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Stability Analysis of Conventional Mix by Crumb Rubber Modified Bitumen

Mr. Kartik Khatri[1], Dr. Chittaranjan Birabar Nayak[2*]

[1]Research Scholar, Dr. D. Y. Patil Unitech Society Dr. D.Y. Patil Institute of Technology, Pimpri, Pune

[2*] Vidya Pratishthan's Kamalnayan Bajaj Institute of Engineering & Technology, Baramati. Dist. Pune, India.

Corresponding Author: Dr. Chittaranjan Birabar Nayak (cbnnayak@gmail.com)

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Abstract:

The incorporation of recycled Crumb Rubber Modified Bitumen (CRMB) in VG30 and VG40 mix pavements represents a significant step toward promoting sustainable infrastructure while creating new opportunities for global investors. Asphalt modifiers, such as crumb rubber, not only improve the performance of flexible pavements but also contribute to environmental sustainability. Crumb Rubber, derived from End-of-Life Tires (ELTs), has been widely recognized for its ability to enhance the performance of asphalt mixes, particularly in mitigating high-temperature rutting and low-temperature thermal cracking, owing to its unique properties. This paper reviews key findings from previous research, focusing on the process of grinding ELTs to produce CR, the technologies involved, and the evaluation of the physical and mechanical properties of CR-modified asphalt binders. Although this study primarily emphasizes the use of Hot Mix Asphalt (HMA) incorporating CR, it also acknowledges other applications such as Warm Mix Asphalt (WMA), Reclaimed Asphalt Pavement (RAP), and Porous Asphalt, where CR has been effectively used either as a modifier or additive. A comprehensive review of the literature indicates that crumb rubber enhances pavement performance and is particularly suitable for top paving layers, where it helps in reducing traffic noise and offers additional functional benefits.

Keywords: CRMB, VG30, VG40, sustainable infrastructure, Performance, Noise.

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1. Introduction

In the pursuit of sustainable highway construction, researchers are exploring alternative materials that can help reduce pollution and address disposal issues. Rubber tires, although user-friendly, are not eco-friendly due to their non-biodegradable nature, similar to plastics. However, incorporating scrap tire rubber into bitumen commonly known as crumb rubber modified bitumen (CRMB) has emerged as a promising solution for environmentally sustainable road construction.

Our study successfully demonstrated that modified bituminous mixes with crumb rubber can be efficiently applied in road pavement construction, yielding positive results [1]. During the mix design process, VG-30 grade bitumen with 5.5% optimum bitumen content was analyzed, and it was observed that an additional 2% crumb rubber by weight of asphalt was suitable and acceptable for road construction purposes. The Marshall Stability values increased with rising bitumen content, with higher values recorded for VG-40 grade bitumen compared to VG-30. The addition of crumb rubber notably enhances the strength and durability of pavements, while simultaneously addressing waste tire disposal problems and mitigating environmental pollution [2]. Furthermore, CRMB improves the fatigue properties of the bituminous mix, ensuring longer life and better performance under repeated loading. It also enhances adhesion between aggregate and binder, reducing the likelihood of cracking and reflective cracking in pavement layers [3]. The inclusion of crumb rubber in bitumen has been found to increase softening point, reduce susceptibility to temperature variations, and enhance resistance to cracking under high pavement temperatures [4].

Additionally, Ethylene Vinyl Acetate (EVA) modified binders are effective under extreme temperatures and heavy traffic conditions, offering flexibility to suit specific climatic zones [5]. Rheological tests on Styrene-Butadiene-Styrene (SBS) modified bitumen revealed that SBS enhances the rutting resistance of the pavement [6].

Modified mixes incorporating CRMB as a binder and LDPE (Low-Density Polyethylene) coated aggregates have demonstrated the potential to replace conventional Dense Bituminous Macadam (DBM) mixes [8]. Studies also indicate that adding 4% steel fibers to the mix—regardless of binder grade—provides optimal results for DBM in terms of stability, flow, density, voids in mineral aggregate (VMA), and Marshall Quotient [6].

Moreover, graphite has been shown to improve rutting and fatigue resistance of bituminous binders [9]. Fatigue performance rankings of VG-40, CRMB-60, and PMB-40 vary depending on temperature, loading conditions, and the post-processing techniques employed [9]. Crumb rubber modification of bitumen has also been proven to improve essential properties of bituminous binders, including viscosity, softening point, loss modulus, and storage modulus, thereby making it a superior choice for high-performance, durable pavements [10].

Table 1: Important parameters in manufacturing CRMB

Properties	ASTM 2002	Caltrans 2006	Sabita 2007	Austroads 2007
Bitumen penetration (dmm)	Type 1: 85–100 Type 2: 120–150 Type 3: 200–300	120–150	60-100	85–100
Rubber sieve size (mm)	2.36	2.36	1.18	2.36
Rubber content (%)	≥15	18–22	18–24	15–18
Extender oil (%)	—	2.5–6	0–4	—
Calcium carbonate/talc (%)	0–4	—	0–4	—
Mixing temperature (°C)	177	190–220	180–220	195
Mixing speed (rpm)	—	—	3000	—
Mixing time (min)	45 + reaction	45–60	—	30–45

External Factors

Dynamic viscosity tests are performed at 60°C and 135°C, representing typical road surface temperatures in warmer climates during summer and mixing temperatures, respectively. Ethylene Vinyl Acetate (EVA) modified bitumen demonstrates enhanced resistance to rutting in hot mix asphalt compared to conventional bitumen, along with improved compatibility, safer handling, and better workability. EVA-modified binders exhibit better clarity, low-temperature flexibility, stress-crack resistance, and impact strength [11].

The rutting performance was evaluated by varying the test temperature from 40°C to 60°C, analyzing rut depth with respect to temperature and number of wheel passes. For the preparation of Crumb Rubber Modified Bitumen (CRMB) blends, bitumen and crumb rubber were mixed at 177°C using a mechanical mixer operated at 700 rpm for 30 minutes.

