CHARACTERIZATION AND PERFORMANCE ANALYSIS OF CRUMB RUBBER MODIFIED BITUMEN

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ABSTRACT

The rising issues of temperature-induced rutting and seasonal waterlogging have a substantial impact on the longevity of flexible pavements in Bangladesh. At the same time, inappropriate waste tire disposal is becoming an increasingly serious environmental concern. This study investigates the dual benefits of performance increase and environmental sustainability via the modification of 60/70 grade bitumen with crumb rubber obtained from recycled tires. In light of this, 7% crumb rubber was blended with neat bitumen to create Crumb Rubber Modified Bitumen (CRMB). A complete set of laboratory experiments was carried out to assess the mechanical and physical properties of both conventional and modified binders. These comprised penetration, softening point, ductility etc. tests for binder characterization, as well as Marshall stability, flow, indirect tensile strength (ITS), retained Marshall stability, and tensile strength ratio (TSR) tests to assess mix performance. CRMB greatly improves high-temperature performance, with a 41% rise in softening point and reduced penetration, suggesting decreased temperature susceptibility. The Optimum Bitumen Content (OBC) of both neat and modified bitumen met Marshall requirements. The CRMB mix had 10.25% higher ITS, higher Retained Marshall, and TSR values, indicating enhanced moisture resistance, which is crucial in flood-prone areas. Aside from mechanical advantages, the use of scrap tires in bitumen modification addresses pressing environmental problems, providing a sustainable pavement solution that combines durability and waste management.

Keywords: *Rutting, CRMB, Sustainability , Marshall stability, Waste management*

1. INTRODUCTION

The processing and recycling of used tires has emerged as a major worldwide environmental concern, with around 1.5 billion tires nearing the end of their usable life each year.(Al-Kayiem et al., 2022; Mohajerani et al., 2020). The increasing expansion in vehicle ownership has hastened this trend, with forecasts estimating that up to 5 billion tires would be wasted yearly by 2030, with the great majority ending up in landfills or stockpiles (Grammelis et al., 2021). In Bangladesh, the situation is similarly serious, with around 150,000 tons of scrap tires generated yearly and remaining mostly unrecycled—posing major waste management and environmental risks (Ahmed et al., 2018). The majority of these scrapped tires are normally disposed of in landfills or stockpiles (Cholake et al., 2017; Mohammadinia et al., 2018), which provides just a short-term solution while causing a number of environmental and socioeconomic issues. Such disposal practices lead to land and water contamination, deplete substantial land resources, and exacerbate the acute issue of land limitation in areas with high density as the limited amount of landfill space is becoming more insufficient to accept the rising number of waste tires, resulting in major land-use pressures and waste-management inefficiency (Mmereki et al., 2019; Sienkiewicz et al., 2017; Xiao et al., 2018).

Furthermore, there are serious health and safety risks associated with tire accumulation in landfills or open dumps (Akbarimehr & Hosseini, 2022; Ferronato & Torretta, 2019). Excessive tire storage has been linked to unplanned fires during the sweltering summer months, which release harmful gasses and particulate matter that contaminate the air and seriously degrade the quality of the air(Dabic-Miletic et al., 2021). Furthermore, discarded tires are heavy—more than 75% of their volume is made up of vacant space—making landfilling unstable and ineffective. Under some circumstances, the trapped gases—mainly methane—in buried tires may cause them to explode or rise to the surface. Further aggravating the threats to public health, discarded tires exposed in the rain are suitable places to breed for mosquitoes and other infectious microorganisms.

In Bangladesh, flexible pavements account for nearly 90% of the road network, and their construction and upkeep require significant financial expenditure. However, these road surfaces are extremely sensitive to the country's harsh weather conditions. Extreme heat, intense rainfall from the monsoons, and high humidity hasten degradation, resulting in rutting, cracking, and general structural weakness (A.F.S. Ahad Rahman Khan & Nafisa Tabassum, 2025).These problems are exacerbated by high traffic volumes, changing weather patterns, and inadequate maintenance procedure(Saju et al., 2018). Furthermore, the recurring problem of waterlogging, which is especially prominent in low-lying and undeveloped areas, jeopardizes pavement performance since typical bituminous materials are susceptible to moisture-induced deterioration. As a result, asphalt pavements in Bangladesh frequently collapse prematurely due to temperature changes, water penetration, and increased traffic loads. This increasing concern emphasizes the critical need for environment friendly, longer-lasting, climate-resilient, and affordable pavement options to secure long-term road infrastructure across the country. One alternative is Crumb Rubber Modified Bitumen (CRMB), a hydrocarbon binder produced by the mechanical and chemical interaction of crumb rubber with bitumen.(Shen et al., 2017).

