

Performance Evaluation of Crumb Rubber Modified Bituminous mix with Zycotherm and Lime

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Abstract—The performance of flexible pavements is greatly influenced by rutting, fatigue, and durability. The limitations of traditional bitumen in flexible asphalt pavements are due to the significant rise in traffic loads and volumes. The process of producing standard bitumen asphalt is expensive and it pollutes the environment. On the other hand the disposal of waste tyre is a real problem. The use of these waste crumbed rubber (CR) in bitumen has been already achieved successfully in modifying the properties of bitumen and also provides a viable solution to the tyre disposal problem. This paper takes a further step in that direction by mixing crumb rubber modified bitumen (CRMB) with Zycotherm (at a fixed dose of 0.05%, 0.1% and 0.15%) and Lime (3%) in Warm mix asphalt (WMA) at a fixed temperature 165°C and 135°C and performing tests like Marshall Stability Test, Marshall Flow value while also testing Marshall Flow Value Parameters. The values are then compared with the results of the same tests performed on the conventional bitumen to find out whether any improvement has been achieved with the above-mentioned modifications. It was observed that the 0.1% of zycotherm helps in reduction of environment pollution and sustainable development along with enhanced performance of Marshall Stability, Flow Value and Marshall volumetric parameters.

Index Terms—Warm Mix Asphalt, Crumb Rubber Modified Bitumen, Zycotherm, Lime.

I. INTRODUCTION

Transportation engineering is a discipline that applies scientific and technical principles to the development and management of systems that facilitate the safe, efficient, and sustainable movement of people and commodities [1]. Within this field, pavement engineering plays a crucial role, concentrating on the design, construction, and maintenance of road surfaces, both flexible and rigid, while addressing key factors such as material selection, soil behavior, and

traffic-induced stresses [2][3][10]. Flexible pavements consist of layered systems— including the sub-grade, sub-base, base course, and surface course—designed to distribute traffic loads through particle interlock. These pavements are widely adopted due to their economic advantages and ease of repair [1][2][4]. Hot Mix Asphalt (HMA), a standard material in flexible pavement construction, is produced by blending heated aggregates with asphalt binder at elevated temperatures ranging from 150°C to 180°C, resulting in a surface that is both durable and resilient [5][7]. The manufacturing process includes selecting suitable aggregates, heating, mixing, compacting, and cooling to create a strong, cohesive pavement layer [5][6]. An environmentally improved alternative to HMA, Warm Mix Asphalt (WMA), is manufactured at lower temperatures (100°C to 140°C) using additives that reduce energy use and minimize greenhouse gas emissions [5][7][8]. WMA presents several performance and sustainability advantages, including enhanced workability, better compaction, resistance to moisture damage, and reduced risk of thermal cracking. It also supports the incorporation of recycled materials like fly ash, which can lower costs and environmental impact [5][6][7]. In addition to extending pavement life, WMA improves occupational health and safety by reducing fumes and odors, accelerates construction timelines, and adapts well to different climatic conditions and traffic demands [5][6]. The use of polymer-modified binders, anti-stripping agents, and hydrophobic fillers further enhances the performance of WMA, making it a promising solution for modern, sustainable road infrastructure.[31]. This research supports the advancement of long-lasting, efficient, and eco-friendly transportation systems [6][7]. Cutting waste rubber into pieces and using it in bitumen forms Crumb rubber modified bitumen (CRMB) is a new

polymer-modified binder which solves the problem of discarding of waste tyre. Crumb Rubber Modified Bitumen (CRMB-60) is a high-performance binder specifically developed to boost the durability and functionality of asphalt in demanding conditions, such as highways, runways, and zones with substantial traffic loads. This modification enhances several critical properties—viscosity, elasticity, thermal crack resistance, and adhesion—making CRMB-60 especially effective in hot climates and areas experiencing frequent load and temperature variations [5][6]. When incorporated into Warm Mix Asphalt (WMA), CRMB-60 offers numerous benefits, including better compaction at reduced temperatures, decreased oxidation, and improved synergy with additives like Zycotherm and lime-based fillers. Its inherent elasticity contributes to achieving optimal compaction while maintaining long-term structural integrity. Additionally, the lower production temperatures associated with WMA technology result in significant energy efficiency and reduced environmental emissions [7]. Few of the benefits of CRMB are improved durability, cost effectiveness, better performance, environmental benefits etc. Despite the advantages of Warm Mix Asphalt (WMA), certain challenges persist, including heightened vulnerability to low-temperature cracking, early fatigue failure, and moisture-related damage. These issues highlight the need for continued research to fine-tune the role of additives like Zycotherm and fillers such as lime. Since these additives influence the rheological behavior of WMA, identifying their optimal combinations is essential for enhanced performance. The primary aim of this study is to evaluate the physical characteristics of CRMB when modified with Zycotherm and lime, and to assess their impact on the mechanical behavior of WMA. Specific focus is given to parameters such as Marshall stability, flow values, and performance across different temperature conditions. Additionally, the study involves a comparative performance analysis of CRMB-based mixes incorporating Zycotherm and lime, along with the determination of the Optimum Binder Content (OBC) for various asphalt mix designs [5][7].

