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ReviewonCharacterizationofPolymerModifiedBitumenwith Reclaimed Asphalt Pavement used in HMA

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ABSTRACT—*Thethreemainoptionsfor bituminouspavement rehabilitationareexcessive capacity,recycling,andreconstruction. The processof recyclinginvolvesreusingsome orall of the damaged pavement's material, known as reclaimed asphalt pavement (RAP), in new construction.Asthecostofbitumenbinderisrisingandpolymerwastefromdifferentindustries are increasing whichcauseenvironmental affected. Reuse of aresource 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 modifiedbitumen(PMB)wasproducedwitha7%styrene-butadiene-styrene(SBS)copolymer. Marshallhammerswereusedtoproducetheasphaltsampleat10,20,and30%RAPmaterial. Tominimizeoverheadcostandutilizethepolymerwasteitinaway,thisresearchwouldfocus 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

Polymermodifiedbitumencanbeusedforvariouslevelsofapavementstructurebasedonthe project'sspecificrequirements.Theuseofmodifiedbindersisoneofthemostpopular 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 recyclingtechnologies [5].Hossainetal.[6]evaluatedchangeinhighandlowtemperaturePG 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 reclaimedasphaltpavement(RAP)materials,PMBandRAPmaterialsareblendedtogetherto maximizecostsavingandforenvironmentalbenefits.GubbalaChaitanyaetal(2016)[8].RAP material was characterized and optimum binder contents were determined for mixes prepared withdifferentRAPcontentof0%,15%,25%,35%and50%.V.Antunesa,b,A.C.Freireb,et al (2019) [9]. RAPmixes' mechanical performanceisinfluenced by bothinternaland 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 materialswere identifiedandselectedasbinder/mixtureadditives, includingligninfibre (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. SaharBasim AL-Ghurabi et al (2021), [12] the use of PMBbindersignificantlyimprovesthemechanicalpropertiesandperformanceofHMA.Also, itshowsthatthesubstitutionofcoarseaggregatewithRAPproducesasubstantialimprovement inmechanicalpropertiesandperformanceofHMA.ASEltwatiet.al.(2021)[13].SaraSpadoni 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 whichrequired for construction,conservenatural resources, and reduce the amount of waste sent to landfills.

Reclaimed Asphalt Pavement has gained significant attention inthefield 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, researchershaveexploredvariousadditivesandtechniquestoenhance thepropertiesofRAP.

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

1. ReclaimedAsphaltPavement:

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 reducedcosts, conservation of natural resources, and energy savings. Acost 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 CO_2equivalent and 20% energy per tonne of paved mixture.

