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Review on Characterization of Polymer Modified Bitumen with Reclaimed Asphalt Pavement used in HMA

Rajeshwari Kaushal¹, Dr. (Mrs.) Vandana Tare², Tarun Kumar Narnaure³, Priyank Patel⁴

¹M. Tech Transportation

²Professor and Head of Department

³ Assistant Professor,

⁴M. Tech Transportation

Civil Engineering and Applied Mechanics Department,
SGSITS, Indore, India.

kaushal.rajeshwari5@gmail.com, vtare4@gmail.com,

tarunnarnaure1@gmail.com, priyankpatel097@gmail.com

ABSTRACT—The three main options for bituminous pavement rehabilitation are excessive capacity, recycling, and reconstruction. The process of recycling involves reusing some or all of the damaged pavement's material, known as reclaimed asphalt pavement (RAP), in new construction. As the cost of bitumen binder is rising and polymer waste from different industries are increasing which cause environmental affected. Reuse of a resource such as RAP, lessens the depletion of natural resources, such as natural aggregate and bitumen binder. In the current study, to increase the workability of RAP asphalt mixtures, a softer-graded polymer modified bitumen (PMB) was produced with a 7% styrene-butadiene-styrene (SBS) copolymer. Marshall hammers were used to produce the asphalt sample at 10, 20, and 30% RAP material. To minimize overhead cost and utilize the polymer waste it in a way, this research would focus on a warranted technique to recycle the Reclaimed asphalt pavement (RAP) in making the flexible pavements. A thorough laboratory analysis has been carried out to evaluate the effectiveness of the changed mixture. The results of the primary tests, such as those for penetration, softening points, viscosity, and others, will show that the previously mentioned mixture performs significantly better than the normal mix.

Keyword: Reclaimed asphalt pavement (RAP), Styrene butadiene styrene (SBS), flexible pavement, Polymer Modified Bitumen (PMB), Marshall stability test, Flow value test.

1. INTRODUCTION

Polymer modified bitumen can be used for various levels of a pavement structure based on the project's specific requirements. The use of modified binders is one of the most popular

techniques for increasing the strength qualities of bituminous mixes [1][2]. PMB is a type of bituminous material that is modified with polymers to improve its mechanical and physical properties, making it more durable, resistant to deformation, and able to withstand extreme temperatures [3]. The polymer modified binder have potential to reduce rutting and fatigue distresses, thus they are preferred for construction of flexible pavements [4]. RAP materials have been used as a substitution for virgin binder and aggregate in HMA- Hot mix asphalt pavements as a finding of the increased the availability of RAP and the advancement of the recycling technologies [5]. Hossain et al.[6] evaluated change in high and low temperature PG grade of PG64-22 with addition of different percentages (i.e., 10, 25 and 40%) of two RAP (RAP1 and RAP2). Dharamveer Singh et al(2016),[7]. With increase demand of utilizing reclaimed asphalt pavement (RAP) materials, PMB and RAP materials are blended together to maximize cost saving and for environmental benefits. Gubbala Chaitanya et al (2016) [8]. RAP material was characterized and optimum binder contents were determined for mixes prepared with different RAP content of 0%, 15%, 25%, 35% and 50%. V. Antunes a,b, A.C. Freire b, et al (2019) [9]. RAP mixes' mechanical performance is influenced by both internal and external factors. Gradation, bitumen content, and volumetric characteristics are intrinsic variables that might influence various behaviours. Yuefeng Zhu, et al (2020) [10]. Different types of fibre materials were identified and selected as binder/mixture additives, including lignin fibre (LF), polyester fibre (PF), and basalt fibre (BF). Various samples of fibre modified binders and asphalt mixtures with different RAP contents (0%, 20%, and 40%) were prepared and were evaluated. Zhang et al.(2020),[11] Comparing to mixes containing virgin material, mixes contain higher percentages of RAP binder substitution demonstrated better performance. In addition, increase the amount of RAP improves rutting resistance, also caused an increase in the stiffness of recycled asphalt mixes. Sahar Basim AL-Ghurabi et al (2021), [12] the use of PMB binder significantly improves the mechanical properties and performance of HMA. Also, it shows that the substitution of coarse aggregate with RAP produces a substantial improvement in mechanical properties and performance of HMA. A S Eltwati et.al. (2021) [13]. Sara Spadoni et al (2022) [14]. The stiffness and rutting resistance (i.e., high-temperature performance) of asphalt mixtures can be improved using the dry technique.