II. LITERATURE REVIEW

The reviewed literature highlights progressive developments in asphalt modification techniques that

significantly enhance pavement durability and sustainability. Crumb Rubber Modified Bitumen (CRMB) improves elasticity, rutting resistance, and temperature susceptibility in flexible pavements, particularly in high-stress traffic conditions [13]. Studies show that integrating CRMB into Warm Mix Asphalt (WMA) provides added benefits, including enhanced fatigue life, better resistance to deformation, and reduced environmental impact through lower production temperatures [14].

Zycotherm, a widely used warm mix additive, reduces moisture damage and enhances asphalt-aggregate bonding through chemical interaction, leading to improved compatibility and workability in WMA [15]. When combined with CRMB, Zycotherm contributes to improved adhesion and resilience in both dry and wet conditions [16]. Lime fillers, on the other hand, are well-known for their anti-stripping properties and improved stiffness, moisture resistance, and aging performance in bituminous mixes [17]. Their interaction with CRMB and Zycotherm offers a synergistic effect that boosts mechanical performance, especially in terms of Marshall stability, flow value, and resistance to cracking [18].

Research on multi-component modified binders confirms that combining chemical and mineral additives such as CRMB, lime, and Zycotherm can significantly improve the rheological, mechanical, and moisture resistance characteristics of asphalt mixes [19]. Such mixes exhibit better compatibility, prolonged service life, and environmental benefits due to lower energy consumption and emissions [20]. Studies have also shown that the Optimum Binder Content (OBC) shifts when these modifiers are introduced, requiring careful calibration to ensure performance optimization [21].

Overall, the integration of CRMB, Zycotherm, and lime into WMA systems has shown promising results in terms of enhancing performance under thermal, load-induced, and moisture-related stresses. These developments align with global trends in sustainable infrastructure, where the focus is on balancing durability with environmental and economic efficiency [22].

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 60 (CRMB 60) is a specialized type of bitumen blended with crumb Rubber derived from recycled vehicle tires. This

modification significantly enhances the physical properties of conventional bitumen, making it more resistant to deformation, rutting and cracking. CRMB 60 is particularly suitable for use in hot and heavily trafficked regions due to its higher softening points and improved elasticity. CRMB 60 in our case is acquired from Maruti Bitumen, Mehsana, Gujarat.

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

Sr. No.	Test Name	Unit	Result	Specification
1	Penetration	mm/	34	50
	at	10		
	25°C,			
	100gm			
2	Softening Point, (R&B), Min.	*C	68	60
		5sec.		
		Max.		
3	Elastic recovery of Half thread in Ductilometer at 15°C, Min.	%	72	50
4	Flash Point, COC, Min.	*C	262	220
5	Separation, Difference in Softening Point	*C	2.2	4

	, (R&B), Max.			
Thin Film Oven Test (TFOT) On Residue (IS:9382-1992)				
6	Loss in mass, Max.	%	0.18	1
7	Increase	*C	3.2	5
	in Softening Point, (R&B), Max.			
8	Reduction in Penetration of residue, at 25°C, Max.	%	16	40
9	Elastic recovery of Half thread in Ductilometer at 25°C, Min.	%	62	35

Zycotherm: - is a Warm Mix Asphalt (WMA) additive developed to lower asphalt production temperatures while enhancing overall pavement performance. This non-hazardous, odorless liquid significantly improves the bonding between asphalt binder and aggregates, promoting better coating and compaction even at reduced temperatures. By enhancing workability, reducing energy consumption, and minimizing emissions during mixing and laying, Zycotherm plays a key role in sustainable road construction [5]. The recommended dosage ranges from 0.05% to 0.5% by weight of the binder, depending on aggregate characteristics and traffic demands. Manufactured by the Zydex Group in Gotri, Vadodara, Gujarat, Zycotherm supports innovations in asphalt technology [11]. When used alongside additives like lime and polymer-modified binders such as CRMB 60, it further

improves adhesion, minimizes moisture damage, and enhances compaction efficiency. These combined benefits make Zycotherm essential for building durable, environmentally friendly, and cost-effective pavements by improving Voids in Mineral Aggregate (VMA) [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].

