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A comprehensive analysis of warm mix Asphalt with additives and RTFOT-modified Bitumen

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ABSTRACT

This study investigates the influence of various warm mix asphalt (WMA) additives, including Sasobit, Evotherm, and Advera, on the properties of asphalt mixtures. Additionally, it compares the performance of these WMAs with traditional hot mix asphalt (HMA) using two types of bitumen, VG30 and PMB40. The research method includes a systematic analysis of Marshall Stability, Marshall Flow Value, and other parameters across different bitumen contents (4%, 4.5%, 5%, and 5.5%) with and without additives. Additionally, it explores the utilization of HMA and WMA with RTFOT-modified bitumen, emphasizing potential enhancements in strength and durability. The results reveal that Sasobit is the most effective additive, consistently improving both Marshall Stability 50% higher and Flow Value 30% higher in comparison of various asphalt mixes. Evotherm primarily enhances stability 40% Higher compare to Sasobit, while Advera exhibits mixed effects. The findings emphasize Sasobit's significant role in enhancing asphalt performance, especially in achieving a balance between stability and flow resistance. This research contributes valuable insights into optimizing asphalt mix designs, particularly in the context of sustainable and energy-efficient paving technologies & provide guidance for selecting appropriate additives to meet specific project requirements, promoting the development of eco-friendly and durable asphalt pavements.

Keywords: Asphalt Aging, Bitumen Additives, Bitumen Performance, hot mix asphalt (HMA), warm mix asphalt (WMA)

INTRODUCTION

Developing a sustainable road network presents the challenge of aligning projects with principles of sustainable development. To address this, the road industry seeks eco-friendly, energy-efficient, and cost-effective alternatives for road construction and maintenance. The current reliance on naturally sourced aggregates from quarries in road construction leads to deforestation and pollution, causing environmental harm and raising global concerns.[1] Ensuring adequate reserves to meet present and future aggregate demands is vital for resource sustainability, as these resources are non-renewable and depleting rapidly. Simultaneously, fluctuating asphalt binder prices underscore the need for research into alternate technologies to reduce virgin asphalt binder consumption in rehabilitation strategies. This effort aims to lower overall construction and maintenance costs.[2] Introduced in 1995 by pavement communities in Europe, Warm Mix Asphalt (WMA) technology is attracting worldwide attention due to its multiple advantages over traditional asphalt concrete mixtures.[3]

WMA technology is rapidly emerging as a transformative force in asphalt mixture production. It enables the mixing and compaction of asphalt at temperatures 30°C to 40°C lower than those required for Hot Mix Asphalt (HMA). This innovation can cut production temperatures by up to 30 percent, with WMA mixes

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produced around 120ºC or lower compared to the usual 150ºC for hot asphalt mixes.[4] The popularity of WMA is on the rise due to its ecological benefits while maintaining asphalt quality. WMA is manufactured at much lower temperatures (slightly above 100°C), resulting in reduced energy consumption, fewer emissions, slower aging effects, lower mixing and compaction temperatures, better construction conditions in cooler weather, and improved mixture manoeuvrability.[5]

Objectives of the research

The primary research objectives are as follows

- Investigate the influence of material properties on the performance of Warm Mix Asphalt (WMA).
- Create samples of Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA) by incorporating additives such as Sasobit, Evotherm, and Advera.
- Analyse the outcomes obtained from bitumen samples of both HMA and WMA for Marshall Properties, employing the Digital Marshall Apparatus.
- Compare the Marshall Properties of the samples prepared with HMA and WMA to assess any differences in their characteristics.

Literature Review

Stringent environmental regulations have prompted the asphalt industry to seek energy-saving and eco-friendly alternatives. Warm Mix Asphalt (WMA) technology, achieved through the reduction of asphalt binder viscosity, presents a promising solution.[6] Studies have assessed the effectiveness of WMA additives such as Sasobit, Evotherm, and Advera synthetic zeolite in enhancing asphalt mixture properties and overall performance.[7] Additionally, innovative foaming chemical additives have been developed for both Warm Mix Asphalt (WMA) and Half Warm Mix Asphalt (HWA). WMA has demonstrated improved resistance to moisture susceptibility, resulting in substantial energy savings.[8] Research has also investigated the performance of Evotherm 3G as a compaction technology additive and its impact on moisture resistance [9]. MeadWestvaco has introduced various versions of Evotherm warm mix asphalt technologies, significantly reducing production temperatures.[10] Furthermore, studies have explored the use of polymer-modified bitumen and crumb rubber-modified bitumen in warm mixes with Sasobit, achieving higher density and stability values at lower production temperatures.[11] In India, the road construction sector, primarily reliant on energy-intensive Hot Mix Asphalt (HMA), is actively exploring WMA technologies to reduce energy consumption and minimize environmental impact.[12] Additionally, research has emphasized the importance of addressing bitumen aging in asphalt pavement and highlighted the potential benefits of RTFOT-modified bitumen in enhancing strength and durability.[13]

Material & Methodology

Material

Bitumen: In our current research, we are working with two types of bitumen: unmodified bitumen, specifically VG30, and modified bitumen, designated as PMB40. Before proceeding to prepare the Marshall Mold, we carried out testing to assess the physical properties of both the bitumen and the bitumen modified through the Rolling Thin Film Oven Test (RTFOT).

Coarse Aggregate: In our current research, we're using 10mm (36%) and 6mm (34%) coarse aggregates for Bituminous Concrete Layer-I. We have determined this gradation through sieve analysis to achieve the desired mix composition.

Fine Aggregate: In our current research, we incorporated stone dust with a particle size of 2.36mm as a fine aggregate. This stone dust constitutes 28% of the total weight of the aggregate in the mix.

Filler: In our present research, we employed Portland Cement (Grade 43) as a filler, comprising 2% of the total weight of the aggregate in the mixture.

Additives: In the current study, we incorporated three additives: Sasobit at a rate of 2.5%, Advera at 0.25%, and Evotherm at 0.7%.

