RECENT TREND IN CIVIL ENGINEERING AND BUILT ENVIRONMENT
e-ISSN: 2773-5303

RTCEBE

Vol. 6 No. 2 (2025) 108-116
https://publisher.uthm.edu.my/periodicals/index.php/rtcebe

Investigation of Marshall Properties of HMA Rubberised Asphalt Mixture

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DOI: https://doi.org/10.30880/rtcebe.2025.06.02.012

Article Info

Received: 13 January 2024
Accepted: 15 April 2024
Available online: 30 December 2025

Keywords

Hot Mix Asphalt (HMA), Crumb Rubber (CR),

Abstract

Asphalt pavements are critical components of contemporary transportation infrastructure, providing long-lasting and cost-effective road surfaces. Traditional asphalt mixtures, on the other hand, are prone to cracking, rutting, and ageing, resulting in early pavement deterioration. Alternatively, researchers have investigated the use of crumb rubber obtained from recycled tyres in asphalt mixes. This study aims to determine the ideal proportion of crumb rubber in the asphalt mixture in order to produce mechanical features such as higher resistance to cracking and rutting, increased durability, and decreased environmental effect. The Marshall stability, flow, air voids, bulk density, and indirect tensile strength of asphalt mixes are among the key factors researched. This study's results add to a better understanding of the impact of bitumen content on the performance of gap-graded HMA mixes with crumb rubber. The findings may be utilized to improve bitumen concentration in future mix designs while keeping desirable performance criteria and environmental factors in mind. Furthermore, the research sheds light on the viability of using crumb rubber as a sustainable addition in asphalt pavement construction, increasing waste material reuse and lowering the environmental effect of the transportation industry.

1. Introduction

Hot Mix Asphalt (HMA) is a common material for flexible pavement, consisting of aggregates, asphalt binder, and a bit of mineral filler. Aggregates, like gravel and crushed stone, form the structure. Asphalt, a byproduct of the petroleum industry, acts as a binder, holding the aggregates together and providing waterproofing.

The study aims to compare crumb rubber modified HMA (CRMA) with traditional HMA in terms of Marshall stability, flow, and key properties like bulk density, voids in total mix (VTM), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA). The stiffness of HMA mixtures is assessed using Marshall stability and flow values.

The use of crumb rubber (CR) in asphalt has grown due to its positive impact on asphalt binder and its origin as recycled material from used tires. Waste rubber disposal, often through landfills and incineration, can have negative environmental effects. To address this, incorporating waste polymers like CR into asphalt can improve pavement performance and mitigate waste disposal issues. CR addition to asphalt binder enhances performance in both high and low temperatures, making it a cost-effective and environmentally friendly solution.

2. Literature Review

This literature review aims to comprehensively explore the research and advancements in gap-graded Hot Mix Asphalt (HMA) with crumb rubber. It covers various aspects of this innovative pavement material, including its manufacturing process, engineering capabilities, performance characteristics, and long-term durability. The goal is to identify the constraints, challenges, and potential associated with using crumb rubber in gap-graded HMA through a critical examination of existing knowledge. By integrating current information, this review aims to offer a complete understanding of the advantages, limitations, and prospects of gap-graded HMA with crumb rubber.

2.1 Hot Mix Asphalt

Hot Mix Asphalt (HMA) typically consists of aggregates, an asphalt binder, and a small amount of mineral filler. It is commonly used in flexible pavement construction. The aggregates, often a mix of gravel, crushed stone, and sand, form the structure, while asphalt, a petroleum waste product, acts as a binder, gluing the aggregates together and providing waterproofing. In Malaysia, AC 14 and SMA 14 are popular HMA mixes, meeting JKR requirements. PG76 is a wearing course in flexible pavements with specific criteria for binder grade and mixture percentage. SMA 14, a gap-graded HMA, has unique characteristics, with a higher binder percentage according to JKR standards. Gap-graded asphalt, or Stone Matrix Asphalt (SMA), is designed with distinct aggregate size distribution and voids. It enhances pavement performance, resisting moisture damage, peeling, cracking, rutting, and deformation under heavy traffic. The intentional gaps in the mix allow for optimal binder coating, adhesion, excess binder storage, and improved drainage, contributing to increased resilience and durability (National Asphalt Pavement Association, 2020).