Material

In the current investigation, RAP materials and SBS (3.5%) co-polymer modified binder of Performance Grade (70-10) were gathered. Using recycled asphalt pavement as a coarse aggregate in polymer modified bitumen mixtures can provide a sustainable and cost-effective solution for pavement construction. The use of RAP can help to reduce the amount of natural aggregate which required for construction, conserve natural resources, and reduce the amount of waste sent to landfills.

Reclaimed Asphalt Pavement has gained significant attention in the field of road construction due to its potential for sustainability and cost-effectiveness [15]. RAP is obtained by milling and recycling existing asphalt pavements, which reduces the demand for virgin materials and promotes environmental conservation[16]. However, the performance and durability of RAP can be compromised compared to conventional asphalt mixtures. To address this issue, researchers have explored various additives and techniques to enhance the properties of RAP.

This research review seeks to give a broad overview of how particular additives, including polymer-modified bitumen, affect the characteristics of RAP.

1. Reclaimed Asphalt Pavement:

RAP is a recycled material comprising aged asphalt binder, aggregates, and potentially other additives from the original pavement [9]. Using RAP offers several advantages, including reduced costs, conservation of natural resources, and energy savings. A cost analysis revealed at least a 50% reduction in material-related costs, while a cradle-to-gate analysis of the environmental effects revealed 18kg or 35% CO₂eq reductions per t of produced 100% RAP asphalt mixture compared to virgin mix[15]. However, The Federal Highway Administration (FHWA) estimates that costs associated with milling up to 100 million ton of hot-mix asphalt per year[17]. The majority of life cycle analyses unequivocally show that using high content RAP reduces emissions and energy use. Utilizing RAP lessens the need for binder, which in turn lessens the environmental impact [15]. According to the calculations shown in Fig. 1, manufacturing asphalt entirely from recycled materials can save 18 kg of CO₂ equivalent and 20% energy per tonne of paved mixture.

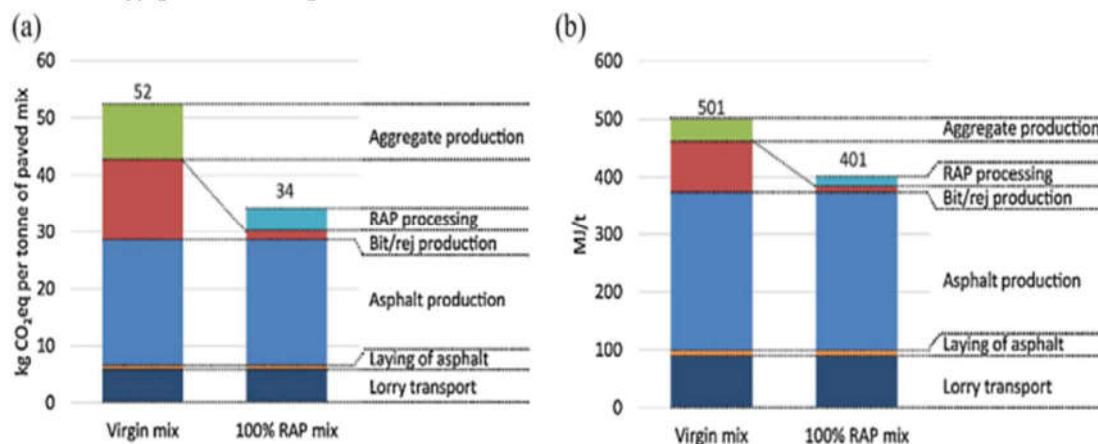


Figure 1 Emission

RAP is primarily used to reduce the need for aggregates and asphalt in the existing pavements [18]. RAP consist of High-quality, properly sorted aggregates covered with asphalt cement with a high moisture content. Because of its unique qualities, RAP can effectively replace virgin resources, lowering the demand for virgin aggregates. As a result, RAP is a sensible and affordable replacement for virgin aggregates. Reduced utilization of expensive new asphalt binders in asphalt paving mixtures is another benefit of using RAP [19]. Utilizing recovered asphalt pavements has three main benefits: it's environmentally friendly, it's economical, and it performs well. The low cost and environmental friendliness of recycled materials, particularly RAP, have made their use appealing in some regions of the world [20]. Furthermore, more than 100 million tonnes of RAP were collected for reuse in the United States in 2018, saving

