EXPERIMENTAL STUDY ON THE BEHAVIOR OF BITUMINOUS MIX PAVEMENT BY UTILIZING THE CRUMB RUBBER (CRMB-60) WITH VARIOUS WEIGHT CONCENTRATION

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ABSTRACT

Sustainable infrastructure planning is essential for creating adaptable built environments, particularly in road construction where natural resource availability is a critical concern. This study emphasizes the use of waste rubber, specifically Crumb Rubber Modified Bitumen (CRMB-60), as a sustainable solution in highway construction to reduce environmental pollution and dependency on raw materials. The study's first priority was on assessing the aggregates and bitumen for their physical and other engineering qualities. By incorporating waste rubber into bitumen, the research aims to enhance the performance and longevity of pavements. Six specimens (CN45, CN50, CN55, CN57, CN60, and CN65) with varying CRMB concentrations (4.5% to 6.5%) were tested using the Marshall method to determine the optimal mix for road pavement. The study found that stability increased with CRMB concentration up to 5.7%, with the CN57 specimen showing the highest stability at 1618.57 kgs. Beyond 5.7%, stability decreased, with the CN45 specimen, containing 4.5% CRMB, exhibiting the lowest stability at 1370.41 kgs.

Keywords: Crumb rubber modified bitumen (CRMB), Bituminous mixture, Flexible pavement; Stability; Marshall method.

INTRODUCTION

Many advances have been achieved in the fields of science and technology since the new century began. One cost of these innovations is the acceleration of global warming, which is causing severe changes to the climate. One has to be more adaptable or adept at addressing problems in order to function well and efficiently in these kinds of settings [1]. Therefore, it is a key strategy to create sustainability and resilient built environment by means of sustainable infrastructure development and eco-friendly construction materials to withstand extreme weather. One of the neglected subjects in the field of road construction is their dependency on natural resources [2]. The road network in India has grown throughout the years, and it is now the world's second-longest, behind only the United States. The road building project relies heavily on raw materials, in addition to financial resources [3]. To keep costs down and resource consumption to a minimum, it is essential to build and maintain roads using a tried-and-true method. Recycled aggregates may partly or entirely replace natural aggregates, which are produced in large quantities by the building industry [4]. Reducing waste, conserving energy, and helping to build a more sustainable road system are all benefits of recycling. An important step towards sustainable growth in the transportation sector and better waste management is the use of recycled

aggregates in road building. Flexible pavements have historically relied on crushed stone and gravel, both of which are naturally occurring materials, for their foundation and subbase components [5].
Contrast this with the sidewalk; it is the portion of the road that conducts traffic and is constructed of a series of layers of material laid over the subgrade, the underlying natural layer. To prevent the vehicle loads from being too great for the subgrade, the pavement layers distribute them [6]. The engineer constructing the road has the difficult task of ensuring the pavement will remain functional for the whole duration of its design life by choosing the appropriate material and layer thicknesses. It is common practice to talk about the amount of cars that can be supported by road pavement while assessing its strength [7]. The next phase is to establish the construction specifications once determined the road paving's needs in terms of traffic support and the desired lifespan. Pavement type, whether rigid or flexible, is an important design consideration alongside materials and layer thickness [8].
Rigid pavement, which often has one layer, and flexible pavement, which usually has numerous layers, are the two most common road surfaces and pavement building processes. Asphalt and concrete are common materials for pavements. Other than that, there are a variety of materials used to pave roads, such as synthetic stone, flagstone, cobblestone, bricks, tiles, or even wood [9].
Asphalt mixes and other bituminous materials are some of the first examples of man-made engineered materials. The first worldwide use of bituminous binders in road paving technology was by the Romans, who used them as binding and waterproofing materials and subsequently built roads throughout their empire [10]. As the primary binder of bituminous pavements, bitumen is crucial to their development and reinforcement. The amount of bituminous binder needed to coat the filler and aggregates, make the mixture easy to work with during mixing, laying, and compacting, and increase the mixture's flexibility under traffic loads and durability throughout its estimated lifespan should all be considered [11], [12].
Every year, more than 1.5 billion tyres hit their expiration date throughout the globe, making waste tyre management and recycling an urgent issue for the planet's ecosystems. More and more people are buying cars, which means there will be more and more used tyres. By 2030, experts predict that five billion tyres will be thrown away every year, with the majority of them ending up in landfills [13]. Among the options are disposal of waste tyres, namely landfilling, burning, use as fuel, pyrolysis, and production of carbon black. Even though burning tyres is the simplest and the cheapest way of getting rid of them, it has important drawbacks including the emission of toxic smoke and the uncontrolled release of toxic substances [14]. To avoid any environmental hazards connected with the stockpiling of waste tyres, most of the countries have been recycling the scrap tyres and producing them as Crumb Rubber (CR) or granulate [15]. Along these lines, there occurred a great curiosity about the alternative ways of utilizing worn-out tires as construction materials in the context of the development of more sustainable and longer-lasting built infrastructures, and the field of flexible pavements is seen as one of the applications that would benefit from that [16].