Methodology

The initial phase of this research methodology involves assessing the properties of raw materials such as gravel, liquid asphalt (VG30 and PMB40), and additives (Sasobit, Evotherm, and Advera). The subsequent step is to formulate hot mix and warm mix designs at various bitumen percentages (4%, 4.5%, 5%, and 5.5%) using the available components and determining the asphalt content for each configuration. The third stage entails subjecting the molds to testing using a Marshall apparatus to obtain data on Marshall stability, Marshall flow value, and other relevant Marshall parameters. The fourth phase involves a comparative analysis of the Marshall properties between the warm mix and hot mix designs.

In the Warm Mix Asphalt (WMA) process, virgin aggregates are sieved, blended to meet specified gradation, heated to 110°C, mixed with liquid asphalt, and hand-mixed until aggregates are fully coated. For Hot Mix Asphalt (HMA), virgin aggregates and filler are sieved, combined for gradation, heated to 160°C, mixed with hot bitumen, and manually mixed until proper coating is achieved. Both methods involve different bitumen percentages, and Marshall specimens are tested after compaction at 100°C.[14,15]

Gradation of Aggregate

The aggregates for BC mixes are sorted following MORTH (2013) guidelines for Grading-I in bituminous concrete. We manually determine the aggregate grading without utilizing a sieve shaker. We select the aggregate grading that aligns with the MoRTH 2013 specifications for the midpoint gradation in Grading-I of Bituminous Mix. This data is presented in Table 1.[16, 17]

Table 1. Gradation of Aggregate

Sieve Size (mm)	Weight Retained (gms)	Weight Retained (%)	Cumulative Weight Retained (%)	Cumulative % by Weight of total Aggregate Passing Obtained values	Cumulative % by Weight of total Aggregate Passing (MoRT&H, 2013)	
					Lower Limit	Upper Limit
19	00	00	00	100	100	100
13.2	470	9.4	9.4	90.6	79	100
9.5	380	7.6	16	84	70	88

4.75	1140	22.8	38.8	61.2	53	71
2.36	490	9.8	47.6	52.4	42	58
1.18	280	5.6	53.2	46.8	34	48
0.600	580	11.6	64.8	35.2	26	38
0.300	490	9.8	73.6	26.4	18	28
0.150	560	11.2	84.2	15.2	12	20
0.075	480	9.6	94.4	5.6	4	10

Table. 2 Grading applied to the Filler Material

S. No.	IS Sieve (mm)	Cumulative % passing by weight of total aggregate (Obtained Value)	Cumulative % passing by weight of total aggregate (MoRTH, 2013)
1	0.6	100	100
2	0.3	100	95-100
3	0.075	98	85-100

Results

Physical Properties of Bitumen

In the presented research, essential tests were conducted on the PMB40 and VG30 binders. These selections were based on a thorough review of existing literature. One modified binder (PMB40) and one unmodified binder (VG30) were chosen for the study. Notably, all fundamental properties of both PMB40 and VG30 binders were found to be within acceptable limits. These limits adhere to the specifications outlined by MoRTH, incorporating the standards IRC SP: 53, IS 73, and the guidelines governing the use of modified bitumen in road construction. Additionally, the table provided showcases the outcomes from the RTFO abstract Bitumen and facilitates a comparison of its properties.[18,19]

Table 3. Physical Characteristics of VG30 Bitumen Employed in Bituminous Concrete[13]

Properties	Test Method	VG 30	RTFOT Modified VG 30	MoRT&H Specification
Penetration (100 gram, 5second at 25ºC) (1/10th of mm	IS 1203 [31]	55	63	50-70
Softening Point ºC (Ring and Ball Apparatus), Minimum	IS 1203 [31]	55	68	60
Ductility at 27 ºC (5cm/ minute pull), cm	IS 1208 [28]	56	72	+50
Specific Gravity	IS 1202 [25]	1.0	1.03	1.01
Flashpoint, ˚C, minimum	IS 1209 [30]	235	251	220
Fire point, ºC, minimum	IS 1209 [30]	266	258	247

The subsequent table presents the physical characteristics of PMB 40 modified bitumen in comparison to both regular bitumen and bitumen modified through RTFOT. Table 4, on the other hand, displays the parameters associated with VG30 bitumen, encompassing both the modified and RTFOT-modified variants.[18,19]

Table.4 Physical Characteristics of PMB40 Bitumen Employed in Bituminous Concrete[13]

Properties	Test Method	PMB 40	RTFOT Modified PMB 40	MoRT&H Specification
Penetration (100 gram, 5second at 25ºC) (1/10th of mm	IS 1203 [31]	44	47	30 to50
Softening Point ºC (Ring and Ball Apparatus), minimum	IS 1205 [31]	58	69	60
Ductility at 27 ºC (5cm/ minute pull), cm	IS 1208 [28]	63	68	+50
Specific Gravity	IS 1202 [25]	0.92	1.03	1.01
Flashpoint, ˚C, minimum	IS 1209 [30]	265	231	220
Fire point, ºC, minimum	IS 1209 [30]	275	239	247

Physical Properties of AGGREGATE

Subsequent to the bitumen testing, the aggregates employed in the construction of BC mixes underwent testing. The results of these aggregate laboratory tests are presented in Table 5. Various tests, including aggregate impact and abrasion value assessments, were conducted, and the outcomes were in alignment with the MoRTH (2013) specifications. The aggregate properties findings are outlined in Table 5. Furthermore, Table 6 provides a compilation of the physical properties pertaining to the filler material.[15,16,37]

Table 5 Physical Characteristics of Aggregate (Coarse & Fine Aggregate)[37]

S. No.	Properties	Test Method	Natural Aggregate	MoRTH Specification (2013)
Coarse Aggregate				
1.	Aggregate Impact Value	IS:2386 (IV) [21]	17%	Max 24%
2.	Los Angeles Abrasion Value	IS:2386 (IV) [21]	23.15%	Max 30%
3.	Water Absorption Value	IS:2386 (III) [22]	1.013	Max 2%
4.	Specific Gravity	IS:2386 (III) [22]	2.63For10mm, 2.71 For 6mm, 2.86 For Stone Dust	2.5-3.0
5.	Combined Flakiness and Elongation Index	IS:2386 (I) [20]	29.17%	Max 35%
6.	Aggregate Crushing Value	IS:2386 (IV) [21]	35%	Max 45%
Fine Aggregate				
1.	Fineness Modulus	IS 383:2016 [36]	1.44%	2%
2.	Water Absorption	IS 383:2016 [36]	1.18%.	1.67%
3.	Specific Gravity	IS 383:2016 [36]	2.24	2.63
4.	Density	IS 383:2016 [36]	2589 Kg/m^3	2640 Kg/m^3