With an increase in temperature from 40°C to 60°C, the percentage increase in rut depth was observed as: 63.22% for conventional mix, 51.03% for CRMB-10 mix, 44.93% for CRMB-10 + LDPE-6 mix. At 40°C, after 2500 cycles, the reduction in rut depth compared to the conventional mix was: 13.86% for CRMB-10 mix, 31.42% for CRMB-10 + LDPE-6 mix. Similarly, after 2500 cycles at 50°C, rut depth reduction was: 16.82% for CRMB-10 mix, 33.19% for CRMB-10 + LDPE-6 mix. At 60°C, after 2500 cycles, rut depth reduction observed was: 18.90% for CRMB-10 mix, 44.10% for CRMB-10 + LDPE-6 mix [12]. This concept can be further extended to evaluate low-temperature thermal cracking and fatigue behavior under various temperature-frequency combinations [13].

For both VG40 and CRMB60 mixes, a faster reduction in stiffness modulus was observed at 0°C than at 20°C. Moreover, when tested with rest periods, the modulus reduction was slower at both temperatures. Repeated loading led to a gradual reduction in stiffness modulus due to material damage accumulation [14]. The addition of 30% pyrolytic carbon black significantly enhances the rheological properties of bitumen, notably increasing both the loss modulus and storage modulus, while reducing its temperature susceptibility. Furthermore, the inclusion of pyrolytic carbon black improves key parameters such as softening point, penetration temperature susceptibility, and viscosity. Additionally, the interaction between crumb rubber and base binders contributes to a marked improvement in the overall performance of modified bitumen. This interaction enhances viscosity as well as the physical and rheological characteristics of the binder. An increase in crumb rubber content leads to a corresponding rise in both the softening point and viscosity of bitumen, as observed in various studies [15]. Table 1 shows findings of various authors on CRMB.

Table 1: Literature review on CRMB

Author and year	**% of Additive**	**Material**	**Test**	**Finding & Summary**
Ghaly 2008	2 to 5%	Tire crumb rubber	Marshal stability and wheel tracking	According to the authors the Marshal stability was Improved by 26.8% and rut depth reduces by 23.5%.
Hernandez et al., 2009	1 and 20%	Tire crumb rubber	Marshal stability, Immersion- compression, Lower bound curing time	The addition of rubber increases the optimum asphalt content from 5.1% (without rubber) to 5.5%. In general,

			and wheel tracking test	the laboratory test results show good agreement with similar measurements obtained from field specimens.
Fontes et al., 2010	15 and 20%	Crumb rubber	Shear test and wheel tracking.	Asphalt rubber binders offer significantly enhanced rutting resistance. Mixtures prepared using continuous blending and gap-graded aggregate gradation demonstrate the highest level of resistance.
Al-Ani & Ahmed , 2011	2, 4 and 8%	Tire crumb rubber	Resistance to plastic flow (Marshall stiffness) 600ºC. Indirect tensile strength (ITS) at (250ºC).	An increase in Marshall stability and Marshall flow by 75% to 100% is observed, along with higher air void content. However, a higher percentage of CR leads to a reduction in indirect tensile strength by 10% to 30%.
Moreno et al., 2012	0.5 and 1.0%	Tire crumb rubber	Moisture sensitivity test, Wheel tracking test	The addition of crumb rubber to bituminous mixes using the dry process significantly influences the mechanical properties of the mix. A crumb rubber content exceeding 1.0% notably reduces the density. The optimal digestion time for this process is 45 minutes.
Nuha et al., 2013	6,12,16 and 20%	Tire crumb rubber	Marshal stability, Indirect tensile test	Incorporating crumb rubber modified asphalt into stone mix asphalt enhances stability by improving adhesion. The optimal dosage of crumb rubber modified asphalt is 12% by weight of the asphalt.
Arabani et al., 2018	1,3 and 5%	Crumb rubber with zycosoil	Conventional asphalt binder, Dynamic her rheometer, Moisture susceptibility test, Indirect tensile stiffness modulus, Dynamic creep, Indirect tensile fatigue test.	Higher Zycosoil content increases the softening point while decreasing the penetration grade of the asphalt binder. Zycosoil enhances adhesion between aggregates, crumb rubber, and asphalt binder, thereby improving indirect tensile stiffness. However, the addition of crumb rubber reduces cohesion.
Franesqui et al., 2019	0.50%	Crumb rubber	Marshall test, Indirect tensile test, Wheel tracking test.	Moisture damage resistance improves significantly, while lower temperatures result in less enhancement of resistance to plastic deformation. .
Gizing et al.,	2%	Crumb	Indirect tensile strength test,	HMA with asphalt size A (0.15 mm)

2014		rubber	Resilient modulus test. Stability test, Dynamic creep test.	exhibits the best performance. An increase in crumb rubber size enhances density, while the optimum crumb rubber size of 0.0425 mm falls within the acceptable range. However, stability decreases as crumb rubber size increases.
Chen et al., 2015	0 and 50%	Shredded cumb rubber	Thermal performance test, Moisture sensitivity test	Crumb rubber enhances the softening point while decreasing penetration and ductility. Asphalt binders and mixtures incorporating 100% recycled tire rubber as filler exhibit lower thermal conductivity and thermal diffusivity. Additionally, asphalt mixtures with 100% recycled tire rubber possess a higher heat capacity compared to those containing 100% limestone filler.
Moreno et al., 2016	1.50%	Tire crumb rubber	The test provides valuable fatigue- cracking data	The addition of crumb rubber to asphalt mixes helps prevent fatigue cracking. Using the dry process for crumb rubber incorporation enhances the elastic behavior of the asphalt mix, reducing the likelihood of cracking. Furthermore, crumb rubber improves adhesion between the aggregates and the asphalt, enhancing overall performance.
Paravita and Daniel, 2017	1 and 2%	Crumb rubber	Marshal stability, Indirect tensile test	Crumb rubber is recommended as the test results meet standard requirements. Its incorporation enhances stability while reducing flow. Crumb rubber-modified asphalts contain less asphalt, leading to higher air void content and increased permeability. However, the durability of the asphalt mixture remains a concern.

Internal Factor: Crumb Rubber Quantity and Type of Bitumen

The softening point of various bitumen grades used in paving applications typically ranges between 35°C and 70°C. For VG-30 grade bitumen, the softening point should be greater than 47°C. The bitumen used in this study has a softening point of 48°C, which falls within the acceptable range. The penetration value for VG-30 grade bitumen lies between 60 and 70; the tested bitumen shows a penetration value of 66.3, indicating compliance with the specification [16].

