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Performance-Based Optimization of Additive and Filler Systems in Warm Mix Asphalt

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***Abstract*—Warm mix asphalt (WMA) is gaining popularity because it uses lower temperatures during production and paving. This means less fuel used, less harmful fumes and potentially a longer laying period. WMA offers similar performance to traditional asphalt while being more environmentally and worker friendly. The purpose of this research work is to investigate effect of warm mix additive in asphalt mixture, using warm mix additive chemical in percentage by total weight of bitumen in asphalt mixture. Using wet bond 0.2%, 0.4%, 0.6% and 3% lime at production temperatures 165℃ and 135℃ used to reduce mixing temperature of bituminous mix that is helps in reduce environment pollution and sustainable development and enhanced performance of Marshall Stability, Flow Value and Marshall volumetric parameters with 0.4% wet bond at 135℃ production temperature.**

***Index Terms*—Bituminous Mix, Lime, Marshal flow, Marshall Stability, WMA additive**

I. INTRODUCTION

Transportation engineering applies scientific principles to the design and management of transportation systems, ensuring the efficient, safe, and sustainable movement of people and goods [1]. Pavement engineering, a key branch of this field, focuses on the planning, construction, and maintenance of both flexible and rigid pavements, incorporating aspects like materials, soil mechanics, and traffic loading [2][3][10]. Flexible pavements, composed of multiple layers—sub-grade, sub-base, base course, and surface course—distribute loads through grain-to-grain contact and are widely used due to their cost-effectiveness and ease of maintenance [1][2][4]. Hot Mix Asphalt (HMA), commonly used in flexible pavements, is produced by mixing heated aggregates and asphalt binder at high temperatures (around 150–180°C), offering excellent durability and flexibility [5][7]. The process involves careful selection and blending of aggregates, heating, mixing, compaction, and cooling to form a dense and long-lasting pavement surface [5][6]. Warm Mix Asphalt (WMA) represents a sustainable evolution of HMA, produced at lower temperatures (100–140°C) using various additives, which reduce energy consumption and greenhouse gas emissions [5][7][8]. WMA offers multiple benefits, including better workability, enhanced compaction, reduced thermal cracking, improved moisture resistance, and compatibility with recycled materials such as fly ash [5][6][7]. These attributes not only extend pavement life but also contribute to environmental sustainability and cost savings. Furthermore, WMA improves worker safety by reducing fumes and odors, supports faster construction with minimal traffic disruption, and can be adapted to diverse climatic and traffic conditions [5][6]. Optimizing WMA using polymer-modified binders, anti-stripping agents, and hydrophobic fillers can enhance its long-term performance, making it a viable alternative for modern road construction. This research contributes to building durable, efficient, and environmentally conscious infrastructure [6][7]. Polymer Modified Bitumen (PMB) 76-10 is a specially engineered binder designed to enhance the performance of asphalt, particularly in high-stress environments such as highways, airfields, and areas with heavy traffic. It is produced by modifying conventional bitumen with polymers like Styrene Butadiene Styrene (SBS) and stabilizers. This modification improves its viscosity, elasticity, resistance to thermal cracking, and adhesion properties, making PMB 76-10 particularly suitable for use in high-temperature conditions and areas subject to heavy loads and temperature fluctuations [5][6]. Incorporating PMB 76-10 into Warm Mix

Asphalt (WMA) brings multiple advantages, including improved compaction at lower temperatures, reduced oxidation, and enhanced compatibility with warm mix additives like Wetbond and lime fillers. The elasticity of PMB 76-10 helps in improving compaction without compromising the asphalt's long-term performance. Furthermore, using WMA technology reduces the production temperatures, leading to energy savings and lower emissions [7]. However, challenges in WMA, such as increased susceptibility to low-temperature cracking, premature fatigue failure, and moisture-induced damage, need further research to optimize the effects of additives like Wetbond and fillers such as lime. These additives can alter the rheological properties of WMA, and their optimal combinations require thorough investigation. The objective of this study is to analyse the physical properties of PMB modified with Wetbond and lime, determine their impact on the mechanical properties of WMA, and evaluate their effects on parameters like Marshal stability, flow value, at various temperatures. This study also aims to perform a comparative analysis of the performance of PMB mixes using Wetbond and lime, while determining the optimal binder content (OBC) for various asphalt mixtures [5][7].