Table.6 Physical Characteristics of Filler (Cement)[38]

S. No.	Property	Test Method	Res ults	Standard Value
1	Normal Consistency	IS 4031 (Part IV) [33]	33,4	33-35 mm
2	Initial Setting Time	IS 4031 (Part V) [34]	40.5	≥ 45 min
3	Final Setting Time	IS 4031 (Part V) [34]	360	≤ 375 min
4	Compressive Strength at 28 days	IS 4031 (Part VI) [35]	15.2 6	≥ 19 Mpa

Marshall Properties of HMA

In the provided table, we present the Marshall Properties of Hot Mix Bitumen. We have utilized two types of bitumen, VG30 and PMB 40, and experimented with various percentages (4%, 4.5%, 5%, 5.5%) relative to a total aggregate weight of 1200 grams. Additionally, we incorporated three additives—Sasobit (2.5%), Advera (0.25%), and Evotherm (0.7%)—with their respective weight configurations detailed in Table 7. Table.8 displays the resulting Marshall Properties of HMA.

Table.7 Weight of Additives

Admixture & Their Mixing Percentage	Weight of Admixture (As Per the Weight of Bitumen) in gram	Weight of Bitumen After reducing the weight of Admixture in gram
Evotherm (0.7%)	4%= 0.34	47.66
	4.5 % = 0.38	53.62
	5% = 0.42	59.58
	5.5 % = 0.46	65.64
Advera (0.25%)	4%= 0.12	47.8
	4.5 % = 0.14	53.8
	5% = 0.15	59.9
	5.5 % = 0.17	65.8
Sasobit (2.5%)	4%= 1.2	46.8
	4.5 % = 1.4	52.6
	5% = 1.5	58.5
	5.5 % = 1.65	64.3

Table 8 Marshall Properties of HMA VG30

Unmodified VG30				
Properties	**Bitumen Content by Weight of Aggregate**			
	4%	4.5%	5%	5.5%
Marshall Stability	7.18	7.52	8.10	8.24
Marshall Flow Value	2.81	2.94	3.06	3.25
Bulk Density	2.65	2.70	2.79	2.87
Volume of Voids	2.40	2.48	2.64	2.70
Voids in Mineral aggregate	17.10	18.25	20.10	22.15
Voids Filled with Bitumen	65.66	67	70.81	73.10
Marshall Quotient	2.55	2.56	2.64	2.54
RTFOT Modified VG30				
Marshall Stability	8.15	8.58	8.9	9.20
Marshall Flow Value	3.11	3.34	3.60	4.00
Bulk Density	3.67	4.26	4.51	4.94
Volume of Voids	2.40	2.78	3.14	3.70
Voids in Mineral aggregate	24.01	27.35	29.40	31.20
Voids Filled with Bitumen	71.32	71.92	72.81	73.70
Marshall Quotient	2.62	2.56	2.47	2.3
VG30 + Sasobit (2.5%)				
Marshall Stability	11.61	12.15	12.99	13.21
Marshall Flow Value	2.96	3.24	3.96	4.18
Bulk Density	1.70	2.06	2.66	3.60
Volume of Voids	2.10	2.44	2.94	3.20
Voids in Mineral aggregate	12.41	12.80	13.20	13.75
Voids Filled with Bitumen	68.66	69.71	72.22	74.65
Marshall Quotient	3.92	3.75	3.28	3.16
VG30 + Evotherm (0.75%)				
Marshall Stability	10.11	10.65	11.29	11.81
Marshall Flow Value	2.11	2.64	3.19	3.48
Bulk Density	2.09	2.56	2.81	3.25
Volume of Voids	2.43	2.85	3.29	3.65
Voids in Mineral aggregate	11.87	12.65	13.26	13.50
Voids Filled with Bitumen	67.31	68.22	70.93	72.89
Marshall Quotient	4.79	4.03	3.53	3.39
VG30 + Advera (0.25%)				
Marshall Stability	13.41	13.81	14.25	15
Marshall Flow Value	3.31	3.81	4.21	4.81
Bulk Density	1.91	2.21	2.56	3.16
Volume of Voids	3.41	4.21	4.51	5.30
Voids in Mineral aggregate	14.23	15.40	16.20	17.10
Voids Filled with Bitumen	68	70	72.44	75.19
Marshall Quotient	4.02	3.62	3.38	3.11

In the provided table, we have presented the Marshall Properties specifically for PMB 40 bitumen. This data is outlined in Table 9, offering insights into the properties of PMB 40

Table 9 Marshall Properties of HMA PMB40

Unmodified PMB40				
Properties	Bitumen Content by Weight of Aggregate (PMB40)			
	4%	4.5%	5%	5.5%
Marshall Stability	11.33	12.08	12,65	13.02
Marshall Flow Value	2.91	3.24	3.60	4.00
Bulk Density	2.35	2.60	2.89	3.17
Volume of Voids	2.40	2.78	3.14	3.70
Voids in Mineral aggregate	16.10	16.85	18.10	19.15
Voids Filled with Bitumen	66.66	68	72.81	74.10
Marshall Quotient	3.89	3.95	3.51	3.25
RTFOT Modified PMB40				
Marshall Stability	13.15	13.80	14,20	14.52
Marshall Flow Value	3.20	3.54	3.780	4.10
Bulk Density	3.67	4.26	4.51	4.94
Volume of Voids	2.40	2.78	3.14	3.70
Voids in Mineral aggregate	24.01	27.35	29.40	31.20