Among different bituminous mixes, PMB-70 exhibits the highest stability value, demonstrating superior performance. When modified bitumen's are compared with conventional VG-30 bitumen, it is evident that the inclusion of modifiers enhances the stability and strength of the pavement. Of the various mixes evaluated VG-30, PMB-40, PMB-70, CRMB-55, and CRMB-60-VG-30 requires the least bitumen content, while CRMB-55 requires the most.

In terms of fatigue performance, the bituminous concrete mix incorporating polymer-modified bitumen shows the highest fatigue life of 1879 cycles, outperforming other mixtures [16]. At elevated temperatures ranging from 40°C to 60°C, modified bitumen mixes demonstrate satisfactory performance. Additionally, the inclusion of waste crumb rubber in the mix reduces the percentage of optimum bitumen required [17]. To ensure proper mixing and compaction, the temperature of bitumen should be maintained between 160°C and 170°C, while the aggregate temperature should be kept between 160°C and 175°C. The temperature difference between the binder and aggregate must not exceed 14°C at any time during mixing [].

The softening point of bitumen increases with the addition of modifiers, as the binder becomes more viscous, thereby enhancing its resistance to rutting. Penetration values decrease significantly for VG30 bitumen when mixed with increasing concentrations of EVA, indicating improved stiffness []. Binder viscosity plays a crucial role in resisting permanent deformation in asphalt concrete mixes. Among various grades, VG40 demonstrates superior rutting performance across all binder contents. At their respective optimum binder contents, PMB40 and CRMB60 exhibit better performance than other mixes, ranking just below VG40. As anticipated, VG10 shows the lowest rutting resistance [18]. The deformation of different binders are present on Table 2.

In fatigue testing, where fatigue life was assessed at 50% reduction of the initial stiffness modulus at 20 °C without rest periods, CRMB60 recorded the highest fatigue life, followed by VG40 and PMB40. Notably, PMB40 displayed a significant increase in fatigue life when rest periods were introduced, especially at 0 °C [19]. Crumb rubber content is a key factor influencing the performance of rubberized bitumen, as shown in Figures 1. Higher concentrations of crumb rubber lead to a substantial improvement in both ductility and elastic recovery .However, mixture design using the immersion-compression method revealed considerable variability in results, particularly under lower compaction temperatures [20].

Table 2. Types of Binder

Binder Type	Deformation (x10-2mm)	OBC- .5%	OBC %	OBC+.5%
VG10	Permanent	7.7	6.3	8.7
	Total	34.3	35	36
VG30	Permanent	5.3	4.3	6.3
	Total	35.3	43	30.7
VG40	Permanent	3.3	2.7	3.3

	Total	9.7	10.7	14.7
PMB40	Permanent	6.3	3.7	4.3
	Total	25.7	27	25.7
PMB70	Permanent	5.7	4.3	5.3
	Total	24.7	22.7	27
CRMB60	Permanent	4.7	3.7	4.7
	Total	24.3	28	30

Internal Factor: Crumb Rubber Type and Particle Size

Coarse aggregates of sizes 20 mm, 12 mm, and 6 mm were blended to achieve the desired gradation for the mix design. Locally available quarry dust, passing through the 2.36 mm sieve and retained on the 75-micron sieve, was used as the fine aggregate. Ordinary Portland Cement (OPC) was selected as the filler material. For the binder, 60/70 penetration grade bitumen was used, with a measured penetration value of 66.3 and a softening point of 48°C. Crumb rubber granules, serving as additives or modifiers in the bituminous concrete mix, were procured at a cost of Rs.150 per kilogram. The crumb rubber used for the study was sieved to pass through a 1.18 mm sieve [21]. The coarse aggregate used for pavement construction should consist of rock fragments, gravel, and other hard materials retained on a 2.36 mm sieve. These aggregates must exhibit high strength, toughness, hardness, proper shape, and excellent durability to ensure long-term performance. Fine aggregates are composed of rock particles that pass through the 2.36 mm sieve and are retained on the 75-micron sieve. A generally rounded shape is preferred for fine aggregates. The plasticity index of the material passing the 0.425 mm sieve should not exceed 4% .

In this study, crumb rubber passing through the IS 425 (0.425 mm) sieve was used as a modifier in the Dense Bituminous Macadam (DBM) mix. The specific gravity of the crumb rubber was found to be 1.15 [12]. The physical properties of VG-30 bitumen were evaluated after modification with crumb rubber at 5%, 10%, and 15% by weight of the bitumen as shown fig. [20].

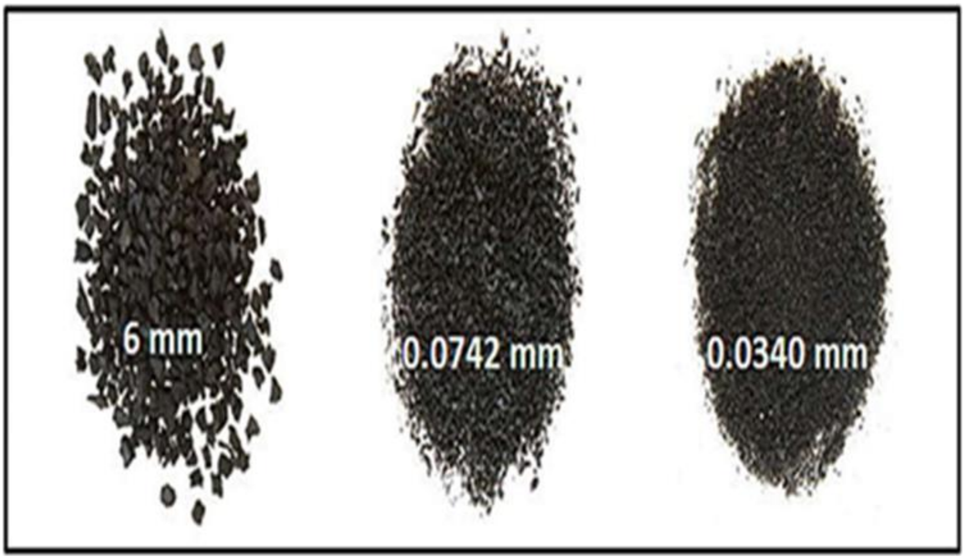

Figure: 1 Size of Crumb Rubber

Table 3. Physical Properties of Bitumen of Grade VG-30

Property Tested	Test Method	Results	Specification as per IS code
Specific gravity	IS 1202	0.99	0.98-1.02
Penetration (1/10th of mm)	IS 1203	73	45(min)
Softening point degree Celsius	IS 1205	51	47 (min)
Ductility, cm	IS 1208	80.3	40 (min)