approximately 61.4 million cubic yards of landfill space [21]. A higher RAP content should increase the value of recycled pavements while also having the ability to reduce waste [22]. To avoid any negative impacts on the mix qualities, most road authorities allow no more than 30% RAP in hot mix asphalt (wearing course). The Department of Transportation (DOT) usually uses the most RAP in surface layers, especially for federal projects. Despite the fact that RAP is still used by a limited number of HMA, the percentage never reaches 15%. However, the increase in the cost of asphalt binder as well as the scarcity of aggregates in 2006 and 2013 led in the creation of more RAP, which has become a serious concern in the HMA business [23]. Recent research from the United States and certain regions of Canada has demonstrated that mixes with 30% RAP perform similarly as with Virgin aggregate [24]. Addressing potential drawbacks associated with RAP, such as reduced stiffness, increased susceptibility to rutting and cracking, and inferior performance compared to conventional asphalt mixtures, is essential [25].



Figure 2 RAP recycling process

1.1 Characterization of RAP:

RAP, a milled material, can be recycled, reducing the amounts of new materials utilised in pavement building. When there is no operation, a variety of rheological and physical aspects must be considered for the combination of binders and aggregates. As a result, the performance of RAP including HMA is guaranteed to be on the same level with that of HMA mixes made with virgin materials, particularly during the design phase. The benefit-cost ratio and lifespan of road pavements may be enhanced by the usage of RAP [26]. Using RAP as the foundation material for pavements resulted in savings of up to 30% [27]. Figure no.3 shows the thorough mixing of RAP and virgin binder [28].

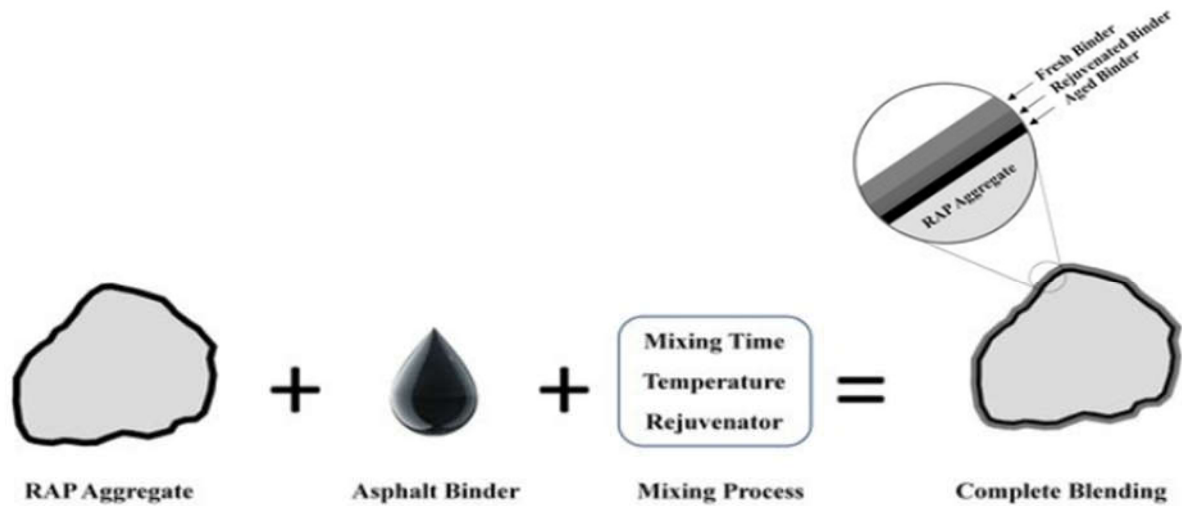


Figure 3 A thorough mixing of RAP binder and virgin binder.

The physical properties of RAP like specific gravity, moisture content, gradation are shown in Table No.1 [29]. RAP's gradation is comparable to that of a crushed natural aggregate, while having a larger fines concentration. The material's deterioration during milling and crushing processes led to the high fine concentration[27]. A general overview of the usual physical and mechanical characteristics of RAP is shown in Tables 1 and Table 2.