Voids Filled with Bitumen	71.32	71.92	72.81	73.70
Marshall Quotient	2.62	2.56	2.47	2.3
PMB40 + Sasobit (2.5%)				
Marshall Stability	11.81	12.25	13.49	13.91
Marshall Flow Value	3.10	3.55	3.79	4.18
Bulk Density	1.90	2.26	2.76	2.90
Volume of Voids	2.42	2.84	3.19	3.50
Voids in Mineral aggregate	12.61	12.90	13.50	13.95
Voids Filled with Bitumen	69.66	71.47	73.43	75.55
Marshall Quotient	3.80	3.45	3.55	3.32
PMB40 + Evotherm (0.75%)				
Marshall Stability	13.24	13.55	14.19	14.31
Marshall Flow Value	3.25	3.84	4.19	4.68
Bulk Density	2.35	2.76	3.26	3.89
Volume of Voids	2.85	3.15	3.69	4.15
Voids in Mineral aggregate	12.77	13.15	13.66	14.23
Voids Filled with Bitumen	71.34	72.55	74.13	75.19
Marshall Quotient	4.07	3.52	3.38	3.05
PMB40 + Advera (0.25%)				
Marshall Stability	12.31	12.45	13.19	13.41
Marshall Flow Value	2.91	3.21	3.50	3.90
Bulk Density	1.80	2.16	2.66	2.80
Volume of Voids	2.91	3.2	3.43	3.80
Voids in Mineral aggregate	14.31	14.50	15	15.30
Voids Filled with Bitumen	71	73	74	76.65
Marshall Quotient	4.23	3.87	3.76	3.43

Marshall Properties of WMA

In the provided table, we present the Marshall Properties of Warm Mix Bitumen. We have utilized two types of bitumen, VG30 and PMB 40, and experimented with various percentages (4%, 4.5%, 5%, 5.5%) relative to a total aggregate weight of 1200 grams. Additionally, we incorporated three additives—Sasobit (2.5%), Advera (0.25%), and Evotherm (0.7%). Table 10 and table 11 displays the resulting Marshall Properties of WMA.

Table 10 Marshall Properties of WMA VG30

Unmodified VG30				
Properties	**Bitumen Content by Weight of Aggregate**			
	4%	4.5%	5%	5.5%
Marshall Stability	9.45	10.50	11.51	13.90
Marshall Flow Value	2.4	2.92	3.20	3.49
Bulk Density	1.86	2.10	2.29	2.45
Volume of Voids	3.71	4.58	4.81	5.10
Voids in Mineral aggregate	13.41	14.20	17.52	18.05
Voids Filled with Bitumen	68.49	72.45	76.43	78.25
Marshall Quotient	5.14	4.34	4.25	4.04
RTFOT Modified VG30				
Marshall Stability	9.60	11.15	12.71	14.00
Marshall Flow Value	3.20	3.58	3.78	4.20
Bulk Density	2.50	2.68	2.82	2.96
Volume of Voids	3.32	3.89	4.15	4.35
Voids in Mineral aggregate	13.90	14.70	17.90	18.60
Voids Filled with Bitumen	70.10	74.20	77.15	80
Marshall Quotient	3.00	3.11	3.36	3.33
VG30 + Sasobit (2.5%)				
Marshall Stability	11.81	12.39	13.19	13.63
Marshall Flow Value	3.11	3.44	3.69	4.38
Bulk Density	1.93	2.36	2.86	3.12
Volume of Voids	3.13	3.46	3.56	3.90
Voids in Mineral aggregate	12.71	12.88	13.32	13.85
Voids Filled with Bitumen	69.76	71.11	73.76	75.9
Marshall Quotient	3.79	3.60	3.57	3.11
VG30 + Evotherm (0.75%)				
Marshall Stability	11.11	11.55	12.39	12.81
Marshall Flow Value	2.31	2.94	3.29	3.81
Bulk Density	2.19	2.66	3.11	3.35
Volume of Voids	2.65	2.95	3.39	3.75
Voids in Mineral aggregate	12.27	12.55	13.16	13.33
Voids Filled with Bitumen	69.31	71.22	72.93	73.89
Marshall Quotient	4.8	3.95	3.76	3.36
VG30 + Advera (0.25%)				
Marshall Stability	13.61	14.10	14.70	15.61
Marshall Flow Value	3.51	4.10	4.31	4.89
Bulk Density	2.10	2.51	2.89	3.15
Volume of Voids	3.60	4.22	4.65	5.7
Voids in Mineral aggregate	14.23	15.40	16.20	17.10
Voids Filled with Bitumen	70	71.32	73.65	76
Marshall Quotient	3.88	3.43	3.58	3.19

Table 11 Marshall Properties of HMA PMB40

Unmodified PMB40				
Properties	Bitumen Content by Weight of Aggregate (PMB40)			
	4%	4.5%	5%	5.5%
Marshall Stability	12.35	12.70	13.60	14.10
Marshall Flow Value	3.2	3.5	3.7	4.02
Bulk Density	2.35	2.46	2.53	2.69
Volume of Voids	4.28	4.72	5.20	5.53
Voids in Mineral aggregate	15.02	15.64	15.99	16.47
Voids Filled with Bitumen	71.20	77.78	84.27	87.16
Marshall Quotient	2.95	3	3.38	3.45
RTFOT Modified PMB40				
Marshall Stability	12.60	12.85	13.90	14.30
Marshall Flow Value	3.4	3.7	4.08	4.15
Bulk Density	2.8	3.75	3.9	4.19
Volume of Voids	3.36	3,89	4,34	4,85
Voids in Mineral aggregate	14.42	15.10	15.90	16.20
Voids Filled with Bitumen	72	74.58	76.90	78.10
Marshall Quotient	3.70	3.47	3.4	3.44
PMB40 + Sasobit (2.5%)				