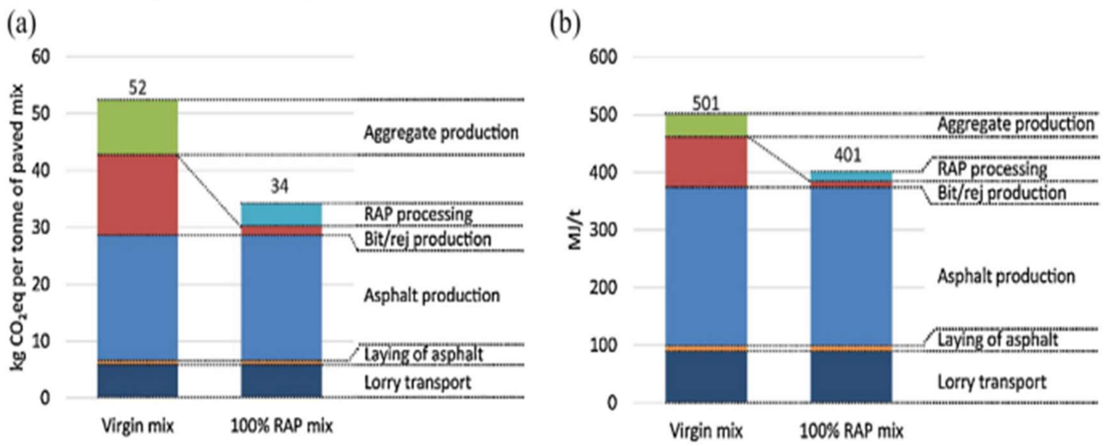

Figure1Emission

RAP isprimarily usedtoreducetheneedfor aggregatesandasphalt intheexisting pavements [18].RAPconsistofHigh-quality,properlysortedaggregatescoveredwithasphaltcementwith 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 asphaltpavementshasthreemainbenefits:it'senvironmentallyfriendly,it'seconomical,andit performs well.Thelowcost andenvironmentalfriendlinessof recycledmaterials,particularly RAP, have made their use appealing in some regions of the world [20].Furthermore, more than100milliontonnesofRAPwerecollectedforreuseintheUnitedStatesin2018,saving approximately 61.4 million cubic yards of landfill space [21]. A higher RAP content should increasethevalueofrecycledpavementswhilealsohavingtheabilitytoreducewaste[22].To avoidanynegativeimpactsonthemixqualities,mostroadauthoritiesallownomorethan30% RAP in hot mix asphalt (wearing course). The Department of Transportation (DOT) usually uses the most RAP in surface layers, especially for federal projects. Despitethe fact that RAP is still used by a limited number of HMA, the percentage never reaches 15%. However, the increaseinthecostofasphaltbinderaswellasthescarcityofaggregatesin2006and2013led 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 andcracking,andinferiorperformancecomparedtoconventionalasphaltmixtures,isessential [25].

Figure2RAPrecyclingprocess

1.1 CharacterizationofRAP:

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 mustbeconsideredforthecombinationofbindersandaggregates.Asaresult,theperformance 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 ofRAP [26]. Using RAP as the foundation material for pavements resulted in savings of up to 30% [27]. Figure no.3 showsthe thorough mixing of RAP and virgin binder [28].

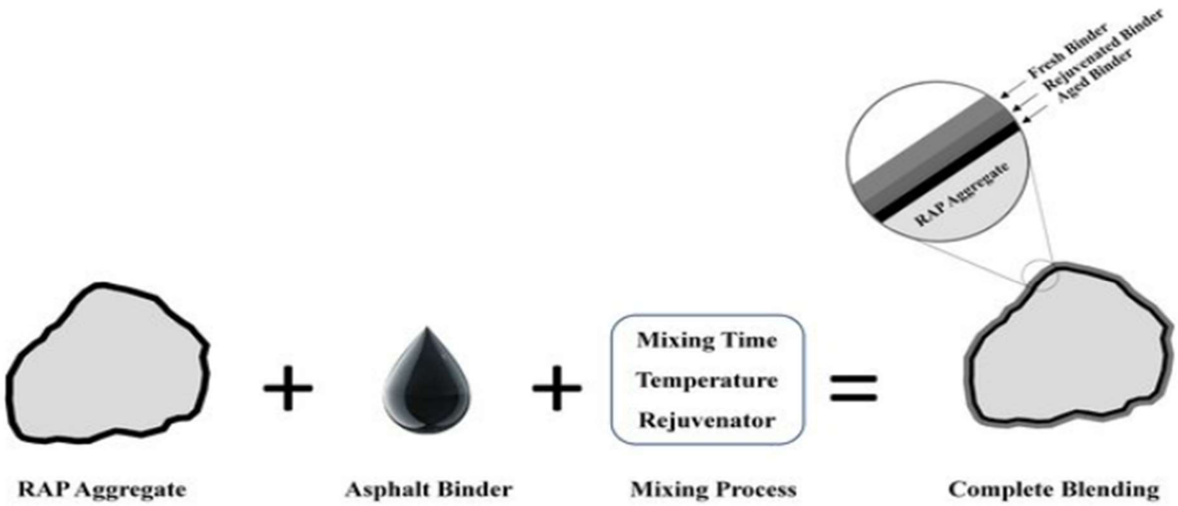

Figure3Athoroughmixingof RAPbinder andvirginbinder.