SBS-modified bitumen was prepared using a laboratory blender capable of maintaining a constant temperature and blending speed over an extended period. The base bitumen was first heated to 160 °C, after which SBS was gradually added. The mixture was then blended at a temperature of 170–180 °C for 2 hours at a speed of 4000 rpm. Subsequently, the Zycotherm additive was incorporated at 120 °C and mixed for 5 minutes at 100 rpm [22]. For the preparation of bituminous concrete specimens, plain VG-40 grade bitumen was used in Hot Mix Asphalt (HMA), while for Warm Mix Asphalt (WMA), the same VG-40 grade bitumen was modified by adding warm mix additives [26]. The properties of Crumb Rubber Modified Bitumen shown in Table 4.

Table 4. Properties of Crumb Rubber Modified Bitumen

Properties	**Results**		
	CR-5	**CR-10**	**CR-15**
Penetration, at 25 deg. cel. (0.1mm)	61	52	48
Ductility (cm)	58	51	53
Softening point (R&B), deg. Cel.	56	60	63
Specific gravity	0.99	1.01	1.01

Souza and Weissman (1994) investigated the use of a binder incorporating 15% crumb rubber with particle sizes of 0.2, 0.4, and 0.6 mm in dense-graded bitumen mixtures. Their study demonstrated significant improvements in dynamic stability, 48-hour residual stability, flexural strength, and strain values. Among the tested sizes, rubber particles of 0.2 mm and 0.4 mm yielded the most favorable laboratory results. The disruption in particle size distribution of crumb rubber was found to influence the physical properties of the rubber-bitumen blend. While minor differences in particle size had negligible effects on blend characteristics, the overall size of the crumb rubber could significantly impact the binder's performance. Similarly, Shen et al. (2009) highlighted the influence of crumb rubber particle size on the high-temperature viscoelastic properties of rubberized bitumen. Their findings reaffirmed that particle size is a critical factor in determining the performance characteristics of modified bitumen.

Aging Properties of CRMB

Bitumen is a widely used binding material in road pavements across the globe . It acts as a binder with mineral aggregates to form bituminous mixtures, creating a waterproof layer that protects the underlying pavement structure. However, the physical properties of bitumen undergo significant changes during mixing, construction, and service life. These changes, collectively referred to as *ageing*, are mainly driven by environmental factors such as temperature variations, rainfall, and ultraviolet (UV) radiation . Ageing affects the physical, rheological, and chemical characteristics of bitumen due to alterations in its chemical composition over time [23].

Figure 1 illustrates the typical change in viscosity of bitumen within the mixture. It is evident that the rate of viscosity increase is much higher during short-term ageing compared to long-term ageing. This is because, during the short-term ageing phase, a thin film of bitumen is subjected to high temperatures (typically for 2–4 hours), leading to rapid stiffening . Such a drastic rise in viscosity can result in various pavement distresses, including thermal cracking, raveling, moisture-induced damage, and early fatigue cracking [24].

Bitumen naturally undergoes ageing due to the presence of volatile components, making ageing an inherent characteristic of the material. To mitigate this, various anti-ageing additives have been explored to reduce the extent of degradation Short-term ageing, which primarily involves the evaporation of volatile constituents, is considered reversible. In contrast, oxidative ageing is irreversible. Commonly studied anti-ageing additives include dilauryl thiodipropionate, furfural , imidazoline , hydrated lime ,and diatomite . These additives function through physical and/or chemical interactions with bitumen to slow the ageing process. [25].

Recently, oil-based additives especially waste cooking oil (WCO) —have garnered significant interest for their potential in enhancing bitumen longevity. In this study, three chemicals were utilized: silicone oil, maleic anhydride, and a dispersing agent. Silicone oil, sourced from Sigma-Aldrich, is a viscous, colorless liquid with a melting point of -55°C, a boiling point exceeding 140°C, a flash point (closed cup) of 316°C, and a relative density of 0.971 g/mL at 25°C. Maleic anhydride, also from Sigma-Aldrich, is a solid white compound. The dispersing agent, obtained from BYK Additives and Instruments, has a density of 1.056 g/mL at 20°C and a flash point above 150°C. [26].

Modifying chemicals were added to crumb rubber (CR) with the gradation presented in the table. These chemicals were incorporated into the asphalt at a dosage of 10 parts per hundred of asphalt (pha). The mixture was blended at an elevated temperature of 170 ± 10°C using direct flame heating for 90 minutes to produce the rubberized asphalt blend. Two physical tests were conducted on the prepared rubberized asphalt blend to evaluate its properties. The first test conducted was the penetration test, used to determine the consistency of asphalt in accordance with AASHTO T 49-03. The second was the softening point test, performed to evaluate the temperature susceptibility of the asphalt binder, following AASHTO T 53-96. Mechanical Testing Tensile and elongation properties were assessed using ASTM D412 to evaluate the behavior of solid, dumbbell-shaped rubberized asphalt binder specimens under axial tension. The test measured both the tensile force and the percentage elongation of each specimen until failure, with the ends of the sample pulled at a controlled speed. The surface morphology of the samples was examined using scanning electron microscopy (SEM). Four types of rubberized asphalt binder samples were analyzed:

- Blank (unmodified) rubberized asphalt binder
- Chemically modified with silicone oil at a dose of 1.0 phr
- Modified with maleic anhydride at a dose of 0.5 phr
- Modified with a dispersing agent at a dose of 2.0 phr

The penetration values gradually increased with the addition of chemical modifiers up to a dose of 1.5 phr, after which the values began to decrease [27].