LITERATURE REVIEW

(B et al., 2023) [9] added substance in hot mixes 0%, 2%, 4%, 6%, 8%, 10%, 12% concentrations of waste rubber by the weight of bitumen. Similar research is continuing to be done in bituminous pavement utilising waste rubber tyre at varying ratios as a percentage of the bitumen. The objectives of this study are to find a successful practice by using the rubber waste that can reduce costs, provide environmental benefits, and exhibit even better physical characteristics rather than the asphalt had by the tests scheduled. The findings are that optimal bituminous pavement with 10% of rubber.
(Khaleel et al., 2023) [2] examine the bitumen's engineering properties are affected by adding recycled rubber and plastic. Specifically, the study looks at the effects of mixing 4% and 6% recycled tyre rubber

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and 4% and 6% recycled polyethylene terephthalate (PET) with 85/100 grade bitumen. The findings indicate that the penetration of bitumen decreased by 9% when 6% waste tire rubber and PET were added, in comparison to the 4% combination of both waste materials. Not only that, bitumen treated with tyre rubber had higher viscosity and "softening points" (79 °C, 2580 s) than both regular bitumen (48 °C, 1800 s) and bitumen modified with PET (53 °C, 2150 s). The differences that have been seen indicate that bitumen's engineering properties are improved when used with recycled PET and tyre rubber
(G. Singh & Chauhan, 2020) [1] use of waste materials, such as plastic and rubber tires, is being promoted more and more in flexible pavement construction. Marshall Stability test was used to evaluate samples that were partially replaced with bitumen using "waste plastic" (3%, 5%, 7%, 9%, and 11%) and "crumb rubber" (4%, 8%, 12%, 16%, and 20%). Crumb rubber provides satisfactory results by using it to substitute bitumen for various bitumen & bitumen mix tests in 12 %of the proportion. Waste plastic provides satisfactory results by using it to substitute bitumen for various bitumen & bitumen mix tests in 7 %of the proportion.
(Issa, 2020) [7] Examine that rubber is included into bitumen at four distinct proportions: 5%, 10%, 15%, and 20%. It is recommended to do the marshal test and the ductility test with bitumen percentages of 4%, 4.5%, 5%, 5.5%, and 6%. This research used a variety of experimental ratios—95 percent bitumen to 5 percent rubber, 90 percent bitumen to 10 percent rubber, 85 percent bitumen to 15 percent rubber, and 80 percent bitumen to 20 percent rubber—to investigate the optimal asphalt and rubber mixtures. According to the findings, 10% and 15% of the rubber meet the specified requirements.
(Wulandari & Tjandra, 2017) [16] Examine the results of employing 40 and 80 crumb rubber sizes as well as 1 and 2 percent of crumb rubber by weight of asphalt mixture respectively. Asphalt concrete mixtures that had been altered and those that had not were compared in terms of their volumetric characteristics and Marshall Stability value. It is advised to include crumb rubber as an ingredient in asphalt mixtures since the test results satisfy the required standards. The quality and strength of the asphalt mixture were consistently improved by adding crumb rubber.

The Reduce Reuse Recycle mentality which reduces waste and encourages resource efficiency is the best way to achieve sustainability. This strategy is essential for sustainability in the building industry when it comes to managing the disposal of waste rubber that cannot be composted. In order to increase stability and durability this study repurposes waste rubber in pavement construction by mixing natural aggregates with Crumb Rubber Modified Bitumen (CRMB-60). Through the use of recycled materials the study promotes the development of sustainable structures and emphasizes the need to increase public awareness of the harmful environmental effects of improper waste rubber management. The creation of environmentally friendly building methods and the reduction of negative environmental effects depend on such initiatives. The primary objective of this project is to investigate the viability of recycling waste materials in construction with CRMB-60 (crumb rubber modified bitumen). Look at how different CRMB-60 concentrations affect bituminous mix pavements flow specific gravity and stability. Examine bituminous mix pavement properties for various densities and concentrations of CRMB-60.

MATERIAL AND METHODOLOGY

Crumb Rubber Modified Bitumen

Bitumen that has been enhanced by the addition of crumb rubber (waste rubber typically from old tires) is known as Crumb Rubber Modified Bitumen (CRMB). By adding ground rubber bitumens elasticity age resistance and overall durability are all increased. CRMB is frequently used when constructing new roads to produce pavement that is more resilient in areas that see extreme weather or heavy traffic. It improves the flexibility of the pavement, making it less prone to cracking and rutting. In this research, CRMB-60 bitumen was used; it is a grade that is specifically designed for warm regions; it is a combination of bitumen and crumb rubber that increases the bitumen's elasticity and softening point, creating a material that is more resistant to high temperatures. The road surface is therefore less likely to be damaged by rutting and heat. Obtaining CRMB-60 binders was done by "M/S Tina Rubber & Infrastructure Ltd". Which, before to being included in bituminous mixes, were first tested for physical properties in accordance with criteria stated in code IS:17079-2019, IS:1208-1979, IS:1202-1980, and IS:1209 - 1978 for CRMB-60. Table 1 summarises the findings of several physical property testing. In accordance with the requirements of IS:17079-2019, IS:1208-1979, IS:1202-1980, and IS:1209 - 1978, it was noted that all of the metrics for CRMB-60 bitumen fell within the stipulated ranges.

