Performance Evaluation of Bitumen Mixes Incorporating Crumb Rubber as Bitumen Substitute and Alternative Mineral Fillers

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***Abstract*—This research explores how replacing part of the bitumen with crumb rubber—using varying amounts of 5%, 10%, 15%, 20%, and 25%—affects the performance of asphalt mixtures, along with incorporating glass powder and limestone powder as mineral fillers. The goal is to boost the durability of pavements while also fostering environmental sustainability through the use of recycled materials. Crumb rubber derived from old tires was mixed with bitumen to create a modified binder, whereas glass and limestone powders acted as mineral fillers. Laboratory tests, including Marshall Stability, flow value, moisture susceptibility, rutting resistance, and shear strength, were carried out to evaluate the performance of these modified mixtures. The findings revealed that the best mechanical performance, particularly in stability and tensile strength, was achieved with 10-15% crumb rubber content, although workability suffered when the crumb rubber content exceeded 20%. Notably, combining glass powder with limestone filler significantly boosted moisture resistance and shear strength. Overall, these results indicate that the suggested modifications not only improve asphalt performance but also support sustainable paving practices.**

***Index Terms*—Crumb Rubber Modified Bitumen, Asphalt Performance, Glass Powder Filler, Limestone Powder Filler, Waste Material Utilization, Sustainable Pavement Materials, Bitumen Replacement**

1. INTRODUCTION

The increasing demand for sustainable infrastructure has prompted researchers and engineers to seek alternative materials for road construction that enhance performance while adhering to ecological standards. One promising approach involves incorporating recycled waste materials into asphalt mixtures to reduce the environmental impact of pavement production. Crumb rubber, sourced from used tires, has proven effective in restoring the elasticity and durability of the binder. By modifying asphalt with crumb rubber, we not only address the issue of tire waste but also bolster the pavement's resistance to deformation and cracking.

In addition, some researchers are exploring other mineral fillers such as glass powder and limestone powder, which can either replace or complement traditional fillers in asphalt mix designs. Glass powder, a by-product of recycling, is recognized for its ultra-fine particle size and pozzolanic properties, enhancing the stiffness and moisture resistance of asphalt mixtures. Meanwhile, limestone powder, a staple in road construction, improves cohesiveness and workability, and it can be combined with various recycled materials to further elevate performance.

This study investigates the effects of substituting bitumen with crumb rubber at varying levels (5%, 10%, 15%, 20%, and 25%), alongside the inclusion of glass powder and limestone powder as fillers, on the performance of asphalt mixtures. The objective is to identify optimal mix ratios that maximize mechanical properties, sustainability, and durability. A series of laboratory tests, including the Marshall stability test, indirect tensile strength test, rutting resistance test, and moisture susceptibility tests, will be conducted to assess the modified mixtures. The findings from this project are expected to contribute significantly to the development of asphalt pavements that excel in performance while remaining environmentally friendly.

2. OBJECTIVES

1) We aim to explore how replacing bitumen with crumb rubber in varying proportions (5%–25%) affects the performance of asphalt.
2) Our goal is to investigate how adding glass powder and limestone powder as fillers impacts the mechanical properties and durability of asphalt mixtures.
3) We want to identify the perfect blend of crumb rubber and fillers to enhance strength, flexibility, and ease of workability.
4) We'll measure performance indicators such as Marshall Stability, flow values, and resistance to rutting.
5) Additionally, we will evaluate how modified asphalt mixes perform under moisture conditions and their overall environmental durability.
6) Finally, we are committed to promoting sustainable pavement solutions by incorporating waste materials into flexible pavement designs.

3. REVIEW OF LITERATURE

Moreno et al. (2012) conducted a study on the behavior of asphalt mixtures enhanced with crumb rubber added through the dry method. They focused on how these mixtures responded to humidity and their ability to resist plastic deformation. The study revealed that the percentage of crumb rubber was the most significant factor affecting the performance of the mixtures, while the digestion time—essentially the interval between mixing and compaction—had a minimal impact. Optimally, the best performance was noted with crumb rubber percentages ranging from 0.5% to 1.0% of the total mixture weight and a digestion time set at 45 minutes.

