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Comparative rutting analysis of hot mix Asphalt and warm mix Asphalt incorporating Bitumen additives

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ABSTRACT

Rutting, or the permanent deformation of the road surface, is a common problem that affects the performance and safety of roadways, particularly in regions with high temperatures and heavy traffic loads. The study analyzed rutting performance in asphalt mixtures using different binders and additives. The research focuses on comparing Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA) in terms of rut depth performance. A series of tests involving different types of bitumen, including modified bitumen (Polymer Modified Bitumen - PMB40) and unmodified bitumen (Viscosity Grade - VG30), as well as the influence of RTFOT aging on rutting performance were conducted. The effects of additives such as Advera (0.25%), Sasobit (2.5%), and Evotherm (0.7%) were also examined. Results indicate that WMA consistently exhibited lower rut depths compared to HMA, suggesting its improved resistance to rutting. Additionally, the incorporation of additives, particularly Evotherm and Sasobit, demonstrated the potential to further enhance rutting resistance in WMA. These findings emphasize the significance of binder selection and additive incorporation in mitigating rutting issues and pavement durability especially in regions with high temperatures and heavy traffic. This research contributes to the ongoing efforts to develop resilient and sustainable asphalt pavements, ultimately improving transportation infrastructure performance.

Keywords: Bitumen additives, HMA, Pavement durability, Rutting analysis, WMA

INTRODUCTION

Bituminous concrete, a commonly used material in road construction, is primarily employed for the upper layer of pavements. Additives can be incorporated into the mixture to enhance its characteristics and overall effectiveness. Rutting, a significant issue in flexible pavements, refers to depressions formed by continuous wheel paths, indicating permanent deformation. The main contributors to rutting include elevated pavement temperatures, insufficient subgrade strength, and heavy vehicular loads. Bituminous concrete is particularly suited for high-traffic pavements such as major highways and runways. Various types of asphalt concrete exhibit distinct performance attributes like surface robustness, braking efficiency, and road noise. It's important to think about things like traffic volume by category and the desired frictional performance while creating the asphalt mixture. Comparatively, bituminous concrete surfaces generate less noise than Portland cement concrete surfaces.[1] Rutting refers to the creation of a groove or depression along the length of the wheel tracks on a road surface. These grooves typically match the width of the wheel path. Swiftly veering out of a rutted wheel path at high velocities can pose a risk. When these grooves hold water, they can induce skidding. The occurrence of rutting might also involve the adjacent road surface bulging, offering a clue about the depth of the underlying issue. Also referred to as permanent deformation, rutting denotes the gradual accumulation of irrecoverable strains due to applied loads on a pavement. This phenomenon transpires as the pavement consolidates under traffic loads and possibly experiences lateral shifting of the heated bituminous mixture. This lateral movement constitutes a shear failure, usually manifesting in the uppermost pavement layer. The consequence of rutting is a

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shortened pavement lifespan. In cases where rutting becomes pronounced, water might pool in these depressed areas, raising the risk of vehicles hydroplaning.[2]

The selection of Sasobit, Advera, and Evotherm is indeed driven by the research's aim to investigate the specific impacts of these additives on asphalt properties. Each of these additives is formulated to modify asphalt characteristics, and the study's primary objective is to assess how they influence asphalt performance in various conditions, particularly in terms of resistance to rutting. Sasobit, for instance, is a wax-based additive that serves to lower the production and compaction temperatures of hot mix asphalt, making the process more environmentally friendly and energy-efficient. Advera, on the other hand, is known as an asphalt rejuvenator, commonly employed with reclaimed asphalt pavement (RAP) to enhance the performance of recycled asphalt. Meanwhile, Evotherm represents another warm mix asphalt additive, designed to reduce production temperatures and enhance workability. The inclusion of these additives in the research is aimed at determining which, if any, delivers the most beneficial effects on asphalt mixes, particularly in enhancing resistance to rutting. This valuable information can guide the asphalt industry in making well-informed decisions about the use of additives across various asphalt applications.

OBJECTIVES OF RESEARCH

The primary aims of this research are outlined as follows:

- Learning how different material qualities affect Warm Mix Asphalt's (WMA) functionality.
- Including enhancers such as Sasobit, Evotherm, and Advera in both Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA) specimens.
- Analysing the outcomes derived from testing the bitumen samples of both HMA and WMA with a focus on Rutting Properties.
- Comparing the Rutting Properties exhibited by the samples prepared using HMA and WMA methods.

LITERATURE REVIEW

Warm-Mix Asphalt (WMA) produced at lower temperatures than Hot-Mix Asphalt (HMA) is more environmentally friendly, although there are difficulties with disposing of brick dust and fly ash, as discussed in the reviewed literature. Improved mechanical characteristics and microstructural behavior are seen in SEM investigation of WMA with binary blended fillers (BBF).[3] In a single research inquiry investigating the impact of warm mix modification on asphalt rutting resistance, two modifiers under examination are polyethylene wax (PEW) and waste cooking oil (WCO). The results show that PEW outperforms WCO when just 1%-2% of the bitumen's weight is modified. Weibull's failure rate function (WFRF)[4] is used to create a rutting prediction model. The effects of short-term ageing, curing time, and thermal equilibrium time under laboratory settings on WMA mechanical characteristics are the topic of another study. Increased aging leads to higher asphalt binder viscosity, improving mixture stiffness. Longer curing times enhance adhesion, while increased thermal equilibrium time reduces asphalt binder cohesion, affecting rutting potential.[5]