Table 1. Physical Properties of RAP

Unit Weight	1940-2300 kg/m ²
Moisture Content	Standard to 5% Maximum up to 7-8%
Asphalt Content	Standard 10-80% at 25°C
Asphalt Viscosity	Normal 4000-25000 poise at 60°C

Table 2. Mechanical Properties of RAP

Compacted Unit Weight	1600-2000 kg/m ³
California Bearing Ratio (CBR)	100% RAP: 20-25%, 40% RAP and 60% Natural Aggregate: 150% Higher

2. Polymer Modified Bitumen:

Polymer-modified bitumen is a commonly used additive to enhance the performance of road mixtures[30]. Asphalt can perform better when polymers, or sequences of repeated tiny molecules, are added. Pavement with polymer modification is more resistant to thermal cracking and rutting and is less susceptible to fatigue damage at high temperatures [31]. Polymer modified binders have been effectively used in high stress environments such as congested intersections of streets, airports, vehicle weigh stations, and race tracks [32]. A variety of polymers have been used to modify asphalt, including styrene-butadiene-styrene (SBS), styrene-butadiene rubber (SBR), Elvaloy, rubber, ethylene vinyl acetate (EVA), polyethylene, and others. Desirable characteristics of polymer modified binders include a higher softening point, more elastic recovery, enhanced viscosity, cohesive strength, and ductility [31, 32].

Styrene-butadiene-styrene or styrene-butadiene rubber are polymer modifiers that are used with bitumen to create PMB [33]. Asphalt's qualities, such as its increased stiffness, resistance to deformation, and improved durability, are improved with the inclusion of PMB.

A number of research studies have looked into how PMB affects RAP mixes. [34] carried out an experimental research's on RAP mixtures that had bitumen treated with SBS polymers. According to the study, adding PMB increased the RAP mixes' low-temperature cracking resistance, fatigue life, and rutting resistance. The authors came to the conclusion that PMB can successfully improve the functionality and service life of RAP mixes.

likewise [33] examined the impact of bitumen treated with SBR polymers on the mechanical characteristics of RAP mixes. The results showed that the stiffness, rutting resistance, and fatigue performance of RAP mixes were all improved by the addition of SBR PMB. The researchers came to the conclusion that SBR PMB would be a useful ingredient for enhancing the performance of RAP combinations.

2.1. Modifier used in PMB

2.1.1. Crumb rubber modifier:

The characteristics of crumb rubber are dependent on the type of rubber, the composition of the asphalt, the size of the rubber particles, the reaction time, and the reaction temperature [32]. The rubber is often recycled from used automotive tyres, which has the extra benefits of being less expensive and freeing up landfill area that tyres would otherwise occupy [35]. Rubber made from recycled tyres has a lower incidence of reflective cracking, making it more durable. The following concerns of utility arise when using natural rubber [35].

2.1.2. Styrene butadiene styrene

Asphalt's flexibility is increased by the block copolymer styrene-butadiene-styrene (SBS) [35]. Although the inclusion of block copolymers of the SBS type has cost limitations, it is likely the most suited polymer for asphalt modification and can demonstrate major technical difficulties, according to a 2001 assessment in Vision Technologic by Becker [18]. Although flexibility increases at low temperatures, other authors contend that at higher temperatures, strength and resistance to penetration decrease. However, "reclaimed tyre rubber is the next most commonly used polymer for asphalts, followed by SBS." [35]. The increase in the complex modulus, a sign of rutting resistance, is caused by the creation of the crucial network between the binder and polymer [33]. The usage of SBS-modified binders has recently received attention in India [31]. The surface life of the Delhi-Ambala roadway would almost double while the thickness of the bituminous layers would be reduced, calculations found, despite the greater cost per kilometre for polymer modified binders.

2.1.3. Styrene butadiene rubber:

As a binder modifier, styrene butadiene rubber (SBR) has frequently been employed, typically as a water-based dispersion (latex). On the US Federal Aviation Administration website, there is an Engineering Brief from 1987 that details the benefits of SBR treated asphalt in boosting the qualities of bituminous concrete pavement and seal coats [36]. The viscosity, elastic recovery, cohesiveness, adhesion, and low-temperature ductility of the pavement are all enhanced. Due to SBS's greater compatibility and tensile strength under tension, SBR has mostly been replaced. SBS is currently the polymer that is most frequently used to modify asphalt [37].