Aggregates

In the current research, natural aggregates (NA) were carefully chosen and submitted to a variety of physical property tests in accordance with the requirements defined by the "Ministry of Road Transport and Highways (MoRTH)", "Government of India", as stated in the 2013 guidelines. These experiments were conducted to confirm that the materials fulfilled the necessary performance requirements and to assess the suitability of the natural aggregates for use in the construction of roads. Every physical characteristic of the natural aggregates as shown by the test results and shown in Table 2 is found to be within the permitted bounds set by MoRTH. The aggregates were found to have an adequate specific gravity indicating that they possessed the necessary density and strength to function well under the load conditions commonly observed in road pavements. Other metrics that evaluate the aggregates toughness and resistance to wear were also discovered to be below the MoRTH maximum limits. This demonstrates the aggregates great durability and their ability to withstand the structural stresses brought on by vehicle activity without suffering significant deterioration.

Table 1 Physical properties of CRMB-60 bitumen

Test name	Code of practice	Test result	Minimum requirement as IS17079;2019
Penetration	IS 17079-2019	42.33 mm	50-70mm
Softening point	IS 17079-2019	64.50 °C	Min. 60 °C
Ductility	IS:1208-1979	102 mm	Min. 75 mm
Specific gravity	IS:1202-1980	1.020 gm/cc	Min. 0.99-1.02 gm/cc
Flash point	IS: 1209 – 1978	241.00°C	Min 220°C

Antistripping agent

"Wetbond-S" is an anti-stripping additive for asphalt that is based on next-generation nanotechnology and silicon. For use in Hot-mix and Warm-mix road projects, this product is an exceptionally thermally resistant addition that requires a minimal dosage. This product is ideal for aggregates with a high and difficult-to-manage stripping profile. "Wetbond-S" has a distinct citrous smell and is a brownish-clear liquid at room temperature. While polar and hydrocarbon solvents mix well with this product, water does not. During the regular course of Hot-mix and Warm-mix pavement constructions, this product remains thermally stable in hot bitumen (at 160°C) for more than 15 days without the need for extra dosage addition or modification. This guarantees the pavement will last for a long time without sacrificing the quality of the job. Use this material to make industrial bituminous coatings, hot-mix pavements, warm-mix pavements, and refinery-treated non-stripping bitumen.

Table 2 Physical properties of Natural aggregate

Test name	Code of practice	Test result	Recommended value as per MoRTH, 2013
Aggregate impact value (%)	IS 2386 (Part-4)	12%	Max. 24%
Aggregate abrasion value (%)	IS 2386 (Part-4)	25.5 %	Max 30%
Combined flakiness and elongation index (%)	IS: 2386 (Part-1)	22 %	Max. 35 %
Water absorption (%)	IS: 2386 (Part-3)	0.25 %	Max. 2 %
Specific gravity	IS: 2386 (Part 3)	C.A.- 2.72 F.A. – 2.76	2.5 – 3.0

Mixing process for the bitumen mix pavement

The mixing process for manufacturing a bitumen mix pavement using Crumb Rubber Modified Bitumen (CRMB), aggregate, and Wetbond-S antistripping agent involves several key steps to ensure a uniform and durable pavement mixture. Below is a detailed description of the process:

1. **Preparation of Materials**

CRMB is prepared by blending crumb rubber (recycled rubber particles from tires) with bitumen at elevated temperatures. This modification process enhances the elasticity and durability of the bitumen. The aggregates are selected based on their size, shape, and gradation as per the specifications required for the pavement layer. These include coarse aggregates, fine aggregates. Wetbond-S is an additive used to strengthen the stickiness between the bitumen and the aggregate, minimising the danger of stripping (loss of bond caused by water penetration).

2. **Heating of Materials**

To eliminate any moisture content, the chosen aggregates are heated in a drier. In order to make sure the aggregates are dry and capable of effectively binding with the bitumen, they are usually warmed to a temperature of 150°C to 170°C. In another tank, the CRMB gets heated simultaneously to a temperature between 160°C and 180°C. This assures you that the bitumen will be liquid and easy to combine with the aggregates.

