

Investigation of warm mix asphalt with using chemical Additive

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Abstract—This study investigates the effect of warm mix additives on the performance of polymer-modified bitumen (PMB-40) in asphalt mixtures. Warm mix asphalt (WMA) technologies allow production at lower temperatures, reducing fuel consumption, emissions, and improving workability. In this work, Zycotherm was added at 0.05%, 0.1%, and 0.15%, and lime was used as an additive at mixing temperatures of 165°C and 135°C. The mechanical performance was evaluated through Marshall Stability, Flow Value, Resilient Modulus, and volumetric parameters. Results indicate optimal performance at 0.1% Zycotherm at 165°C and lime at 135°C, demonstrating enhanced mechanical properties and environmental benefits.

Key words—WMA, PMB, ZYCOTHERM, Lime Additive, Marshall Stability

I. INTRODUCTION

Transportation engineering focuses on the efficient and sustainable movement of people and goods, with roadways playing a critical role in economic and social development [1]. Pavement engineering, a vital sub-discipline, deals with the design, construction, maintenance, and rehabilitation of both flexible (asphalt) and rigid (concrete) pavements. This field integrates knowledge of materials, soil mechanics, and hydraulics to ensure durable and resilient infrastructure. Over the past 40 years, significant advancements have been made in bitumen polymer modification, addressing evolving societal needs and environmental concerns [1] [2]. This paper explores key aspects of pavement engineering and highlights innovations that support the development of sustainable and high-performance road systems.

Hot Mix Asphalt (HMA) is a widely used material in road construction due to its strength, durability, and cost-effectiveness. It is composed of aggregate—such as crushed stone, gravel, or sand—and an asphalt binder that holds the mixture together while providing flexibility. During production, both

components are heated to high temperatures (typically 150–175°C) and thoroughly mixed to ensure uniform coating of the aggregate. The resulting hot mixture is transported to the construction site and laid while still at high temperature to maintain workability. HMA plays a vital role in modern pavement engineering, offering reliable performance under various traffic and environmental conditions [2] [3] [4].

Warm Mix Asphalt (WMA) is a modern, environmentally friendly alternative to Hot Mix Asphalt (HMA), offering similar durability and performance at significantly lower production and placement temperatures—typically between 100°C and 140°C, compared to over 150°C for HMA [5] [6]. This reduction leads to multiple benefits including lower energy consumption, reduced greenhouse gas emissions, enhanced worker safety, and the ability to extend the construction season in cooler climates.

WMA can be produced through various technologies such as foaming techniques, chemical additives (e.g., Zycotherm), and wax-based additives. These methods reduce the viscosity of the asphalt binder, improving workability and compaction at lower temperatures [5] [6] [7]. Additionally, they enable the use of alternative materials and modified binders, promoting sustainability.

Advancements in WMA technology now include the integration of nanomaterials, which enhance the mechanical and durability properties of asphalt mixes. These innovations represent a significant step forward in the pursuit of sustainable, high-performance pavement solutions [6] [7].

Warm Mix Asphalt (WMA) encompasses various technologies that aim to reduce the production and placement temperatures of asphalt mixtures

compared to traditional Hot Mix Asphalt (HMA) [24]. These technologies offer several benefits, including environmental sustainability, improved workability, and enhanced pavement performance. One approach involves the use of additives or modifiers that lower the viscosity of asphalt binders at lower temperatures, allowing for easier mixing and compaction [23] [24]. Another method utilizes foaming agents to generate tiny air bubbles within the asphalt mixture, reducing its viscosity and facilitating compaction. Additionally, chemical additives can modify the asphalt-aggregate bond, enhancing moisture resistance and overall durability. The adoption of WMA technologies results in reduced energy consumption, lower emissions of greenhouse gases and other pollutants, and decreased reliance on virgin materials. Furthermore, WMA allows for the incorporation of reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles (RAS) into asphalt mixes, promoting recycling and reducing waste. Overall, the diverse array of WMA technologies provides flexibility in addressing specific project requirements while advancing sustainability and performance in asphalt pavement construction [24] [25] [26].