2.2. Classification of Polymer Modified Bitumen:

The Polymer modified bitumen shall be classified into five grades as Grade PMB 64-10, Grade PMB 70-10, Grade PMB 76-10, Grade PMB 82-10, Grade PMB 76-22. Polymer Modified Bitumen is generally constructed for pavement carrying heavy to heavy traffic load and area where pavement temperature vary widely. [38] PMB is also used in wearing course and Dense Bituminous Macadam with less thickness in other roads due to its superior resistance to oxidation as compared to viscosity grade bitumen. Selection of grade depend on service conditions of pavement temperature and traffic [39]. Table No 3 shows the different studies on comparisons of different percentage of Polymer modified bitumen.

Table No 3. Comparisons of PMB

S No.	Authors	Material	Properties	Method	Code
1	Burak Sengoz et. al. [40]	SBS PMB	Mechanical Properties	Marshall Conventional Method	ASTM D1559
2	Tan Yiqiu [33]	5% SBS	Satisfied limit of 3-5% Air-voids	Marshall Conventional Method	
3	Sumit K. Singh et. al. [41]	3% SBS	10% Properties reduction and increases stability and service life	Marshall Conventional Method	ASTM D5,36,6373,7405
4	Nikhil Saboo et.al. [42]	3%SBS & 5% EVA	Physical properties, it increases the fatigue life compare to other polymers	Marshall Conventional Method	
5	Sara Spadoni et. al. [14]	PG 76-16	Physical properties, it increases the fatigue life compare to other polymers	VECD Theory	AASTHO TP 133
6	Jan Króla et.al. [3]	PMB 45/80-55	viscoelastic properties, PMB with same hardness provide high temperature properties	MSCR Test Method	

3. Combined Effect of Reclaimed Asphalt Pavement and Polymer Modified Bitumen

While the individual effects of PMB on RAP mixtures have been extensively studied, limited research has focused on the combined effect of these additives. The synergistic interaction between PMB can potentially lead to further improvements in the properties of RAP mixtures[\[43\]](#). The study emphasized that the combined use of RAP and SBR PMB can effectively enhance the moisture resistance of RAP mixtures, ensuring their long-term performance under varying environmental conditions [\[42\]](#).

The performance of RAP mixes was also examined in research by [\[44\]](#) and [\[45\]](#) that looked at the impact of various PMB kinds and dosages. The maximum RAP content that governmental agencies are permitted to use is typically not more than 40% [\[45\]](#). These investigations looked

at variables like stiffness, resistance to rutting, fatigue life, and resistance to low-temperature cracking.

4. Effects of PMB on the performance of RAP mixtures

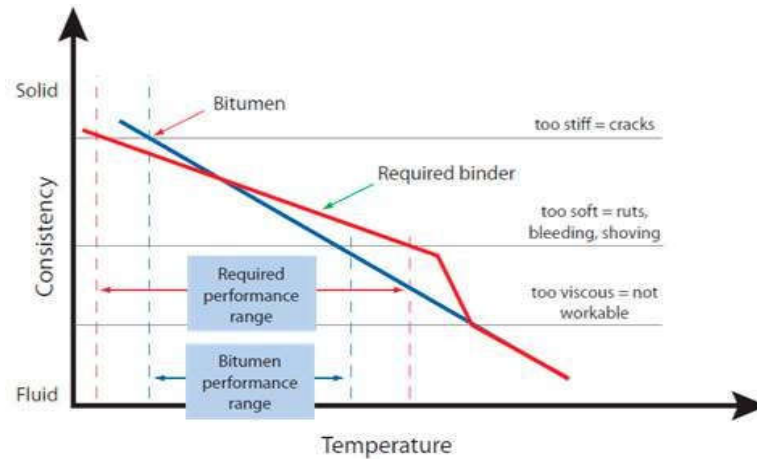


Figure 4. Polymer modified bitumen (PMB) temperature variation graph

Polymer-modified bitumen has emerged as a popular additive for enhancing the performance and durability of asphalt mixtures, including RAP mixtures. PMB consists of bitumen blended with polymers, such as styrene butadiene styrene or styrene butadiene rubber, which change the rheological properties of the binder.[33]

According to the study [46], the use of bitumen treated with SBR polymers enhanced the stiffness of RAP mixes. It has been discovered that PMB improves the resilience of RAP combinations. The impact of bitumen modified with SBS polymers on the ageing resistance of RAP mixes was assessed by research by [33].