ThephysicalpropertiesofRAPlikespecificgravity,moisturecontent,gradationareshownin 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 processesledtothehighfineconcentration[27].Ageneral overviewof theusualphysical and mechanical characteristics of RAP is shown in Tables 1 and Table 2.

Table1.PhysicalPropertiesofRAP

UnitWeight	1940-2300 kg/m^2
MoistureContent	Standard to 5% Maximumupto7-8%
Asphalt Content	Standard10-80%at 25°C
Asphalt Viscosity	Normal4000-25000poiseat60°C

Table2.MechanicalPropertiesofRAP

CompactedUnit Weight	1600-2000 kg/m^3
CaliforniaBearingRatio(CBR)	100%RAP:20-25%,40%RAPand 60%NaturalAggregate:150% Higher

2. PolymerModifiedBitumen:

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-styreneorstyrene-butadienerubberarepolymermodifiersthatareusedwith 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,fatiguelife,andruttingresistance.TheauthorscametotheconclusionthatPMBcan 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 researcherscametotheconclusionthatSBRPMBwouldbea usefulingredientforenhancing the performance of RAP combinations.

2.1. ModifierusedinPMB

2.1.1. Crumbrubber modifier:

Thecharacteristicsofcrumbrubberaredependentonthetypeofrubber,thecompositionofthe asphalt, the size of the rubber particles, the reaction time, and the reaction temperature [32]. Therubberisoftenrecycledfromusedautomotivetyres,whichhastheextrabenefits ofbeing less expensive and freeing up landfill area that tyres would otherwise occupy [35]. Rubber madefromrecycledtyreshasalowerincidenceofreflectivecracking,makingitmoredurable. The following concerns of utility arise when using natural rubber [35].

2.1.2. Styrenebutadienestyrene

Asphalt'sflexibilityisincreasedbytheblockcopolymerstyrene-butadiene-styrene(SBS)[35]. Althoughtheinclusionofblockcopolymersofthe SBStypehascostlimitations,itislikelythe mostsuitedpolymerforasphaltmodificationandcandemonstratemajortechnicaldifficulties, 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 resistancetopenetrationdecrease.However,"reclaimedtyrerubberisthenextmostcommonly 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 bindershas recently received attention inIndia [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. Styrenebutadienerubber:

Asabindermodifier,styrenebutadienerubber(SBR)hasfrequentlybeenemployed,typically asa water-baseddispersion(latex).Onthe USFederalAviationAdministrationwebsite,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. ClassificationofPolymerModifiedBitumen:

ThePolymermodifiedbitumenshallbeclassifiedintofivegradesasGradePMB64-10,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 wherepavementtemperaturewarywidely.[38]PMBisalsousedinwearingcourseandDense 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 conditionsofpavementtemperatureandtraffic[39].TableNo3showsthedifferentstudieson comparisons of different percentage of Polymer modified bitumen.

TableNo3.ComparisonsofPMB

S No.	Authors	Material	Properties	Method	Code
1	BurakSengoze t. al.[40]	SBS PMB	MechanicalProperties	Marshall Conventional Method	ASTM D1559
2	TanYi-qiu[33]	5%SBS	Satisfiedlimitof3-5%Air- voids	Marshall ConventionalMethod	
3	Sumit K. Singh et.al. [41]	3%SBS	10%Propertiesreductionand increasesstabilityandservice 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 comparetootherpolymers	Marshall Conventional Method	
5	Sara Spadoni et. al. [14]	PG 76-16	Physical properties, it increases the fatigue life comparetootherpolymers	VECD Theory	AASTHOTP 133
6	Jan Królа et.al. [3]	PMB 45/80-55	viscoelasticproperties,PMB with same hardness provide high temperature properties	MSCRTest Method	

3. CombinedEffectofReclaimedAsphaltPavementandPolymerModifiedBitumen

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].