II. LITERATURE REVIEW

The collected studies demonstrate significant advancements in asphalt production and pavement performance through various additives and technologies. Waste engine oil (WEO) and Zycotherm [13] effectively reduce preparation temperatures, improve aging resistance, and enhance rutting performance, while warm mix asphalt (WMA) technology is praised for its reduced emissions and energy efficiency [14]. The use of reclaimed asphalt pavement (RAP) in WMA improves mechanical performance and fatigue resistance, confirming its sustainability potential [15]. Fillers like fly ash, calcium carbonate, and Kao wax enhance WMA durability and low-temperature cracking resistance [16], while polymer additives such as SBS, PTFE, and PVC significantly improve elasticity, stability, and longevity [17]. Retona Blend 55 outperforms Wetbond-SP in asphalt mixtures, proving its superiority in stability and durability [18], and SBS polymer-modified bitumen further enhances WMA and HMA applications [19]. Half-warm mix asphalt (HWMA) offers a sustainable option for urban roads [20], and Zycotherm proves highly effective in mitigating moisture damage in bituminous mixes [21]. Cashew Nut Shell Liquid (CNSL) demonstrates potential for lowering production temperatures while enhancing WMA durability [22]. Anti-stripping agents like Zycotherm and Bitugrip improve adhesion and moisture resistance [23], and additives like Sasobit, Advera, and Rediset enhance asphalt-aggregate bonding [24]. Zycotherm and Sasobit improve binder content and mix properties [25], while reduced temperatures and chemical additives enhance polymer-modified bitumen performance [26]. Rediset shows promise in reducing production temperatures and improving compatibility [27], and optimization through surfactant-wax additives streamlines WMA production [28]. Oxidized polyethylene wax enhances rheological properties but poses challenges at low temperatures, while siloxane-based additives provide better durability [29]. Rediet demonstrates environmental benefits with variable performance based on mix design [30]. In India, WMA pavements perform on par with or better than HMA despite challenging conditions [31], and surfactant-based additives improve asphalt rubber and concrete mixtures by lowering production temperatures and enhancing key properties [32]. These advancements emphasize the potential of innovative additives and processes for more sustainable and efficient asphalt production.

III. MATERIALS AND EXPERIMENTS

MATERIALS:

AGGREGATE:

Aggregates are the primary component of asphalt mixes, accounting for 90-95% of the total weight and playing a crucial role in providing strength, durability, and stability to the pavement [5]. Typically derived from crushed rock, gravel, or sand, aggregates are graded by size to ensure proper gradation and compatibility within the mix [6]. The size and gradation of aggregates significantly influence the performance characteristics of the asphalt mix, impacting factors such as load distribution, compaction, and overall pavement durability [7]. (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, also known as asphalt cement, is a black or dark brown sticky substance that serves as the binding agent in asphalt concrete by adhering aggregate particles together. Derived as a byproduct of petroleum refining, it is an essential component of asphalt paving mixtures, offering adhesive and waterproofing properties that are critical for pavement durability and performance under varying conditions [5][9]. Polymer Modified Bitumen (PMB) is a specialized type of bitumen that incorporates polymers, to enhance its mechanical and thermal properties. It can be stretched repeatedly without breaking, making it an ideal additive for improving flexibility and strength in bitumen. PMB-76-10, sourced from Maruti Bitumen, Mehsana, Gujarat.