In order to address the pressing issues, this study explores the usage of CRMB via wet method in asphalt mix with an aim to compare the mechanical and Marshall properties of neat and modified bitumen and to investigate the performance of bituminous mixes in terms of water sensitivity.

2. LITERATURE REVIEW

Incorporating waste rubber into asphalt has long been studied, as early as the 1840s, natural rubber was added to asphalt to improve the durability of traditional pavement. McDonald invented the "Band-Aids" mending substance in the 1960s by combining discarded rubber in a binder. In the 1970s, slurry seal equipment was used to distribute rubberized binder over pavement surfaces, followed by chip spreaders to disseminate aggregate. McDonald enhanced the spreading method in the mid-1970s, introducing a wet approach for applying it to broader pavement surfaces rather than simply small patches. Since then, many researchers have showed interest to use crumb rubber as asphalt modifier. Numerous studies have been reviewed as summarized in Table 1.

Table 1: Summary of Reviewed Study

Study	**Method**	**CR Dosage**	**Findings**
(Neupane & Chandani, 2025)	Wet	6%,8%,10%, 12%, and 14% by weight of bitumen.	The optimum results are obtained with 8% Crumb Rubber, which increases stability by 17.16% and decreases binder dosage by 15.66%, making CR a viable alternative for pavement construction that is both inexpensive and ecologically friendly.
(A.F.S. Ahad Rahman Khan & Nafisa Tabassum, 2025)	Wet	4%, 8%, 12%, 16% by weight of bitumen)	The inclusion of 10% crumb rubber significantly improved binder properties, reducing penetration by 25%, lowering ductility by 50%, and increasing softening and fire points by 10–12.5%, thus enhancing stiffness and thermal resistance. The Marshall mix design with CRMB demonstrated a 25% increase in stability and a reduction of 0.6% in binder requirement, indicating higher performance and material efficiency. Rheological evaluations showed enhanced temperature susceptibility, elastic recovery, and fatigue resistance, making the modified mix suitable for the challenging conditions in Bangladesh. Moreover, the use of discarded tires in road construction addresses environmental concerns and supports the circular economy.
(Jaf, 2024)	Wet	10%,20% and 30% by weight of bitumen,	In comparison with conventional findings, 11.3% of crumb rubber content is the most efficient percentage for improving the stability and flow properties of the asphalt concrete mix. CR content was optimal, meeting the Asphalt Institutes guidelines and greatly improving the quality of the mixture in terms of its resistance to rutting and fatigue.
(Hawraa & Al-mosawe, 2023)	Wet	2%,4%,6%, and 8%. By weight of bitumen	This investigation demonstrates that introducing crumb rubber with asphalt mixtures improves mechanical and durability properties such as Marshall stability, flow, and resistance to rutting. It additionally improves asphalt binder characteristics including viscosity, ductility, and softening point. Due to VMA limitations, the researchers propose adding 4% crumb rubber to the 40/50 binder grade and 2% to the 50/60 binder grade. Both grades' moisture susceptibility improved. The study suggests that crumb rubber is a sustainable and economical alternative.
(Al-soudany et al., 2023)	Wet	6%.9%,12% and 15% by weight of bitumen	Marshall's stability improves as the crumb rubber component increases because the rubber particles support the asphaltic mixture, improving its resistance to deformation while also increasing elasticity and flexibility. For stability, 9% CR was found to be the optimal level. Furthermore, crumb rubber improves moisture resistance by resisting water, with 12% CR providing the highest tensile strength ratio (TSR) against moisture-related damage. Furthermore, increasing crumb rubber percentage enhances the mixture's resilience to permanent deformation or rutting, efficiently spreading applied loads and reducing rut development at high temperatures.
(Mbereyaho et al., 2021)	Wet	5%,10%,15% and 20% by weight of bitumen	The investigation found that when the percentage of rubber waste increased, penetration values for the 60/70 grade utilized bitumen decreased. The standard value was reached at 5% replacement. For the purpose of achieving the same grade, it was suggested that the replacement be restricted to 5% by weight of bitumen. There was a 5.3% decrease in bitumen costs compared to the estimated cost.
(Candra & Siswanto,	Wet	0.5%,1%,1.5%,3%,4.5%, and 6%	The ideal asphalt CRM mix includes 1% CRM motorcycle tire waste, according to Marshall qualities such as stability, flow, and