Marshall Stability	12.11	12.55	13.69	14.11
Marshall Flow Value	3.11	3.64	3.99	4.18
Bulk Density	2.19	2.46	3.11	3.65
Volume of Voids	2.65	2.95	3.39	3.75
Voids in Mineral aggregate	12.87	13.15	13.66	14.23
Voids Filled with Bitumen	70.31	72.22	73.93	75.89
Marshall Quotient	3.89	3.44	3.43	3.37
PMB40 + Evotherm (0.75%)				
Marshall Stability	13.41	13.78	14.36	14.65
Marshall Flow Value	3.38	3.98	4.21	4.78
Bulk Density	2.49	2.90	3.36	4.10
Volume of Voids	2.95	3.15	3.79	4.23
Voids in Mineral aggregate	12.87	13.45	13.76	14.43
Voids Filled with Bitumen	72.41	72.32	74.23	75.39
Marshall Quotient	3.96	3.46	3.41	3.06
PMB40 + Advera (0.25%)				
Marshall Stability	12.61	13.25	13.79	14.21
Marshall Flow Value	3.11	3.44	3.69	3.98
Bulk Density	1.90	2.26	2.76	2.90
Volume of Voids	3.10	3.24	3.49	3.90
Voids in Mineral aggregate	14.41	14.70	15.20	15.45
Voids Filled with Bitumen	71	73	74	76.65
Marshall Quotient	4.23	3.87	3.76	3.43

Comparison between HMA & WMA

Comparison between HMA & WMA VG30

Table 12 presents a comparison of the compression properties of HMA and WMA. The table illustrates the differences in Marshall Stability and Marshall Flow Value between HMA (standard VG30 and RTFOT VG30) and WMA (standard VG30 and RTFOT VG30).

Table 12 Comparison Between Marshall Properties of HMA and WMA VG30

Marshall Stability						
S. No.	**Properties**	**Bitumen Content (%)**	**Different types of Bitumen**			
			HMA VG 30	**HMA RTFOT VG30**	**WMA VG 30**	**WMA RTFOT VG30**
1	**Marshall Stability**	4.0%	7.18	8.15	9.45	9.60
2		4.5%	7.52	8.58	10.50	11.15
3		5.0%	8.10	8.9	11.51	12.71
4		5.5%	8.24	9.20	13.90	14.0
Marshall Flow Value						
1	**Marshall Flow Value**	4.0%	2.81	3.11	2.4	3.20
2		4.5%	2.94	3.34	2.92	3.58
3		5.0%	3.06	3.6	3.2	3.78
4		5.5%	3.25	4.00	3.49	4.20

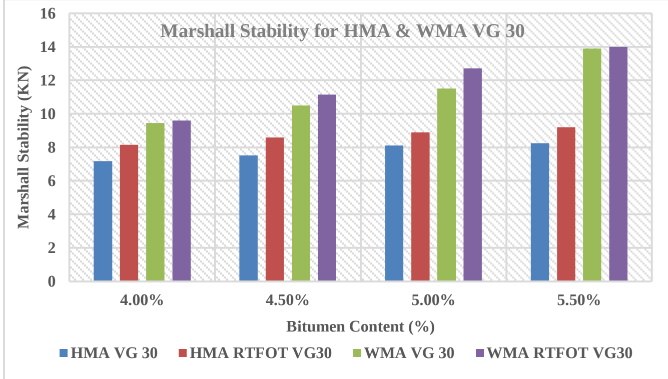

Figure 1 Marshall Stability Comparison For Hma & WMA (VG 30 & RTFOT VG30)

The figure 1 representing Marshall Stability shows a consistent increase as the bitumen content rises from 4.0% to 5.5% for both HMA and WMA. However, HMA RTFOT VG 30 consistently exhibits higher Marshall Stability values than HMA VG 30 across all bitumen content percentages. Among the WMAs, WMA RTFOT VG 30 demonstrates the highest Marshall Stability values, especially at higher bitumen percentages. This indicates that the warm mix technology with RTFOT-modified bitumen enhances Marshall Stability compared to conventional HMA and WMA with VG 30 bitumen.

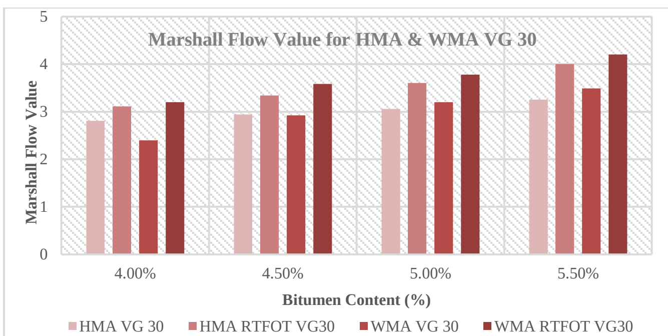

Figure 2 Marshall Flow Value Comparison For HMA & WMA (VG 30 & RTFOT VG30)

The figure 2 representing Marshall Flow Value also shows an increase as the bitumen content increases from 4.0% to 5.5% for both HMA and WMA. Similar to Marshall Stability, HMA RTFOT VG 30 consistently exhibits higher Marshall Flow Values than HMA VG 30 across all bitumen content percentages. Among the WMAs, WMA RTFOT VG 30 consistently shows higher Marshall Flow Values, particularly at higher bitumen percentages. This suggests that the warm mix technology with RTFOT-modified bitumen provides better resistance to flow deformation compared to conventional HMA and WMA with VG 30 bitumen.

Comparison between HMA & WMA PMB 40

Table 13 presents a comparison of the compression properties of HMA and WMA. The table illustrates the differences in Marshall Stability and Marshall Flow Value between HMA (standard PMB40 and RTFOT PMB40) and WMA (standard PMB40 and RTFOT PMB40).