M. Ghasemi (2013) found that enhancing asphalt with plastic led to significant improvements. Specifically, the bitumen modified using crumb rubber (CR) and recycled glass powder (RGP) exhibited greater flexibility compared to the unmodified version. In terms of rutting parameters, the samples with CR and RGP showed a remarkable increase of about 180% over the control sample and approximately 40% more than those modified with CR alone. Furthermore, the mixtures containing RGP demonstrated greater stiffness than the control mixture, resulting in pavements that endured less strain at lower temperatures.

AR Prasad et al. (2015) explored the potential of using waste plastic and rubber as partial replacements for conventional materials, specifically bitumen, to enhance the mechanical properties of road mixes. In this study, a comparative analysis was conducted between various waste plastics, such as PET bottles, and crumb rubber, with replacement percentages of 3%, 4.5%, 6%, 7.5%, and 9% by weight of bitumen in bitumen concrete mixes. The aim was to determine which of these materials is more effective at modifying bitumen for road construction applications. The findings revealed that a 6% incorporation of waste material yielded the most favorable results in terms of Marshall stability.

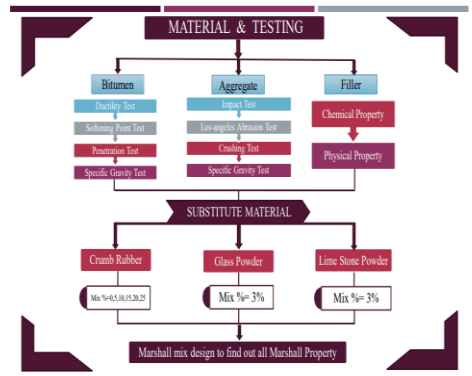
Sara Bressia et al. (2017) introduces a specialized mix design method for rubberized asphalt using a dry process. This approach considers how crumb rubber behaves during both compaction and the subsequent stages. To refine the compaction process, an analytical method has been developed to measure the deformation of the crumb rubber after compaction, allowing for necessary adjustments to the gyration numbers recommended by the SUPERPAVE method when incorporating crumb rubber. The ultimate objective is to establish a suitable compaction method that ensures the asphalt mixture meets the specified voids content criteria. A mathematical formula has also been created to determine the maximum amount of rubber that can be incorporated into the mixture, provided the target voids content is met. Finally, the study outlines a comprehensive step-by-step protocol for producing and compacting crumb rubber mixtures in a laboratory setting.

Arabani et al. (2018) observed that incorporating crumb rubber in amounts up to 3% of the mixture's weight enhances the stiffness modulus and minimizes permanent deformations. However, exceeding this 3% threshold can have detrimental effects on the mixture's mechanical properties, leading to a reduced lifespan. This decline is attributed to the inadequate adhesion between the bitumen and aggregates when higher percentages of crumb rubber are present.

Shaurya Sharma et al. (2019) conducted a study aimed at finding a sustainable alternative to bitumen that meets its physical and binding properties, specifically concerning strength, durability, and flexibility. The asphalt industry is actively seeking eco-friendly binders that can partially replace bitumen to promote environmental sustainability while increasing the availability of these materials. In this research, crumb rubber was incorporated into bituminous mixes to identify the optimum content percentage. The crumb rubber was utilized in powdered form and was used to partially replace the bitumen quantity. The study employed standard Marshall Mix design along with Penetration and Ductility tests. Various percentages of crumb rubber, ranging from 2% to 10% by weight of bitumen, were tested, establishing an optimum bitumen content of 5%. The findings revealed that the ideal crumb rubber content was at 6% by weight of bitumen, alongside the 5% optimum bitumen content. The test results indicated an enhanced stability of the modified bitumen mix when compared to the standard plain bitumen mix. Additionally, the physical attributes of the modified bitumen showed improvement; the penetration test indicated a harder consistency, while the ductility test suggested it was less flexible than the original bitumen.