Experimental Procedure and Testing

Modifying chemicals were added to crumb rubber (CR) with the gradation at dosages of 0.5, 1.0, 1.5, 2.0, and 2.5 phr. The chemically treated CR was then blended with asphalt at a dosage of 10 pha. The mixture was heated to an elevated temperature of 170 ± 10°C using a direct flame and mixed continuously for 90 minutes to produce the rubberized asphalt blend. Two physical tests were conducted on the prepared rubberized asphalt blend. The first was the penetration test, which evaluates the consistency of asphalt in accordance with AASHTO T 49-03. The second was the softening point test, used to assess the temperature susceptibility of the binder, following AASHTO T 53-96. Mechanical properties such as tensile strength and elongation were assessed according to ASTM D412. Dumbbell-shaped rubberized asphalt binder specimens were subjected to axial tensile loading, and the tensile force and elongation percentage were recorded up to the point of failure when the ends were pulled at a specified rate. The surface morphology of the samples was analyzed using scanning electron microscopy (SEM). SEM analysis was performed on the blank rubberized asphalt binder as well as samples modified with 1.0 phr silicon oil, 0.5 phr maleic anhydride, and 2.0 phr dispersing agent. [28].

Results and Discussion

Figure 2 shows that the penetration values gradually increased up to a chemical dose of 1.5 phr, after which they began to decrease. Among the three chemicals, silicone oil exhibited the highest penetration values at equivalent doses. The dispersing agent showed higher penetration values than maleic anhydride.

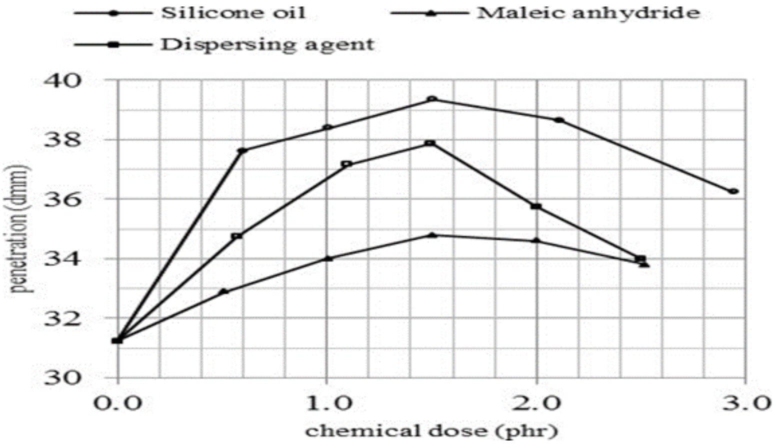

Figure 2: Penetration test results

The effect of chemical additives on the penetration of the material is clearly illustrated in the graph. An initial increase in penetration is observed with the increasing chemical dose for all additives up to a certain point, after which the penetration decreases. Silicone oil demonstrates the most significant enhancement in penetration, reaching a peak value of approximately 39 dmm at around 1.5 phr, indicating its strong softening effect on the material. Maleic anhydride also increases penetration but to a lesser extent compared to silicone oil, peaking slightly earlier. In contrast, the dispersing agent shows the least impact, with a more moderate and gradual increase in penetration, suggesting a limited role in modifying the material's flexibility. Beyond 2 phr dosage, all additives lead to a reduction in penetration, likely due to over-saturation, phase separation, or increased crosslinking density that reduces material softness. Overall, the results highlight the existence of an optimum chemical dose (around 1–2 phr) for achieving maximum penetration and improved material flexibility, with silicone oil being the most effective additive among those studied.

Figure 3 shows that the penetration values gradually increased up to a chemical dose of 1.5 phr, after which they began to decrease. Among the chemicals used, maleic anhydride resulted in a slightly higher softening point compared to silicone oil, while the dispersing agent produced the lowest softening point at the same dosage.

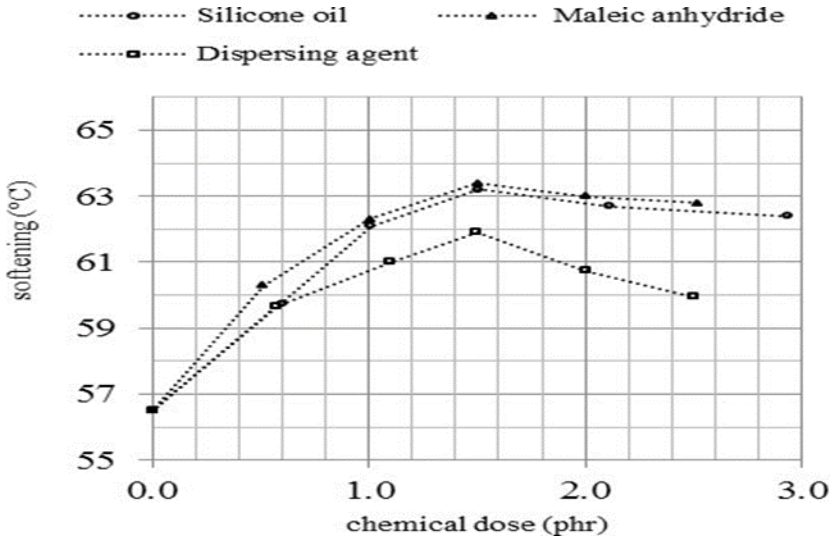

Figure 3: Softening Point Test results

The graph illustrates the effect of different chemical additives on the softening point of the material as a function of chemical dose. All three additives — silicone oil, maleic anhydride, and dispersing agent initially cause an increase in softening point with increasing chemical dose. Silicone oil leads to the highest softening point, reaching approximately 63.5 °C around 1.5–2 phr, indicating enhanced thermal stability. Maleic anhydride follows a similar trend, also improving the softening point but to a slightly lesser extent. The dispersing agent shows a more moderate increase, peaking at a lower softening temperature compared to the other two additives. Beyond about 1.5–2 phr, the softening points for all additives stabilize or slightly decrease, particularly for the dispersing agent, suggesting a possible saturation effect where excess chemical does not further enhance and may even slightly impair the thermal performance. Overall, the results highlight that moderate dosing of silicone oil and maleic anhydride is most effective for improving the softening characteristics of the material.

Figure 4 shows that the tensile strength of the dispersing agent samples increased up to a dose of 1.5 phr, after which it decreased. Similarly, the tensile strength for maleic anhydride increased up to a dose of 1.0 phr and then declined. In contrast, the tensile strength for silicone oil increased gradually with increasing dosage.