The impact of SBS polymer-modified bitumen on the low-temperature characteristics of RAP mixes dramatically improved the fracture temperature and fracture energy, showing increased resistance to low-temperature cracking. This shows that in RAP pavements, PMB can successfully minimise low-temperature cracking. The impact of bitumen treated with SBR polymers on the moisture damage to RAP mixes was studied by [40] and Zhang et al. (2021) [12]. According to the findings, adding PMB improves the bond between aggregates and asphalt binder, reducing moisture damage in RAP mixtures.

PMB (70-10) is going to use as 70 defines the Average 7 Day maximum pavement temperature and 10 as Average 7 days minimum pavement temperatures. Table 3 shows the other physical properties of PMB [39].

Table No 4. Physical Properties of PMB (70-10)

Physical properties	PMB (70-10)	Code
Softening point $^{\circ}\text{C}$ Min.	65	IS-205
Flash Point $^{\circ}\text{C}$ Min.	230	IS-1209
Viscosity at 150 $^{\circ}\text{C}$ Min.	1.2	ASTM D 4402
Half-thread elastic recovery in a ductile metre at 15 $^{\circ}$ C Min.	70	IS-5426

5. Evaluate To reduce the cost of flexible pavement using RAP

**Figure 5. Effect of RAP Recycling [9]**

The cost of constructing and maintaining flexible pavements can be a significant financial burden for transportation agencies. To address this challenge, researchers and practitioners have explored the use of reclaimed asphalt pavement (RAP) as cost-effective alternatives in construction of pavement [20]. This section of the literature review aims to evaluate the potential of RAP in reducing the cost of flexible pavements based on findings from various research papers and academic journals.

RAP Utilization: RAP is a recycled material obtained from milled or excavated asphalt pavements. Its utilization in flexible pavements can significantly reduce costs by minimizing the need for new materials and reducing waste disposal expenses. Research by [47] investigated the economic benefits of incorporating RAP in asphalt mixtures. The study revealed that the

use of RAP led to cost savings in terms of material acquisition and processing, contributing to overall cost reduction in pavement construction. Environmental Benefits: The use of RAP in flexible pavements aligns with sustainable practices and can offer environmental benefits, which indirectly contribute to cost reduction[9]. The recycling of RAP reduces the demand for virgin materials and conserves natural resources. Additionally, reducing the need for frequent repairs and the associated environmental impacts. The available research suggests that using RAP in flexible pavements can potentially reduce costs.[48]

6. RESULT

This literature review has provided a comprehensive overview of the effect of glass fibre reinforcement and polymer-modified bitumen (PMB) on reclaimed asphalt pavement (RAP) mixtures. Through an analysis of various research papers and academic journals, several key findings and trends have emerged. Permanent deformation reduces as diatomite and SBS polymer concentrations increase [49].

Increasing Nano polymer composite percentage in modified binders will result in a decrease and increase in the penetration and softening point of the mixtures, respectively, indicating a rise in hardness and stiffness in these mixes. In comparison to unmodified bitumen, modified bitumen is less sensitive to high temperatures and likely more resistant to rutting (plastic deformation)[50]. Use of RAP with polymer may lower rutting depth and may offer resistance against permanent deformation [51]. Improve the durability and it also helps in the reduction of solid waste and it also helps in the reduction of environmental problems [52].

7. CONCLUSION

1. As compared with unmodified mixtures containing 30% RAP, the addition of PMB enhanced rutting resistance and also increase dynamic stability by 54.9%
2. Polymer-modified asphalt mixes outperformed matrix asphalt mixtures in terms of high- and low-temperature stability, moisture susceptibility, fatigue, and self-healing capabilities[10].
3. The use of both elastomeric and plastomeric PMB in asphalt mixtures increases the mixture's resistance to the distress mechanisms of both permanent deformation and fatigue cracking[53].
4. SBS is the most commonly used polymer in asphalt modification. SBS makes asphalt more elastic and allows for the recycling of SBS-modified asphalt. In low temperature applications, SBS modified binders perform better than neat binders or binders modified with chemically reactive polymers [31].
5. As a result, many authorities restrict the usage of the RAP proportion in the creation of asphalt mixes. However, a few studies have been conducted to examine how RAP impacts the rheological and chemical properties of PMB binders [54].

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