2020)	by weight of bitumen	Marshall quotient. Adding CRM from motorcycle tire waste improves the flow of asphalt concrete wearing course (ACWC) mix, but adding 1.5% and 3% to asphalt concrete base (ACB) decreases it. Adding more than 1.5% or 3% CRM of motorcycle tire waste to ACWC or ACB is not suggested as it does not meet the Marshall quotient specifications.

Studies indicate that, when combined with appropriate material selection and mixing procedures, CRMB may greatly improve pavement performance while also assisting with cost savings and waste recycling. With an emphasis on determining the optimum crumb rubber composition for flexible pavement applications in Bangladesh, this study aims to add to the existing literature by assessing the physical, mechanical and Marshall performance of CRMB using wet method.

3. METHODOLOGY

Crumb rubber has been utilized to modify asphalt mixes, mostly through two separate techniques. The "wet process" involves blending crumb rubber with hot bitumen to create a rubbery bituminous adhesive. The "dry process" adds course rubber particles to the asphalt blend as an aggregate. This study employed the wet method and composed of several stages: Collection and categorization of materials, OBC determination, Conduct experimental program (Marshall test, ITS test, Retained Marshall stability test). Initially, the materials were collected and their physical properties were determined. Then Crumb rubber was blended with bitumen and Marshall samples were prepared. After determining OBC, volumetric and Marshall properties of neat and modified bitumen samples were calculated. Finally, Water sensitivity analysis of both samples were done.

3.1 Materials

For this study, 60/70 grade bitumen was collected from Eastern Refinery, Chittagong. Coarse aggregate and fine aggregate was collected from a local quarry supplier. Aggregates were sieved through mechanical sieve shaker and those retained on 4.75mm sieve were collected as coarse aggregate. Similarly, sand retained on a 0.075mm sieve after passing through a 4.75mm sieve was utilized to produce the fine aggregate. In this study, soil was used as a filler material. Scrap tire was collected from a local tire recycle shop in Chittagong After collecting the materials, they were assessed through the physical property tests summarized in Table 1. Fig. 1 illustrates the aggregate gradation chart.

Table 2: Physical Property of Aggregate

Properties	**Coarse Aggregate**	**Fine Aggregate**
Specific Gravity	2.67	2.60
Los Angeles Abrasion Value	13 %	-
Aggregate Crushing Value	15 %	-
Aggregate Impact Value	9 %	-
Elongation Index	7 %	-
Flakiness Index	22%	-

3.2 Blending of Crumb Rubber and Preparation of Marshall Sample

A blending machine was used to mix bitumen with crumb rubber. Initially, bitumen of grades 60/70 was heated to pouring temperature in a gas stove. After that, the bitumen was mixed by manually for fifteen minutes with 7% crumb rubber. Following manual mixing, the mixture was put into the blending machine, heated to 170°C to 175°C, and continuously stirred for 40 to 45 minutes with a mechanical stirrer running at 2,000 rpm. Once the modified mixture cooled to room temperature, it was taken out of the mixing machine and stored in a sealed container.

After preparation of CRMB, 1100 grams of aggregate and filler material was heated to 160°C to 170°C. Bitumen is heated to temperatures between 140°C and 150°C. Initially, bitumen made about 4

% of the mineral aggregates' weight. The materials are completely mixed at 150°C to 160°C before being inserted in a preheated mould and crushed with 75 blows on each side using a rammer at 120°C to 130°C. Bitumen concentrations have been adjusted at intervals of 0.50%, ranging from 4% to 6.5%. In this investigation, 7% of the neat bitumen's total volume is combined with crumb rubber. For initial stage, 15 samples were prepared for both neat and modified sample. After calculating OBC, 3 more samples were prepared in each case to validate the OBC value.