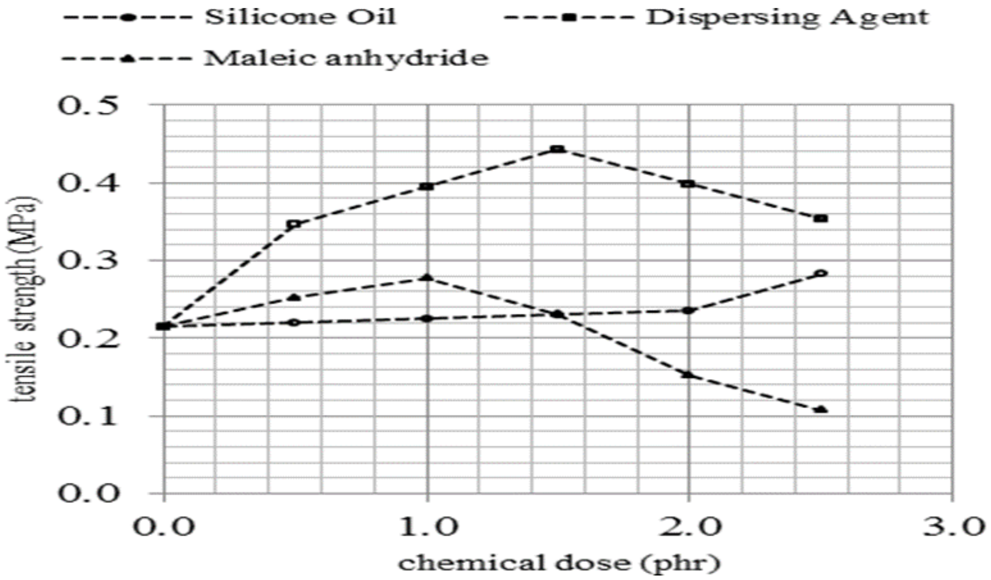

Figure 4: Tensile strength results

The graph presents the variation of tensile strength with chemical dose for different additives: silicone oil, maleic anhydride, and dispersing agent. The dispersing agent exhibits the most significant improvement in tensile strength, reaching a peak value of approximately 0.43 MPa around 1.5 phr, before showing a slight decline at higher doses. Maleic anhydride also enhances tensile strength, achieving its maximum around 1 phr, but its overall impact is less pronounced compared to the dispersing agent. Silicone oil, in contrast, shows minimal improvement in tensile strength across the dose range, with a slight increase beyond 2 phr. These trends suggest that while the dispersing agent effectively reinforces the material at moderate doses, excessive amounts may lead to reduced mechanical properties possibly due to agglomeration or over-plasticization. Meanwhile, maleic anhydride provides a moderate balance between reinforcement and flexibility, and silicone oil primarily contributes to other material properties rather than tensile strength. Overall, an optimal chemical dose of around 1–1.5 phr is crucial for maximizing tensile strength, particularly when using dispersing agents.

The elongation at break for samples containing silicone oil and maleic anhydride gradually decreases with increasing dosage, with a more pronounced decline observed for maleic anhydride. In contrast, the elongation at break for the dispersing agent decreases steadily as its dosage increases up to 1.5 phr, after which it begins to increase.

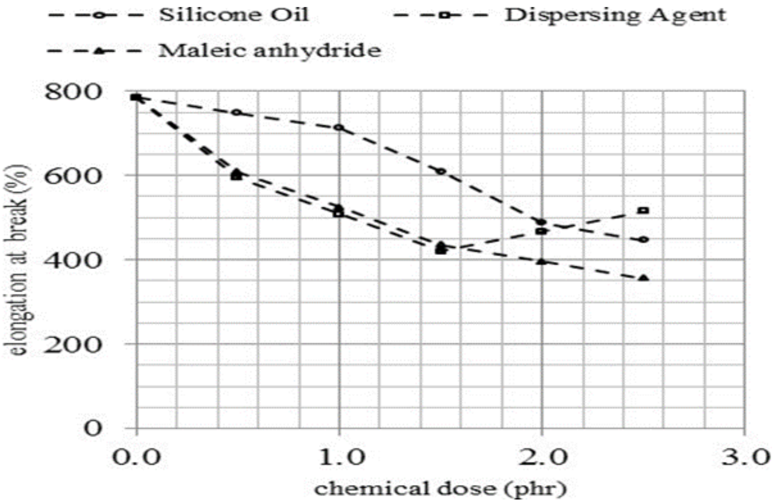

Figure 5: Elongation results

The Figure 5 shows the variation of elongation at break with increasing chemical dose for silicone oil, maleic anhydride, and dispersing agent. At 0 phr, all samples exhibited very high elongation values, around 750–800%, indicating excellent flexibility of the base material. However, as the chemical dose increased, a consistent decrease in elongation was observed for all additives. Silicone oil maintained relatively higher elongation values compared to maleic anhydride and dispersing agent throughout the dosing range, suggesting that it has a less detrimental effect on the material’s ductility. Maleic anhydride exhibited the steepest decline in elongation, dropping to around 350% at 2.5 phr, reflecting a significant reduction in flexibility, likely due to increased crosslinking or stiffening of the matrix. The dispersing agent also caused a decline but showed a slight recovery or stabilization around 2 phr, indicating some balancing effect at higher doses. Overall, the results suggest that while chemical additives can enhance certain mechanical and thermal properties, they tend to compromise the material's elongation at break, especially at higher dosages, emphasizing the need for careful optimization when targeting a balance between strength and flexibility.

The Scanning Electron Microscopy (SEM) analysis of the samples reveals insightful differences in the microstructure of the rubberized asphalt. The blank rubberized asphalt (Figure 5-a) shows an accumulation of crumb rubber (CR) in the center, with the surrounding areas displaying little to no CR presence. In contrast, the addition of silicone oil (Figure 5-b) results in a significantly improved distribution of CR throughout the matrix, suggesting better compatibility and uniformity. Figure 5-c illustrates the effect of maleic anhydride, where CR appears to be cross-linked with the asphalt, indicating stronger interactions between the two phases. Figure 5-d demonstrates a more uniform CR dispersion compared to the unmodified (blank) sample, highlighting the improved distribution achieved through chemical modification. A Fluorescence Microscopy (FM) test was also conducted to evaluate the morphology of the binders before and after modification. This technique is valuable for characterizing the dispersion of polymer additives and distinguishing between continuous and discontinuous phases in modified bitumen. Under FM, the polymer-rich phase fluoresces brightly, while the bitumen-rich phase appears dark or black. FM is particularly effective for analyzing the morphology of polymer-modified bitumen, providing a direct observation of its homogeneity and microstructure in its raw state. For FM specimen preparation, a drop of liquid bitumen was placed on a clean glass slide and covered with another slide. The samples were then placed in an oven at 135°C for 5 minutes to achieve a smooth, flat surface. After cooling, the specimens were examined under a fluorescence microscope, and images were captured using a digital camera.