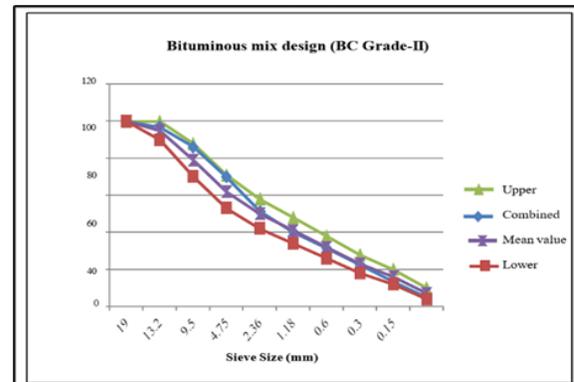


Figure.1 Bituminous Mix Design
In this experimental study, asphalt specimens were prepared using an Optimum Binder Content (OBC) of

83.90g, which corresponds to 6.8% 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). Zycotherm additive was added at 0.05%, 0.10%, and 0.15% 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 Zycotherm 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 Crumb Rubber Modified Bitumen (CRMB 60), Zycotherm additives (0.05%, 0.10%, 0.15%), 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 Zycotherm 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.

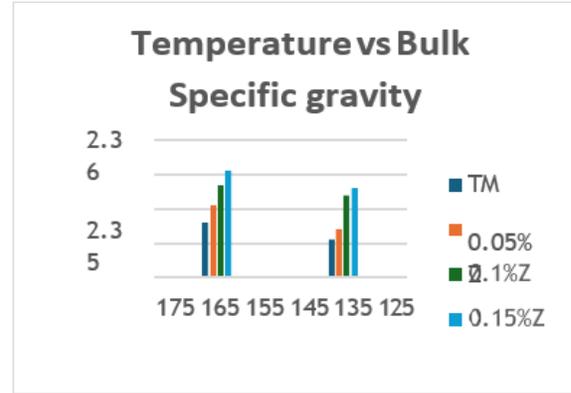


Figure.2 Temperature Vs Bulk Spe. Gravity
Despite this, the lower temperature still allows for better workability compared to conventional Hot Mix Asphalt (HMA) at higher temperatures.

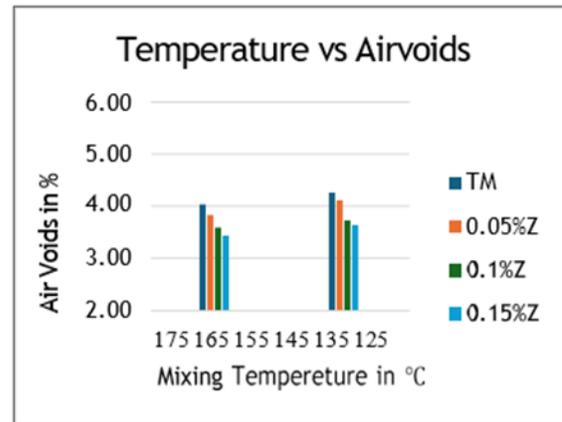


Figure.3 Temperature Vs Air voids
Air Void Content (Va) measures the air spaces within the asphalt mix. With the addition of Zycotherm and lime, Va typically decreases, leading to a denser mix. In this case, the target is to maintain Va at around 4%. At 165°C, effective compaction reduces Va significantly 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, Zycotherm 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.

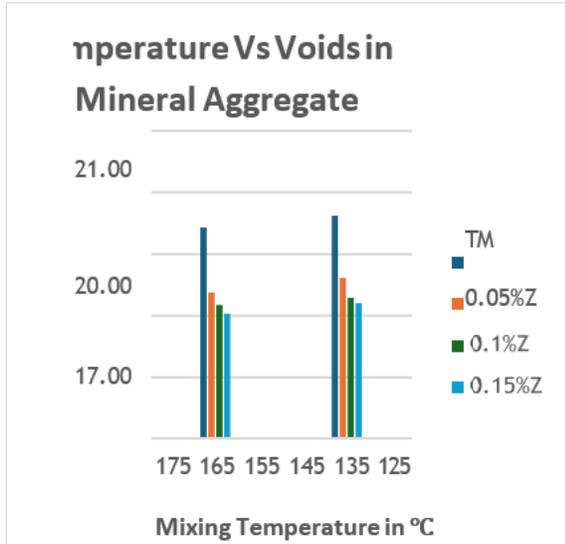


Figure.4 Temperature Vs Voids in Mineral Aggregate

As Zycotherm 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.