II. MATERIAL COLLECTION

Aggregates form the dominant component in asphalt mixes, representing 90-95% of the total weight, and are essential in providing the necessary strength, durability, and stability to the pavement [4]. Sourced from materials such as crushed rock, gravel, or sand, aggregates are classified by size to ensure optimal gradation and compatibility within the mix [4]. The particle size and gradation of aggregates are critical factors that affect the performance of the asphalt mix, influencing key attributes like load distribution, compaction, and the long-term durability of the pavement [5]. (Source: Pawan Construction, Rajkot)

Table 1: Physical properties of aggregate

Sr. No.	Test Name	Result	Specification as per MoRTH -V and (IRC 135:2022)
1.	Specific Gravity test	2.67	>2.5
2.	Impact Value test	11 %	<24 %

3.	Abrasion Value test	26 %	<30 %
4.	Water Absorption test	0.45 %	2 % Max
5.	Flakiness and Elongation test	29.6 %	35 % Max

BITUMEN:-

Bitumen, commonly referred to as asphalt cement, is a dark brown or black viscous substance that acts as the binder in asphalt concrete, ensuring cohesion between aggregate particles. It is a byproduct of petroleum refining and plays a crucial role in asphalt paving mixtures due to its adhesive and waterproofing properties, which are vital for the durability and performance of pavements under various conditions [4][8]. Polymer Modified Bitumen (PMB) is a variant of bitumen that includes polymers, enhancing its mechanical and thermal properties. This modification allows the bitumen to stretch without breaking, improving its flexibility and strength. The PMB-76-10 used in this study was sourced from Maruti Bitumen, Mehsana, Gujarat.

Table 2 Physical Properties of Polymer Modified Bitumen (PMB-76-10)

Sr. no.	Test Name	Unit	Result	Specific ation as per IS 15462-2019
Tests to be carried out on original binder				
1.	Softening point (R and B)	°C	78	70 Min.
2.	Elastic recovery of Half thread in Ductilomete r at 15°C	%	75	70 Min.
3.	Flash Point	°C	288	230 Min.
4.	Viscosity at 150°C	Pa.S	1.178	1.2 Max
5.	Complex modulus (G*) divided by Sin delta (G*/Sin Ω)	kPa	2.086	1.0 Min

	as min 1.0 kPa, 25mm plate, 1 mm gap, 10 rad/s, at a temperature, 70°C			
6	Phase Angle Ω	Degr e	63.6	75 Max
7	Separation, Difference in Softening points, (R&B)	°C	0.90	Max
B) Tests to be carried out on Rolling Thin Film Oven (RTFO) Residue 2				
1.	Loss in Mass	%	0.14	1.0 Max
2.	Complex modulus (G^*) divided by $\sin \delta$ ($G^*/\sin \delta$) as min 2.2 kPa, 25mm plate, 1 mm gap, 10 rad/s, at a temperature, 76°C	kPa	3.476	2.2 Min
3.	MSCR test, Jnr 3.2 at 76°C	kPa	0.6180	4.5 Max.
4.	MSCR test, Jnr Diff 3.2 at 76°C	%	35.49	75 Max.

ZYCOTHERM:-

Zycotherm is a warm mix asphalt (WMA) additive designed to reduce the production temperature of asphalt pavements. This odorless, non-corrosive liquid is compatible with all aggregate types and works by modifying the surface of aggregate particles, enhancing the adhesion of asphalt binder at lower temperatures. By reducing the viscosity of the binder, Zycotherm improves workability, allowing for better coating of aggregates and easier mixing [6]. It enables asphalt to be mixed and laid at temperatures 20-30°C lower than traditional hot mix asphalt, leading to significant energy savings, reduced emissions, and improved sustainability. Additionally, it enhances the performance of

asphalt, improving durability, moisture resistance, and reducing rutting and cracking [8]. Zycotherm is widely used in the production of WMA for various pavement applications, including highways, airfields, and parking lots, where long-lasting performance is critical.

Lime Powder (especially hydrated lime) is a vital additive in asphalt mixes, commonly added at a rate of 3% by the weight of the bitumen in the mix. For a mixture containing aggregates like 10 mm, 6 mm, and stone dust, this dosage refers to 3% of the total weight of the bitumen. The incorporation of lime improves the bond between the asphalt binder and the aggregates, enhancing the durability of the pavement. It helps prevent rutting, reduces the growth of fractures at low temperatures, minimizes age-related hardening, and boosts moisture resistance [7]. Lime also plays a key role in stabilizing low-quality soils and acts as an effective anti-stripping agent, improving the overall performance of asphalt pavements.