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

Sr. no.	Test Name	Unit	Result	Specification as per IS 15462-2019
Tests to be carried out on original binder				
1.	Softening point (R and B)	℃	78	70 Min.
2.	Elastic recovery of Half thread in Ductilometer at 15℃	%	75	70 Min.
3.	Flash Point	℃	288	230 Min.
4.	Viscosity at 150℃	Pa.S	1.178	1.2 Max
5.	Complex modulus (G*) divided by Sin delta (G*/Sin Ω) as min 1.0 kPa, 25mm plate,1 mm gap,10 rad/s, at a temperature , 70℃	kPa	2.086	1.0 Min
6	Phase Angel Ω	Degree	63.6	75 Max
7	Separation, Difference in Softening points, (R&B)	℃	0.90	Max
B) Tests to be carried out on Rolling Thin Film Oven (RTFO) Residue2				
1.	Loss in Mass	%	0.14	1.0 Max
2.	Complex modulus (G*) divided by Sin delta (G*/Sin Ω) as min 2.2 kPa, 25mm plate,1 mm gap,10 rad/s, at a temperature , 76℃	kPa	3.476	2.2 Min
3.	MSCR test, Jnr 3.2 at 76℃	kPa	0.6180	4.5 Max.

4.	MSCR test, Jnr Diff 3.2 at 76°C	%	35.49	75 Max.

WETBOND: -

Wetbond is a Warm Mix Asphalt (WMA) additive designed to reduce asphalt production temperatures. It is a non-hazardous, odorless liquid that improves the adhesion between asphalt binder and aggregates, ensuring better coating and compaction even at lower temperatures. This additive enhances WMA performance by improving workability, reducing energy consumption, and lowering emissions during production [5]. The recommended dosage of Wet bond is between 0.2% and 0.6% by weight of the binder, depending on factors like aggregate type and traffic conditions. Manufactured by Petrochem Specialties in Muzaffarnagar, Uttar Pradesh, Wet bond contributes to advancements in asphalt technology [11]. When combined with additives like lime and polymer-modified binders such as PMB 76-10, Wet bond improves adhesion, reduces moisture susceptibility, and optimizes compaction, making it vital for durable, sustainable,and Voids in Mineral Aggregate (VMA) is the volume of voids in the mineral aggregate that is not filled with binder.cost-effective road construction [5][11].

LIME POWDER:

Lime, particularly hydrated lime, is a crucial additive in pavement mixes, typically used at a dose of 3% by weight of the bituminous mix. For a mix containing 10 mm, 6 mm aggregates, and stone dust, this 3% dosage refers to 3% of the total weight of the bitumen in the mix. The addition of lime enhances the bond between asphalt binder and aggregates, improving the pavement's durability by resisting rutting, reducing low-temperature fracture growth, minimizing age hardening, and enhancing moisture resistance [6]. Additionally, lime stabilizes low-quality soils and serves as an effective anti-stripping agent in asphalt pavements.

EXPERIMENTS

Gradation For Bituminous Mix Design (BC Grade II)

Gradation is crucial in Marshall Mix design for BC grade 2 asphalt, optimizing the balance of coarse aggregates (10 mm, 6 mm), fine aggregates, and stone dust for stability, durability, and workability. Proper gradation ensures effective binder coating, minimal voids, and aggregate interlock. The mix design process involves selecting and blending aggregates to meet specifications, verified through sieve analysis, ensuring strength and performance under traffic and environmental conditions [12].