The adoption of WMA and chemical compaction aids in the construction industry is explored through a study comparing HMA and WMA performance in pavement overlay projects in Iowa. Dynamic modulus tests and finite element simulations reveal that viscoelastic theory offers more accurate rutting predictions than linear elastic theories.[6] Slack wax (SW), an organic component to Warm Mix Asphalt (WMA), is studied for its effect on the rutting and fatigue resistance of rubberized asphalt. Both SW and rubber modifiers were shown to increase rutting resistance and fatigue life in the investigation. There is a robust relationship between the toughness index (TI) and fatigue life.[7] WMA is found to be comparable to HMA in terms of rutting resistance after field ageing, according to a study that examined the two materials' performance in a number of U.S. projects. The study also highlights the environmental benefits, including CO2 reduction, associated with WMA technologies.[8] Comparisons between HMA and WMA in Iowa overlay projects reveal that finite element simulations based on viscoelastic theory provide more accurate rutting predictions than MEPDG based on linear elastic theories. Calibration coefficients are proposed to improve overlay thickness calculations.[9] In both laboratory and field settings, the Long-Term Pavement Performance (LTPP) project in New Mexico assesses the rutting properties of Warm Mix Asphalt (WMA). The incorporation of a polymer-modified binder in WMA substantially improves its resistance to rutting.[10] In 2009, Iowa conducted asphalt overlay projects comparing HMA and WMA with recycled asphalt pavement (RAP) mixtures. A finite element (FE) viscoelastic analysis was used to evaluate rutting performance, supporting the use of local calibration for accurate rutting distress prediction.[11] The impact of WMA additives and RAP (Reclaimed Asphalt Pavement) on asphalt binder rutting and fatigue performance is assessed. Findings indicate that RAP folio and added substance M improve rutting opposition and traffic stacking grades, while additive R can be mitigated by increasing RAP binder content.[12] When tested in the lab and in the field, WMA with chemical additions demonstrates rutting behavior that is on par with or even better than that of HMA. Chemical WMA additions with a polymer modifier provide even better rutting qualities.[13] Researchers found that WMA additions lowered viscosity, cut energy expenditures, and cut emissions in basic bitumen. When comparing the rut depth of HMA and WMA combinations, the latter performs better.[14] The effect of WMA additives on WMA containing different amounts of RAP is the subject of another investigation. The resilience modulus and rutting resistance of Zycotherm-based WMAs are lower than those of Sasobit-based WMAs. The robust modulus and resistance to rutting are also improved with increased RAP content.[15] Focusing on rutting performance and the need of antistripping chemicals in pavement mixes to avoid moisture damage, this article compares the long-term field performance of WMA pavements to that of HMA pavements across a variety of projects in the United States.[16] Research leading to a provisional standard (AASHTO TP 79-13) is reviewed, and the Flow Number (FN) test is introduced as a performance assessment for asphalt mixes. There should be a change in the conditioning requirements since the FN test results for plant-delivered WMA blends are genuinely lower than those for field blends.[17]

MATERIAL & METHODOLOGY

MATERIAL

The study employed various materials including aggregates, conventional Viscosity Grade 30 (VG30) and modified Polymer Modified Bitumen Grade 40 (PMB40) binders. The aggregates used were various sizes ranging from 20 millimeters down to stone dust. For the purpose of creating rutting specimens, cement was used as a filler. The VG-30 standard binder and the PMB40 modified binder were used.[18]

RUTTING

A rut is an enduring, long, and narrow depression that emerges on a flexible asphalt road surface due to the movement of vehicles. The development of ruts is a gradual process: every time a heavy vehicle travels along the road, it creates a small and permanent deformation or compression in the surface. Over time, this surface distortion may be accompanied by an upward bulge on each side of the rut as the road surface undergoes aging .

FATIGUE

Fatigue cracking in pavement refers to a series of interconnected fractures that develop in either asphalt or concrete surfaces. When alligator cracking, a common type of fatigue cracking, is not adequately repaired, the damage can rapidly propagate, posing a threat to the overall durability and aesthetics of the pavement. Several primary factors can contribute to the occurrence of fatigue cracking in pavement, including the following:

- Excessive Pavement Load
- Deterioration of Subsurface Foundation
- General installation errors

METHODOLOGY

Using a solid, molded rubber wheel on top of bituminous concrete, researchers may evaluate the effects of rutting according to the standard test technique of the Wheel Rut Equipment designed for this purpose. The procedure involves determining the depth of rut on beam specimens through multiple passes of the wheel under varying applied pressures. The study also aims to evaluate the rutting effects on different asphalt mixtures, encompassing both HMA and WMA, and employing varying binder grades such as VG30 and PMB40.[18]

GRADATION OF AGGREGATE

Sieve examination is performed on aggregates ranging in size from 20 millimeters down to 12.5 millimeters, ten millimeters, six millimeters, and dust. By employing trial-and-error techniques with Microsoft Excel, the bituminous concrete's desired gradation is derived to align with the midpoint gradation.[19-21]

RESULTS

PHYSICAL PROPERTIES OF BITUMEN

Based on a review of the existing literature, the suggested research performed primary testing on PMB40 and VG30 binders. Two binders, one modified (PMB40) and one unmodified (VG30), were used for this study. All critical characteristics of PMB40 and VG30 were found to be within a reasonable range. MoRTH standards, which include IRC SP: 53, IS 73, and recommendations for modified bitumen usage in road construction, specify these boundaries. Table 2 provides RTFO abstract Bitumen results and a property comparison.[19,22,23]

Table 1 Gradation 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 (MoRTH, 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