III. EXPERIMENTS

Gradation for Bituminous Mix Design (BC Grade II)

Gradation plays a vital role in the Marshall Mix design for BC Grade II asphalt by optimizing the proportions of coarse aggregates (10 mm, 6 mm), fine aggregates, and stone dust. This ensures the right balance for stability, durability, and workability. Proper gradation promotes effective binder coating, reduces voids, and enhances aggregate interlock. The mix design process involves selecting and blending aggregates according to specific standards, which are verified through sieve analysis. This ensures that the mix can withstand the demands of traffic and environmental conditions, ensuring optimal strength and performance [09].

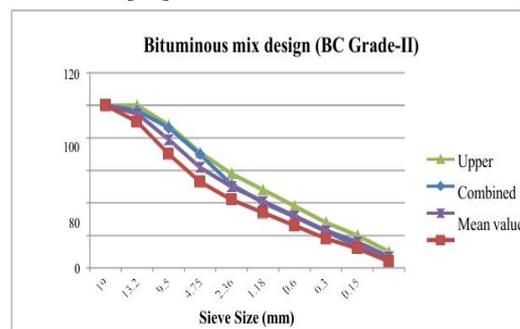


Figure.1 Bituminous Mix Design

In this experimental study, asphalt specimens were prepared using an Optimum Binder Content (OBC) of 78.06 g, equivalent to 6.4% of the total mix weight (1150 g). The aggregate mix consisted of 287.5 g of 10 mm aggregate, 345 g of 6 mm aggregate, 460 g of stone dust, and 34.5 g of hydrated lime (3% of the total aggregate weight). The study incorporated Zycotherm additive at 0.05%, 0.1%, and 0.15% by weight of the binder. The aggregates were heated to 135°C, while the bitumen was heated to 165°C, and mixing and compaction were conducted at 135°C to simulate warm mix conditions.

The Marshall Method was employed to assess key strength parameters, including stability, flow value, and volumetric properties such as air voids, bulk density, and Voids Filled with Bitumen (VFB). This methodology provided insights into the durability, workability, and moisture resistance of the mix. The inclusion of Zycotherm and hydrated lime was found to enhance binder-aggregate adhesion, improve compaction at lower temperatures, and reduce moisture-induced damage, contributing to the development of high-performance warm mix asphalt.

VOLUMETRICS PARAMETERS OF MARSHALL MIX

The Marshall Stability test was performed on Warm Mix Asphalt (WMA) using Polymer Modified Bitumen (PMB 76-10), Zycotherm additives (0.05%, 0.1%, 0.15%), and 3% lime filler, all by weight of the bituminous mix. The aggregate gradation included 10 mm and 6 mm aggregates, as well as stone dust. Three Marshall moulds were compacted with 75 blows per face at temperatures ranging from 135°C to 145°C, with specimens conditioned at 60°C to assess Marshall Stability and flow.

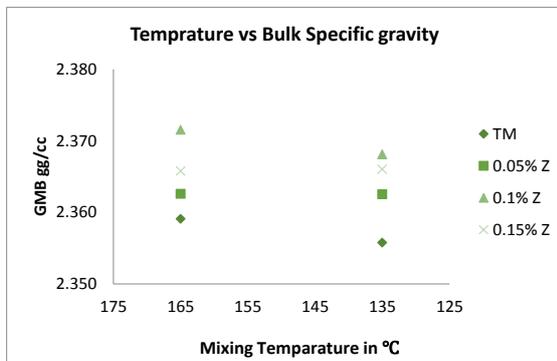


Figure.2 Temperature Vs Bulk Specific Gravity

Volumetric parameters—such as Bulk Density (Gmb), Maximum Specific Gravity (Gmm), Air Voids (Va), Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB)—were calculated, with air voids maintained at 4% to ensure optimal performance and durability of the mix. The Bulk Specific Gravity (Gmb) reflects the degree of compaction of the asphalt mix. As Zycotherm and hydrated lime were incorporated, Gmb increased due to enhanced binder-aggregate adhesion and filling of voids. At 165°C, the mix exhibited high workability, facilitating excellent compaction and resulting in higher Gmb values. However, at 135°C, compaction was slightly reduced.

