Comparative Marshall Performance of Asphalt Concrete and Stone Mastic Asphalt Mixtures for Taxiway Pavements Based on FAA Specifications

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ABSTRACT

Taxiway flexible pavements are subjected to high shear stresses from slow-moving aircraft with large wheel configurations, making mixture stability and resistance to permanent deformation critical performance requirements. Asphalt Concrete (AC) and Stone Mastic Asphalt (SMA) are commonly used wearing course mixtures; however, their performance characteristics under taxiway loading conditions may differ significantly. This study presents a comparative evaluation of the Marshall performance of AC and SMA mixtures designed in accordance with Federal Aviation Administration (FAA) specifications for taxiway pavements. Laboratory experiments were conducted using the Marshall mix design method to determine key parameters, including stability, flow, Marshall Quotient (MQ), Voids in Mix (VIM), Voids in Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA), and Optimum Asphalt Content (OAC). The results indicate that the AC mixture exhibits higher average Marshall stability, reflecting superior load-bearing capacity, whereas the SMA mixture demonstrates lower flow values, indicating greater resistance to permanent deformation. The OAC of the SMA mixture is higher than that of the AC mixture due to its stone-on-stone aggregate structure and larger VMA. These findings highlight the trade-off between structural stiffness and deformation resistance in selecting wearing course mixtures for taxiway pavements and provide technical insights for mixture selection based on FAA performance requirements.

Keywords: *Taxiway pavement; Asphalt Concrete; Stone Mastic Asphalt; Marshall performance; FAA specifications*

Introduction

Taxiway pavements experience severe loading conditions characterized by low-speed aircraft movements, high wheel loads, and frequent braking and turning actions. These conditions generate substantial shear stresses within the pavement structure, increasing the risk of distress such as rutting, cracking, and raveling, which may compromise airport operational safety and pavement serviceability [1] [2] [3].

The wearing course of a taxiway plays a critical role in resisting these stresses while maintaining adequate surface durability and deformation resistance. Among commonly used Hot Mix Asphalt (HMA) mixtures, Asphalt Concrete (AC) and Stone Mastic Asphalt (SMA) exhibit distinct aggregate structures and mechanical behaviors. AC mixtures are characterized by dense gradation and continuous aggregate distribution, providing high stiffness and load-bearing capacity, whereas SMA mixtures rely on a stone-on-stone skeleton that enhances resistance to permanent deformation [4][5][6].

Despite the widespread use of both mixtures, comparative evaluations focusing on their Marshall performance under taxiway-specific FAA requirements remain limited. Most existing studies emphasize roadway applications or focus on individual mixture performance rather than direct comparison under identical design criteria. Consequently, the selection of optimal wearing course mixtures for taxiway pavements is often based on empirical preferences rather than performance-based evidence.

This study addresses this gap by systematically comparing the Marshall performance of AC and SMA mixtures designed in accordance with FAA specifications for taxiway pavements. The objective is to identify the relative advantages and limitations of each mixture with respect in stability, deformation resistance, and optimal asphalt content, thereby supporting performance-based mixture selection for airfield pavements.

Mixture gradation is the distribution of aggregate grain size in an asphalt mixture. Asphalt mixtures come in several types, including Hot Mix Asphalt, a mixture of coarse aggregate, fine aggregate, filler, and hot asphalt [7]. Optimal gradation and asphalt mixtures are able to withstand deformation due to the loads received because they determine the density, porosity, stability, and bonding ability *that* receives resistance to tensile and shear forces in the *patching area* [8]. There are 3 types of gradations, including:

a. Dense Gradation

In dense gradation, the distribution is continuous between coarse and fine aggregates so that they complement each other. Layers with dense gradation are generally used because they have high stability values, good load-bearing capacity, and can be used in any climate. However, dense gradation is susceptible to cracking or easy to deform because it is stiffer [4]. Dense gradation is often used to produce Asphalt Concrete (AC) wearing-course mixtures. Specifically, the dense gradation design for AC taxiway layers has been determined by *the Federal Aviation Administration* (FAA)-AC as shown in Table 1 below [2].