Table No.13 Comparison between HMA & WMA PMB40

Marshall Stability						
S. No.	Properties	Bitumen Content (%)	Different types of Bitumen			
			HMA PMB40	HMA RTFOT PMB40	WMA PMB40	WMA RTFOT PMB40
1	Marshall Stability	4.0%	11.33	13.15	12.35	12.60
2		4.5%	12.08	13.80	12.70	12.85
3		5.0%	12.65	14.20	13.60	13.90
4		5.5%	13.02	14.52	14.10	14.30
Marshall Flow Value						
1	Marshall Flow Value	4.0%	2.91	3.20	3.3	3.4
2		4.5%	3.24	3.54	3.5	3.5
3		5.0%	3.60	3.78	3.7	3.7
4		5.5%	4	4.10	4.02	4.02

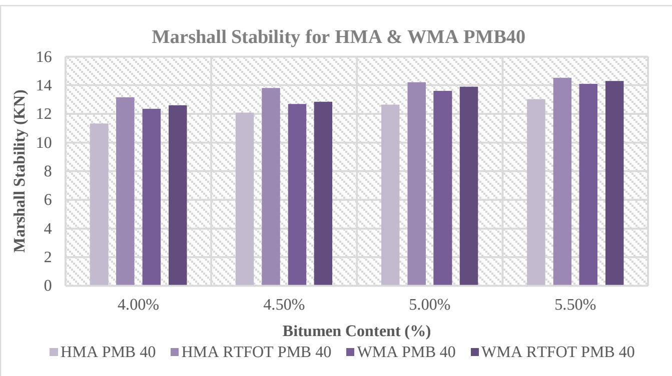

Figure 3 Marshall Stability Comparison for HMA & WMA (PMB40 & RFTOFT PMB40)

In terms of Marshall Stability, the data indicates that increasing the bitumen content generally leads to higher stability values for all types of bitumen. Among the bitumen types, HMA RTFOT PMB40 consistently exhibits the highest Marshall Stability values, indicating greater resistance to deformation. HMA PMB40 also performs well but slightly lower than HMA RTFOT PMB40. Among the WMA, WMA RTFOT PMB40 shows slightly better stability compared to WMA PMB40 across all bitumen content percentages.

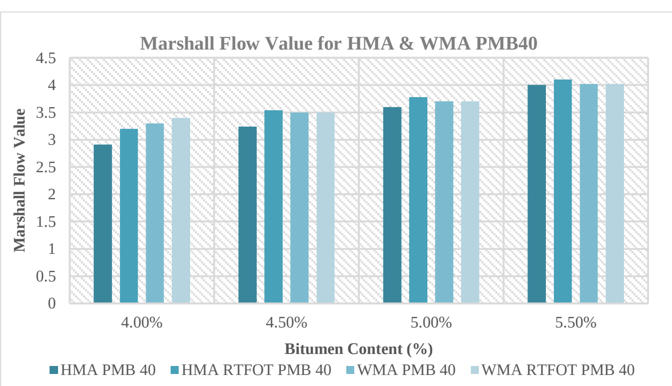

Figure 4 Marshall Flow Value Comparison For HMA & WMA (PMB 40 & RTFOT PMB 40)

Regarding Marshall Flow Value, higher bitumen content tends to result in lower flow values, indicating better resistance to flow or deformation. The data suggests that HMA RTFOT PMB40 has the lowest Marshall Flow Values among all types of bitumen, demonstrating superior resistance to deformation. Both HMA and WMA with PMB40 bitumen generally have lower Marshall Flow Values compared to their counterparts with RTFOT PMB40, indicating better performance in terms of deformation resistance

Comparison of Marshall Stability and Marshall Flow Value between HMA and WMA for both VG30 and PMB40 with Sasobit additives

In the given table, we are analyzing and contrasting the characteristics of HMA and WMA. This study includes a comparison of the Marshall Stability & Marshall Flow Value for HMA with two distinct binders, specifically Normal VG30 and Normal PMB 40, along with the inclusion of 2.5% Sasobit. Furthermore, we are making a similar comparison for WMA using the same binders and Sasobit. The table 14 presents a side-by-side evaluation of HMA and WMA

Table. 14 Comparison between Marshall Properties of HMA and WMA (VG30 & PMB 40) with inclusion of Sasobit (2.5%) additives

S. No.	Properties	Bitumen Content (%)	Admixtures	Different types of Bitumen (HMA PMB 40)			
				HMA VG30	HMA PMB 40	WMA VG30	WMA PMB 40
1	Marshall Stability	4.0%	Sasobit	11.61	11.81	11.81	12.11
2		4.5%		12.15	12.25	12.39	12.55
3		5.0%		12.99	13.49	13.19	13.69
4		5.5%		13.21	13.91	13.63	14.11
1	Marshall Flow Value	4.0%		2.96	3.10	3.11	3.11
2		4.5%		3.24	3.55	3.44	3.64
3		5.0%		3.96	3.79	3.69	3.99
4		5.5%		4.18	4.18	4.38	4.18

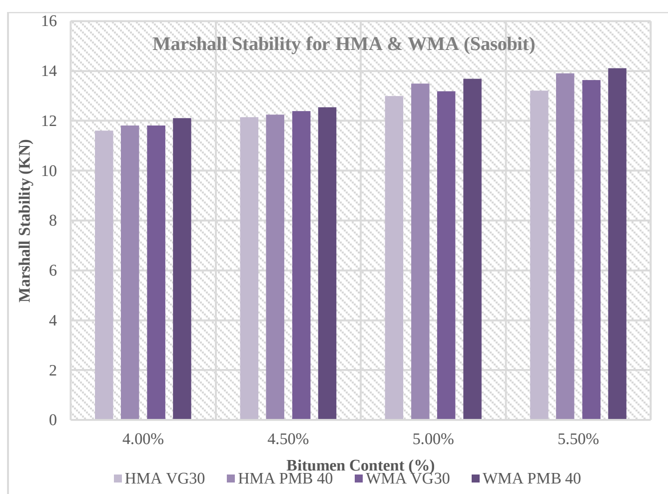

Figure 5 Marshall Stability Comparison for HMA & WMA (VG30 & PMB40) with Sasobit additives

Figure 5 depicts increasing bitumen content from 4.0% to 5.5% enhances Marshall Stability in both HMA and WMA. Sasobit admixture generally improves stability. WMA tends to exhibit slightly higher stability than HMA with similar bitumen content.