2.2 Crumb Rubber

Rubber from waste tires has been used in asphalt pavements since the 1960s, offering elasticity to improve skid resistance and durability. There are two main processing methods for crumb rubber (CR): the 'wet process' involves blending fine rubber with hot bitumen, creating a 'rubberized bitumen' binder, while the 'dry process' replaces part of the mix aggregate with coarse rubber, acting as an elastic aggregate in the mixture (Moreno et.al., 2011). CR is derived from shredded tires, removing reinforcing materials. Its chemical composition is challenging to determine due to variations in tire types. Asphalt mixture design methodologies, shaped by past field testing and lab studies, show that dry process CR mixes often perform less favorably compared to wet process or traditional mixes. Studies emphasize the sensitivity of dry process mixes to changes in rubber content, underscoring the importance of aggregate gradation, bitumen content, and air voids content in formulation. Achieving an ideal mix with minimal air spaces and sufficient stability requires careful laboratory design, addressing challenges like 'rubber swelling' that can cause fluctuations in air voids content.

Fig. 1 *Crumb Rubber*

2.3 Asphalt Mixture (Dry Method)

The dry process for crumb rubber-modified asphalt (CRMA) originated in Sweden as "Rubit" in the 1960s and gained popularity in Europe as "PlusRide" in 1978. In this method, crumb rubber (CR) is mixed with aggregate in a hot mix central plant before adding bitumen. The dry process involves modifying the grading and may exhibit some reactivity during manufacturing. Data suggests that factors like mixing temperature duration, rubber-to-bitumen ratio, and bitumen type influence the reaction. Dry process mixes have higher binder levels than traditional mixes by 10 to 20%. The granulated rubber is dry mixed with aggregate in the lab, and the resulting blend requires higher compaction temperatures in the field. The mixing occurs in batch plants at temperatures between 149°C to 177°C. Compaction begins promptly to limit rubber swelling. Monitoring parameters like rubber gradation, percentage, pre-treatment, and mixing duration is crucial. Due to partial reaction with CR, the characteristics of binders in dry process mixes cannot be directly determined. Matching aggregate and CR gradations is essential to accommodate swollen rubber in gaps typically filled by aggregate. While there's no formal guideline, the two common dry process procedures in North America are PlusRide (gap graded) and Generic mixes (dense graded). Mixture design factors for CRMA, following the traditional Marshall approach, include aggregate and CR gradations, bitumen concentration, and low air voids content.

Fig. 2 *Dry process method* content (Hassan et al., 2014)

3. Materials and Method

This chapter focuses on achieving the research goal of determining the optimal bitumen composition for gap-graded hot mix asphalt with crumb rubber (CR-GGA). Laboratory experiments were conducted at the Advanced Highway Engineering Laboratory, Faculty of Civil Engineering and Built Environment, UTHM. Two stages of tests were outlined in a flowchart. The first stage involved assessing the physical properties of Bitumen Penetration Grade (PEN) PG76 (6-8%), gap-graded aggregates, and CR (substituting 50% of bitumen weight based on sieve size). Tests included Sieve Analysis for aggregates, Softening Point and Penetration evaluation for bitumen, and Sieve Analysis for CR. The second stage aimed to determine the optimal bitumen content for hot mix rubberized asphalt. Marshall mix design was employed to analyze parameters like flow, stability, stiffness, VTM (voids in total mix), and VFB (voids filled with bitumen). All tests were conducted to ensure the study's objectives were met. For bitumen grade PG76 the temperature also set on 165°C for 1 hours before can mix the sample. Next, prepare a mole for compaction the sample for a temperature of 155°C and 75 blows by the automatic Marshall compact.

3.1 Penetration Test

The penetration test involves gently rotating the knob until the needle makes contact with the bitumen specimen, and the dial reading is set to zero. The test begins with the start button when the needle is at a 90° angle to the specimen surface. After one hour in a water bath, the needle is brought into contact with the sample surface, and the dial is set to zero. The needle penetrates for 5 seconds before taking the final reading. At least three observations are made at least 10 mm apart. The needle is cleaned and dried after each test. The accuracy depends on factors like pouring temperature, needle size, weight on the needle, and test temperature. The penetration test is a crucial measure, and its accuracy is influenced by various factors.

