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Influence of ZycoTherm Dosage on Polymer Modified Bitumen and Marshall Performance of Hydrated Lime Incorporated Warm Mix Bituminous Concrete

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Abstract

This study examines the effect of ZycoTherm on PMB 76-10 binder characteristics and the performance of PMB-based Bituminous Concrete (BC) Grade-II prepared at reduced mixing temperatures, with and without hydrated lime. PMB 76-10 was modified with ZycoTherm at dosages of 0.05%, 0.10%, 0.15%, and 0.20% by weight of binder and evaluated using conventional and residue-based tests. Increasing ZycoTherm dosage decreased penetration, while softening point, flash point, and elastic recovery increased, indicating improved stiffness, thermal stability, and recoverable behaviour. Residue properties after short-term aging also improved with additive dosage. For mixture evaluation, BC Grade-II mixtures with 6.4% binder were prepared at mixing temperatures of 165, 135, 125, and 115 °C with 0% and 3% hydrated lime. Marshall stability, flow, Marshall Quotient, and volumetric parameters were assessed. Stability and Marshall Quotient increased up to 0.10% ZycoTherm and decreased at higher dosages, while flow showed the opposite trend. Reducing mixing temperature adversely affected Marshall and volumetric properties, and the minimum stability requirement of MoRTH-V Revision and IRC: SP:135-2022 was not satisfied at 115 °C. Hydrated lime improved mixture performance. Overall, 0.10% ZycoTherm was found optimum, and reduced-temperature production was feasible up to 125 °C.

Keywords: ZycoTherm, polymer-modified bitumen, PMB 76-10, warm mix asphalt, hydrated lime, Marshall stability, bituminous concrete, ANOVA, Regression analysis.

INTRODUCTION

Polymer-modified bitumen (PMB) is extensively used in asphalt materials because the incorporation of polymers improves the durability of asphalt pavements [1], elasticity, deformation resistance [27], and recovery behaviour of the binder [2–4]. However, PMB is also a thermally sensitive multicomponent material [5], and its final properties depend on formulation, compatibility, and processing conditions. Therefore, reduced-temperature production of PMB-based asphalt mixtures should be studied not only from the viewpoint of construction practice but also in terms of polymer-modified material behaviour [3, 6]. Owing to the continuous increase in traffic volume and axle loads, along with the need to resist severe weather conditions, PMB has been increasingly used in pavements as an alternative to neat bitumen [7].

For sustainable pavement development, warm mix asphalt technology offers the possibility of reducing asphalt production temperature while maintaining acceptable engineering performance [8, 9, 25, 26]. In PMB systems, reduced thermal exposure may be beneficial in limiting overheating and short-term aging [10, 11]. However, lower processing temperatures may

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also influence coating, compaction, internal structure, and binder–aggregate interaction [12, 13]. Chemical warm mix additives such as ZycoTherm are therefore important because they can affect both processability and final material response [14–16].

Hydrated lime is another important modifier in such systems because it can improve adhesion and contribute to mastic and interface modification [17–20]. When PMB, ZycoTherm, and hydrated lime are used together, the resulting asphalt mixture behaves as a multicomponent composite in which mechanical and volumetric responses are controlled by both composition and thermal processing history.

In the present study, PMB 76-10 was modified with ZycoTherm at dosages of 0.05%, 0.10%, 0.15%, and 0.20% by binder content. The modified binders were characterized using penetration, softening point, flash point, elastic recovery, and thin-film residue-related tests. The corresponding PMB-based Bituminous Concrete Grade-II mixtures were prepared using ZycoTherm dosages of 0.05%, 0.10%, 0.15%, and 0.20% at production temperatures of 165°C, 135°C, 125°C, and 115°C, with hydrated lime contents of 0% and 3%. These mixtures were evaluated using Marshall and volumetric parameters. Thus, the study links binder-level modification with mixture-level behaviour in a reduced-temperature PMB system.

Since the study involves multiple formulation and processing variables, ANOVA and regression modelling were used to quantify the significance of additive dosage, production temperature, and hydrated lime content, and to establish predictive relationships for the measured responses. The main objective of this study is to understand how ZycoTherm modifies PMB 76-10 and how these changes are reflected in the performance of PMB-based warm mix bituminous concrete.

Research Gap and Objective

Despite the growing use of polymer-modified binders and warm mix technologies, limited studies have linked the binder-level effect of ZycoTherm on PMB 76-10 with the mixture-level performance of PMB-based Bituminous Concrete Grade-II under reduced mixing temperatures. The combined influence of ZycoTherm dosage, hydrated lime, and temperature reduction remains insufficiently explored, particularly within a statistically structured framework. Therefore, the objective of this study is to characterize ZycoTherm-modified PMB 76-10 and to evaluate the corresponding Marshall and volumetric response of PMB-based warm mix bituminous concrete produced at reduced temperatures with and without hydrated lime, supported by ANOVA and regression modelling.