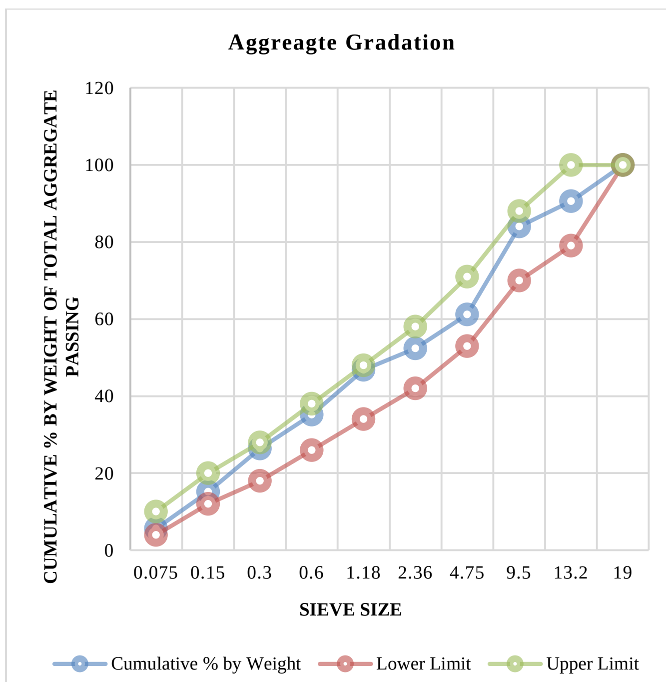

Figure 1 Gradation of Aggregate

Table 2. Physical Characteristics of VG30 Bitumen Employed in Bituminous Concrete [22,25]

Properties	Test Method	VG 30 Results	RTFOT VG 30 Results	MoRTH Specification
Penetration (100 gram, 5second at 25ºC) (1/10th of mm	IS 1203 [39]	55	63	50-70
Softening Point ºC (Ring and Ball Apparatus), Minimum	IS 1205 [35]	55	68	60
Ductility at 27 ºC (5cm/ minute pull), cm	IS 1208 [36]	56	72	+50
Specific Gravity	IS 1202 [40]	1.0	1.03	1.01
Flashpoint, ˚C, minimum	IS 1209 [38]	235	251	220
Fire point, ºC, minimum	IS 1209 [38]	266	258	247

The following table compares PMB 40 modified bitumen's physical properties to those of unmodified bitumen and RTFOT-modified bitumen. Table 3 shows the characteristics of VG30 bitumen, including those of the modified and RTFOT-modified forms.[19,22,23]

Table.3 Physical Characteristics of PMB40 Bitumen Employed in Bituminous Concrete[13]

Properties	Test Method	PMB 40 Results	RTFOT PMB 40 Results	MoRTH 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

The aggregates used in the creation of BC mixes underwent testing after the bitumen had been evaluated. Table 5 presents the comprehensive laboratory test results. These results, obtained through a series of tests, including assessments of aggregate impact and abrasion values, consistently met the requirements specified in MoRTH (2013). Table 4 provides a breakdown of the results for each property, and it also offers an overview of the physical characteristics of the filler material.[19,20,24]

Table 4 Physical Characteristics of Aggregate (Coarse & Fine Aggregate)[18, 20-23,38]

S. No.	Properties	Test Method	Natural Aggregate	MoRTH Specification
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 [30]	1.44%	2%
2.	Water Absorption	IS 383:2016 [30]	1.18%.	1.67%
3.	Specific Gravity	IS 383:2016 [30]	2.24	2.63
4.	Density	IS 383:2016 [30]	2589 Kg/m^3	2640 Kg/m^3

Table.5 Physical Characteristics of Filler (Cement) [21]

S. No.	Property	Test Method	Results	Standard Value
1	Normal Consistency	IS 4031 (Part IV) [32]	33,4	33-35 mm
2	Initial Setting Time	IS 4031 (Part V) [33]	40.5	≥ 45 min
3	Final Setting Time	IS 4031 (Part V) [33]	360	≤ 375 min
4	Compressive Strength at 28 days	IS 4031 (Part VI) [34]	15.26	≥ 19 Mpa

RUTTING CHARACTERISTIC

The provided table discusses rutting values obtained through testing various prepared samples. The research involved preparing samples with Unmodified bitumen (VG30 and RTFOT VG 30), Modified bitumen (PMB 40 and RTFOT PMB40), and admixtures (Sasobit 2.5%, Advera 0.25%, Evotherm 0.7%), in both WMA and HMA formats. Each specimen comprised a total aggregate weight of 5000gm and a bitumen content of 5.5%. Table 6 displays the rutting values of HMA VG30, while Table 7 presents the rutting values of HMA PMB 40.

Table.6 Rutting Performance of VG30 for HMA

No. of Passes (in Thousands)	VG 30	RTFOT Modified VG 30	VG30 + Advera	VG30 + Sasobit	VG30 + Evotherm
0	0.05	0	0	0	0
0.25	0.05	0.05	0.06	0.1	0.2
0.39	0.46	0.46	0.32	0.23	0.33
0.5	0.87	0.87	0.67	0.4	0.5
0.57	1.33	1.03	0.73	0.73	0.73
1.07	1.95	1.55	1.05	1.35	1.25
1.29	2.76	2.36	1.46	1.86	1.76
2	3.63	3.13	2.03	2.13	2.23
2.68	4.1	3.68	2.68	2.38	2.39
2.93	4.61	3.91	2.91	2.88	2.88
3.32	5.48	4.18	3.48	3.38	3.38
3.96	6.04	4.74	4.74	3.74	3.74
4.29	7.17	5.07	5.07	4.32	4.42
5.04	7.83	5.73	6.13	4.85	4.89
5.86	8.91	6.31	6.31	5.35	5.31
6.34	9.24	6.79	6.45	6.45	5.9
6.96	9.63	7.63	6.93	6.69	6.69
7.14	10.02	7.86	7.14	7.23	6.98
8	10.45	7.95	7.35	7.34	7.34
8.35	10.56	8.12	7,65	7.56	7.76
8.96	10.71	8.41	7.81	7.81	7.81
9.21	11.11	8.89	8,19	8.26	8.43
10.07	11.32	9.32	8.32	8.32	8.32

The accompanying graph illustrates the comparisons, showcasing the variations in rut depth over a range of passes. The graph clearly indicates that WMA with additives Sasobit, Advera, and Evotherm demonstrates lower rut depths compared to the reference VG30 asphalt, signifying enhanced rutting resistance with these additives.