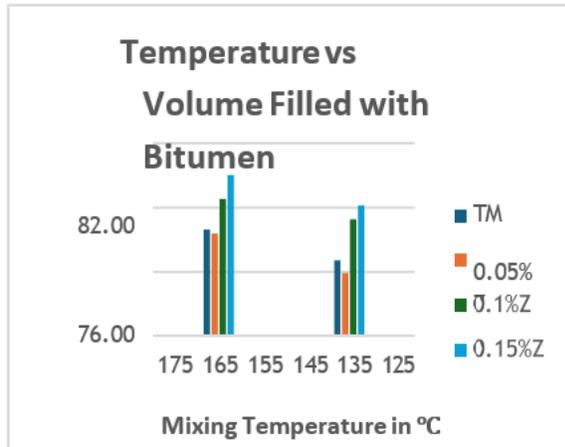


Figure.5 Temperature Vs Volume filled with Bitumen

Voids Filled with Bitumen (VFB) represents the percentage of voids that are filled with bitumen. With the addition of Zycotherm 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 Crumb Rubber Modified Bitumen (CRMB 60), 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 Zycotherm at 0.05%, 0.10%, and 0.15% 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.

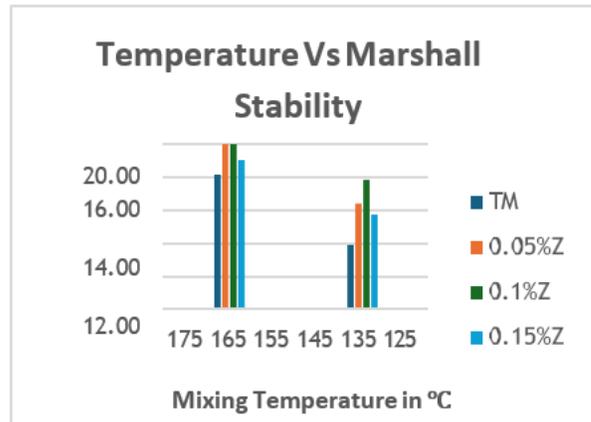


Figure.6 Temperature Vs Marshall Stability

Stability measures the load-bearing capacity of the mix. As Zycotherm 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.

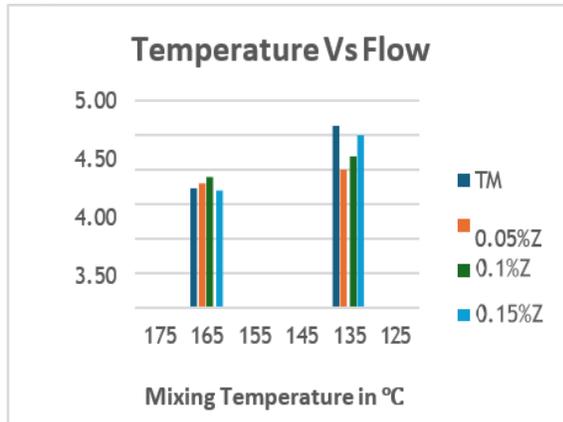


Figure.7 Temperature Vs Flow

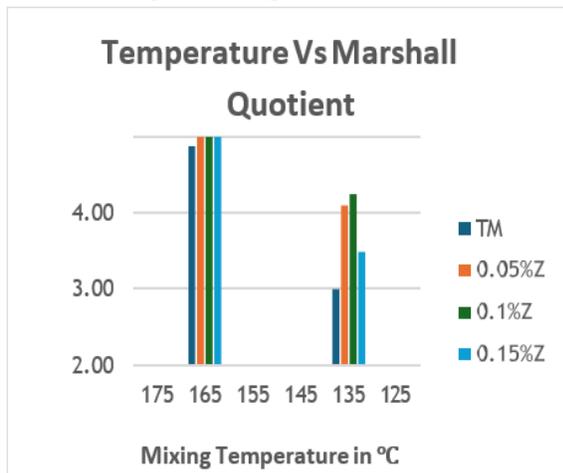


Figure.8 Temperature Vs Marshall Quotient

The Marshall Quotient (MQ), the ratio of stability to flow, provides an overall performance indicator of the mixture. The addition of Zycotherm 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

In conclusion, the combination of Marshall Stability, Marshall Flow, and Marshall Quotient indicates that 0.1% zycotherm is the most suitable chemical additive for warm mix asphalt at temperatures of 135°C. The results demonstrate improved stability, with higher

Marshall Stability values suggesting enhanced strength and resistance to deformation under traffic loads. The Marshall Flow at this dosage remains within the ideal range, ensuring flexibility without excessive deformation. Additionally, the Marshall Quotient, which reflects the balance between stability and flow, shows favorable results, highlighting the optimal performance of the mix. Overall, 0.1% zycotherm enhances the overall durability and workability of the asphalt mix, making it ideal for these temperature ranges.

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