MATERIALS AND METHODS

PMB 76–10 was used as the binder in this study. ZycoTherm was added to the binder at dosages of 0.05%, 0.10%, 0.15%, and 0.20% by weight of binder to evaluate its influence on binder properties. The binder was tested in accordance with IRC:53-2010. The evaluated properties included penetration at 25°C, softening point, flash point, elastic recovery, and thin-film oven residue properties, including loss in mass, increase in softening point, reduction in penetration of residue, and elastic recovery after residue testing.

For mixture-level evaluation, Bituminous Concrete Grade-II mixtures were prepared using a binder content of 6.4% in accordance with MoRTH, 5th Revision [21], and IRC: SP:135-2022 [22]. The mixtures were produced using ZycoTherm-modified PMB at dosages of 0.05%, 0.10%, 0.15%, and 0.20%. Four mixing temperatures, namely 165°C, 135°C, 125°C, and 115°C, were considered. These temperatures corresponded to reductions in mixing temperature of 0°C, 30°C, 40°C, and 50°C, respectively, with reference to the conventional mixing temperature of 165°C. Hydrated lime was incorporated at two levels, 0% and 3%, to evaluate its effect on mixture performance.

A conventional control mixture was also prepared at 165°C without ZycoTherm and hydrated lime for comparison. Marshall specimens were prepared for each experimental condition, and three replicate specimens were tested to ensure reliability of the results. The prepared mixtures were evaluated in terms of Marshall stability, flow, Marshall Quotient (MQ), bulk density, air voids (Va), voids in mineral aggregate (VMA), and voids filled with bitumen (VFB) [24].

The experimental data were statistically analyzed using analysis of variance (ANOVA) to determine the significance of ZycoTherm dosage, mixing temperature reduction, and hydrated lime content on Marshall stability. Regression analysis was further performed to develop predictive relationships between the experimental variables and selected response parameters. Statistical significance was assessed at a 95% confidence level.

RESULTS AND DISCUSSION

The experimental findings are presented and interpreted in terms of the combined effects of ZycoTherm dosage, mixing temperature, and hydrated lime content on both binder and mixture properties. The discussion begins with the binder-level characterization of ZycoTherm-modified PMB 76-10, as changes in penetration, softening point, elastic recovery, and residue properties provide the basis for understanding the subsequent behaviour of the asphalt mixtures.

Thereafter, the Marshall and volumetric performance of BC Grade-II mixtures prepared at reduced temperatures is discussed with reference to the conventional control mixture. This binder-to-mixture framework provides a comprehensive interpretation of the processing–property relationship in the modified PMB system. Furthermore, the use of ANOVA and regression modelling supports a statistically grounded evaluation of the observed trends.

Effect of ZycoTherm Dosage on the Characteristics of PMB 76-10

The effect of ZycoTherm dosage on PMB 76-10 was evaluated using conventional and residue-based binder tests. As presented in Table 1, ZycoTherm produced a clear dosage-dependent modification in binder properties. With an increase in additive content from 0% to 0.20%, penetration decreased from 40 to 36, indicating increased binder stiffness. In contrast, the softening point increased from 68°C to 72°C, suggesting improved high-temperature resistance. The flash point also increased from 288°C to 298°C, confirming that ZycoTherm did not adversely affect thermal safety during binder handling and heating.

Elastic recovery at 15°C improved from 75% to 88% with increasing ZycoTherm dosage, indicating enhanced recoverable deformation behaviour of the polymer-modified binder. This result suggests that the elastic characteristics of PMB 76-10 were preserved and improved after the addition of ZycoTherm.

Table 1 further shows that the thin-film residue properties improved with increasing additive dosage. The loss in mass decreased from 0.16% to 0.12%, the increase in softening point reduced from 3.2°C to 2.5°C, and the reduction in penetration of residue decreased from 18% to 13%. In addition, the elastic recovery of residue at 25°C increased from 65% to 78%. These trends indicate that ZycoTherm reduced the aging-induced hardening tendency and enhanced the retained elastic response of PMB 76-10 after short-term aging. Overall, ZycoTherm positively influenced the consistency, high-temperature performance, elastic response, and aging resistance of PMB 76-10. All measured values remained within the limits specified by IRC:53-2010.

Effect on Marshall Stability

Figure 1(a) and Figure 1(b) show that Marshall stability increased with ZycoTherm dosage up to 0.10% and then decreased for both 0% and 3% hydrated lime mixtures. This trend indicates that 0.10% ZycoTherm was the optimum dosage for achieving maximum Marshall stability in the present study. The initial improvement may be attributed to better aggregate coating, enhanced workability, and more effective compaction of the PMB-based mixture. However, beyond 0.10%, the reduction in stability suggests that excess additive did not contribute positively to structural resistance and may have disturbed the balance between binder stiffness and internal mixture strength.

Table 1. Effect of ZycoTherm dosage on the conventional and residue-based characteristics of PMB 76-10 in comparison with IRC:53-2010 requirements.