Adeola Alogba et al. (2020) conducted a study focusing on the incorporation of non-biodegradable waste materials, specifically plastic water bottles and recycled glass, into the construction of flexible pavements. Traditionally, these pavements rely on bitumen as the binder and cement or stone dust as the filler. In their approach, the researchers modified both the binder and the filler by introducing varying proportions of pulverized plastic and recycled glass powder. The results revealed that the modified binder exhibited enhanced properties compared to the unaltered bitumen. Furthermore, the asphalt produced from these modified materials achieved a stability measure of 3.33 kg at an optimal 6% plastic replacement. This figure surpasses the stability of 2.017 kg recorded without any modifications to the bitumen.

4. METHODOLOGY



5. MATERIAL USED

Aggregate: - Aggregates are essential building materials that can be either natural or processed, including sand, gravel, crushed stone, slag, or recycled concrete. They act as the structural backbone in concrete, asphalt, and the foundational layers of roadways. Aggregates are divided based on their size into fine aggregates (like sand) and coarse aggregates (such as gravel or crushed rock). Their main functions include providing compressive strength, ensuring stability, minimizing shrinkage, and boosting the durability of the combined materials.

Bitumen: - Bitumen is a thick, black, thermoplastic substance produced during the distillation of crude oil. Comprised mainly of complex hydrocarbons, it serves as a binding agent in asphalt mixtures, effectively anchoring aggregates together to create a strong, lasting pavement layer. Beyond its role in road construction, bitumen is also widely used for roofing, waterproofing, and sealing due to its strong adhesive qualities and resistance to water. Its performance can be significantly improved with the addition of modifiers like polymers, enhancing its elasticity, temperature sensitivity, and resistance to aging.

Crumb Rubber: - Crumb rubber is made by mechanically shredding used automobile tires into small particles, typically under 1 mm. This recycled material retains the elastic properties of natural rubber and is commonly incorporated into rubberized asphalt mixtures to boost performance regarding flexibility and resistance to fatigue and deformation. Its use in pavement construction also supports environmental sustainability by lowering landfill waste from tires. In this study, crumb rubber that meets a 300-micron IS sieve standard was utilized, and the wet mixing method was employed, where the rubber is blended with bitumen prior to merging with aggregates.

Limestone Powder: - Limestone powder is a fine material sourced from natural limestone, primarily comprising calcium carbonate ($CaCO_3$). In asphalt mixtures, it serves as a mineral filler that improves the mix's consistency, workability, and compactability. Its tiny particle size helps reduce porosity and fosters durability. Moreover, limestone powder is often used as a partial substitute for cement in concrete, which aids in lowering CO_2 emissions and encouraging sustainable construction methods.

Glass Powder: - Glass powder is a pozzolanic material created by finely grinding glass waste, whether from post-consumer sources or industrial processes. It mainly consists of silica (SiO_2) along with various other oxides, and it reacts with calcium hydroxide in cement-based systems. When incorporated as a filler in asphalt mixtures, glass powder boosts mechanical strength, enhances durability, and improves chemical resistance. Its angular shape and ultra-fine particle size promote better inter-particle bonding within the matrix. Additionally, utilizing glass powder supports recycling efforts for waste glass, contributing positively to environmental conservation. It also finds applications in several industries, including ceramics, coatings, and road marking materials.

6. EXPERIMENTAL ANALYSIS

The following tests were conducted in order to determine the physical properties of aggregates: -

- Specific gravity test
- Aggregate Water absorption test
- Aggregate impact test
- Aggregate crushing test
- Aggregate Shape test
- Los-angeles abrasion test

Figure 1. Aggregate Sample Preparation and Testings

The following tests were conducted in order to determine the properties of modified bitumen: -

- Penetration Test
- Ductility Test
- Softening Point Test
- Flash and Fire Point Test
- Marshall Stability Test

Figure 2. Penetration Test

Figure 3. Softening Point Test

Figure 4. Ductility Test

Fig.5. Sample Preparation

Fig.6. Marshall Testing

Fig.7. Analyzing Data

7. RESULT & DISCUSSION

Table 7.1 Sieve Analysis Result

Sieve Size (mm)	Aggregate Weight(gm)	Weight Percent (Passing)	Passing Percent Limit
19	0	100%	100
13.2	90	92.5%	79-100
9.5	180	77.5%	59-79
4.75	204	60.5%	52-72
2.36	162	47%	35-55
1.18	120	37%	28-44
0.6	108	28%	20-34
0.3	108	19%	15-27
0.15	108	10%	10-20
0.075	72	4%	4-13
Pan	36	2%	2-8