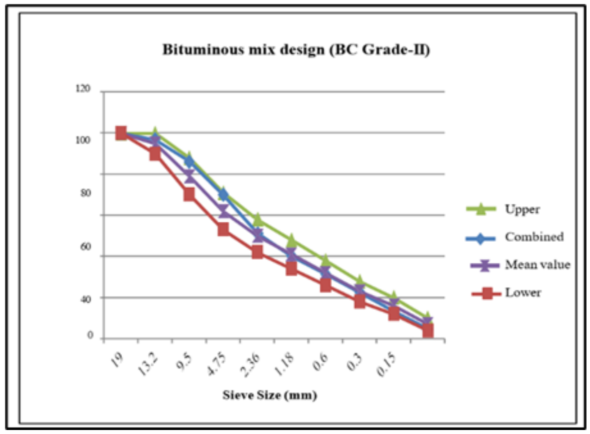

Figure.1 Bituminous Mix Design

In this experimental study, asphalt specimens were prepared using an Optimum Binder Content (OBC) of 78.06 g, which corresponds to 6.4% of the total mix weight (1150 g). The aggregate blend included 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 aggregate weight). Wet Bond additive was added at 0.2%, 0.4%, and 0.6% by weight of the binder. The aggregates were heated to 135°C and bitumen to 165°C, with mixing and compaction conducted at temperatures of 135°C, simulate warm mix conditions. The Marshall Method was used to determine strength parameters such as stability and flow value, as well as volumetric properties like air voids, bulk density, and voids filled with bitumen (VFB). This approach evaluates the durability, workability, and moisture resistance of the mix. The use of Wet Bond and hydrated lime helped in enhancing adhesion, improving compaction at lower temperatures, and reducing moisture-induced damage, leading to the development of high-performance warm mix asphalt.

VOLUMETRICS PARAMETERS OF MARSHALL MIX

The Marshall Stability test was conducted on Warm Mix Asphalt (WMA) with Polymer Modified Bitumen (PMB 76-10), Wetbond additives (0.2%, 0.4%, 0.6%), and 3% lime filler, all by weight of the bituminous mix. The aggregate gradation included 10 mm, 6 mm aggregates, and stone dust. Three Marshall moulds were compacted with 75 blows per face at 135–145°C, and the specimens were conditioned at 60°C to test Marshall Stability and flow. Volumetric parameters—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 mix performance and durability

The Bulk Specific Gravity (Gmb) is an indicator of how well the asphalt mix is compacted. As Wetbond and hydrated lime are added, the Gmb increases due to improved binder-aggregate adhesion and the filling of void spaces. At 165°C, the mix is highly workable, facilitating excellent compaction and resulting in higher Gmb values. However, at 135°C, compaction is slightly less efficient due to the lower temperature, which can lead to a slight reduction in Gmb, especially if compaction is not thoroughly executed.

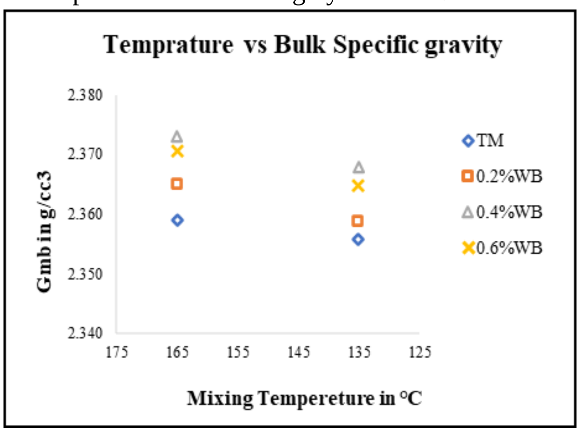

Figure.2 Temperature Vs Bulk Specific Gravity

Despite this, the lower temperature still allows for better workability compared to conventional Hot Mix Asphalt (HMA) at higher temperatures.

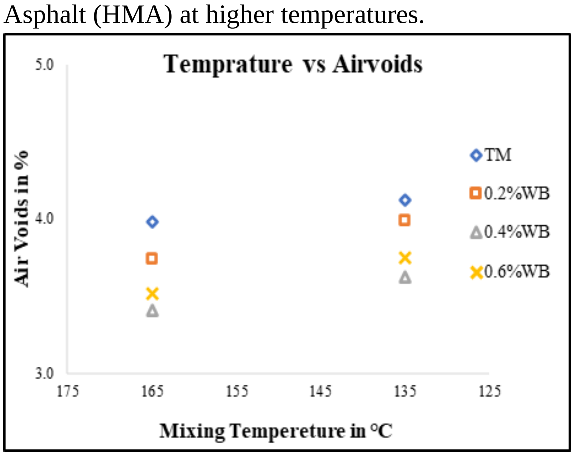

Figure.3 Temperature Vs Air voids

Air Void Content (Va) measures the air spaces within the asphalt mix. With the addition of Wetbond and lime, Va typically decreases, leading to a denser mix. In this case, the target is to maintain Va at around 4%. At 165°C, effective compaction reduces Va significantly to the desired range of 4%. However, at 135°C, compaction efficiency drops slightly due to the cooler temperature, which may result in a slight increase in Va if compaction is not optimal. Even so, Wetbond and lime help reduce Va by improving binder-aggregate adhesion, maintaining the 4% Va target for durability and performance.