Sr. No.	Test Name	ZycoTherm Doses in %					Specification as per IRC 53-2010 [23].
		0	0.05	0.10	0.15	0.20	
1	Penetration at 25°C, 100gm, 5 Sec.	40	39	38	37	36	30–50 (mm/10)
2	Softening Point	68	69	70	71	72	60°C min.
3	Flash Point	288	290	292	295	298	220°C min.
4	Elastic recovery of Half thread in Ductilometer at 15°C	75	78	82	85	88	60 % min.
Thin film test and Tests Residue.							
5	Loss in mass	0.16	0.15	0.14	0.13	0.12	1 % max.
6	Increase in softening point	3.2	3	2.8	2.6	2.5	5°C max.
7	Reduction in penetration of residue at 25°C	18	16	15	14	13	35 % max.
8	Elastic recovery of half thread in Ductilometer at 25°C	65	68	72	75	78	50 % min

Figure 1 further shows that Marshall stability decreased continuously as the mixing temperature was reduced from 165°C to 115°C at all ZycoTherm dosages. This reduction indicates that lower production temperatures adversely affected aggregate coating, binder fluidity, and compaction efficiency, resulting in a weaker internal structure and reduced load-carrying capacity

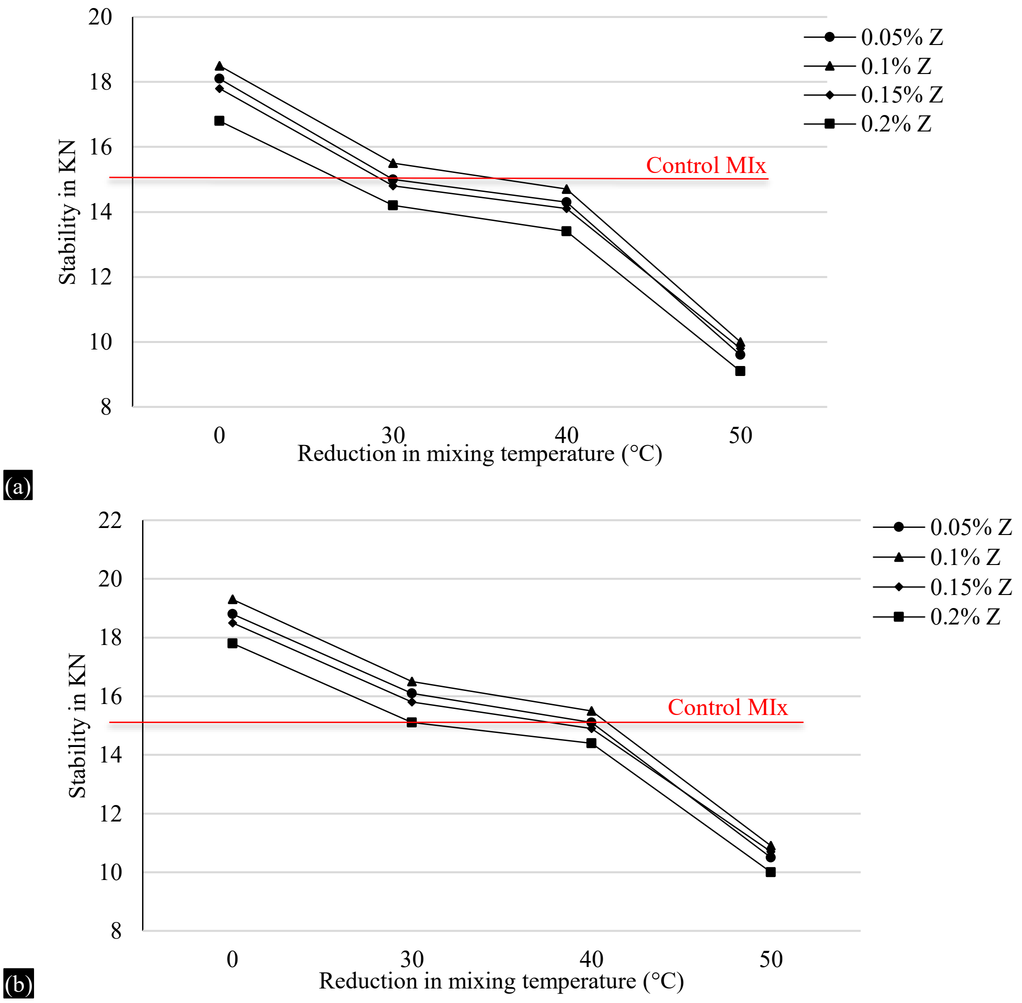

Figure 1. (a) Marshall stability of PMB-based BC grade-II at 0% hydrated lime; (b) Marshall stability of PMB-based BC grade-II at 3% hydrated lime.