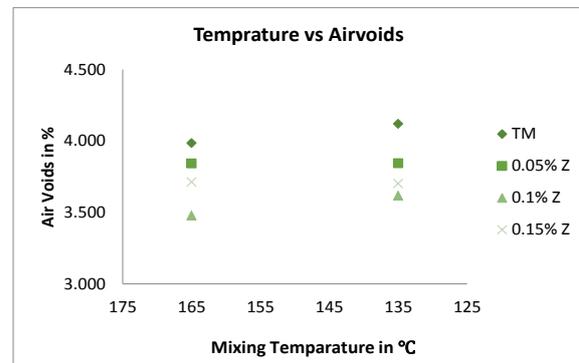


Figure.3 Temperature Vs Airvoids

Despite the lower production temperature, Warm Mix Asphalt (WMA) still demonstrates better workability compared to conventional Hot Mix Asphalt (HMA) produced at higher temperatures. Air Void Content (Va), which represents the air pockets within the asphalt mix, is a critical parameter for pavement performance. The addition of Zycotherm and hydrated lime typically leads to a reduction in Va by enhancing binder-aggregate adhesion, resulting in a denser and more cohesive mix. The target Va is maintained at approximately 4% to ensure optimal durability and mechanical performance. At 165°C, compaction is highly effective, achieving the desired Va range. However, at 135°C, compaction efficiency slightly decreases due to the lower temperature, which can cause a marginal increase in Va if not properly managed. Nonetheless, the presence of Zycotherm and lime helps offset this by improving adhesion and compactability, maintaining Va within acceptable limits.

Voids in Mineral Aggregate (VMA) refer to the volume within the mineral aggregate framework that is not occupied by the binder. With the addition of Zycotherm and hydrated lime, VMA tends to

decrease as the improved binder adhesion and void-filling action of the additives result in a denser and stronger mix. At 165°C, compaction efficiency is optimal, significantly reducing VMA. At 135°C, while the mix remains workable, the reduced compaction effectiveness may lead to slightly higher VMA due to less efficient aggregate packing. However, the continued presence of Zycotherm and lime mitigates this by partially filling the voids.

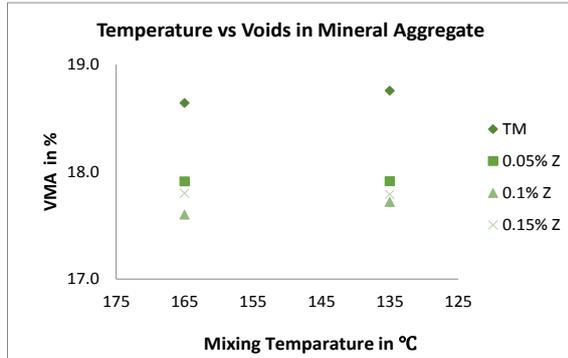


Figure.4 Temperature Vs Voids in Mineral Aggregate

Voids Filled with Bitumen (VFB) represent the percentage of VMA that is filled with bitumen. The incorporation of Zycotherm and lime increases VFB, as these additives enhance binder distribution and adhesion within the mix. At 165°C, high workability facilitates better compaction, resulting in higher VFB values. Although compaction is less effective at 135°C, leading to potential slight reductions in VFB, the additives help sustain a relatively high VFB by promoting improved coating and filling of the aggregate voids.

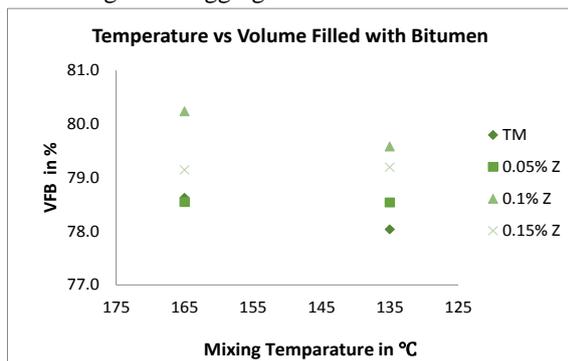


Figure.5 Temperature Vs Volume filled with Bitumen

Marshall Stability and Flow: Temperature vs. Flow In Warm Mix Asphalt (WMA) incorporating Polymer Modified Bitumen (PMB 76-10), the key Marshall strength parameters—Marshall Stability, Marshall Flow, and Marshall Quotient (MQ)—serve as critical indicators of the

mix's load-bearing capacity, deformation resistance, and overall performance. The inclusion of Zycotherm at dosages of 0.05%, 0.10%, and 0.15%, along with 3% hydrated lime by weight of the mix, significantly enhances binder-aggregate adhesion and moisture resistance.