Table 1. AC Flexible Pavement Gradation

Sieve Size		***Percentage by Weight Passing Sieves***		
		Gradation 1	***Gradation 2***	***Gradation 3***
1”	25	100	-	-
¾“	19	90-100	100	-
½”	12.5	68-88	90-100	100
$^{3}/_{8}$"	9.5	60-82	72-88	90-100
No. 4	4.75	45-67	53-73	58-78
No. 8	2.36	32-54	38-60	40-60
No. 16	1.18	22-44	26-48	28-48
No. 30	0.600	15-35	18-38	18-38
No. 50	0.300	9-25	11-27	11-27
No. 100	0.150	6-18	6-18	6-18
No. 200	0.075	3-6	3-6	3-6
Minimum Voids in Mineral Aggregate (VMA)		**14.0**	**15.0**	**16.0**
Asphalt percent by total weight of mixture:				
Stone or gravel		4.5-7.0	5.0-7.5	5.5-8.0
Slag		5.0-7.5	6.5-9.5	7.0-10.5
Recommended Minimum Construction Lift Thickness		3”	2”	1.5”

b. Gradation Gap
The characteristics of this gradation consist of medium aggregate size, so that the gaps are filled by asphalt called *stone to stone.* Large aggregates help provide support and resistance to wear, thereby inhibiting cracks, especially at joints [6]. In general, this gradation variation has high stability, so it is good for use to resist deformation and as a wearing layer with high traffic loads. SMA gradation for *airport airside pavement* has been determined directly by the Federal Aviation Administration (FAA) SMA, as shown in Table 2 below[5].

Table 2. AC Flexible Pavement Gradation

Sieve Size		**Diabase**	**Columbus Granite**		**Ruby Granite**	**Gravel**	**Limestone**	**Target Design Range**
		Blend 2	Blend 2	Blend 1	Bland 8B	Blend 1	Blend 4	
25.4	1”	100	100	100	100	100	100	96-100
19.1	¾”	100	97	94	100	95	90	70-100
12.7	½”	95	68	62	69	65	64	45-85
9.5	3/8”	32	29	25	26	28	23	20-43
4.75	No. 4	22	24	18	20	22	12	16-30
2.38	No. 8	20	21	17	17	20	10	14-22
3.26	No. 10	18	19	13	15	16	9	12-19
0.74	No. 16	16	17	11	13	15	9	10-16
0.590	No. 30	13	15	10	12	13	8	9-14
0.427	No. 40	9.8	12.5	8.7	11	9.4	7.8	7-13

c. Open Gradation

This gradation consists of predominantly coarse aggregates with little or no filler. This creates relatively large pores between the aggregates, making them permeable to water. The primary purpose of selecting this type of gradation is to increase friction on the surface layer. However, the presence of less fine aggregate results in lower stability [9].

Both mixed gradations have been the subject of much research, but the focus has been on highway pavements rather than airport pavements. So that the explanation of the characteristics of airport pavement, especially taxiways with the dominance of heavy loads, low friction, and high shear tension, has not been conveyed perfectly [10]. In addition, researchers using Federal Aviation Administration (FAA) specifications are still limited in the mix design criteria and performance evaluation parameters for both HMA Concrete Asphalt (AC) and Stone Mastic Asphalt (SMA) mixtures. This limitation leads to a lack of a comprehensive technical basis for comparing the structural performance in terms of deformation resistance under taxiway operational conditions [11]. Therefore, there is a need for specialized research on the comparative evaluation of air conditioners and high schools, based on FAA specifications, to support the selection of the appropriate mixed gradation for taxiway pavement.