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The stability values approached the lower acceptable limit at 125°C, whereas at 115°C, the minimum Marshall stability requirement specified by MoRTH-V and IRC: SP:135-2022 was not satisfied. Therefore, although ZycoTherm supported reduced-temperature production, excessive temperature reduction was not suitable from the viewpoint of Marshall stability compliance.

Effect on Flow

Figure 2(a) and Figure 2(b) show the effect of ZycoTherm dosage and reduced mixing temperature on the flow values of PMB-based BC Grade-II mixtures without and with 3% hydrated lime, respectively. The results indicate that flow increased continuously as the mixing temperature decreased for all additive dosages. This trend suggests that lower mixing temperatures reduced the internal resistance of the mixture and resulted in higher deformation under loading. This may be attributed to reduced aggregate interlock and lower compaction efficiency at reduced temperatures.

Figure 2(a) and Figure 2(b) also show that flow values initially decreased up to 0.10% ZycoTherm and then increased at higher dosages. This indicates that 0.10% ZycoTherm provided the most favourable balance between workability and structural stiffness. At lower and optimum dosages, the additive improved coating and compaction without excessively increasing mixture deformability. However, beyond 0.10%, the increase in flow indicates a relatively more deformable mixture response. Overall, the modified mixtures showed higher flow values than the control mixture, although all values remained within acceptable limits.

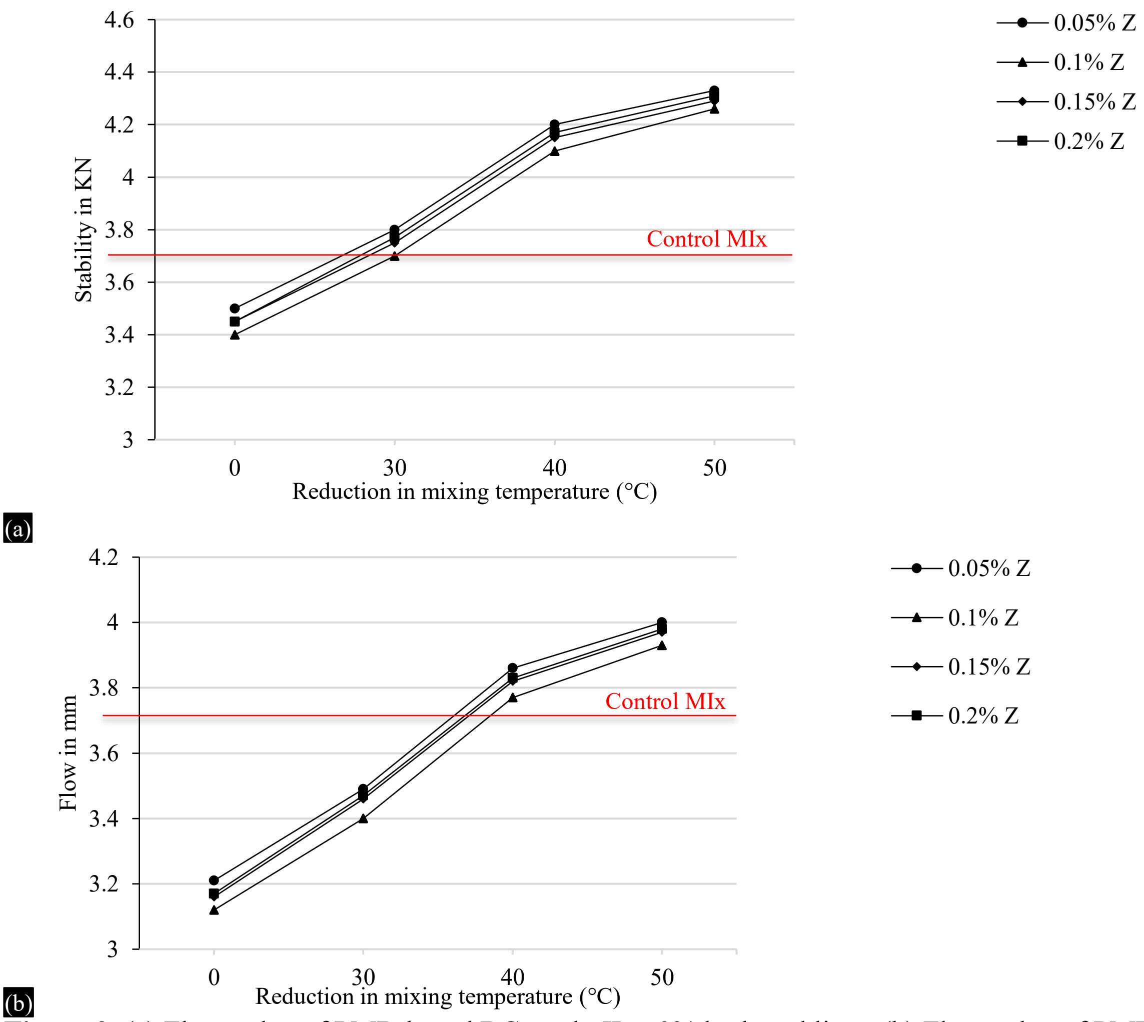

Figure 2. (a) Flow value of PMB-based BC grade-II at 0% hydrated lime; (b) Flow value of PMB-based BC grade-II at 0% hydrated lime.