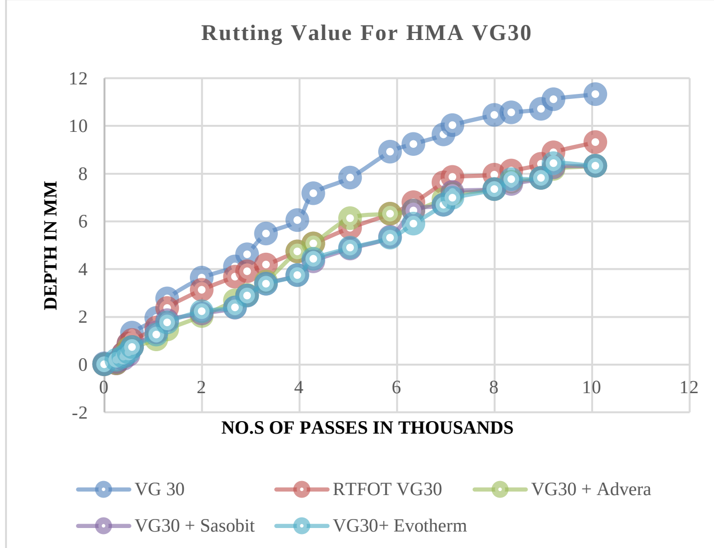

Figure 2 Rutting Performance Comparison of Different VG30 HMA

Table 7 Rutting Performance of PMB40 for HMA

No. of Passes (in Thousands)	PMB 40	RTFOT Modified PMB40	PMB40 + Advera	PMB40 + Sasobit	PMB 40 + Evotherm
0	0	0.00	0	0	0
0.25	0.06	0.07	0.06	0.1	0.2
0.39	0.56	0.48	0.26	0.28	0.33
0.5	0.97	0.9	0.57	0.46	0.5
0.57	1.13	1.08	0.93	0.83	0.73
1.07	1.65	1.65	1.35	1.35	1.25
1.29	2.46	2.76	1.86	1.96	1.76
2	3.03	3.33	2.03	2.03	2.23
2.68	3.88	3.88	2.38	2.38	2.39
2.93	4.11	3.99	3.11	2.98	2.88
3.32	4.48	4.2	3.48	3.28	3.38
3.96	5.74	4.84	3.74	3.84	3.74
4.29	6.07	5.27	4.4	4.4	4.42
5.04	6.73	5.83	4.73	4.83	4.89
5.86	7.31	6.51	5.31	5.31	5.31
6.34	7.76	7.14	6.45	6.76	5.97
6.96	7.93	7.83	6.93	6.93	6.69
7.14	8.27	8	7.19	7.23	7.16
8	8.35	8.15	7.35	7.24	7.34
8.35	8.69	8.63	7.58	7.49	7.64
8.96	8.81	8.71	7.81	7.66	7.89
9.21	9.13	8.98	8.28	8.1	8.25
10.07	9.32	9.22	8.32	8.12	8.32

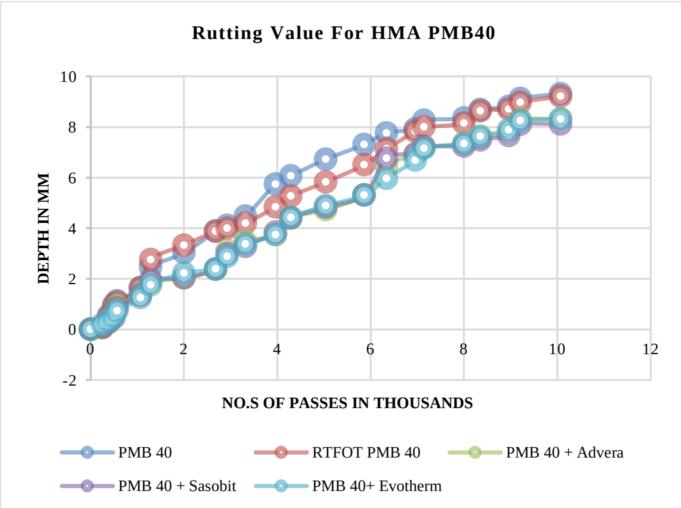

Figure.3 Rutting Performance Comparison of Different PMB40 HMA

The associated graph depicts the comparative rut depths across the associated graph depicts the comparative rut depths across varying pass counts. The graph clearly reveals that WMA with additives Advera, Sasobit, and Evotherm shows reduced rut depths compared to the reference PMB40 asphalt, indicating improved rutting resistance with these additives. Following the discussion on HMA, we are now addressing the rutting values of WMA, which are presented in the following table. Table 8 and Table 9 display the rutting performance of WMA for both VG30 and PMB40

Table 8 Rutting Performance of VG30 for WMA

No. of Passes (in Thousands)	VG 30	RTFOT Modifie d VG 30	VG30 + Adver a	VG30 + Sasobi t	VG30 + Evother m
0	0	0	0	0	0
0.25	0.25	0,18	0.03	0.09	0.13
0.39	0.58	0.46	0.28	0.18	0.28
0.5	0.78	0.64	0.5	0.32	0.42
0.57	0.93	0.86	0.63	0.69	0.69
1.07	1.11	1.05	0.95	1.1	1.16
1.29	1.88	1.66	1.3	1.5	1.45
2	2.8	2.4	1.76	2.06	2.09
2.68	3.35	3.23	2.2	2.3	2.27
2.93	3.9	3.75	2.75	2.7	2.7
3.32	4.11	4.03	3.33	3.24	3.24
3.96	4.68	4.37	4.4	3.62	3.62
4.29	5.1	4.99	4.8	4.34	4.27
5.04	5.66	5.49	5.75	4.65	4.67
5.86	5.99	5.79	6.2	5.21	5.19
6.34	6.24	6.37	6.27	6.31	5.47
6.96	6.89	6.66	6.41	6.361	6.36
7.14	7.28	6.76	6.56	6.82	6.41
8	7.85	7.24	6.9	6.9	7.2
8.35	8.13	7.56	7.32	7.43	7.32
8.96	8.32	8.13	7.4	7.62	7.69
9.21	8.56	8.34	7.69	7.83	7.77
10.07	9.15	8.94	8.1	8.15	8.19