Marshall Performance

The Marshall method is a procedure for determining the characteristics of hot-mix *asphalt* (HMA) based on laboratory tests. The basic principle of the Marshall test is to determine the stability and flow of the test sample based on the AASTHO T-245 standard. In addition, the following parameters were obtained: *Voids in Mix* (VIM), *Voids in Mineral Aggregate* (VMA), and *Voids Filled with Asphalt* (VFA). Each parameter resulting from the Marshall test contributes to the performance of the asphalt mixture, as follows:

a. Stability aims to determine the resistance of the mixture, so the higher the value obtained, the higher the load the asphalt mixture can withstand. A high stability value indicates that the mixture can withstand permanent deformation (*rutting*) [12][13].
b. Flow indicates the strength of the mixture in resisting plastic deformation, so the higher the flow value, the softer the mixture will be, and vice versa. In general, flow functions to ensure the mixture is flexible enough to withstand deformation but remains rigid so that the surface does not easily become damaged [14].
c. *Voids in Mix* (VIM)
VIM, or air pore volume in the mixture, is the percentage of air voids in the asphalt mixture to the volume of the mixture after compaction. The main function of VIM is to indicate the remaining air space after the pounding process. If the VIM is low, it can cause bleeding, whereas a high VIM can reduce bearing capacity and accelerate asphalt aging [15][16].
d. *Voids in Mineral Aggregate* (VMA)
VMA or Voids in Mineral Aggregates is the percentage of voids between grains after compaction, including the space filled with asphalt, or can be called the total space between aggregates. A small VMA value indicates that the asphalt layer is thin so it is prone to cracking, whereas a high VMA indicates a mixture rich in asphalt so it tends to be resistant to aging [15][16].
e. *Voids Filled with Asphalt* (VFA)
VFA is the voids between aggregates filled with asphalt in a compacted mixture. The VFA value ensures that the asphalt has filled the voids, thereby increasing the durability of the mixture. If the Marshall analysis results show a low VFA value, the voids are not filled with asphalt, making them prone to cracking [15][16].

The Marshall test parameters are also used to determine the Optimum Asphalt Content (OAC) of the mixture. OAC is a crucial component because it influences the stability and voids of the mixture, both VIM and VMA. Especially for very heavy airport loads and frequent repeated loads, a detailed evaluation is needed to prevent *rutting* and surface damage [1]. So that the study contributes by showing a comparison of performance based on the analysis of marshall parameters as wearing coarse for taxiway.

Research Method

This study employed an experimental laboratory approach to evaluate the Marshall performance of Asphalt Concrete (AC) and Stone Mastic Asphalt (SMA) mixtures designed for taxiway wearing courses. The experimental program was conducted at the Transportation and Pavement Materials Laboratory, Institut Teknologi Sepuluh Nopember (ITS). Aggregates were obtained from an Asphalt Mixing Plant (AMP) operated by PT Tripalindo Paserpan, while PEN 60/70 asphalt binder supplied by Pertamina was used in all mixtures. The AC and SMA mixtures were designed according to FAA specifications using the Marshall mix design procedure. Marshall specimens were compacted with 75 blows per face for AC mixtures and 50 blows per face for SMA mixtures, reflecting their respective structural characteristics and FAA recommendations. For each asphalt content variation, three replicate specimens were prepared. Marshall testing was conducted in accordance with AASHTO T 245 and ASTM D6927 to determine stability, flow, VIM, VMA, VFA, Marshall Quotient, and Optimum Asphalt Content (OAC). The experimental results were analyzed comparatively to assess the influence of mixture gradation on load-bearing capacity and resistance to permanent deformation under taxiway loading conditions.

This method was chosen because it is listed in the Advisory Circulars AC 150/5370 and AC 150/5320, which explicitly establish the Marshall parameter as the main criterion in the design of the flexible airport pavement mixture. The parameters in the Marshall test are expected to reflect the balance between the structural bearing capacity of the mixture and the repeated loading of the warp. However, this method cannot present the actual field conditions, as there are external factors that influence. This study only provides a basic overview of the comparison of Marshall performance results between AC and SMA mixtures, so it is considered quite good using the specified method. The research steps are shown in Figure 1.