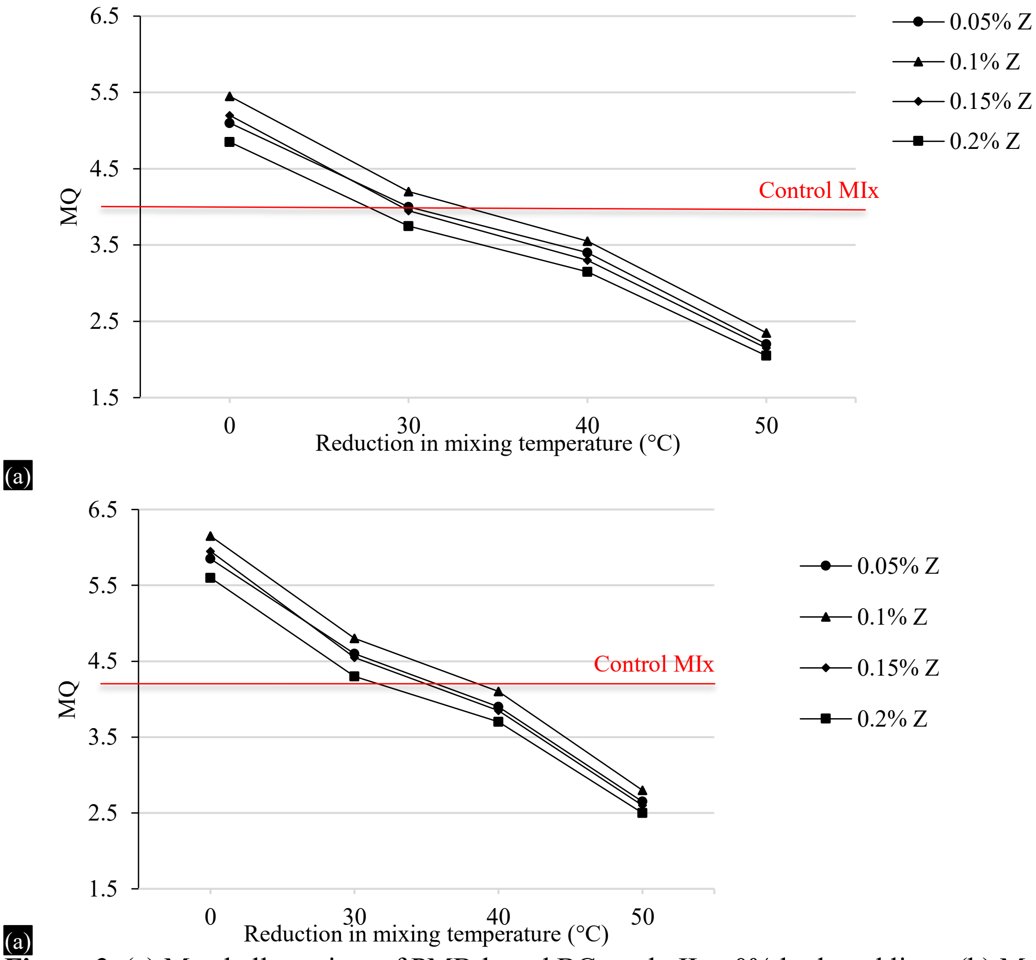

Figure 3. (a) Marshall quotient of PMB-based BC grade-II at 0% hydrated lime; (b) Marshall quotient of PMB-based BC grade-II at 0% hydrated lime.

Effect on Marshall Quotient (MQ)

Marshall Quotient (MQ) decreased continuously with the reduction in mixing temperature for all ZycoTherm dosages in both 0% and 3% hydrated lime mixtures, as shown in Figure 3(a) and Figure 3(b). This trend indicates that lower mixing temperatures reduced the stiffness and load-carrying efficiency of the mixture, mainly due to lower stability and greater deformation at reduced temperatures.

A dosage-dependent response was also observed, where MQ increased up to 0.10% ZycoTherm and then decreased at higher dosages. This suggests that 0.10% ZycoTherm provided the most favourable balance between stability and flow. The initial increase in MQ may be attributed to improved aggregate coating, better compaction, and enhanced structural resistance. However, the reduction beyond 0.10% indicates that higher additive dosages increased mixture deformability and reduced relative stiffness.

Figure 3(a) and Figure 3(b) further show that mixtures containing 3% hydrated lime exhibited comparatively higher MQ values than the corresponding mixtures without lime. This confirms the beneficial role of hydrated lime in improving mixture stiffness and internal strength.