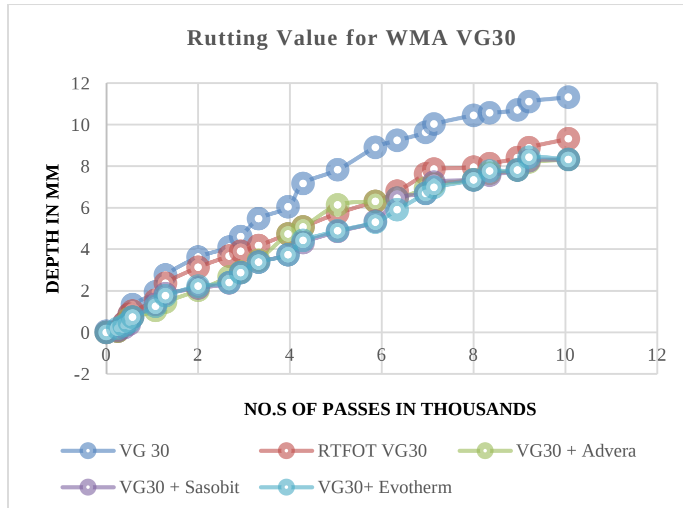

Figure 4 Rutting Performance Comparison of Different VG30 WMA

The graph showcases the comparative rut depths over different pass counts. From the graph, it's evident that WMA with additives Advera, Sasobit, and Evotherm exhibits lower rut depths compared to the reference VG30 asphalt, suggesting enhanced rutting resistance due to the incorporation of these additives.

Table. 9 Rutting Performance of PMB40 for WMA

No. of Passes (in Thousand s)	PMB 40	RTFO T Modifie d PMB40	PMB40 + Advera	PMB40 + Sasobit	PMB 40 + Evother m
0	0	0	0	0	0
0.25	0.06	0.03	0.03	0.1	0.13
0.39	0.56	0.35	0.25	0.28	0.28
0.5	0.97	0.8	0.4	0.46	0.42
0.57	1.13	0.99	0.79	0.83	0.69
1.07	1.65	1.45	1.15	1.35	1.16
1.29	2.46	1.9	1.5	1.96	1.45
2	3.03	2.76	1.96	2.03	2.09
2.68	3.88	3.2	2.2	2.38	2.27
2.93	4.11	3.9	2.9	2.98	2.7
3.32	4.48	4.33	3.33	3.28	3.24

3.96	5.74	4.4	3.5	3.84	3.62
4.29	6.07	5.8	4.1	4.4	4.27
5.04	6.73	6.3	4.3	4.83	4.67
5.86	7.31	6.8	5.1	5.31	5.19
6.34	5.98	6.78	5.34	5.45	5.76
6.96	7.93	7.41	6.41	6.93	6.36
7.14	8.13	7.65	6.83	7.11	6.58
8	8.35	7.9	6.9	7.24	7.2
8.35	8.5	8.28	7.27	7.38	7.5
8.96	8.81	8.4	7.4	7.81	7.69
9.21	9.16	8.8	7.7	7.98	7.87
10.07	9.32	9.1	8.1	8.12	8.19

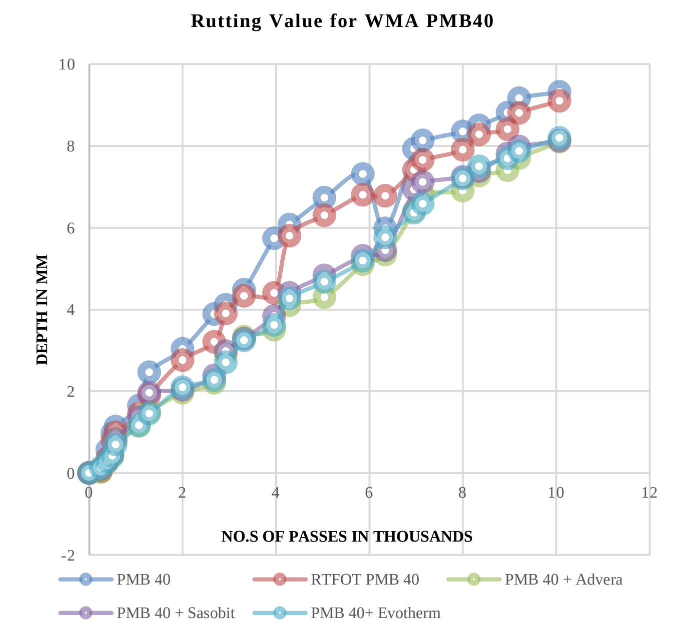

Figure.5 Rutting Performance Comparison of Different PMB40 WMA

The graph visually displays how the rut depths change over varying pass counts. It is evident from the graph that WMA incorporating additives Advera, Sasobit, and Evotherm exhibit decreased rut depths compared to the reference PMB40 asphalt. This suggests that the incorporation of these additives in WMA leads to improved resistance against rutting.