TheperformanceofRAPmixeswasalsoexaminedinresearchby [44]and[45]that lookedat theimpact of various PMBkindsanddosages.Themaximum RAPcontentthatgovernmental agenciesarepermittedtouseistypicallynotmorethan40%[45].Theseinvestigationslooked at variables like stiffness, resistance to rutting, fatigue life, and resistance to low-temperature cracking.

4. EffectsofPMBontheperformanceofRAP mixtures

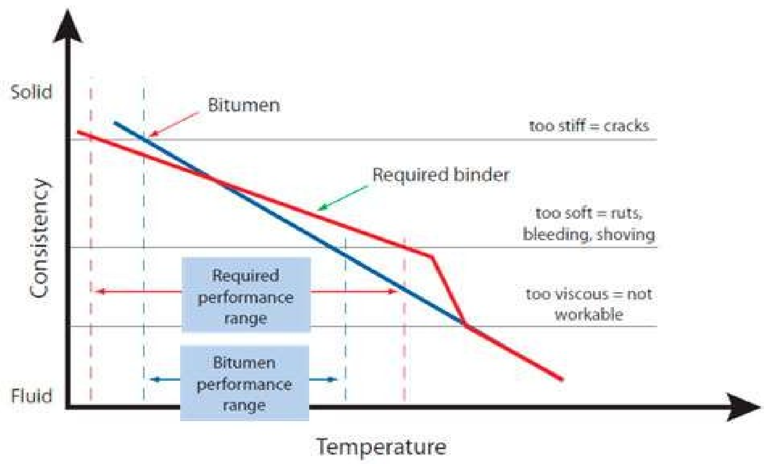

Figure 4. Polymer modified bitumen (PMB) temperature variation graph

Polymer-modified bitumen has emerged as a popular additive for enhancing the performance anddurabilityofasphaltmixtures,includingRAPmixtures.PMBconsistsofbitumenblended 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.TheimpactofbitumenmodifiedwithSBSpolymersontheageingresistanceof RAP mixes was assessed by research by [33].

The impactof SBS polymer-modifiedbitumen onthelow-temperature characteristics of RAP mixes dramaticallyimproved the fracture temperatureand 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)isgoingtouseas70definestheAverage7Daymaximumpavementtemperature and10as Average7daysminimumpavementtemperatures.Table 3showstheotherphysical properties of PMB [39].

TableNo4.PhysicalPropertiesofPMB(70-10)

Physicalproperties	PMB(70-10)	Code
Softeningpoint ^{0}C Min.	65	IS-205
FlashPoint ^{0}C Min.	230	IS-1209
Viscosityat 150^{0}CMin.	1.2	ASTMD4402
Half-threadelasticrecoveryinaductile metre at 15^{0} C Min.	70	IS-5426

5. EvaluateToreducethecostofflexiblepavementusingRAP

Figure5.EffectofRAPRecycling [9]

The cost of constructing and maintaining flexible pavements can be a significant financial burdenfortransportationagencies.To address this challenge,researchersandpractitioners 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 theneedfornewmaterialsandreducingwastedisposalexpenses.Researchby[47]investigated theeconomicbenefitsofincorporatingRAPinasphaltmixtures.Thestudyrevealedthatthe use of RAPledto costsavingsin termsofmaterialacquisitionandprocessing,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, whichindirectlycontributetocostreduction[9].TherecyclingofRAPreducesthedemandfor virgin materials and conserves natural resources. Additionally, reducing the needfor 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].UseofRAPwithpolymermaylowerruttingdepthandmayofferresistance 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 outperformedmatrix 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'sresistancetothedistressmechanismsofbothpermanentdeformationandfatigue 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 thanneat 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 asphaltmixes.However,afewstudieshavebeenconductedtoexaminehowRAPimpacts the rheological and chemical properties of PMB binders [54].

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