Effect on Volumetric Properties

The volumetric properties of the mixtures, including bulk density, air voids, VMA, and VFB, were evaluated to assess the internal structure and compactability of PMB-based BC Grade-II mixtures under different ZycoTherm dosages, mixing temperatures, and hydrated lime contents. Overall, these parameters showed trends consistent with the Marshall performance of the mixtures.

As shown in Figure 4 and Table 2, bulk density generally decreased with the reduction in mixing temperature. In contrast, air voids and VMA increased, indicating reduced binder fluidity, less effective aggregate coating, and lower compaction efficiency at reduced temperatures. The resulting changes in void structure also influenced VFB, which varied depending on the combined effects of ZycoTherm dosage and mixing temperature.

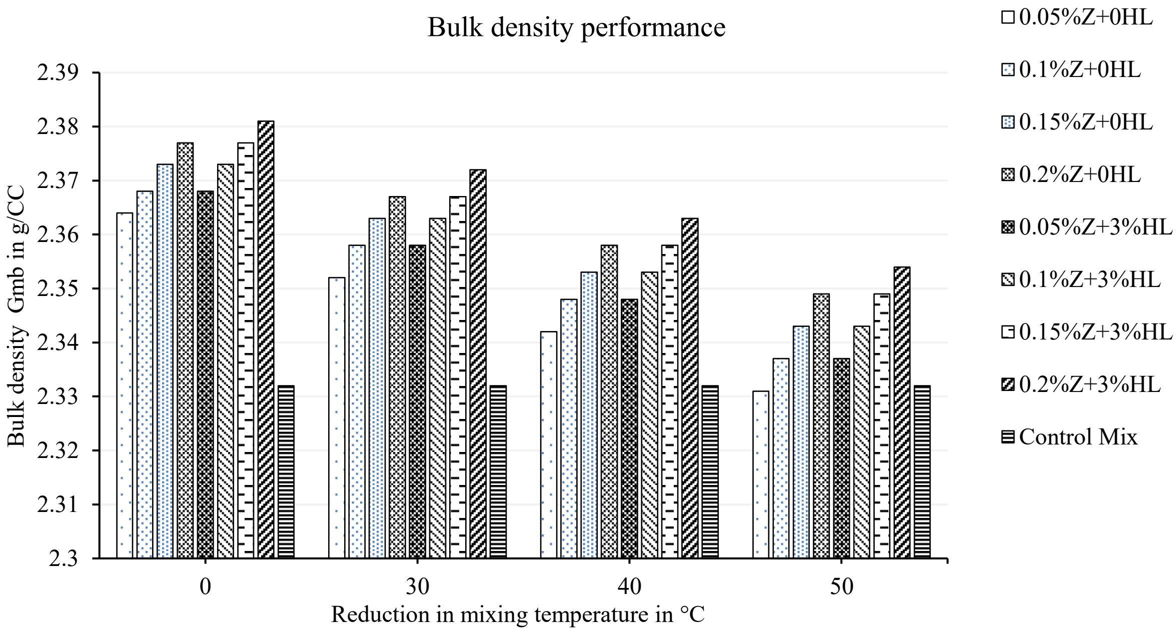

Figure 4. Bulk density of PMB-based BC grade-II at with and without hydrated lime (HL).

Table 2. Presents air voids, VMA, and VFB values for the studied mixtures under different ZycoTherm dosages, mixing temperatures, and hydrated lime contents.

RMT in °C	**Air Voids in % and CM=4**							
	0% HL				***3% HL***			
	0.05%Z	***0.1%Z***	***0.15%Z***	***0.2%Z***	***0.05%Z***	***0.1%Z***	***0.15%Z***	***0.2%Z***
0	3.8	3.61	3.43	3.258	3.61	3.43	3.258	3.095
30	4.256	4.043	3.841	3.649	4.043	3.841	3.649	3.467
40	4.682	4.448	4.225	4.014	4.448	4.225	4.014	3.813
50	5.15	4.892	4.648	4.415	4.892	4.648	4.415	4.195
RMT in °C	**VMA in % and CM=17.2**							
	0% HL				***3% HL***			
	0.05%Z	*0.1%Z*	*0.15%Z*	*0.2%Z*	*0.05%Z*	*0.1%Z*	*0.15%Z*	*0.2%Z*
0	18.485	18.324	18.171	18.026	18.324	18.171	18.026	17.887
30	18.871	18.691	18.52	18.357	18.691	18.52	18.357	18.202
40	19.232	19.033	18.845	18.666	19.033	18.845	18.666	18.496
50	19.628	19.41	19.203	19.006	19.41	19.203	19.006	18.819
RMT in °C	**VFB in % and CM=75**							
	0% HL				***3% HL***			
	0.05%Z	*0.1%Z*	*0.15%Z*	*0.2%Z*	*0.05%Z*	*0.1%Z*	*0.15%Z*	*0.2%Z*
0	79.443	80.299	81.126	81.9255	80.299	81.126	81.925	82.6967
30	77.447	78.368	79.26	80.1219	78.368	79.26	80.122	80.9554
40	75.657	76.633	77.58	78.4963	76.633	77.58	78.496	79.3836
50	73.764	74.795	75.797	76.7692	74.795	75.797	76.769	77.7114

The effect of ZycoTherm dosage was also evident in the volumetric response. Up to the optimum dosage, ZycoTherm improved coating and workability, helping to maintain a denser and more stable internal structure. However, beyond the optimum dosage, this improvement was not sustained, and the volumetric parameters indicated relatively less efficient packing.