3.2 Softening test

The Ring and Ball test, conducted following ASTM D 36 standards, is employed to determine the softening point of bitumen. This test uses brass and steel balls to assess the softening point of various bituminous materials or asphalt. The softening point is crucial for understanding the phase changes in asphalt mixture, indicating a reduction in viscosity. Asphalt, being viscoelastic, softens and becomes less viscous with increasing temperature. In this test, two horizontal brass rings filled with bituminous mixture are placed in a ring holder within a glass beaker filled with cooled distilled water. The temperature is maintained at around 5 degrees Celsius through continuous mixing for about 15 minutes. Subsequently, a steel ball is inserted into the middle and on top of the asphalt mixture, which is then heated until it melts and touches the bottom plate.

3.3 Marshall Mix Design

The Marshall Mix Design Method was employed to create mixture samples, and the volumetric parameters were determined using the Marshall test following ASTM D6927-06 (2006). The test involves exposing each sample to various analyses to assess its characteristics. Two samples were prepared for the project: the first, a control sample with 0% crumb rubber (CR), and the second, with 50% CR using 0.075 mm sieves. In the initial steps, aggregate physical properties were determined using gap-graded aggregates. Particle shape, an essential criterion for aggregate quality, was evaluated. The asphalt, with a penetration grade of PG76, was mixed at 165°C and compacted at 155°C. Stability and flow tests were conducted following ASTM D1559. After passing these tests, specific gravity density and air void tests were performed to estimate the percentage of air voids in mineral aggregates (VMA) and air voids in the compacted mix (VIM). This ensures the final product has optimal amounts of bitumen, aggregate, and air. For the stability and flow tests, specimens were immersed in water at 60±1°C for 30-40 minutes, and then subjected to load until the maximum load was attained. The flow value was observed, indicating the specimen's shift from no load to maximum load. The entire process, from removing the specimen from water to applying the maximum load, should take no more than 30 seconds. After passing stability and flow tests, specimens underwent specific gravity density tests by weighing them in dry and submerged conditions to calculate the bulk specific gravity and estimate air voids. This ensures the final product meets the desired specifications.

Fig. 3 *Marshall Mix Design*

4. Results and Discussions

This chapter extensively explores the outcomes of investigations conducted on bitumen and asphalt mixtures, providing a detailed examination of each test's results and analyses. To compare Marshall properties for conventional asphalt mixture and rubberized asphalt mixture in the JKR Specification (JKR/SPJ/2019).

4.1 Asphalt Binder Properties

4.1.1 Penetration Test

The evaluation of bitumen hardness, or consistency, is conducted by determining its penetration value. This value signifies the vertical distance a standard needle can penetrate a bituminous material under specific conditions of stress, time, and temperature. The penetration values for the samples are presented in Table 4.1. In this study, Bitumen Penetration Grade PG76 (Polymer modified binder) was utilized for all mixtures. It's noteworthy that as the penetration grade of bitumen increases, the material becomes softer. This characteristic is advantageous for soils with high particle density like clay. Conversely, bitumen with a higher penetration grade is more suitable for soils with low particle density. Essentially, the penetration value serves as a measure of bitumen hardness or consistency, reflecting how deeply the standard needle can penetrate the bituminous material under defined conditions. An increase in penetration value indicates a softer bitumen, allowing for a deeper needle penetration.

Table 1 *Result of Penetration Test*

Number of samples	penetration (dmm)	Average (dmm)
1	42.7	42.4
	41.2	
	43.4	

4.1.2 Softening point

The softening point is determined by establishing the average temperature at which two discs soften enough to allow each enclosed ball in bitumen to descend 25 mm. The results of the softening point test, presented in Table 4.2, are based on the conducted tests. During the test, after the balls descended due to bitumen softening, the temperature was recorded for both rings. Bitumen with a higher softening point is generally more resilient when exposed to temperature variations. In this project, the recorded softening point for the bitumen was 85.5 °C and 84.8 °C, both exceeding the standard requirement of 60 °C. Hence, the results are deemed acceptable.