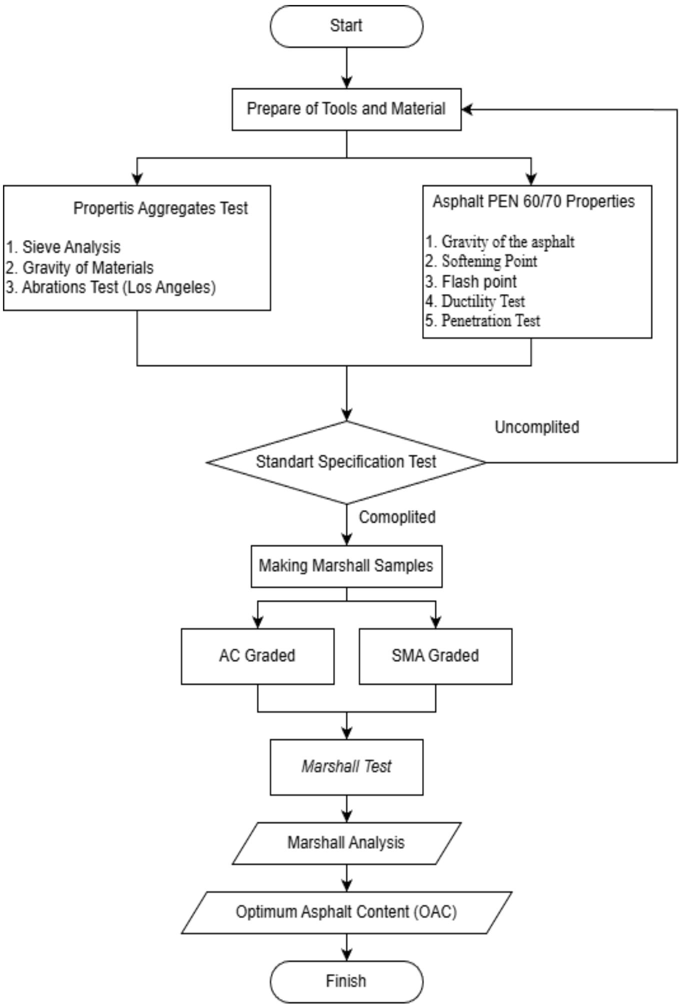

Figure 1. Chart Flow Method

Result and Discussion

The Marshall test results demonstrate distinct performance characteristics between AC and SMA mixtures. The AC mixture consistently exhibits higher Marshall stability values, indicating greater resistance to vertical loads. This behavior is attributed to the dense aggregate gradation, which promotes strong interlocking and higher internal friction. In contrast, the SMA mixture shows lower flow values across the tested asphalt contents, reflecting a stiffer mixture structure with enhanced resistance to permanent deformation. The stone-on-stone aggregate framework in SMA limits lateral aggregate movement, thereby improving rutting resistance despite lower stability values. The Optimum Asphalt Content (OAC) of the SMA mixture is higher than that of the AC mixture, primarily due to its larger VMA. Higher VMA values require additional asphalt binder to adequately fill voids and ensure durability. This finding is consistent with previous studies highlighting the binder demand of SMA mixtures due to their coarse aggregate skeleton [17][18]. Overall, the results indicate a trade-off between structural stiffness and deformation resistance. AC mixtures provide superior load-bearing capacity, while SMA mixtures offer enhanced resistance to permanent deformation, emphasizing the importance of performance-based mixture selection for taxiway pavements.

Table 3. Job Mix Design HMA Mix AC Gradation

Sieve size		**Gradation**		**NT**	**% Retained**	**Cumulative Retained**	**Factions**
mm	**inches**	**Lower**	**Upper**				
25.4	1”	0	0				
19.1	¾”	0	100	100			
12.7	½”	77	99	88	12	144	Course
9.5	3/8”	68	88	78	10	120	
4.75	No. 4	48	68	58	20	240	
2.38	No. 8	33	53	43	15	180	
3.26	No. 10						
0.74	No. 16	20	40	30	13	156	
0.590	No. 30	14	30	22	8	96	
0.427	No. 40						Fine
0.279	No. 50	9	21	15	7	84	
0.268	No. 80						
0.149	No. 100	6	16	11	4	48	
0.074	No. 200	3	6	4.5	6.5	78	
	PAN				4.5	54	*Filler*
					100	1200	