The incorporation of 3% hydrated lime generally improved the volumetric characteristics compared with the corresponding mixtures without lime. This indicates its beneficial role in mastic modification and binder–aggregate interaction. Overall, the volumetric results support the Marshall stability, flow, and MQ findings by confirming that excessive temperature reduction adversely affected mixture structure, whereas the combined use of ZycoTherm and hydrated lime improved the internal characteristics of the PMB-based warm mix asphalt.

ANOVA and Regression Analysis

The effect of hydrated lime content, ZycoTherm content, and reduction in mixing temperature (RMT) on Marshall stability was analyzed using three-factor ANOVA, and the results are presented in Table 3. The ANOVA showed that the overall model was significant ($F = 139.713$, $p < 0.001$), and the main effects of hydrated lime, ZycoTherm content, and RMT were all statistically significant ($p < 0.001$), whereas all interaction effects were non-significant. The post hoc comparisons presented in Table 4 and Table 5 further confirmed significant differences among most levels of ZycoTherm content and all levels of RMT.

The descriptive statistics presented in Table 6 show that the mean Marshall stability increased from 14.1 for the mixture without hydrated lime (0% HL) to 15.1 for the mixture containing 3% HL. Similarly, the median stability increased from 14.5 to 15.5, while the minimum and maximum values also remained higher for the 3% HL mixture. These results clearly indicate that the incorporation of hydrated lime improved the overall stability level of the asphalt mix.

Table 3. ANOVA – Marshall stability.

	Sum of Squares	df	Mean Square	F	p	Significant
Overall model	867.428	31	27.982	139.713	<.001	Yes
Lime content	21.660	1	21.660	108.149	<.001	Yes
ZycoTherm content	24.109	3	8.036	40.125	<.001	Yes
RPT	820.754	3	273.585	1366.021	<.001	Yes
Lime content × RPT	0.000	3	0.000	0.000	1.000	No
RPT × ZycoTherm content	0.906	9	0.101	0.502	0.867	No
Lime content × ZycoTherm content	0.000	3	0.000	0.000	1.000	No
Lime content × RPT × ZycoTherm content	0.000	9	0.000	0.000	1.000	No
Residuals	12.818	64	0.200			

Table 4. Post hoc comparisons of ZycoTherm content on Marshall stability.

Comparison								
ZycoTherm content		ZycoTherm content	Mean Difference	SE	df	t	ptukey	Significant
0.05	-	0.1	-0.403	0.129	64	-3.12	0.014	No
	-	0.15	0.322	0.129	64	2.49	0.700	No
	-	0.2	0.967	0.129	64	7.48	<.001	Yes
0.1	-	0.15	0.725	0.129	64	5.61	<.001	Yes
	-	0.2	1.37	0.129	64	10.6	<.001	Yes
0.15	-	0.2	0.645	0.129	64	4.99	<.001	Yes

Table 5. Post hoc comparisons of RMT on Marshall stability.

Comparisons								
RMT		**RMT**	**Mean Difference**	**SE**	**df**	**t**	**ptukey**	**Significant**
0	-	30	2.809	0.129	64	21.74	<.001	Yes
	-	40	3.605	0.129	64	27.9	<.001	Yes
	-	50	8.141	0.129	64	63.01	<.001	Yes
30	-	40	0.796	0.129	64	6.16	<.001	Yes
	-	50	5.332	0.129	64	41.27	<.001	Yes
40	-	50	4.536	0.129	64	35.11	<.001	Yes

Table 6. Descriptives statistics.

	Stability for 0%HL	**Stability for 3%HL**
N	48	48
Missing	0	0
Mean	14.1	15.1
Std. error mean	0.436	0.436
95% CI mean lower bound	13.3	14.2
95% CI mean upper bound	15	16
Median	14.5	15.5
Standard deviation	3.02	9.76
Minimum	8.84	20.1
Maximum	19.1	

Note. *The CI of the mean assumes sample means follow a t-distribution with N - 1 degrees of freedom.*

To develop predictive relationships, separate quadratic regression models were established for mixtures containing 0% HL and 3% HL. For the mixture without hydrated lime, the developed model showed excellent predictive capability with $R^2 = 0.942$, whereas for the mixture containing 3% hydrated lime, the model yielded $R^2 = 0.941$. The regression equations obtained are given by Eqs. (1) and (2), respectively.