These additives contribute to an increase in both Marshall Stability and MQ, while maintaining Flow values within the optimal range. Even at reduced production temperatures typical of WMA (e.g., 135°C compared to the conventional 165°C for HMA), the mixture retains high strength and workability, supporting the construction of durable and sustainable pavements.

Marshall Stability represents the maximum load a compacted asphalt specimen can bear before failure. The addition of Zycotherm and lime strengthens the mix by improving the cohesion between binder and aggregate, leading to increased resistance under traffic loads. As a result, stability values improve even at lower temperatures.

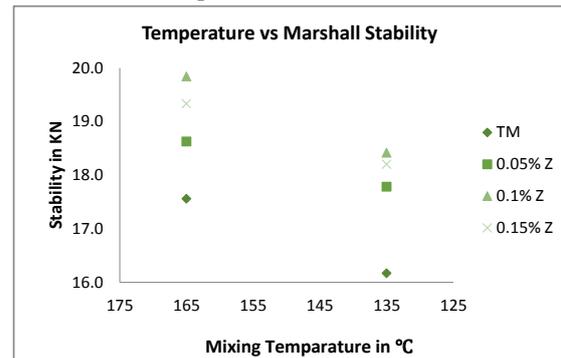


Figure.6 Temperature Vs Marshall Stability

Marshall Flow, which indicates the deformation of the asphalt specimen under load, generally decreases with improved binder-aggregate interaction. At 165°C, the mix exhibits excellent workability and a balanced combination of stability and flow. At 135°C, while workability slightly decreases, flow may increase marginally; however, values remain within acceptable limits due to the beneficial effects of the additives.

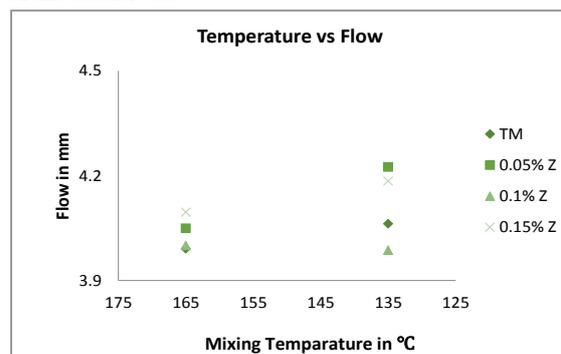


Figure.7 Temperature Vs Flow

The Marshall Quotient (MQ), calculated as the ratio of stability to flow, provides a composite measure of the mix's structural integrity and stiffness. The use of Zycotherm and lime enhances MQ by boosting strength relative to deformation. Although a slight reduction in MQ may occur at 135°C due to increased flow, the overall performance remains robust, confirming the efficacy of these additives in maintaining mechanical strength and durability under lower temperature conditions.

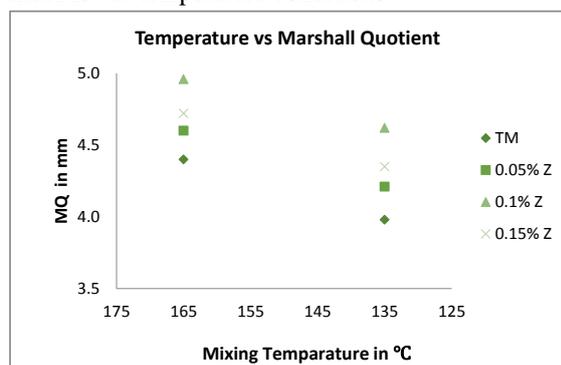


Figure.8 Temperature Vs Marshall Quotient

IV. CONCLUSION

The addition of 0.1% Zycotherm and 3% hydrated lime to Polymer Modified Bitumen (PMB 76-10) significantly improves the performance of Warm Mix Asphalt (WMA), particularly at reduced production temperatures of 135°C. Zycotherm enhances binder-aggregate adhesion, while hydrated lime acts as an effective anti-stripping agent, increasing the mix's resistance to moisture-induced damage.

The observed improvements in Marshall Stability and Flow values confirm enhanced load-bearing capacity, increased resistance to cracking, and reduced susceptibility to traffic-induced deformation such as rutting. This combination ensures optimal mechanical performance and durability, while maintaining sufficient flexibility even at lower temperatures. The results support the use of Zycotherm and lime as effective additives for producing high-performance, sustainable WMA suitable for modern pavement applications.

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