Table 2 *Result of Softening Point Test*

Number of test	Softening point (°C)	Average (°C)
1	85.5	85.15
2	84.8	

4.2 Comparison of Marshall properties between the conventional and rubberized asphalt mixture

Table 3 *Result for Marshall for Control sample*

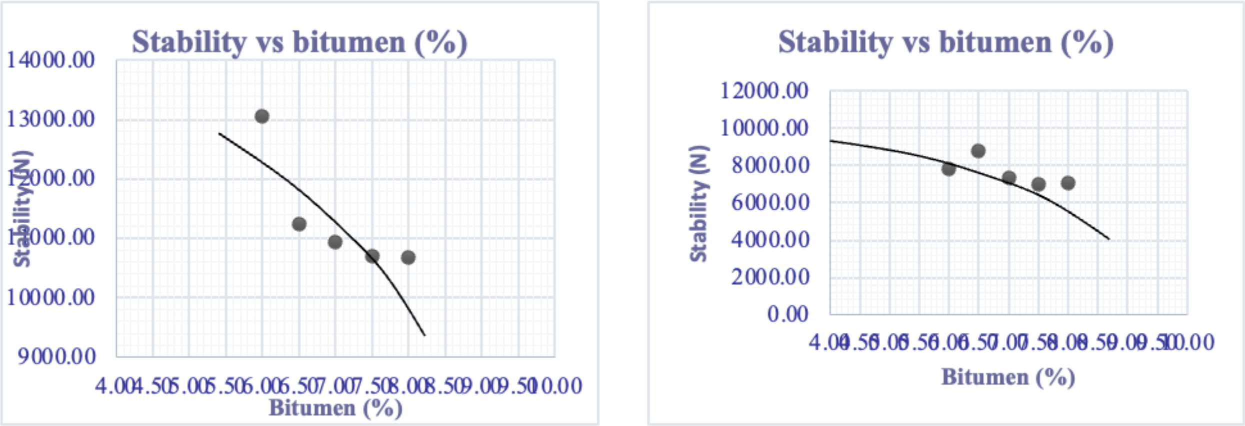
Bitumen	Stability	Density	Flow	VTM	VFB	Stiffness
6.00	13063.47	2.22	3.48	8.97	59.34	4062.17
6.50	11244.34	2.22	3.75	8.11	63.58	3184.90
7.00	10931.98	2.25	4.93	6.20	71.39	2257.52
7.50	10699.02	2.23	3.51	6.23	72.70	3347.17
8.00	10688.60	2.25	3.74	4.63	79.30	2955.99

Table 4 *Result for Marshall for Rubberised HMA*

Bitumen	Stability	Density	Flow	VTM	VFB	Stiffness
6.00	7816.67	2.07	3.18	15.10	44.60	2468.90
6.50	8776.46	2.08	4.69	14.04	48.52	1899.75
7.00	7340.24	2.06	3.57	13.99	50.29	2058.13
7.50	7002.13	2.10	3.95	11.72	56.87	1781.75
8.00	7056.00	2.09	4.56	11.39	59.06	1556.64

4.2.1 Stability

Figures 4 depict the relationship between stability and bitumen content in Hot Mix Asphalt (HMA). The stability values were analyzed for bitumen content percentages ranging from 6.0% to 8.0%. In Figure 4 (a), it is evident that as the bitumen content increases, the stability decreases, particularly noticeable for asphalt mixtures with 7.0% to 8.0% bitumen content. The highest stability value, falling within the range of 10,000 N to 13,500 N, is recorded in Figure 4 (a). This aligns with previous findings indicating a decrease in stability with higher bitumen content (Keymanesh et al., 2014). Similarly, Figure 4 (b) demonstrates a decline in stability with an increase in bitumen content for rubberized HMA. The optimum stability for control HMA is 12,700 N, while for rubberized HMA, it is 8300 N, falling within the range of 7000 N to 9000 N. Higher concentrations of crumb rubber (CR) may lead to increased air voids, impacting viscosity, elasticity, and adhesion in the asphalt mix. These changes can affect overall stability and increase susceptibility to cracking, compromising pavement durability (Carpenter et al., 1997).