Comparative Rutting Performance Analysis of HMA and WMA

Rutting Comparison: HMA vs. WMA with VG30 and PMB40 (Normal vs. RTFOT)

Rutting assessment was performed on all samples crafted with two distinct bitumen variants. The initial variant being Modified Bitumen (PMB40) and the latter being Unmodified Bitumen (VG30). Additionally, Figure 6 illustrates the contrast between HMA and WMA utilizing RTFOT Modified Bitumen for both VG30 and PMB40. Each HMA and WMA specimen underwent 10,000 passes in testing. The bitumen content was maintained at 5.5%, constituting the total aggregate weight.

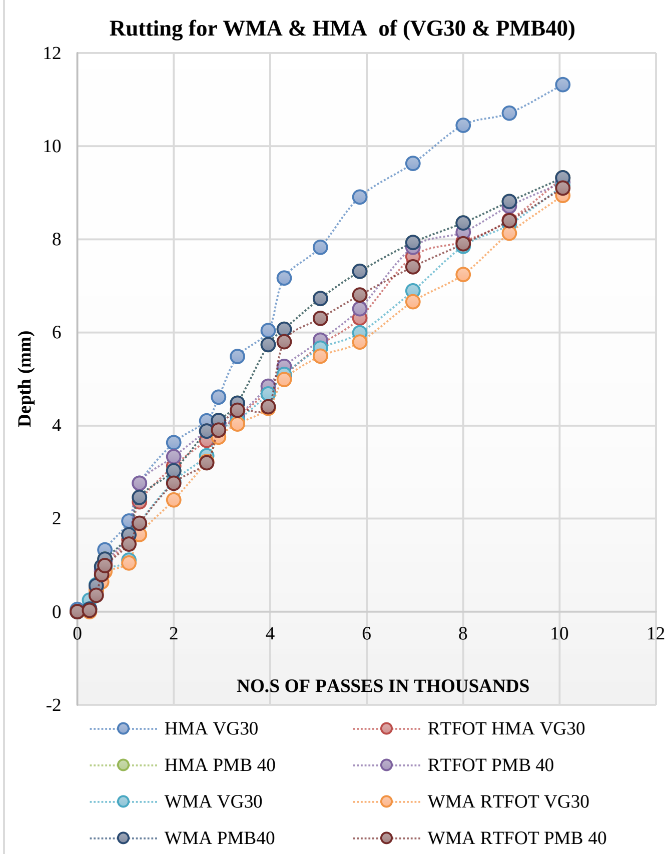

Figure. 6 Rutting Depth Variation in HMA and WMA (VG30 and PMB40)

The graph visually depicts the change in rut depth over a range of pass counts. Notably, for both VG30 and PMB40 binders, the rut depths are generally higher in HMA compared to WMA. This observation suggests that WMA exhibits better rutting resistance than HMA for the given binders, making it a favorable option for road construction in terms of rutting performance.

Comparative Rutting Performance of VG30 and PMB40 in HMA and WMA with Admixture

Rutting analysis encompassed all prepared specimens, employing two distinct bitumen types: Modified Bitumen PMB40 and Unmodified Bitumen VG30. Additionally, showcases a comparison between HMA and WMA employing RTFOT Modified Bitumen (VG30 and PMB40). This comparison extends to include additives like Sasobit, Advera, and Evotherm. For both HMA and WMA, each specimen endured 10,000 passes. Bitumen content maintained at 5.5% represents the total aggregate weight. Admixture, comprising Sasobit (2.5%), Evotherm (0.7%), and Advera (0.25%), collectively contributes to the total aggregate weight.

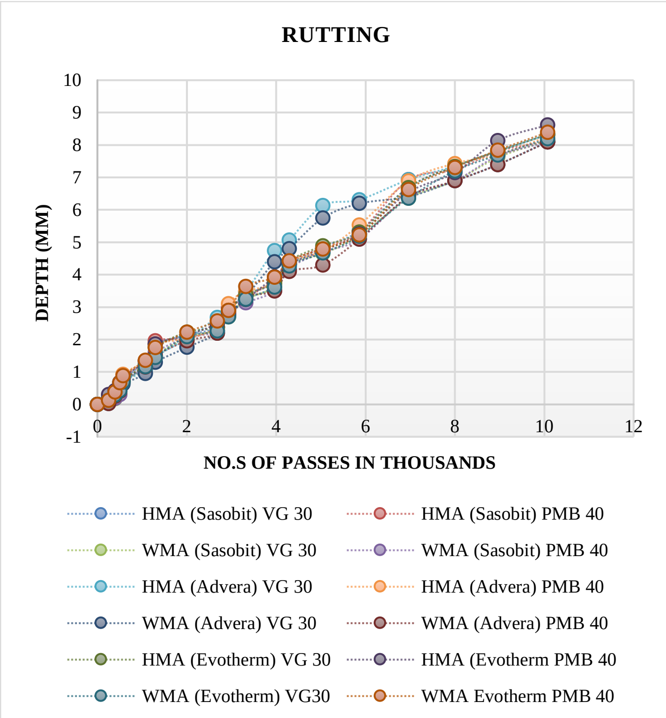

Figure 7 Impact of Additives on Rutting in HMA and WMA Mixtures

The graph visually represents the rut depths at various pass counts, highlighting the influence of the additives. The data indicates varying rutting depths for different additives and binder types. This information can aid in making informed decisions regarding the choice of additives for achieving improved rutting resistance in asphalt mixtures.

Rutting Parameters in HMA & WMA with VG30 and PMB40 Binders (Standard and RTFOT-Aged Specimens) Including Admixtures

In Table 10 and Table 11, we outline multiple parameters from the Wheel Rut Test. These parameters encompass data on Rut Depth, Proportional Rut Depth, Wheel Tracking Slope, and Rut Resistance Index, all pertaining to both WMA and HMA.