3. **Mixing Process**

Hot aggregates are first sent to a pugmill or mixing drum where small amounts of Crumb Rubber Modified Bitumen (CRMB) are continuously mixed. Between 4.5 and 6.5 percent of the total bitumen composition is usually composed of the CRMB. Accumulators and CRMB must be thoroughly mixed to ensure that all aggregate particles are coated equally with bitumen resulting in a homogenous mixture. Wetbond-S antistripping chemical is added after the aggregates and CRMB have been thoroughly combined. The recommended amount of Wetbond-S is usually 0.05% by weight of the total bitumen composition as instructed by the manufacturer. Wetbond-S agent is then added to the bitumen-aggregate mixture and stirred one more time to ensure that it is evenly distributed throughout. To ensure that the binder adheres to the aggregate surface sufficiently and strengthens the pavements resistance to moisture this final mixing step is essential.

4. **Quality Control**

As the bitumen mix is being mixed samples are taken to monitor properties like consistency temperature and particle coating. Any necessary adjustments are made to guarantee that the combination satisfies the stated specifications.

5. **Laying and Compaction**

The bitumen mix laid on mold or die. The mixture spread evenly and compacted to achieve the desired pavement thickness and density. Proper compaction is essential to minimize air voids and ensure long-term pavement performance.

6. **Final Inspection and test**

Pavement is inspected for flaws such as uneven surfaces or improper compaction after it has been laid and compacted. The pavement is given time to cure and dry out before being put through a number of tests including the Marshall and specific gravity tests.

By using this method the bitumen mix pavement is guaranteed to be durable impervious to damage from water and able to withstand the demands of heavy traffic over time.

Table 3 Details of bituminous mix combinations with CRMB-60

Sr. No.	Nomenclature of sample	Proportion of CRMB-60 (%)	Proportion of aggregate (%)
1	CN45	4.50	95.50
2	CN50	5.00	95.00
3	CN55	5.50	94.50
4	CN60	6.00	94.00
5	CN65	6.50	93.50
6	CN57	5.70	94.30

Sample preparation and optimal bitumen content

The bituminous concrete grade-II (BC-II) mixture was adopted in this research. Table 3 details bituminous mix compositions with bitumen that is CRMB-60. To determine the optimal binder content (OBCs) for different mix configurations the Marshall mix design approach was applied. For every experimental bitumen content three Marshall samples were created in compliance with ASTM D2041 guidelines. Six distinct aggregate and CRMB-55 bitumen mix combinations with varied pavement heights were examined in this study. Create three distinct height copies of every specimen used in this study. In addition to ensuring that other volumetric characteristics were met the optimum bitumen content (OBC) was determined using the criteria of greatest Marshall stability and unit weight.

Marshall Test Methods

In particular Crumb Rubber Modified Bitumen (CRMB) mixes are developed and analyzed using the Marshall Method a standard procedure that is utilized when building pavements. This method looks at the mixs stability durability and deformation resistance in addition to helping determine the ideal bitumen concentration. In order to make sure the mix meets the required performance standards the Marshall Method analyzes the mixs mechanical and volumetric properties through a series of tests. The aggregate structures internal friction primarily determines the Marshall Stability value which expresses the resistance to continuous deformation. The term Marshall flow describes the specimens total vertical plastic deformation. The test may also determine the amount of air and void in the mineral aggregate by comparing the specimens masses and theoretical specific gravities. The Marshall apparatus, in accordance with ASTM D2041 standards, was used to evaluate bituminous samples.

RESULT AND DISCUSSION

In this section discussed the result, which get from the conducted test under the Marshall method in each specimen. In this study, manufacture the 3 prototype of each specimen, which is having a different height. Describe the all test result below.

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Figure 1 CRMB-60 mix pavement specimen with various height

Bulk density test

To determine the density of bitumen mix pavement specimens, the mass and volume of each specimen must first be evaluated under three different conditions: in air (normal surroundings), submerged in water, and in a saturated surface dry state in air. In this study, six specimens were tested to identify the optimal bitumen content for CRMB mix pavement. The mass of each specimen was measured in these three states to accurately assess their density. The results, as shown in Table 4, indicate a distinct trend: the mass of the specimens in air decreases as the percentage of "Crumb Rubber Modified Bitumen (CRMB)" rises, while their density increases. It would seem from this that the addition of CRMB causes the total weight of the mixed material to decrease. This is probably because crumb rubber is lighter than other aggregates. Yet the higher density of the CRMB mix implies that it is denser and perhaps more resilient to deformation which is a crucial component for the longevity and toughness of the pavement. The relationship between CRMB concentration and these physical properties is necessary to optimize the blend for better performance in pavement applications.

