum mixture produced a stability of 1,510 kg, flow of 3.62 mm, Marshall Quotient of 414 kg/mm, Bulk Density of 2.40 g/cm³, VIM of 3.76%, VMA of 15.39%, and VFA of 75.20%

B. Recommendations

Based on the findings of this study, several recommendations are proposed for further research and development of modified AC-WC mixtures:

1) Further research may be conducted using different asphalt mixture types or pavement layers, such as HRS-WC, which has a higher filler content, to evaluate the effectiveness of fly ash and styrofoam in different mixture characteristics.
2) Further research is recommended to use variation levels that are closer to the optimum content to obtain more precise results and identify the optimum composition more accurately.
3) Further research may investigate other types of filler substitution materials and additives to compare their effects on the Marshall characteristics and performance of AC-WC mixtures.

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