$$\text{Stability}_{0\text{HL}} = 17.309 + 18.934\text{Z} + 0.05479\text{RMT} - 104.739\text{Z}^2 - 0.00418\text{RMT}^2 \quad (1)$$

$$\text{Stability}_{3\text{HL}} = 18.259 + 18.934\text{Z} + 0.05479\text{RMT} - 104.739\text{Z}^2 - 0.00418\text{RMT}^2 \quad (2)$$

Where Z is the ZycoTherm content and RMT is the reduction in mixing temperature. In both models, the quadratic terms of Zycotherm content and RMT were significant, indicating that the variation in stability followed a nonlinear trend rather than a purely linear one. The higher intercept of the 3% HL model, together with the higher mean stability shown in Table 6, indicates that hydrated lime mainly increased the baseline Marshall stability of the mix, while the response pattern with respect to Zycotherm content and RMT remained nearly unchanged.

CONCLUSION

Based on the experimental investigation on ZycoTherm-modified polymer modified bitumen 76-10 and the corresponding warm mix bituminous concrete mixtures, the following conclusions may be drawn:

- ZycoTherm produced a clear dosage-dependent modification of polymer modified bitumen 76-10. With increase in additive dosage, penetration decreased, while softening point and elastic recovery increased. The residue properties after short-term aging also improved, indicating enhanced thermal stability and retained elastic response of the modified binder.
- At the mixture level, 0.10% ZycoTherm was identified as the optimum dosage. Marshall stability and Marshall Quotient increased up to 0.10% additive content and decreased at higher dosages, while flow showed the opposite tendency beyond the optimum level. This indicates that 0.10%

ZycoTherm provided the most favorable balance between mixture strength, stiffness, and deformation characteristics.

- Reduction in mixing temperature adversely affected the Marshall and volumetric response of the mixtures. As the mixing temperature was reduced from 165°C to 115°C, Marshall stability and Marshall Quotient decreased, while flow increased, indicating lower mixture stiffness, weaker internal structure, and reduced load-carrying capacity at lower temperatures.
- The allowable temperature reduction was limited by Marshall stability requirements. The results showed that the mixture approached the lower acceptable stability range by 125°C, whereas at 115°C the minimum Marshall stability requirement specified by MoRTH-V and IRC:SP:135-2022 was not satisfied. Therefore, excessive reduction in mixing temperature was not suitable for the studied material system.
- The volumetric properties followed trends consistent with the Marshall response. With reduction in mixing temperature, the mixtures generally exhibited less favorable internal structure and compactability, supporting the observed decrease in stability and Marshall Quotient and increase in flow.
- The incorporation of 3% hydrated lime generally improved mixture performance. Compared with the corresponding mixtures without lime, hydrated lime enhanced Marshall and volumetric response, indicating its beneficial role in improving binder–aggregate interaction, mastic characteristics, and internal mixture structure.
- The statistical analysis confirmed that Marshall stability was significantly influenced by hydrated lime content, ZycoTherm dosage, and reduction in production temperature, with all three main factors showing highly significant effects ($p < 0.001$). Among these, reduction in production temperature was the most influential factor, as indicated by the highest F-value. The interaction effects were not significant, indicating that the factors acted largely independently within the investigated range. Post hoc analysis further confirmed that 0.10% ZycoTherm produced significantly better Marshall stability than the higher dosages of 0.15% and 0.20%, while all temperature reduction levels differed significantly from each other. The descriptive statistics also showed higher mean Marshall stability for mixtures with 3% hydrated lime than for mixtures without hydrated lime, confirming the beneficial role of hydrated lime in improving stability.
- The statistical analysis showed that Marshall stability was significantly affected by hydrated lime content, ZycoTherm dosage, and reduction in mixing temperature, with temperature reduction being the most dominant factor. The interaction effects were not significant. The developed quadratic regression models for 0% and 3% hydrated lime mixtures showed excellent fit (R^2 = 0.942 and 0.941), confirming the nonlinear effect of ZycoTherm dosage and temperature reduction on stability and the beneficial influence of hydrated lime on baseline mixture strength.

Overall, ZycoTherm can support reduced-temperature production of polymer modified bitumen based bituminous concrete Grade II, but only within a limited temperature range. Under the present experimental conditions, 0.10% additive dosage was the most favorable, while 115°C was not suitable from the viewpoint of Marshall stability compliance.

Limitations And Future Scope

The present study is limited to binder characterization and Marshall-based evaluation of PMB-based BC Grade-II mixtures. Although the results show that ZycoTherm and hydrated lime influenced binder and mixture properties significantly, further performance-based studies such as moisture susceptibility, rutting, fatigue, long-term aging, and field validation are needed for comprehensive assessment. Advanced binder characterization may also be considered in future to better understand the interaction of ZycoTherm with the PMB system.

Declaration of Interest

The authors declare that there is no conflict of interest regarding thepublication of this manuscript.

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