Table 10 Rutting Properties Comparison for different Asphalt Mixtures WMA

Sample I'd	Rut Depth (mm)	Proportional Rut Depth	Wheel tracking Slope	Rut Resistance Index
VG 30	12.81	25.62	0.732	9920
RTFOT VG 30	13.33	26.66	0.58	9520
VG30 + ADVERA	13.43	26.86	1.06	9440
VG30 + SASOBIT	13.51	27.02	1.072	9380
VG30 + EVOTHERM	13.89	27.78	1.14	9080
PMB 40	13.76	26.92	0.88	9180
RTFOT PMB 40	14.13	28.26	1	8880
PMB 40 + ADVERA	14.13	28.26	1.02	8880
PMB 40 + SASOBIT	14.35	28.7	1.24	8720
PMB 40 + EVOTHERM	14.54	29.08	1.27	8560

Table 11 Rutting Properties Comparison for different Asphalt Mixtures HMA

Sample I'd	Rut Depth (mm)	Proportional Rut Depth	Wheel tracking Slope	Rut Resistance Index
VG 30	15.65	31.3	0.866	7680
RTFOT VG 30	15.33	30.66	1.02	7940
VG30 + ADVERA	15.45	30.9	1.43	7840
VG30 + SASOBIT	15.33	30.66	1.402	7940
VG30 + EVOTHERM	15.75	31.5	1.49	7600
PMB 40	16	32	1.34	7400
RTFOT PMB 40	15.68	31.36	1.22	7660
PMB 40 + ADVERA	16.23	32.46	1.58	7220
PMB 40 + SASOBIT	16.31	32.62	1.63	7160
PMB 40 + EVOTHERM	16.45	32.9	1.63	7060

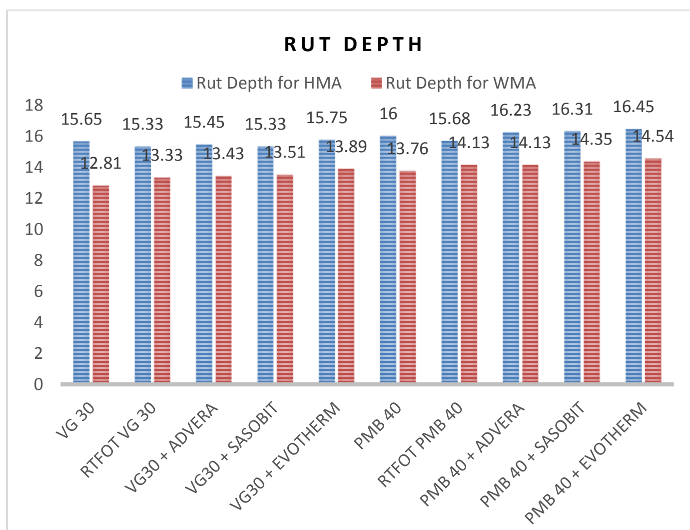

Figure 8 Comparison of Rut Depth for HMA & WMA

The provided diagram illustrates the rut depth of HMA and WMA molds after a series of rutting tests. It is evident from the figure that the rut depth in HMA is more significant than in WMA.

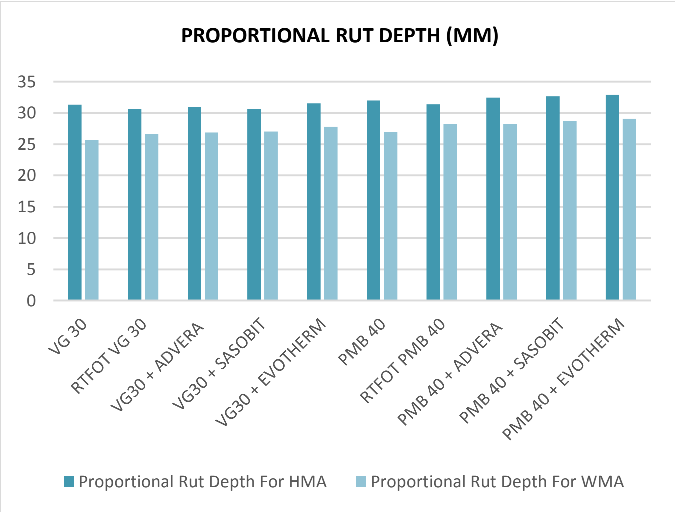

Figure 9 Comparison of Proportional Rut Depth for HMA & WMA

The graph highlights the proportional rut depth comparison between HMA and WMA. It is evident that HMA exhibits greater rut depth values than WMA, emphasizing the potential advantage of WMA in reducing rutting. Proportional Rut depth is found out by the formula of Rut depth when the Rut depth is low although the Rut proportional Depth is also low for WMA.

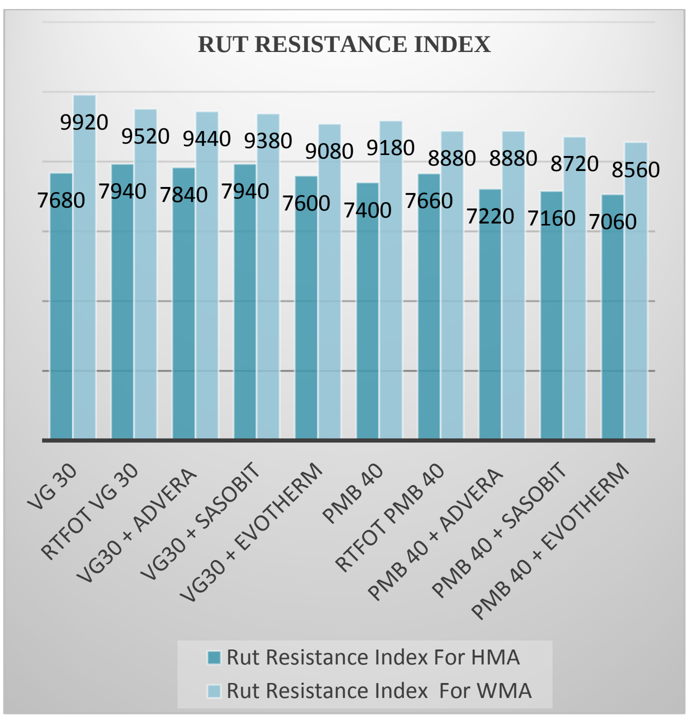

Figure 10 Comparison of Rut Resistance Index for HMA & WMA

The graph showcases the comparison of rut resistance indices between HMA and WMA. Significantly, the graph illustrates that the rut resistance index values for WMA consistently surpass those of HMA. This finding underscores the superior rutting performance of WMA, as evidenced by its higher rut resistance index values displayed in the graph.