Table 4. Job Mix Design of SMA Gradation HMA Mixture

Sieve size		**Gradation**		**NT**	**% Retained**	**Cumulative Retained**	**Factions**
mm	**inches**	**Lower**	**Upper**				
25.4	1”	0	0	100		0	
19.1	¾”	96	100	100	0	0	
12.7	½”	70	100	95	5	60	Course
9.5	3/8”	45	85	65	30	360	
4.75	No. 4	20	43	28	37	444	
2.38	No. 8	16	30	22	6	72	
3.26	No. 10						
0.74	No. 16	14	22	20	2	24	
0.590	No. 30	12	19	16	4	48	
0.427	No. 40						Fine
0.279	No. 50	10	16	15	1	12	
0.268	No. 80						
0.149	No. 100	9	14	13	2	24	
0.074	No. 200	7	13	9.4	3.6	43.2	
	PAN				9.4	112.8	*Filler*
					100	1200	

The marshalling test was conducted to determine the optimum asphalt content (OAC) of the mixture. The results of the marshalling test on variations in AC and SMA gradations are shown in Tables 6 and 7.

Table 5. Marshall Performance Results of AC Gradation HMA Mixture

Marshall performance	**Asphalt Content (%)**					**Standard**
	4.7	**5.2**	**5.7**	**6.2**	**6.7**	
Stability	1820.98	2319.51	2121.08	1844.43	1764.86	Min. 800 kg
Flow	3.37	3.35	3.47	3.89	3.92	2-4 mm
MQ	541.45	698.1	610.94	476.23	449.82	Min. 250 kg/mm
VIM	5.07	3.74	2.16	1.18	1.08	3-5%
VMA	15.18	15.01	14.64	14.8	15.72	Min. 15%
VFA	66.69	75.07	85.31	92.07	93.15	Min. 65%

Table 6. Marshall Performance Results of SMA Gradation HMA Mixture `1

Marshall performance	Asphalt Content (%)					Standard
	5	5.5	6	6.5	7	
Stability	1015.6	1168.36	1052.45	957.45	874.07	Min. 600 kg
Flow	3.15	3.25	3.29	3.3	3.48	2-4.5 mm
MQ	323.97	361.17	320.23	292.07	255.79	Min. 250 kg/mm
VIM	6.42	5.46	4.26	2.68	2.12	4-5%
VMA	17.22	17.37	17.31	16.96	17.47	Min. 17%
VFA	62.76	68.57	75.43	84.26	87.86	Min. 65%

1. Stability

Figure 2 shows that the stability values of both AC and SMA mixtures increased with asphalt content up to an optimum point and subsequently decreased as the asphalt content continued to increase. However, the average AC mixture stability is higher than that of the SMA mixture. This is because the density between aggregates in the AC mixture can withstand better durability, cohesion, and density, while the SMA mixture is predominantly coarse aggregate as a constituent material, so that it cannot withstand the maximum static load optimally. So it can be concluded that the AC gradation mixture is stronger in withstanding loads than the SMA gradation mixture.

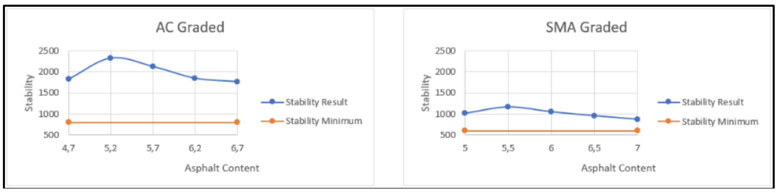

Figure 2. Marshall Performance Graph – Stability

2. Flow

Figure 3 shows that the flow values of the AC- and SMA-graded mixtures increase with increasing asphalt content and are within the minimum and maximum limits specified by the FAA. This increase indicates that the mixture will be more plastic and more easily deformed as the asphalt content increases. The average flow value of the AC-graded mixture is higher than that of the FAA-graded mixture. This indicates that the AC graded layer is more easily deformed because the aggregate framework is less strong and the forming material is predominantly fine aggregate, while the aggregate of the SMA graded mixture tends to be coarse, creating a stiffer layer framework that forms a stone-to-stone.