Table 4 Mass and volume of the sample with various height

Sr. No.	Sample	Height of specimen (mm)	Mass, (Grams)			Volume in (cc)	Density (g/cc)
			in Air	in water	Sat. Surface dry in Air		
1	CN45	63.80	1250.00	736.00	1255.00	519.00	2.408
		63.50	1255.00	740.00	1262.00	522.00	2.404
		63.90	1256.00	740.00	1261.00	521.00	2.411
2	CN50	63.40	1252.00	742.00	1257.00	515.00	2.431
		63.20	1254.00	743.00	1258.00	515.00	2.435
		63.50	1253.00	743.00	1258.00	515.00	2.433
3	CN55	63.10	1255.00	747.00	1259.00	512.00	2.451
		62.90	1254.00	745.00	1257.00	512.00	2.449
		63.20	1259.00	749.00	1263.00	514.00	2.449
4	CN57	63.10	1240.00	737.50	1244.00	506.50	2.448
		63.00	1238.00	738.00	1243.00	505.00	2.451

		63.20	1242.00	740.00	1247.00	507.00	2.450
		62.90	1241.00	738.00	1245.00	507.00	2.448
		63.10	1243.00	739.50	1247.00	507.50	2.449
		63.30	1246.00	742.00	1250.00	508.00	2.453
5	CN60	62.80	1248.00	741.00	1252.00	511.00	2.442
		62.60	1245.00	739.00	1249.00	510.00	2.441
		62.70	1246.00	738.50	1249.00	510.50	2.441
6	CN65	62.60	1244.00	733.00	1247.00	514.00	2.420
		62.70	1242.00	732.00	1245.00	513.00	2.421
		62.50	1245.00	733.60	1248.00	514.40	2.420

Specific gravity test

To comprehend the materials density compaction and general quality it is imperative to examine the specific gravity of Crumb Rubber Modified Bitumen (CRMB) mix pavement. Specific gravity or the ratio of the CRMB mixs density to that of water provides important information about the mixs composition and how well it should perform in real-world pavement applications. In order to ensure that the grade and quantity of aggregate are ideal for producing the desired pavement properties engineers can verify the mix design by analyzing specific gravity. Additionally the specific gravity of the pavement which is remarkably effective in its capacity to endure a variety of environmental conditions and traffic burdens predicts the pavements durability over time**.**

This study which looked at six specimens with varying CRMB quantities (4. 5%, 5% , 5.5% , 5.7%, 6% , and 6.5%) demonstrated a clear correlation between the specific gravity and CRMB content. As the quantity of CRMB increased the concretes specific gravity dropped. Table 5 shows this trend. It shows that the specimen with the highest percentage of CRMB (CN65) had the lowest specific gravity of 2.482 while the specimen with the lowest concentration of CRMB (CN45) had the maximum specific gravity of 2.6. As the amount of CRMB in the mix increases the specific gravity decreases suggesting that while CRMB enhances some desirable qualities like flexibility and durability it also lowers the mixs overall density. To achieve the ideal balance between material efficiency durability and strength it is critical to understand this trade-off when optimizing CRMB mix pavements.

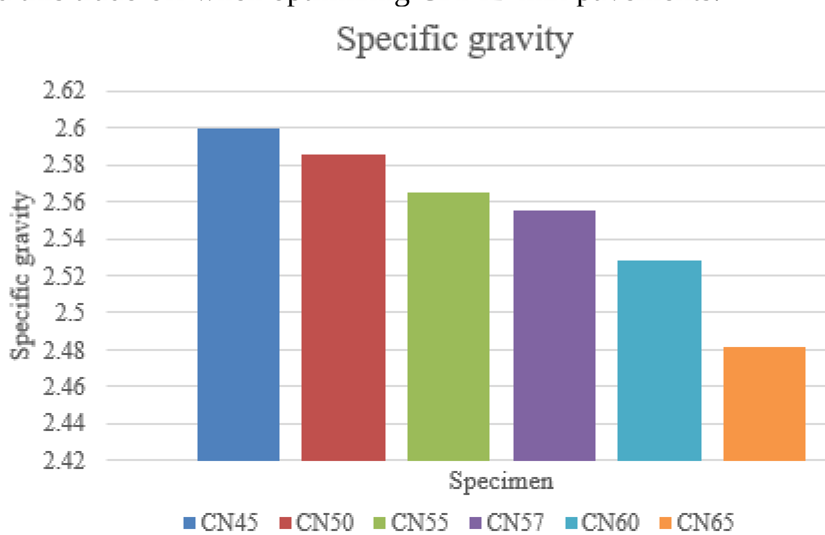

Figure 2 Specific gravity of all six specimen

Air void test

In order to promote bitumen growth and ensure the longevity of the pavement a bitumen mix pavement must have an adequate amount of air voids. When air voids are maintained properly they can avoid issues like rutting which happens when there arent enough voids or fractures which happen when there are too many. By keeping the balance of air spaces the pavements durability and structural integrity must be preserved over time. There is a strong correlation between the percentage of Crumb Rubber Modified Bitumen in this study and the air void content of the pavement. As the amount of CRMB increases the air voids in the pavement decrease as shown in Table 5. The samples that showed the highest average air void amount 7.39 percent were those with the lowest CRMB percentage (CN45) and the samples with the highest percentage (CN65) the lowest average air void amount 2.48 percent. This trend implies that a denser more compact blend with fewer air cavities is the result of higher CRMB concentrations. Durability and deformation resistance are two qualities that can be enhanced by this increased density. To guarantee that there are adequate air voids to avert possible problems like bitumen expansion-induced distress however meticulous attention must be paid to this aspect of mix design. Achieving the right air cavity equilibrium is necessary to maximize the lifespan and performance of CRMB mix pavements.