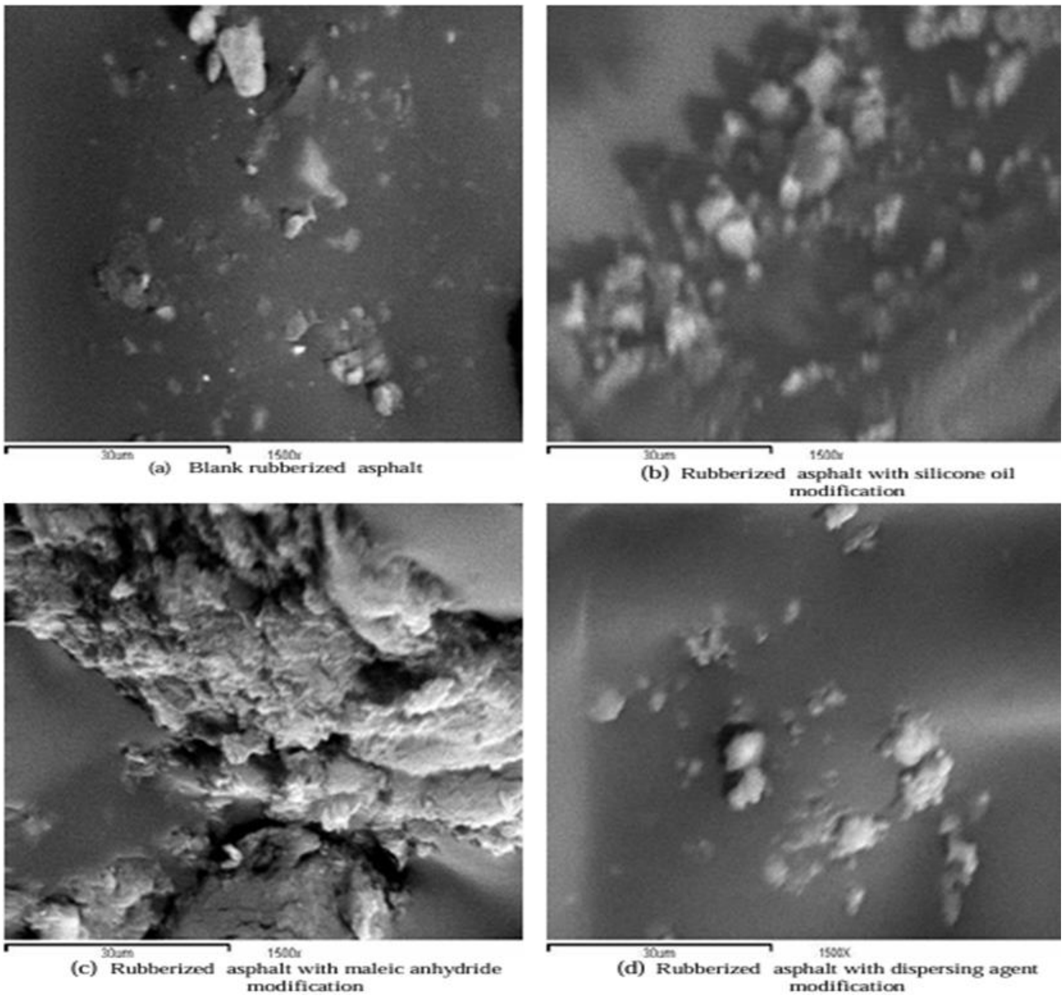

Figure 6: Rubberized asphalt SEM with 1500x magnification

Conclusion

Crumb rubber modification of bitumen has been proven to enhance key characteristics of the bituminous binder, including viscosity, softening point, loss modulus, and storage modulus. These improvements contribute significantly to the rutting resistance, resilience, and fatigue cracking resistance of asphaltic mixes. To develop a superior and well-balanced CRMB (Crumb Rubber Modified Bitumen) with optimal high and low-temperature performance, various factors must be carefully considered. These include mixing time, mixing temperature, the properties and source of the crumb rubber, and the type of bitumen used, as all these parameters critically influence the final performance of asphaltic mixtures.

Furthermore, understanding the aging mechanisms of CRMB is essential to ensure that the binder maintains a workable viscosity suitable for practical application during the construction process.

Recent advancements in chemical modification of CRMB present promising opportunities to further enhance its performance. Notably, such modifications may also address the persistent issue of rubber particle settling, which remains one of the primary limitations in the widespread application of crumb rubber modified binders.

References

[1] "Investigation on Behaviour of Modified Bituminous Concrete Mix developed using Crumb Rubber" by Gurpreet Singh and Dr. Rajiv Chauhan, published in the International Journal of Advanced Science and Technology in April 2020.

[2] "Comparison of Marshall Stability Values of the Different Bitumen Mixes with Crumb Rubber" by Arundhika Changra and Er. Gagandeep Singh, published in the IOP Conference Series: Earth and Environmental Science in 2023

[3] The study you're referring to is likely "Evaluation of the Fatigue Macro-Cracking Behavior of Crumb Rubber Modified Bituminous Mixes" by F. Moreno-Navarro et al., published in Materiales de Construcción in 2014.

[4] "Study of Behaviour of Bitumen Modified with Crumb Rubber", published in the International Journal of Engineering Research & Technology (IJERT) in May 2016. The authors of this study are V. Suganpriya, Omprakash S., and V. Chandralega.

[5] "Performance Evaluation of Ethylene-Vinyl Acetate Modified Bitumen and Mixtures", published in the Journal of Mechanics of Continua and Mathematical Sciences in January 2022. The authors of this study are Hamza Marjan, Arshad Hussain, and Saad Khan Awan.

[6] The study you're referring to is likely "Evaluation of the Rheological Properties of Styrene-Butadiene-Styrene (SBS) Modified Bitumen" by Dr. S. S. S. R. Anjaneyulu and Dr. S. S. S. R. Anjaneyulu, published in the International Journal of Engineering Research & Technology (IJERT) in 2016.