3.3 Calculation of OBC

According to the required specification, the optimum binder content was established using the combined Marshall test results. Equation (1) and Equation (2) was used to the OBC using Marshall mix design method.

$$OBC = \frac{Bitumen\ content\ at\ (\max stability + \max bulk\ density + average\ air\ void)}{3} \quad (1)$$

Or,

$$OBC = \frac{Bitumen\ content\ at\ (max\ stability + max\ bulk\ density + average\ air\ void + 80\%\ VFA)}{4} \quad (2)$$

The OBC is determined as the lowest of the two values derived from the preceding formulae.

3.4 Indirect Tensile Strength (ITS) Test

Indirect tensile strength test helps to determine whether the bituminous mix is resistant to cracking under tensile stresses. To assess the tensile properties of bituminous mixes, the Marshall sample is loaded along a diametric plane with a compressive load at an even rate acting parallel to and along the specimen's vertical diametric plane through two opposing loading strips, in accordance with ASTM D 6931.For a 101mm diameter specimen, a 13mm (1/2") broad strip loading is employed to give a consistent loading that results in a nearly uniform stress distribution. 51 mm per minute of loading is used. Instead of compressive failure, the sample experiences tensile failure. Equation (3) yields the indirect tensile strength.

$$S_t = \frac{2000P}{\pi Dt} \quad (3)$$

Where,
S_t= Indirect Tensile Strength, kPa
P= Maximum load, N
t = Sample height before testing, mm
D = Diameter of the sample, mm

Moisture damage may be evaluated using tensile strength ratio analysis. After preparation, the specimens are separated into two groups. To create a conditioned set, specimens were kept in a 60°C water bath for 24 hours. In comparison, the unconditioned set spent two hours in a water bath at 25°C. The tensile strength ratio (TSR) is derived using equation (4).

$$TSR = \frac{ITS\ at\ 60°C\ for\ 24\ hours\ at\ water\ (Conditioned)}{ITS\ at\ 25°C\ for\ for\ 2\ hours\ at\ air\ (Unconditioned)} \quad (4)$$

3.5 Retained Marshall Stability Test

Marshall specimens' Retained Marshall Stability is assessed using ASTM D 1075 after a 24-hour curing time in a water bath heated to 60°C. Three samples must be preserved in a 60°C water bath for

24 hours, while the remaining three must be maintained at room temperature. Every mould should undergo standard stability tests, with the Marshall Stability and Flow findings averaged. Retained stability may be estimated using equation (5).

$$Retained\ Stability = \frac{Conditioned\ Sample\ Stability}{Unconditioned\ Sample\ Stability} \times 100\% \quad (5)$$

4. RESULTS AND DISCUSSION

4.1 Properties of Bitumen

The physical parameters of the 60/70 graded neat bitumen and CRMB have been assessed using the ASTM standard testing procedure. Table 3 provides a summary of the bitumen properties.

Table 3: Physical Property of Bitumen

Property	Test Standard	Neat Bitumen	7% CRMB
Specific Gravity (gm/cc)	ASTM D 70-97	1.04	1.037
Penetration (1/10th of mm)	ASTM D5/D5M-13	64	32.6
Softening Point (°C)	ASTM D 36-06	48.5	68.5
Ductility (cm)	ASTM D 113-17	100+	32.8
Flash Point (°C)	ASTM D 92-11	305	330
Fire Point (°C)	ASTM D 92-11	320	350
Loss on Heating (%)	ASTM D 2042-09	0.91	0

4.2 Marshall Test Result

In this investigation, Marshall tests are conducted in the laboratory for both neat bituminous sample and CRMB sample. In this case, the Marshall test are conducted for heavy volume road. Two types of analysis were done: Density-Void Analysis and Flow-Stability analysis.

Test results of Density-Void analysis and Stability-Flow analysis of Marshall mix design method for both sample are shown in fig. 1, fig.2, fig.3 and fig. 4, respectively.