Voids in Mineral Aggregate (VMA) Test

The VMA which ensures that the aggregate structure has enough room to accommodate the binder is a crucial parameter in the design of asphalt mixes. A larger VMA usually results in a mix that is more workable and durable because it allows enough binder to fill the cavities strengthening the pavements resistance to deformation and environmental damage.

The connection within the amount of CRMB and VMA was carefully investigated in this study. The findings, as illustrated in Table 5, demonstrate a unique pattern: a reduction in VMA is observed as the CRMB concentration increases to 5.5%, suggesting a more compressed aggregate structure with a smaller area for the binder. To be more precise, the sample with a CRMB amount of 5.5% (CN55) showed the lowest VMA of15.75%. The implication is that the blend has become denser up to this point, which could potentially enhance stability but also pose a danger of insufficient binder accommodation.

Nevertheless, the VMA again increases when the CRMB content surpasses 5.5%. VMA of 17.65% was recorded in the sample with a 6.5% CRMB content (CN65), which was the maximum. The increased VMA at higher CRMB levels suggests that the blend is regaining some of its internal vacant space, which could conceivably enhance workability and facilitate improved binder distribution. While lower CRMB concentrations can result in a denser, more stable blend, larger amounts assist in combining stability with the necessary vacant space for adequate binder accommodation, thereby improving the durability and workability of the pavement. This is supported by the noted trend.

Voids Filled with Asphalt test

The percentage of aggregate cavities filled with bitumen is indicated by the voids Filled with Asphalt (VFA) parameter, which is a crucial parameter in the design of asphalt mixes. A suitable VFA must be used to fill the cavities in the aggregate structure to the required extent in order to improve the overall durability of the pavement and give the mix resistance to moisture penetration. A higher VFA which is generally associated with improved moisture resistance and longer-term performance lessens the chance that water will seep through and compromise the pavement structure.

Table 5 shows that the VFA rises as the percentage of CRMB rises. This analysis reveals a clear pattern. Specifically the mix's resistance to moisture and other environmental variables is improved as the CRMB concentration increases as a result of the increased filling of the aggregate cavities with bitumen. The specimen with the highest concentration of CRMB (CN65) had VFA values of 85.91 percent. This indicates that bitumen occupies almost all of the aggregate structures cavities giving the pavement remarkable resistance to moisture damage.

With a VFA of 54.69 percent the sample with the lowest CRMB concentration (CN45) on the other hand had the lowest VFA value. It is possible that this mixs overall durability and resistance to moisture infiltration will be compromised due to the lower value which indicates that the aggregate cavities are not as fully filled with bitumen. A developing pattern of VFA with higher CRMB concentrations highlights the effectiveness of CRMB in enhancing the bitumens ability to fill aggregate cavities strengthening the pavements defense against moisture-related damage and extending its lifespan.

Stability test

A Crumb Rubber Modified Bitumen mixs utmost burden that can be sustained before failure is determined by the Marshall stability test. This process involves placing the compact specimen inside a Marshall testing apparatus and applying compressive stress to it continuously at a rate of 50.8 mm per minute until it breaks. When evaluating whether a mix is suitable for paving one of the most important factors is how stable the specimen is. This stability determines how well the specimen can withstand deformation under traffic loading.

After the concentration of CRMB reached 5.7% of the total bitumen in this study it was observed that the stability of the CRMB mix increased. The combination obtained a maximum stability reading of 1618.57 kgs at this concentration as demonstrated by the CN57 specimen. Because of its outstanding resistance to deformation and high stability the mix at this concentration is ideally suited for heavy traffic situations. As the amount increased from 5 percent to 6 percent and 6.5 percent, it was observed that the stability of the CRMB decreased. With the lowest CRMB concentration of 4.5 percent the CN45 specimen had the lowest stability value of 1370.41 kgs.

The findings of these investigations indicate that adding more CRMB content initially improves the mixs stability. There is a maximum concentration of 5 percent though above which further increases could cause stability to decline. This drop could be the result of an overabundance of binder, which would make the mix more prone to deformation under stress. Therefore it is essential to keep the concentration of CRMB at the ideal level to create a mix that is stable and long-lasting able to withstand the stresses placed on it by traffic volumes and providing the pavements long-term performance.