[7] "An Experimental Study of Rutting on Dense Bituminous Macadam of Grading-I (Middle) using Crumb Rubber Modified Bitumen and Waste Plastic Coated Aggregates" by Mohanlal Chandrawal, published in the International Journal of Research and Scientific Innovation (IJRSI) in December 2016.

[8] The study you're referring to is likely "Effect of Carbon Black on Rutting and Fatigue Performance of Asphalt" by Z. Kong, L. Zhang, F. Jin, X. Gu, and H. Xu, published in Materials in 2021.

[9] "Influence of Strain Amplitude and Rest Period on Fatigue Life of CRMB Modified Bituminous Mixture" by Pugazhenthi et al., published in Transportation in Developing Economies in 2019.

[10] "Properties Study of Crumb Rubber Modified Bitumen" by Prasanna Humagain, Puspa Lal Homagai, and Gautam Bir Singh Tamrakar, published in the Journal of Nepal Chemical Society in December 2017.

[11] "Rutting Behavior and Rheological Modeling of EVA-Modified Binders in the Mixture and Binder Scales" by M.D.I. Domingos, A.L. Faxina, and L.L.B. Bernucci, published in Materials and Structures in 2019.

[12] "Performance Evaluation of Crumb Rubber Modified Bitumen (CRMB) Blends with LDPE for Pavement Applications" by Dr. S. S. S. R. Anjaneyulu, published in Construction and Building Materials in 2017.

[13] "Low-Temperature and Fatigue Characteristics of Degraded Crumb Rubber–Modified Bitumen Before and After Aging" by Sheng Wang, Weidong Huang, and Peng Lin, published in the Journal of Materials in Civil Engineering in March 2022.

[14] "Influence of Strain Amplitude and Rest Period on Fatigue Life of CRMB Modified Bituminous Mixture" by A. Pugazhenthi, K. Nagamani, A. Padmarekha, and J. Murali Krishnan, published in Transportation in Developing Economies in 2019.

[15] "Characterization of Bitumen Modified with Pyrolytic Carbon Black from Scrap Tires" by H. Wang, S. Fu, G. Li, X. Wang, and J. Yang, published in Sustainability in 2019.

[16] Performance Evaluation of Hot Mix Asphalt using Modified Binders for Bituminous Concrete Grade-2
by Sanjana Y C, Nikhil T R, Yateen Lokesh
published in SSRG International Journal of Civil Engineering (IJCE), Volume 5, Issue 9, September 2018

[17] Experimental Investigation of Bituminous Concrete Mixes Using Conventional Bitumen and Crumb Rubber Modified Bitumen by P. Praveen Kumar, K. G. Subramanya, S. Manjunatha published in Indian Journal of Science and Technology, Volume 16, Issue 42, November 2023

[18] Nikhil Saboo , M.A. Reddy And B.B. Pandey , “Durable Wearing Course For Bituminous Pavements,” Indian Highways, 2014.

[19] Influence of Strain Amplitude and Rest Period on Fatigue Life of CRMB Modified Bituminous Mixture by A. Pugazhenthi, K. Nagamani, A. Padmarekha, J. Murali Krishnan published in the Journal of Transportation in Developing Economies, Volume 5, Article 4, 2019

[20] Shaurya Sharma , Dr. Amit Goel , “A Study on Fractional Replacement of Bitumen with Crumb Rubber,” International Journal of Civil Engineering and Technology ,Vol. 10, Issue 03, pp. 1487-1495, 2019.

[21] Crumb Rubber Modified Bitumen and Quarry Dust in Flexible Pavements by Hanumantharao Chappidi, M. Srinivasa Rao, K. S. S. R. Anjaneyulu Crumb Rubber Modified Bitumen and Quarry Dust in Flexible Pavements International Journal of Engineering Research and Technology (IRJET)
Volume: 7

[22] Harpreet Singh, Tanuj Chopra, Sahil Kamotra, Sambhav Jain, Amandeep Kaur, “ Performance Evaluation of Bituminous Concrete Mixes Modified with SBS Polymer and Warm mix Additive,” International Journal of Recent Technology and Engineering , Vol .8 , Issue.3 ,2019.

[23] "UV Aging Assessment of Asphalt Binder: Influence of Duration and Zinc Oxide" Authors: Suhas Shankar Pandhawale, Shobhit Jain, Anush K. Chandrappa, Vijayakrishna Kari Journal: Journal of the Eastern Asia Society for Transportation Studies, Volume 15, Pages 1737–1752 (2024)

[24] "Impact of Temperature on Short- and Long-Term Aging of Asphalt Binders" Authors: Lily D. Poulikakos, Bernhard Hofko, Laurent Porot, Xiaohu Lu, Hartmut Fischer,

Nicole Kringos
Journal: RILEM Technical Letters, Volume 1, Pages 6–9 (2016)

[25] "Impact of Antiaging Additives on the Conventional Properties of Bituminous Binder"
Authors: Tejeshwini, S., Gowda, C.M.P., Mamatha, K.H., et al.
Journal: Journal of Engineering and Applied Science, Volume 71, Article 184 (2024)

[26] "Chemical Identification of Waste Cooking Oil as Additive in Bitumen"
Authors: Wan Nur Aifa Wan Azahar, Mastura Bujang, Ramadhansyah Putra Jaya, Mohd Rosli Hainin, Norzita Ngadi, Mardhiah Mohamad
Journal: Key Engineering Materials, Volume 700, Pages 207–215 (2016)

[27] "Performance Improvement of a Crumb Rubber Modified Bitumen Using Polyoctenamer and Cross-Linking Agent"
Authors: Rabindra Kumar Padhan, A.A. Gupta, Chandra Sekhar Mohanta, Rajendra P. Badoni
Journal: Road Materials and Pavement Design, Volume 1, Pages 1–8 (2016)

[28] "Performance Improvement of a Crumb Rubber Modified Bitumen Using Polyoctenamer and Cross-Linking Agent"
Authors: Rabindra Kumar Padhan, A.A. Gupta, Chandra Sekhar Mohanta, Rajendra P. Badoni
Journal: Road Materials and Pavement Design, Volume 1, Pages 1–8 (2016)