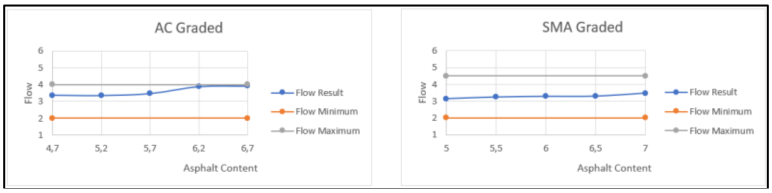

Figure 3. Marshall – Flow Performance Graph

3. Marshall Quotient (MQ)

In Figure 4, the Marshall Quotient (MQ) increases up to the optimum point, indicating that at this condition both the Asphalt Concrete (AC) and Stone Mastic Asphalt (SMA) mixtures exhibit an ideal balance between stiffness and resistance to deformation [19]. However, the average flow values of the SMA mixture are lower, suggesting that it is more flexible than the dense-graded AC mixture [20].

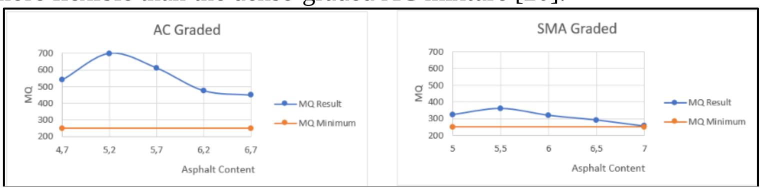

Figure 4. Marshall Performance Graph - Marshall Quotient

4. Void In Mix (VIM)

In Figure 5, both AC and SMA mixtures show a decrease in VIM value along with the increase in asphalt content, this is because the higher the asphalt content in the mixture, the thinner the air cavity due to being filled by the asphalt film [21]. The VIM value of the Asphalt Concrete (AC) mixture is lower than that of the Stone Mastic Asphalt (SMA) mixture because fine aggregates and filler in AC effectively fill the voids between coarse aggregates, allowing a higher level of compaction to be achieved after densification. In contrast, the SMA mixture is characterized by a stone-to-stone contact mechanism, which forms a coarse aggregate skeleton with relatively larger inter-aggregate voids [22].

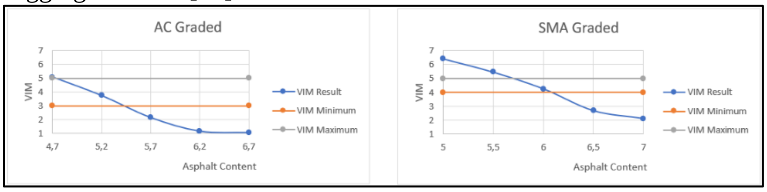

Figure 5. Marshall Performance Graph – Void In Mix (VIM)

5. Void in Mineral Asphalt (VMA)

Based on figure 6 shows that the curve initially decreases up to a certain point and then increases again with the increase in asphalt content. The decrease in VMA was caused by the increase in asphalt content causing the voids between aggregate grains to be filled to the minimum point that can be achieved, while the subsequent increase was due to the addition of asphalt content which resulted in changes to GMM and GMB so that VMA was non-linear [23][24]. The VMA value of the SMA mixture is higher than that of the AC mixture. This is because AC has a dense-graded aggregate structure, in which fine aggregates and filler effectively fill the voids between coarse aggregates, forming a compact structure and resulting in a relatively lower VMA. In contrast, SMA is designed with a gap-graded aggregate structure and a stone-to-stone contact mechanism, whereby coarse aggregates form the primary load-bearing skeleton with limited fine aggregate content [25].