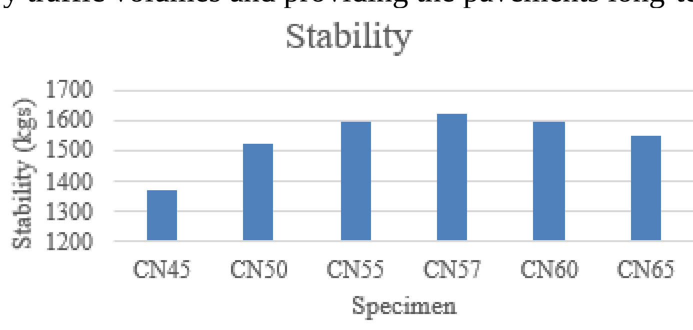

Figure 3 Stability test value of all six specimen

Flow test

A crucial sign of how the specimen will deform or flow in response to the applied load is the flow value obtained from the Marshall stability test. This value, which is expressed in millimeters represents the specimens degree of deformation from the start of loading until the point of failure. An appropriate flow value is a crucial indicator of the mixs flexibility because it shows that the pavement can tolerate minute movements such as thermal contraction and expansion or minor adjustments under traffic loads without collapsing. Extreme flow values especially those that are excessively high or low may expose the performance and durability of the pavement and may be a sign of possible blend problems such as excessive brittleness or excessive flexibility.

The results of this study indicate that the concentration of CRMB increased the flow readings of the Crumb Rubber Modified Bitumen blend as shown in Table 5. There is an increase in flow values as the mix becomes more flexible with an increase in CRMB amount. The sample with the highest flow value of 3.76 mm was found to have a high CRMB content (CN65). This suggests that the mixture is more flexible at this concentration and can tolerate more deformation without breaking. On the other hand at 2.63 mm the sample with the lowest concentration of CRMB (CN45) showed the lowest flow value indicating a more rigid blend with a lower capacity for deformation.

These results highlight the impact of CRMB content on the mixs flexibility. Certain situations can benefit from more flexibility such as preventing fracture under heat stress or minor movements in the pavement. During this process it is important to preserve the mix’s overall stability and resistance to deformation due to traffic pressures. Thus reaching an ideal CRMB concentration is a condition for the pavements endurance under long-term traffic and environmental conditions.

Table 5 Result of various test under Marshall Method

Sr. No.	Specimen	Height of specimen (mm)	Specific gravity (Gmm)	% of Air voids (Pa)	VMA%	VFA%	Stability (kgs)	Flow 0.25 (mm)
1	CN45	63.80	2.600	7.38	16.32	54.78	1402.28	2.60
		63.50		7.54	16.45	54.16	1338.54	2.70
		63.90		7.27	16.21	55.15	1370.41	2.60
	Average			**7.396**	**16.326**	**54.69**	**1370.41**	**2.63**
2	CN50	63.40	2.585	5.96	15.96	62.66	1529.76	2.90
		63.20		5.80	15.82	63.34	1497.89	3.00
		63.50		5.88	15.89	63.00	1529.76	3.10
	Average			**5.88**	**15.89**	**63.00**	**1519.14**	**3.0**
3	CN55	63.10	2.565	4.44	15.71	71.74	1593.50	3.30
		62.90		4.52	15.78	71.36	1561.63	3.50
		63.20		4.52	15.78	71.36	1625.37	3.40
	Average			**4.49**	**15.75**	**71.48**	**1593.5**	**3.4**
4	CN57	63.10	2.555	4.19	15.98	73.80	1624.10	3.40
		63.00		4.07	15.89	74.39	1590.95	3.30
		63.20		4.11	15.93	74.20	1657.24	3.40
		62.90		4.19	15.99	73.80	1557.81	3.30
		63.10		4.15	15.96	74.00	1657.24	3.50
		63.30		3.99	15.82	74.78	1624.10	3.40
	Average			**4.11**	**15.92**	**74.16**	**1618.57**	**3.38**
5	CN60	62.80	2.528	3.40	16.47	79.36	1625.37	3.70
		62.60		3.44	16.50	79.15	1561.63	3.50
		62.70		3.44	16.50	79.15	1593.50	3.70
	Average			**3.42**	**16.49**	**79.22**	**1593.5**	**3.63**
6	CN65	62.60	2.482	2.50	17.66	85.84	1561.63	3.60
		62.70		2.46	17.63	86.05	1593.50	3.80

		62.50		2.50	17.66	85.84	1497.89	3.90
	Average			**2.48**	**17.65**	**85.91**	**1551.00**	**3.76**

Discussion

Marshall stability, specific gravity, air void content, voids in mineral aggregate (VMA), flow and other factors are critical for assessing the state and functionality of CRMB mix pavements in accordance with the guidelines set by the Ministry of Road Transport and Highways (MORT&H). These parameters must meet minimum and consistent values in order to ensure the pavements physical integrity, durability and resistance to deformation under traffic pressures. In order to evaluate the qualities of CRMB mix pavements test methodologies that correspond with the required values for these parameters are listed in Table 6.