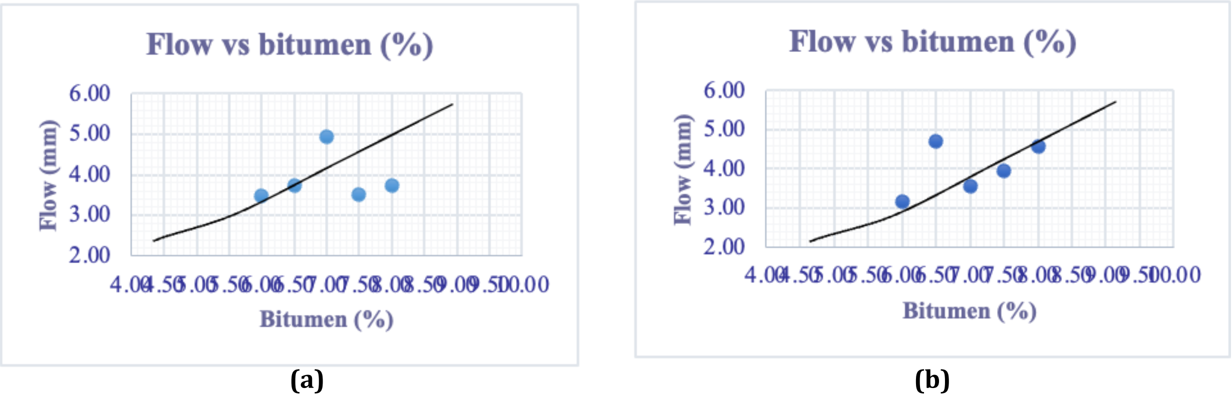


(a) **(b)**

Fig. 4 *Graph of Stability against bitumen control for control and Rubberised HMA*

4.2.2 Flow

Marshall flow, representing the permanent strain at failure for an asphalt mixture, is illustrated across different asphalt binder percentages in Figure 5 (a). The results show an increase in flow value until the bitumen content reaches 7.00%, followed by a decrease at 7.50% and 8.00% bitumen levels. The flow values ranged from 3 mm to 5 mm. In Figure 5 (b), for the HMA with 50% CR sample, the flow increases with higher bitumen content. Notably, rubberized HMA in Figure 5 (b) exhibits lower flow values, ranging from 3.18 mm to 4.16 mm. The lower flow in rubberized HMA may pose challenges in achieving sufficient compaction during construction, potentially leading to air voids and reduced density. However, the inclusion of CR enhances flexibility and flowability in the mixture (Mohammad & Kaya, 2017; Yousefi & Mills-Beale, 2015).