Voids in Mineral Aggregate (VMA) is the volume of voids in the mineral aggregate that is not filled with binder.

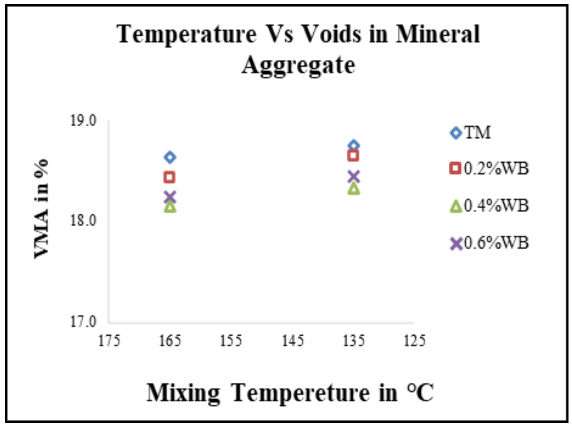

Figure.4 Temperature Vs Voids in Mineral Aggregate

As Wetbond and hydrated lime are added, VMA decreases due to the filling of voids with the binder, leading to a denser and stronger mix. At 165°C, compaction efficiency is at its peak, effectively reducing VMA. At 135°C, while the temperature supports workable conditions, the reduced compaction may lead to a slightly higher VMA due to less effective packing, though the additives continue to fill the void.

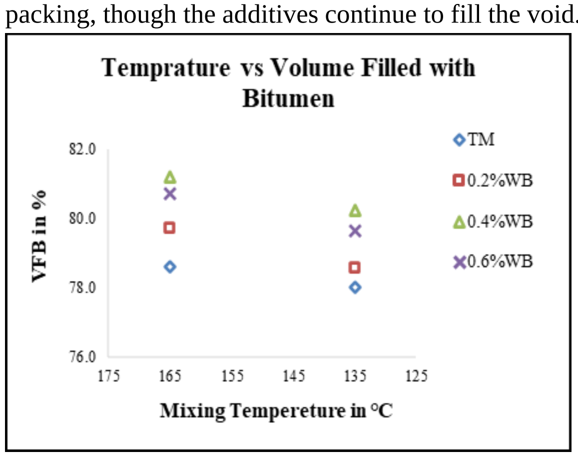

Figure.5 Temperature Vs Volume filled with Bitumen

Voids Filled with Bitumen (VFB) represents the percentage of voids that are filled with bitumen. With the addition of Wetbond and lime, VFB increases because the additives enhance binder adhesion and fill more void spaces. At 165°C, the mix's workability allows for higher VFB values due to better compaction. However, at 135°C, the lower temperature may cause slight variations in VFB, as reduced compaction can prevent complete filling of voids. Still, the effectiveness of the additives helps maintain a reasonably high VFB.

MARSHALL STABILITY AND FLOW

In Warm Mix Asphalt (WMA) incorporating Polymer Modified Bitumen (PMB 76-10), Marshall strength parameters—Marshall Stability, Marshall Flow, and Marshall Quotient (MQ)—are key indicators of load-bearing capacity, deformation resistance, and overall mix performance. The addition of Wet bond at 0.2%, 0.4%, and 0.6% along with 3% hydrated lime improves binder-aggregate adhesion and moisture resistance. These additives lead to increased Marshall Stability and MQ, and maintain Flow values within optimal limits. Even at reduced WMA production temperatures like 135°C (compared to 165°C for HMA), the mix maintains strength and workability, promoting durable and sustainable pavement construction.