Aggregate Tests Result:

Table 7.2 Aggregate Test Result

S.No.	Aggregate Test Performed	Result	Specified Limits	References
1	Specific gravity (i) Coarse Aggregate (ii) Fine Aggregate	2.54 2.48	2.5-3.2 2.3-2.9	IS 2363 (Part III) - 1963
2	Water absorption	2.47 %	0.1-5%	IS 2386 (Part III) - 1963
3	Aggregate impact test	10.29 %	<35%	IS 2386 (Part IV) - 1963
4	Aggregate crushing value test	18.93 %	<30%	IS 2386 (Part IV) - 1963
5	Flakiness index	13.36 %	<15%	IS 2386 (Part I) - 1963
6	Elongation index	22.77 %	<25%	IS 2386 (Part I) - 1963
7	Los Angeles abrasion test	18.27 %	<35%	IS 2386 (Part IV) - 1963

Determination of Softening Point Test of Bitumen:-

The grade of bitumen on which test are performed is VG-30. Method of test according to IS 1205-1978.

Table 7.3 Softening Point Test Result

	% of Crumb Rubber (CR) with respect to weight of bitumen sample.	Mean Temperature
Temperature at which sample touches the bottom plate	0 %	44.5 °c
	5 %	51.5°c
	10 %	53.5°c
	15 %	54.5°c
	20 %	56.5°c
	25 %	57^0 c

Flash and Fire point of Bitumen: -

The grade of bitumen on which test is performed is VG-30. Method of testing is then according to IS 1209-1978.

Table 7.4 Flash and fire point test results of bitumen

% of Crumb Rubber (CR) with respect to weight of bitumen sample.	Flash point	Fire point
0 %	247.66°C	262.66°C
5 %	267.66°C	285.66°C
10 %	284.33°C	317.66°C
15 %	293.66°C	331°C
20 %	304.33°C	335.66°C
25 %	305^0C	342^0C

Penetration Test of Bitumen: -

The grade of bitumen on which test is performed is VG-30. Method of testing is then according to IS 1203-1978

Table 7.5 Penetration test results of bitumen

Method of test is according to IS- 1203-1978. Grade of bitumen used vg-30. % of Crumb Rubber (CR) added with respect to the weight of bitumen sample	Penetration 1/10th mm
0 %	87.67 mm
5 %	75.33 mm
10 %	67.33 mm
15 %	60.66 mm
20 %	53 mm
25%	51 mm

Ductility Test of Bitumen: -

The grade of bitumen on which test is performed is VG-30. Method of testing is then according to IS 1208-1978

Table 7.6 Ductility test results of bitumen

Method of testing according to IS 1208-1978. Bitumen sample used vg-30. % of Crumb Rubber (CR) added with respect to the weight of bitumen sample.	Ductility in cm
0 %	92.34 cm
5%	87 cm
10 %	83.68 cm
15 %	74.33 cm
20 %	65.66 cm
25%	57.33 cm

Marshall Stability Test of Bitumen: -

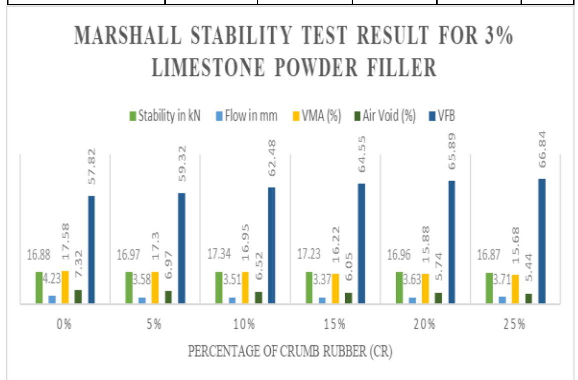
Table 7.7 Results of 3% Limestone Powder Filler for Varying Percentage of CR