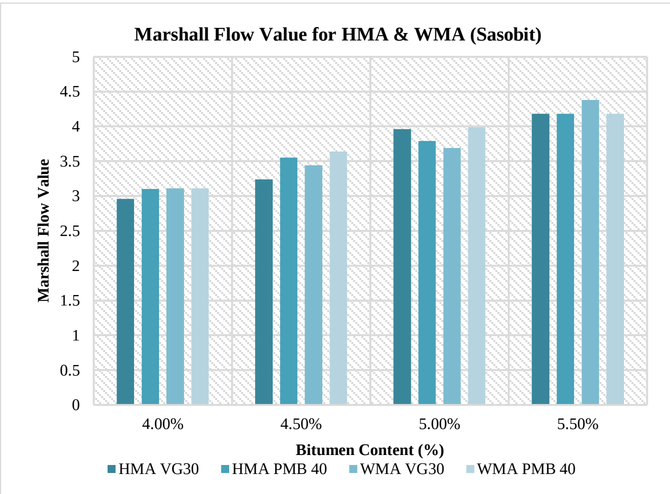

Figure 6 Marshall Stability Comparison for HMA & WMA (VG30 & PMB40) with Sasobit additives

Figure 6 depicts higher bitumen content results in increased flow resistance in both HMA and WMA. Sas obit's impact on flow values is limited. HMA and WMA show similar flow behavior, with no significant differences observed.

Comparison of Marshall Stability and Marshall Flow Value between HMA and WMA for both VG30 and PMB40 with Evotherm additives

In the given table, we are analyzing and contrasting the characteristics of HMA and WMA. This study includes a comparison of the Marshall Stability & Marshall Flow Value for HMA with two distinct binders, specifically Normal VG30 and Normal PMB 40, along with the inclusion of 0.7% Evotherm. Furthermore, we are making a similar comparison for WMA using the same binders and Evotherm. The table 15 presents a side-by-side evaluation of HMA and WMA

Table. 15 Comparison between Marshall Properties of HMA and WMA (VG30 & PMB 40) with inclusion of Evotherm (0.7%) additives

S. No.	Properties	Bitumen Content (%)	Admixtures	Different types of Bitumen (HMA PMB 40)			
				HMA VG 30	HMA PMB 40	WMA VG 30	WMA PMB 40
1	Marshall Stability	4.0%	Evotherm	10.11	11.81	13.41	13.41
2		4.5%		10.65	12.25	13.78	13.78
3		5.0%		11.29	13.49	14.36	14.36
4		5.5%		11.81	13.91	14.65	14.65
1	Marshall Flow Value	4.0%		2.11	3.25	3.38	3.38
2		4.5%		2.64	3.84	3.98	3.98
3		5.0%		3.19	4.19	4.21	4.21
4		5.5%		3.48	4.68	4.78	4.78

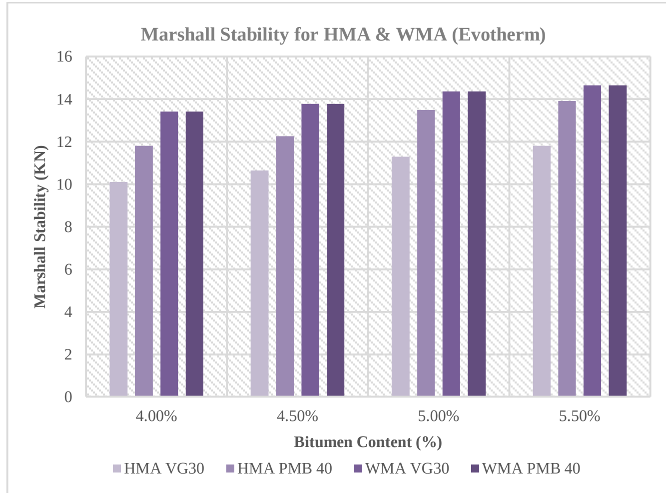

Figure 7 Marshall Stability Comparison for HMA & WMA (VG30 & PMB40) with Evotherm additives

Figure 7 depicts increasing bitumen content from 4.0% to 5.5% generally improves Marshall Stability in both HMA and WMA. The use of Evotherm admixture tends to enhance stability. WMA (both VG30 and PMB 40) exhibits slightly higher stability compared to their HMA counterparts with similar bitumen content.

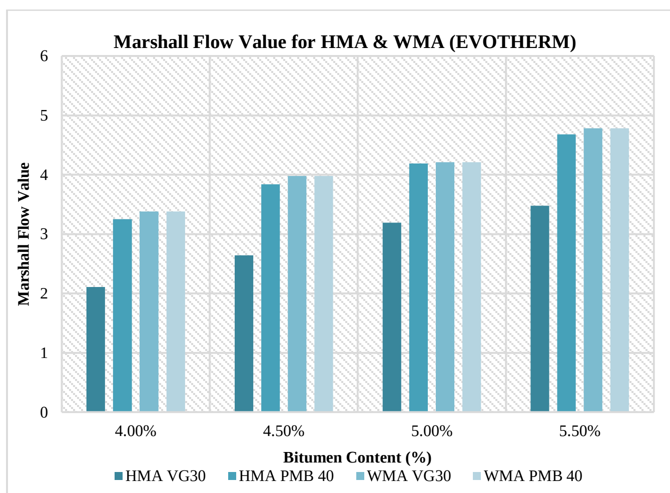

Figure. 8 Marshall Flow Value Comparison for HMA & WMA (VG30 & PMB40) with Evotherm additives

Figure 8 depicts higher bitumen content results in increased flow resistance in both HMA and WMA. Evotherm has a limited impact on flow values. Both HMA and WMA, regardless of bitumen type, demonstrate similar flow behavior with minor differences.