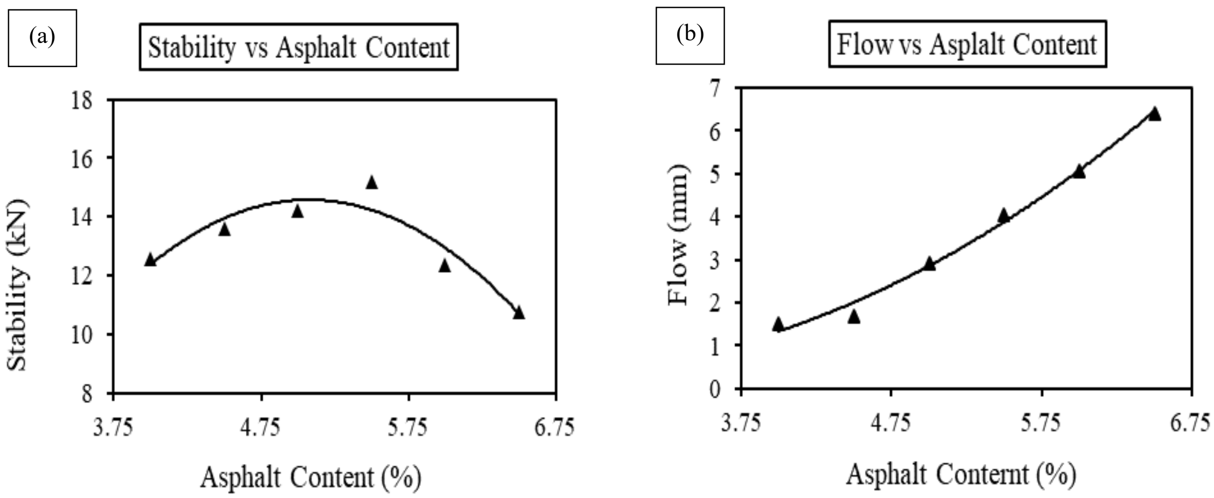

Figure 1: Stability-Flow Analysis of Neat Bituminous Sample

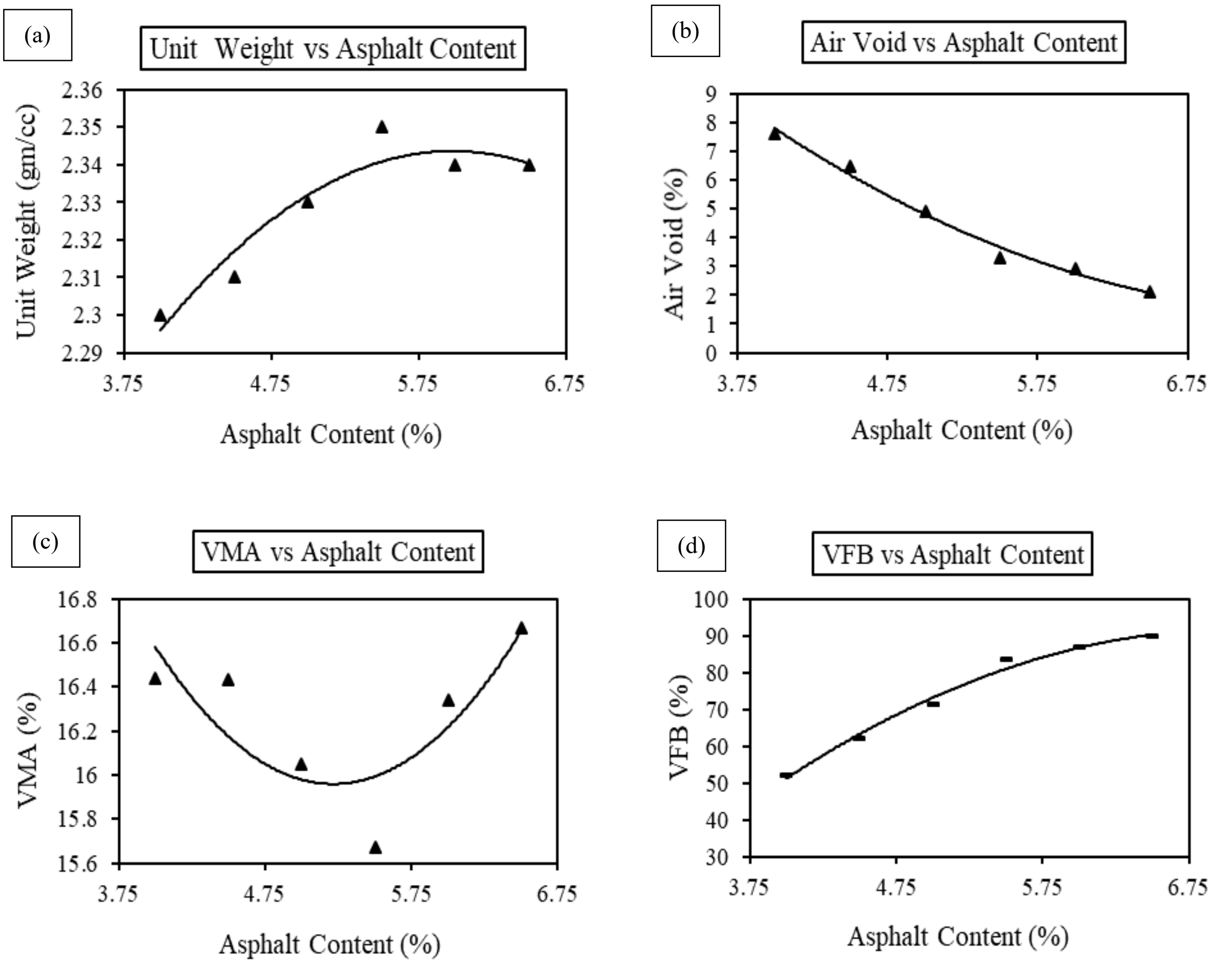

Figure 2: Density-Void Analysis of Neat Bituminous Sample

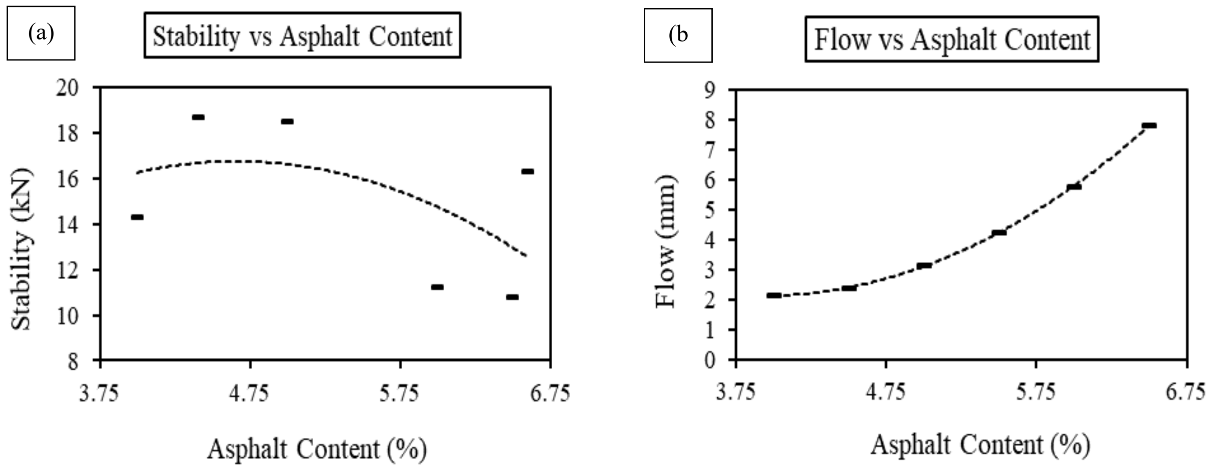

Figure 3: Stability-Flow Analysis of CRMB

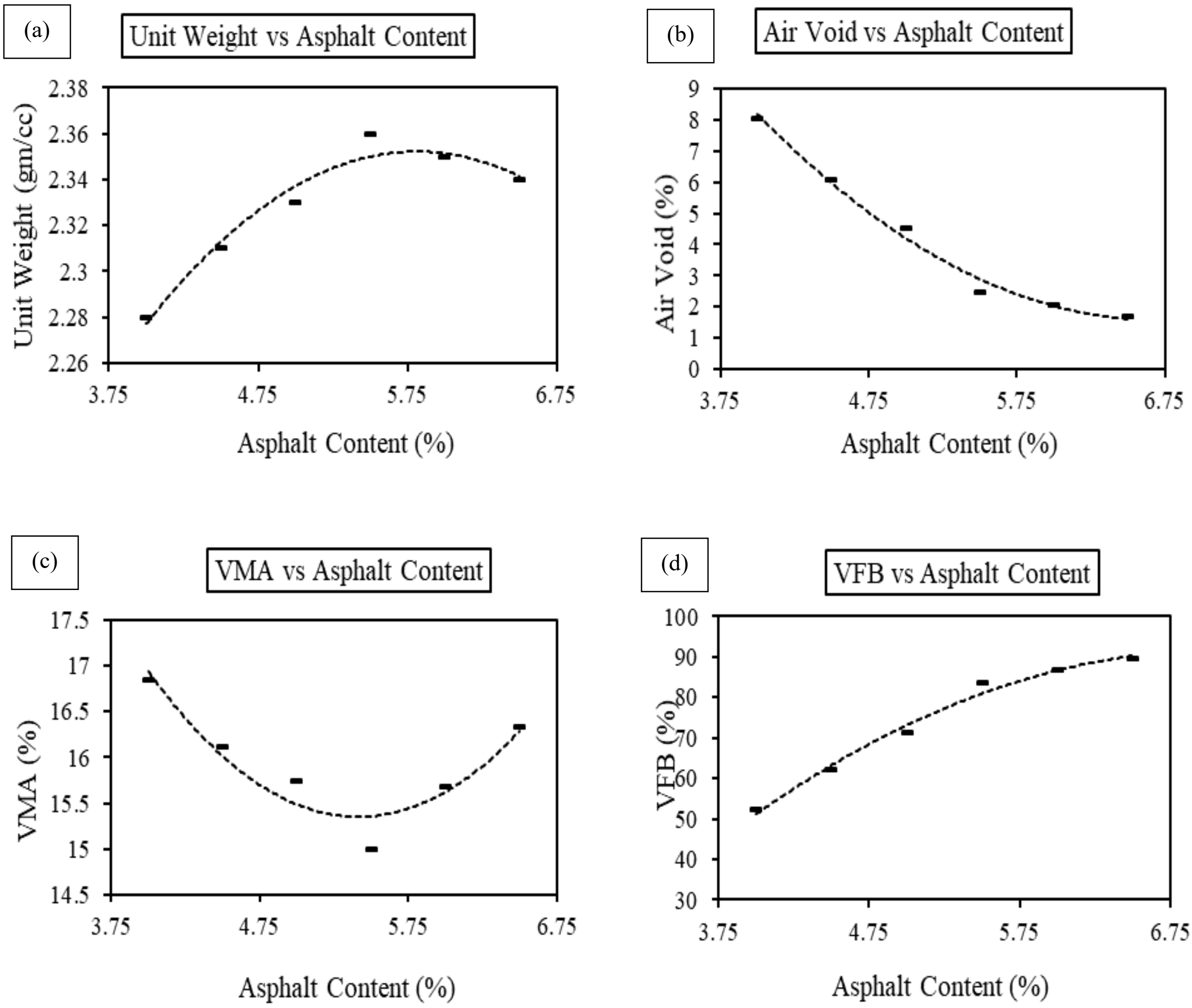

Figure 4: Density-Void Analysis of CRMB

Table 4 summarizes the result of Marshall test at OBC.

Table 4: Marshall Test Result

Marshall Sample	RHD Specification 2017 (Heavy Volume Road)	Neat Bitumen (From Graph)	Obtained Value at OBC	CRMB (From Graph)	Obtained Value at OBC
		OBC = 5.24%	OBC = 5.24%	OBC = 5.15%	OBC = 5.15%
Marshall Stability (KN)	>8	13.72	13.18	17.2	18.1
Marshall Flow (mm)	2-4	3.41	3.36	3.33	3.20
Bulk Density (gm/cc)	-	2.335	2.35	2.34	2.36
Air Voids (%)	3-5	4.05	4.6	3.9	4.02
VFB (%)	65-80	72.4	74.02	76	74.8
VMA (%)	15-20	15.9	14.14	15.4	16.92

4.3 ITS Test

Table 5 shows the comparative result of ITS test between neat bituminous sample and CRMB sample,