In this study a variety of specimens with varied CRMB concentrations were produced and the properties of bitumen mix pavements were meticulously tested and compared to the MORT&H standards. Out of the different concentrations the specimen designated CN57 which contains 5.7 percent CRMB showed the best results. For every crucial parameter this particular concentration closely matches the required values found by MORT&H. The specific gravity, air cavities, VMA, Marshall stability, flow and all other parameters that are within allowable bounds show that the CN57 specimen is well-balanced in terms of density flexibility and strength.

These results suggest that a mixture with a CRMB content of 5.7 percent is the most effective for creating a durable and robust pavement structure. There are enough voids in the mix to keep problems like rutting and splitting and its stability is retained to handle high traffic loads. They will always be present because of this focus. Furthermore the flow value at this concentration indicates that the pavements structural integrity won’t be compromised by slight deformations. Consequently, the CN57 specimen not only meets but also represents the MORT&H requirements making it a feasible choice for high-performance bitumen mix pavements.

Table 6 Marshall Test value for CRMP concentration of 5.7% under MORT&H

Sr. No.	Properties	Test method	Test Result	Specification (As per MORT&H) Table 500-11& IRC SP 53-2010
1	Optimum binder content % by weight of total mix	MS-2	5.70%	Min. 5.60%
2	Bulk specific gravity of paving mixture	Ms-2	2.45	-
3	Maximum specific gravity of Paving Mixture (Gmm)	ASTM D2041	2.555	-
4	Air void in compacted mixture percentage of total volume (Pa)	MS-2	4.00%	3-5%
5	Void in the mineral aggregate (VMA)	MS-2	16.00%	Min. 14.00%
6	Void filled with asphalt (VFA)	MS-2	74.00%	65-75%
7	Marshall stability	AASHTO T245	15.69	Min. 12KN
8	Marshall flow	AASHTO T245	3.40	2.50-4.00

9	Marshall Quotient (Stability/flow)	MS-2 and ASTM D2041	4.61	2.5-5.00
10	Compaction level (No. of Blows)	MS-2	75	75 Blows on each face of the specimen
11	Fines to Bitumen ration (F/B) by weight of total mix	MS-2	0.84	0.6 to 1.2, As per MORT&H clause 505.3

CONCLUSION

The buildup of garbage has become out of control due to factors such as population increase, industrialization, consumerism, and technological advancement. Rubber is environmentally beneficial, yet it cannot be biodegraded. In both urban and rural locations, proper garbage disposal is very crucial. It has been shown that bituminous mixtures may make use of scrap rubber. The mix's qualities are enhanced, and disposal issues are somewhat resolved as well. In order to achieve the appropriate mechanical properties in road mix, this recycled rubber partly substituted for the traditional material. Improved binding properties, stability, density, and water resistance are some of the benefits of adding crumb rubber to modified bitumen mixes. In this study, CRMB-60 bitumen mix for produce pavement of various concentration of 4.5% to 6.5%. The key findings and conclusions are as follows:

- The concentration of Crumb Rubber Modified Bitumen (CRMB) increases, the mass of the specimens in air decreases, while their density increases.
- As the concentration of CRMB increased, the specific gravity of the pavement decreased. The specimen with the lowest CRMB concentration (CN45) had the highest specific gravity of 2.6, while the specimen with the highest CRMB concentration (CN65) had the lowest specific gravity of 2.482.
- As the concentration of CRMB increases, the air voids within the pavement decrease. the specimen with the lowest CRMB concentration (CN45) exhibited the highest average air void content of 7.39%, while the specimen with the highest CRMB concentration (CN65) showed the lowest average air void content of 2.48%.
- The CRMB concentration increases up to 5.5%, there is a decrease in VMA, indicating a more compact aggregate structure with less space for the binder. Specifically, the specimen with a CRMB concentration of 5.5% (CN55) exhibited the lowest VMA of 15.75%.
- When the CRMB concentration exceeds 5.5%, the VMA begins to increase again. The highest VMA was observed in the specimen with a 6.5% CRMB concentration (CN65), which recorded a VMA of 17.65%.
- As the amount of Crumb Rubber Modified Bitumen (CRMB) increases so does the VFA. The specimen exhibiting the highest VFA value of 85.91 percent was the one with the maximum concentration of CRMB (CN65). The lowest VFA value 54.69 percent was seen in the sample with the lowest CRMB concentration (CN45).
- As CRMB concentration increases to 5.7 percent of the total bitumen content, there was an observed increase in the stability of the CRMB blend. At this concentration, the combination yielded a maximum stability reading of 1618.57 kgs as shown by the CN57 specimen.
- As the CRMB content increased from 5.7 percent to 6 percent and 6.5 percent stability nevertheless decreased. With the lowest CRMB concentration of 4.5 percent the CN45 specimen displayed a low stability value of 1370.41 kgs.

- It was shown that the Crumb Rubber Modified Bitumen (CRMB) blends flow values increased proportionately to the CRMB concentration. The sample that had the highest concentration of CRMB (CN65) had the largest flow value measuring 3.76 mm.

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