Comparison of Marshall Stability and Marshall Flow Value between HMA and WMA for both VG30 and PMB40 with Advera additives

In the given table, we are analyzing and contrasting the characteristics of HMA and WMA. This study includes a comparison of the Marshall Stability & Marshall Flow Value for HMA with two distinct binders, specifically Normal VG30 and Normal PMB 40, along with the inclusion of 0.25% Advera. Furthermore, we are making a similar comparison for WMA using the same binders and Advera. The table 16 presents a side-by-side evaluation of HMA and WMA

Table.16 Comparison between Marshall Properties of HMA and WMA (VG30 & PMB 40) with inclusion of Advera (0.25%) additives

S. No.	Properties	Bitumen Content (%)	Admixtures	Different types of Bitumen (HMA PMB 40)			
				HMA VG 30	HMA PMB 40	WMA VG 30	WMA PMB 40
1	Marshall Stability	4.0%	Advera	11.11	12.61	13.41	12.61
2		4.5%		11.55	13.25	13.81	13.25
3		5.0%		12.39	13.79	14.25	13.79
4		5.5%		12.81	14.21	15	14.21
1	Marshall Flow Value	4.0%		3.31	3.11	2.31	3.11
2		4.5%		3.81	3.44	2.94	3.44
3		5.0%		4.21	3.69	3.29	3.69
4		5.5%		4.81	4.98	3.81	3.98

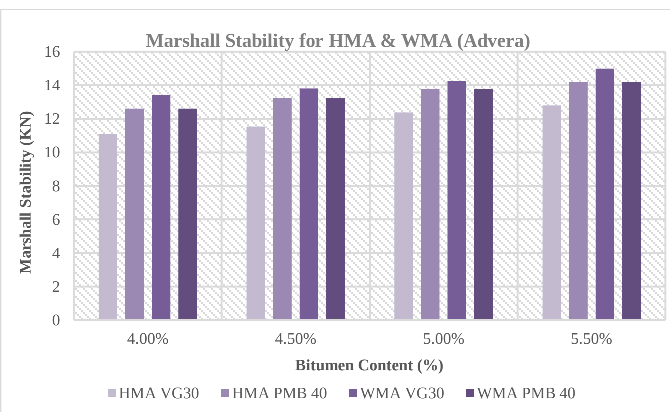

Figure. 9 Marshall Stability Comparison for HMA & WMA (VG30 & PMB40) with Advera additives

Figure 9 depicts increasing bitumen content from 4.0% to 5.5% generally improves Marshall Stability in both HMA and WMA. The use of Advera admixture tends to enhance stability. WMA (both VG30 and PMB 40) exhibits slightly higher stability compared to their HMA counterparts with similar bitumen content. Figure 10 depicts higher bitumen content results in increased flow resistance in both HMA and WMA. Advera has a limited impact

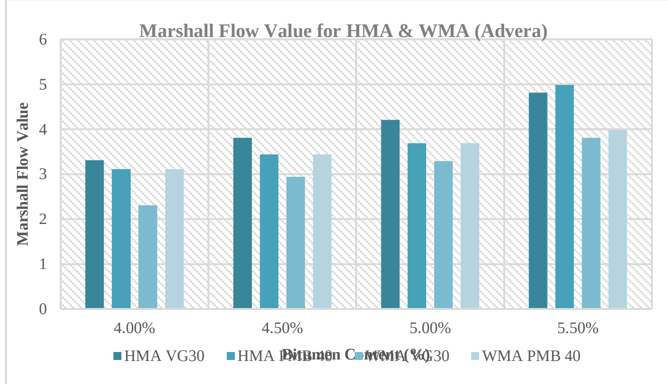

Figure 10 Marshall Flow Value Comparison for HMA & WMA (VG30 & PMB40) with Advera additives

on flow values. Both HMA and WMA, regardless of bitumen type, demonstrate similar flow behavior with minor differences.

Discussion

In our research, we conducted a study comparing two types of asphalt mixes HMA and WMA. We used two types of bitumen: modified bitumen (PMB40) and unmodified bitumen (VG30), with a Bituminous concrete-I grading containing 10mm (36%), 6mm (34%), and 2.36mm (28%) aggregates and 2% filler, which was cement. The total aggregate weight was 1200 grams. We incorporated different additives, namely Sasobit, Evotherm, and Advera, at varying filler weights, as detailed in Table 7. We prepared molds for both HMA and WMA with different percentages of bitumen (4%, 4.5%, 5%, and 5.5%). Additionally, we utilized RTFOT modified bitumen for both mix types. Our results indicated that WMA exhibited greater strength compared to HMA. Furthermore, when using additives, WMA displayed increased strength compared to HMA. Figure 1, depicting Marshall Stability, showed a consistent increase as the bitumen content ranged from 4.0% to 5.5% for both HMA and WMA. However, WMA RTFOT VG30 consistently exhibited higher Marshall Stability values than HMA VG30 across all bitumen content percentages. Among the WMAs, WMA RTFOT VG30 demonstrated the highest Marshall Stability values, particularly at higher bitumen percentages. This suggests that the warm mix technology with RTFOT-modified bitumen enhances Marshall Stability compared to conventional HMA and WMA with VG30 bitumen.

Our findings revealed that Sasobit was the most effective additive, consistently improving both Marshall Stability (50% higher) and Flow Value (30% higher) in comparison to various asphalt mixes. Evotherm primarily enhanced stability (40% higher) compared to Sasobit, while Advera exhibited mixed effects. These results underscore the significant role of Sasobit in enhancing asphalt performance. Overall, WMA performed comparably to HMA in terms of Marshall Stability and Flow Value, with minor variations depending on bitumen type and admixture. WMA represents a promising technology for reducing energy consumption and environmental impact.

Conclusion

The comprehensive study investigated various aspects of HMA and WMA with different types of bitumen and admixtures. Here are the key conclusions drawn from the study:

Bitumen Type and Content: Increasing bitumen content generally improves both Marshall Stability and Flow Value in HMA and WMA, regardless of bitumen type (VG30, PMB 40). However, PMB 40 tends to exhibit better performance than VG30.

Admixtures: The use of admixtures like Sasobit, Evotherm, and Advera has varying effects on asphalt properties. Sasobit improves stability and flow resistance in VG30 and PMB 40 asphalt. Evotherm enhances stability but has a limited impact on flow values. Advera tends to enhance stability but has a mixed effect on flow resistance.

Warm Mix Asphalt: WMA generally performs comparably to HMA in terms of Marshall Stability and Flow Value, with minor variations depending on bitumen type and admixture. WMA is a promising technology for reducing energy consumption and environmental impact.

Bitumen Aging: The study emphasizes the importance of addressing bitumen aging in asphalt pavement. RTFOT-modified bitumen enhances stability and flow resistance, contributing to enhanced pavement durability.

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Conflict of interest

The authors assert that they have no conflicts of interest with regard to the publication of this work.

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