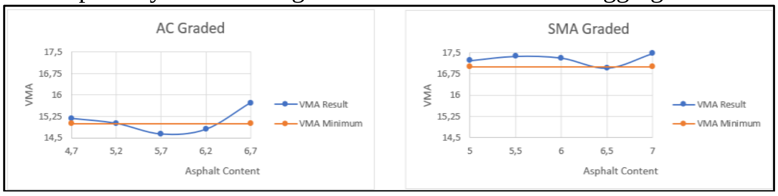

Figure 6. Marshall Performance Graph – Void in Mineral Aggregate (VMA)

6. Void Filled with Asphalt (VFA)

As shown in Figure 7, the AC and SMA gradation mixtures show an increase in VFA values along with the increase in asphalt content. VFA indicates the percentage of voids between aggregates (VMA) that are effectively filled with asphalt, so that if the volume of asphalt content increases, the opportunity for effective asphalt to fill the voids increases, resulting in an increase in the VFA value.

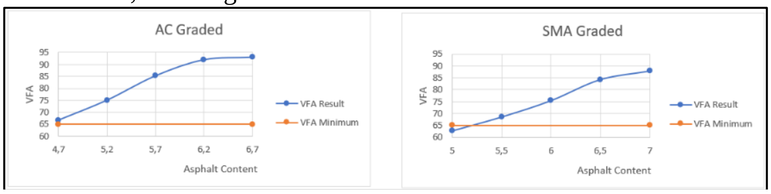

Figure 7. Marshall Performance Graph – Void Filled with Asphalt (VFA)

Optimum Asphalt Content (OAC)

Based on the marshall characteristic analysis, data was obtained to determine the Optimum Asphalt Content (OAC) of the HMA mixture of each gradation. The asphalt content value that meets all Marshall performance is between 4.8% and 5.2%, so the OAC value of the AC graded asphalt mixture is 5.0% according to the following Figure. Meanwhile, the SMA gradation mixture shows that the asphalt content that meets all Marshall performance is in the range of 4.7% to 6.1%, so the OAC value is 6.9% according to the following Figure 8.

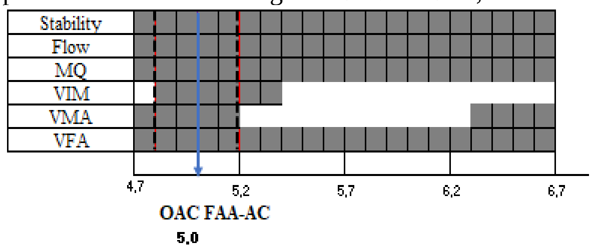

Figure 8. AC Mixed KAO Analysis Graph

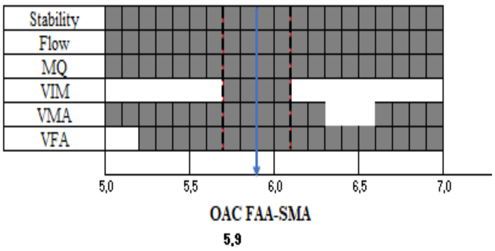

Figure 9. Mixed KAO Analysis Graph for SMA

The difference in KAO between AC and SMA gradations is caused by the Void in Mix (VIM) of each mixture. The higher the VIM, the greater the optimum asphalt content required to fill gaps and bind the aggregate. In addition, mixtures with SMA gradations are more porous so they require more asphalt to prevent loss of aggregate grains and endurance in receiving loads [17][18].

Conclusion

This study presents a comparative evaluation of the Marshall performance of Asphalt Concrete (AC) and Stone Mastic Asphalt (SMA) mixtures designed in accordance with Federal Aviation Administration (FAA) specifications for airport taxiway applications. Based on Marshall parameter assessments, the results indicate that the AC mixture exhibits higher Marshall stability, reflecting greater stiffness and superior structural load-bearing capacity. In contrast, the SMA mixture exhibits lower flow values and higher Voids in Mineral Aggregate (VMA), indicating improved resistance to permanent deformation and enhanced durability due to the stone-to-stone aggregate contact mechanism. These findings confirm that both AC and SMA mixtures offer distinct performance advantages, and their selection should therefore align with the specific operational requirements and design objectives of taxiway pavements. Accordingly, the outcomes of this study provide a performance-based technical reference to support decision-making in selecting taxiway wearing course mixtures, enabling planners and practitioners to tailor material choices to aircraft loading conditions, operational demands, and long-term pavement performance strategies.

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