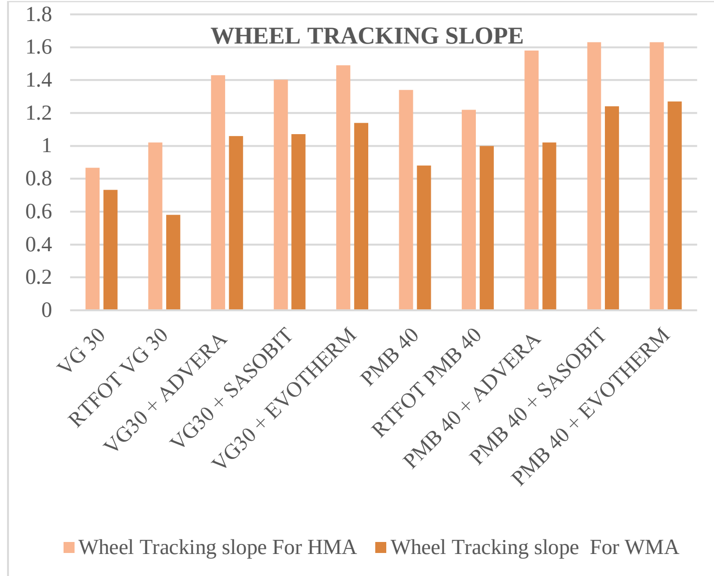

Figure 11 Comparison of Wheel Tracking Slope for HMA & WMA

The graph provides a comparison of wheel tracking slope between HMA and WMA. It is evident that the wheel tracking slope values for HMA consistently exceed those of WMA. This observation highlights that HMA exhibits higher wheel tracking slope values, indicating potentially greater susceptibility to rutting, compared to WMA as reflected in the graph.

DISCUSSION

The two kinds of asphalt mixtures that we looked at were Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA) for this study. The research set out to do just that by comparing the usefulness of two distinct asphalt mixtures. Our study included the use of both modified bitumen (PMB40) and unmodified bitumen (VG30). Bituminous concrete-I grading was used; its components were aggregates with various sizes (36%) and cement for the filler (2%). The total weight of the aggregate material amounted to 5000 grams. Furthermore, we introduced various admixtures, including Sasobit (2.5%), Evotherm (0.7%), and Advera (0.25%), each at different filler weights. To prepare the Molds for both HMA and WMA, we used a consistent percentage of bitumen (5.5%). We also added RTFOT modified bitumen to both compounds. From what we could see, RTFOT aging positively impacts asphalt mixtures by enhancing rutting resistance through binder curing and hardening. The choice of binder is pivotal, with PMB 40 excelling in rutting resistance. Additives such as Sasobit, Advera, and Evotherm bolster resistance, with Evotherm, especially when combined with PMB 40, being the most effective. In summary, WMA naturally resists rutting due to reduced aging, while selecting PMB 40 significantly improves resistance in both WMA and HMA. Additives, particularly Evotherm, further enhance rutting resistance, promoting pavement durability. This study has certain limitations. It primarily examined a limited set of additives, omitting potentially influential ones. The scope was also restricted to two binder types, with countless variations unexplored. The study employed a specific aggregate grading, overlooking the effects of diverse aggregates. Environmental factors were not extensively considered, potentially impacting real-world rutting behavior. Additionally, the research focused mainly on short-term performance.

Conclusion

In conclusion, this research underscores the critical importance of addressing rutting issues in asphalt mixtures, particularly in the context of Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA). The study has shed light on several key findings that have practical implications for pavement engineering and design.

Firstly, Warm Mix Asphalt (WMA) consistently outperformed Hot Mix Asphalt (HMA) in terms of rutting resistance, a crucial finding that can significantly improve the durability and safety of roadways. This superior performance of WMA can be attributed to its reduced aging effects, resulting from lower production temperatures.

Secondly, the incorporation of additives, notably Evotherm and Sasobit, has shown great promise in further enhancing the rutting resistance of WMA. These additives provide an additional layer of defense against rutting, a finding that can significantly benefit pavement longevity.

Furthermore, the study underscores the pivotal role of selecting the appropriate binder. Polymer Modified Bitumen (PMB 40) emerged as highly effective in mitigating rutting. This finding highlights the importance of binder choice in pavement engineering and design.

An interesting observation was the positive impact of RTFOT aging on rutting resistance, suggesting that controlled aging processes can be leveraged to improve asphalt mixtures' resilience to rutting. This result underscores the potential for strategic aging in pavement design and maintenance.

In summary, this research contributes to the ongoing efforts to develop resilient and sustainable asphalt pavements, ultimately improving the performance and safety of transportation infrastructure. These findings are especially relevant in regions characterized by high temperatures and heavy traffic loads, where rutting can pose a significant challenge to road durability and safety.

Future Scope

Future research should encompass a broader range of additives and binders to uncover optimal solutions for rutting resistance in Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA). Field trials and long-term monitoring are crucial to assess real-world performance. Environmental conditions should be integrated, and a comprehensive life cycle analysis undertaken. Exploring recycled materials' influence on rutting resistance and sustainability can contribute to eco-friendly transportation infrastructure.

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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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