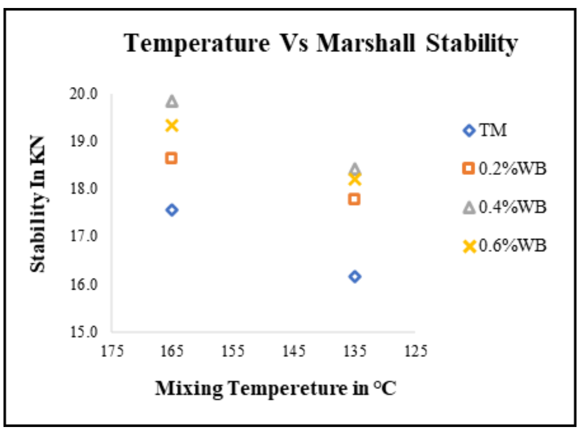

Figure.6 Temperature Vs Marshall Stability

Stability measures the load-bearing capacity of the mix. As Wetbond and lime improve binder adhesion, the stability of the mixture increases, leading to better performance under traffic loads. Flow, which measures the deformation of the mix under load, typically decreases as the binder-aggregate interaction improves. At 165°C, the mix remains highly workable, and both stability and flow are optimal. However, at 135°C, the stability tends to remain high due to better binder adhesion, while flow might slightly increase as the mix is less workable, though still within acceptable limits. The additives support this balance, ensuring durability and load-bearing performance at both temperatures.

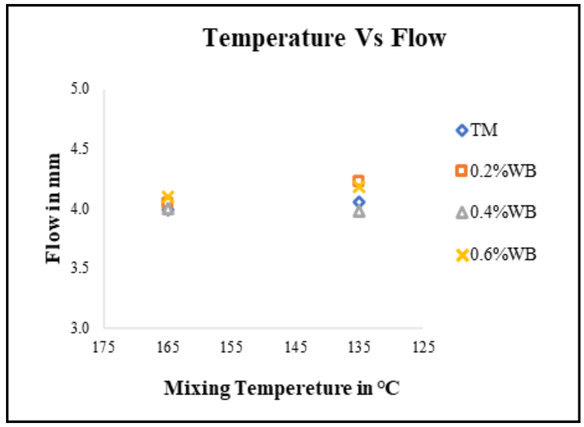

Figure.7 Temperature Vs

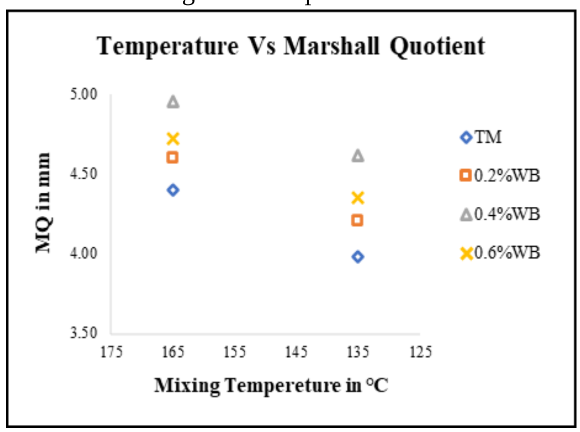

Figure.8 Temperature Vs Marshall Quotient

The Marshall Quotient (MQ), the ratio of stability to flow, provides an overall performance indicator of the mixture. The addition of Wetbond and lime increases MQ by improving the mixture's strength (stability) relative to its flow. At 165°C, the mix's workability supports a higher MQ due to the optimized balance between stability and flow. At 135°C, the reduced compaction may cause a slight decrease in MQ, as flow increases and stability is not as high as at 165°C. However, the overall performance remains solid due to the additives' effects on binder-aggregate adhesion and mix durability.

IV. CONCLUSION

The addition of 0.4% Wetbond and 3% hydrated lime to PMB 76-10 significantly enhances the performance of warm mix asphalt, particularly at reduced production temperatures of 135°C. Wetbond improves binder-aggregate adhesion, while lime serves as an anti-stripping agent, increasing resistance to moisture damage. Marshall Stability and Flow values demonstrate significant improvements, indicating enhanced load-bearing capacity, better resistance to cracking, and the ability to withstand traffic-induced deformation without rutting. This combination ensures optimal mix performance while maintaining flexibility, even at lower temperatures.

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