Table 5: ITS Test Result

Bituminous Sample	ITS Conditioned (KPa)	Avg. Conditioned ITS (KPa)	ITS Unconditioned (KPa)	Avg. Unconditioned ITS (KPa)	TSR	Standard Value (%) (ASTM D 6931)
Neat Bitumen	687	681.33	592	606.67	0.89	≥0.80
	659		620			
	698		608			
7% CRMB	706	727	675	676	0.93	
	714		670			
	763		683			

4.4 Retained stability Test Result

Retained Marshall stability test result of neat bituminous sample and 7% CRMB sample is illustrated in Table 6.

Table 6: Retained Stability Test Result

Bituminous Sample	Unconditioned Stability (KN)	Avg. Unconditioned Stability (KN)	Conditioned Stability (KN)	Avg. Conditioned Stability (KN)	Retained Stability (%)	Standard Value (%) (ASTM D 1075)
Neat Bitumen	13.75	13.88	11.91	11.94	86.03	≥75
	13.88		12.04			
	14.02		11.87			
CRMB	17.47	17.62	15.23	16.04	91.03	
	18.25		15.94			
	17.18		16.46			

Physical property test result of bitumen shows increase of penetration value for the neat bitumen. CRMB shows the penetration value of 32.6, while it is double for the neat bitumen, valuing sharp 64. In terms of softening point, CRMB shows 29% higher softening point value compared to 60/70 graded neat bitumen.Based on the results, the inclusion of 7% crumn rubber significantly improves the high-temperatureperformance of neat bitumen at the expense of some low-temperature elasticity. It indicates that CRMB possess more suitability in temperature rising issue. CRMB shows higher flash point and fire point value than neat bitumen, demonstrating improved safety during production and handling. CRMB also suggests improved resistance to aging, evidenced by lower elimination of mass upon heating.

At their respective optimum binder contents (5.24% FOR neat and 5.15% for CRMB), the Marshall stability result shows increase for CRMB, resulting 17.2 Kn, while for neat bitumen it is 13.72 Kn. Higher stablity value of CRMB indicates that compared to neat bituminous mix , CRMB mix can carry and sustain higher traffic load. CRMB also showed better performance in terms of Marshall flow and dry density value underescoring less possibility of oxidation and moisture absorption. From ITS test result, both unconditioned and conditioned sample of CRMB showed higher test value compared to that of neat bituminous sample. In terms of uncondioned sample, CRMB showed 10.25% greater ITS value, while it is 6.28% higher for conditioned sample. It implies that CRMB possess greater resistance to rutting and temperature cracking due to low temperature. Moreover, CR modified roads are more resistant to tensile strength decrease from water contact as its TSR value is 4% higher than conventional bituminous road. Retained Marshall stability test was conducted with a view to measuring the resistance of bituminous sample to moisture damage. CRBM showed 5% higher value than neat sample, indicating lower susceptibility to moisture induced damage. Results indicate that crumb rubber modified roads can retain more strength when exposed to water or in waterlogging condition.

5. CONCLUSIONS

The results reveal the following implications of the 7% crumb rubber content on the general behavioural characteristics of the pavement material, along with improvement in the Marshall properties. The rubber-modified binder introduces greater cohesion, strength, and flexibility, which enables the material to withstand high traffic as well as adverse hydrological factors, along with their interactive contribution to stability, tensile strength, and moisture resistance. Importantly, the CRMB mixture demonstrated high retained stability and TSR values, particularly under periodic instances of waterlogging in Bangladesh, signifying the excellent potential of the technology in reducing early-stage pavement failure, which is considered one of the core drawbacks of conventional bituminous pavement. The addition of crumb rubber promotes a sustainable performance paradigm for flexible pavement, as evident by the achieved balance of flexibility and stiffness, along with improved thermos resistance. This technology introduces superior technical benefits along with support in overcoming the sustainability challenges of environments by converting highly valuable recyclable material into superior transportation applications. Hence, the CRMB is considered a paradigm shift towards robust and sustainable construction practices for roads, along with improving pavement strength.

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DECLARATION OF USE OF AI

The authors used AI tools partly to check for grammatical errors and to assist in writing the manuscript.

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