% of Crumb Rubber (CR) added with respect to the weight of bitumen mix sample.	Stability in KN	Flow in mm	VMA (%)	Air Void (%)	VFB
0 %	16.88 KN	4.23mm	17.58	7.32	57.82
5%	16.97 KN	3.58mm	17.30	6.97	59.32
10 %	17.34 KN	3.51mm	16.95	6.52	62.48
15 %	17.23 KN	3.37mm	16.22	6.05	64.55
20 %	16.96 KN	3.63mm	15.88	5.74	65.89
25 %	16.87 kN	3.73mm	15.68	5.44	66.84

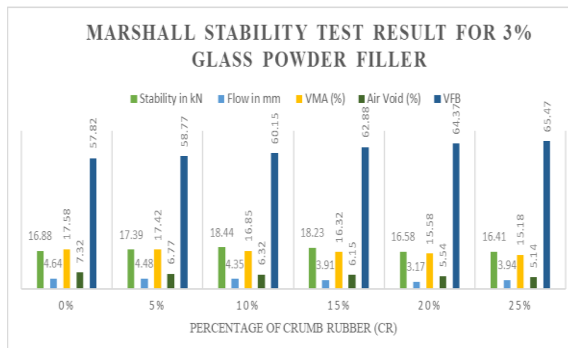
Marshall Stability Test of Bitumen: -

Table 7.8 Results of 3% Glass Powder filler for Varying Percentage of CR

% of Crumb Rubber (CR) added with respect to the weight of bitumen mix sample.	Stability in kN	Flow in mm	VMA (%)	Air Void (%)	VFB
0 %	16.88kN	4.64mm	17.58	7.32	57.82
5%	17.39 KN	4.48mm	17.42	6.77	58.77
10 %	18.44 KN	4.35mm	16.85	6.32	60.15
15 %	18.23 KN	3.91mm	16.32	6.15	62.88
20 %	16.58 KN	3.17mm	15.58	5.54	64.37
25 %	16.41kN	3.84mm	15.18	5.14	65.47



Graph 7.1



Graph 7.2

8. CONCLUSION

1. The addition of crumb rubber to VG-30 grade bitumen brings significant changes to its physical characteristics, making it more suitable for flexible pavement construction. The research showed a steady rise in the softening point of the modified bitumen, with increases of 16%, 21%, 23%, 27.5%, and 28.73% for crumb rubber contents of 5%, 10%, 15%, 20%, and 25%, respectively.
2. Accompanying this was an improvement in the thermal stability of the binder. The flash point increased by 8.10%, 14.86%, 18.24%, 22.97%, and 23.65%, while the fire point saw rises of 9.55%, 21.02%, 26.11%, 28.63%, and 29.93% at the same crumb rubber levels, showcasing better resistance to high temperatures.
3. A significant reduction in penetration values was noted as crumb rubber content rose, indicating the binder's increased hardness. The penetration

dropped by 13.92%, 24.06%, 32.72%, 41.35%, and 43.61%, suggesting a stiffer and more temperature-resistant binder—particularly advantageous for use in hot climates.

4. Ductility tests showed a marked decrease with rising crumb rubber levels, highlighting a potential trade-off in flexibility. The ductility diminished by 4.63%, 11.42%, 21.43%, 31.79%, and 37.50% with each increase. This reduction emphasizes the need to optimize crumb rubber content to ensure adequate elasticity and prevent early cracking due to temperature changes and traffic stresses.
5. Additionally, the introduction of glass powder significantly enhanced Marshall Stability thanks to its pozzolanic properties and angular particle shape, which improved bonding with the bitumen matrix. The best performance was achieved with 8–12% replacement by weight. Limestone powder also improved stability but led to lower values under the same conditions, as its finer and more inert properties limited its effectiveness.
6. While glass powder reduced the flow value—it indicated a stiffer mixture—too much could result in brittleness, negatively impacting flexibility. On the other hand, limestone powder offered a more balanced flow, enhancing workability while retaining sufficient deformation capacity. Consequently, limestone powder generally provides a better compromise in flexibility-flow dynamics.

In summary, these findings indicate that an optimal crumb rubber content of 10% to 15% by weight of bitumen, coupled with appropriate filler selection, can significantly boost the mechanical properties, thermal resistance, and sustainability of flexible pavement mixtures.

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