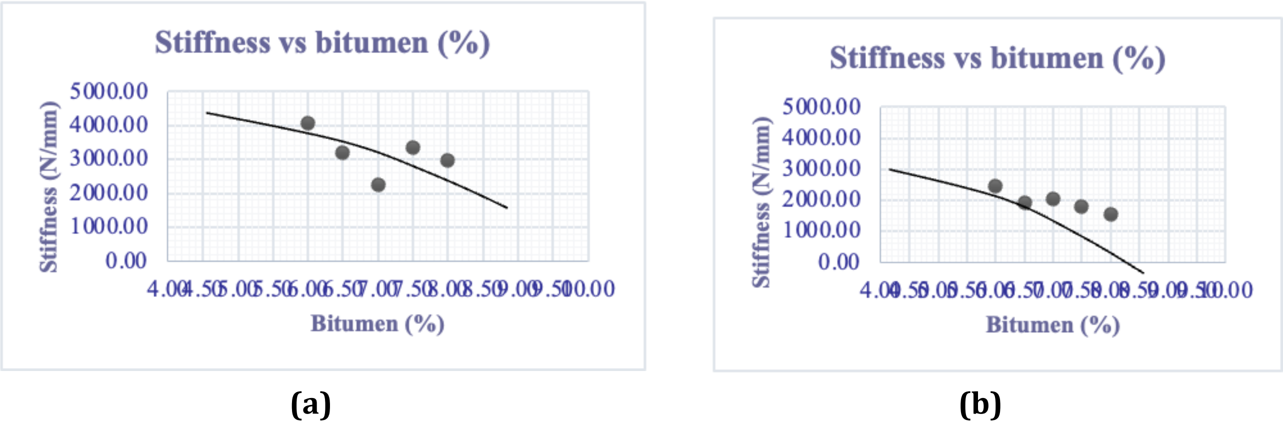


(a) **(b)**

Fig. 5 *Graph of Flow against bitumen control for control and Rubberised HMA*

4.2.3 Stiffness

Figures 6 display the results of stiffness tests at varying bitumen content. The observations reveal that stiffness decreases with an increase in bitumen. In Figure 6 (a), stiffness values range from 2955.99 N/mm to 4100.00 N/mm. Meanwhile, Figure 6 (b) illustrates that rubberized HMA exhibits stiffness values ranging from 1556.64 N/mm to 2468.90 N/mm. A higher amount of bitumen enhances the flexibility of the asphalt mix, resulting in decreased stiffness. This increased flexibility improves resistance to cracking and deformation under stress. Rubberized HMA, in particular, may demonstrate enhanced temperature susceptibility, potentially reducing susceptibility to rutting at high temperatures and cracking at low temperatures. The increased bitumen addition dilutes the concentration of solid components, making the mixture less rigid. Additionally, the incorporation of rubber modifiers tends to increase asphalt mixture stiffness.



(a) **(b)**

Fig. 6 *Graph of Stiffness against bitumen control for control and Rubberised HMA*

4.2.4 Air Void Volume (VTM)

Figures 7 illustrate VTM (%) against bitumen content (%), demonstrating that an increase in bitumen content results in a decrease in VTM value. In Figure 7 (a), covering a bitumen content range of 4% to 9%, a decrease in VTM is observed from 6.00% to 6.50% bitumen content, followed by an increase at 7.00% bitumen content. However, with 8% bitumen content, there is a decrease in VTM (Voids in the Mineral Aggregate) value.

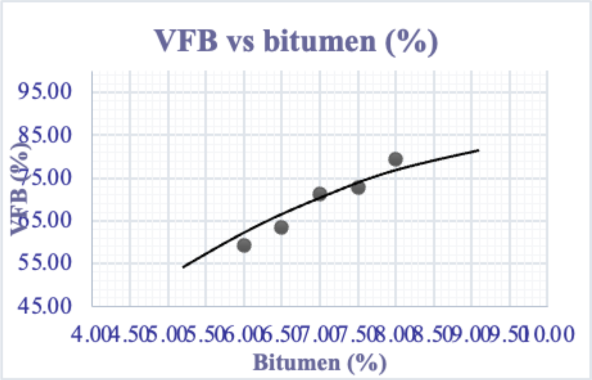
In Figure 7 (b), for rubberized HMA, higher VTM values ranging from 11% to 16% are observed. The addition of crumb rubber increases bitumen content, improving cohesion between aggregate particles and reducing overall void space. This enhancement in aggregation contributes to a denser asphalt mix, leading to a decrease in VTM. Adjusting bitumen content proves to be a crucial factor in optimizing volumetric properties, ensuring durability and performance in pavement applications.

(a) **(b)**

Fig. 7 *Graph of VTM against bitumen control for control and Rubberised HMA*

4.2.5 Air Void Volume (VTM)

Figures 8 illustrate the relationship between VFB (%) and bitumen content (%), revealing that an increase in bitumen results in an increase in VFB value. In Figure 8 (a), VFB values range from 59.34% to 79.30%, showing an upward trend with increasing bitumen content. Meanwhile, for rubberized HMA in Figure 8 (b), VFB values range from 44.60% to 59.06%, demonstrating an increase as the bitumen content rises. Higher bitumen content generally leads to a denser asphalt mix, contributing to reduced voids and improved overall compaction of the mixture. This increased density is advantageous for achieving better pavement performance.



(a) **(b)**

Fig. 8 *Graph of VFB against bitumen control for control and Rubberised HMA*

5. Conclusions

In conclusion, this study aimed to assess the impact of incorporating Crumb Rubber (CR) as a filler in asphalt mixtures. The investigation involved a comprehensive analysis of Marshall Test results, comparing a standard mix (Control) with an asphalt mixture containing 50% CR. Key parameters such as stability, flow, stiffness, bulk specific gravity, voids in mineral aggregate (VIM), and voids filled with bitumen (VFB) were rigorously examined to evaluate the performance of conventional and rubberized asphalt mixtures. These analyses were conducted in accordance with JKR standards, ensuring adherence to established criteria. The study also involved the sieving of aggregates based on design requirements and in accordance with JKR standards. The physical properties of bitumen grade PG76 were assessed through penetration tests, confirming that the bitumen met ASTM standards. Overall, these findings provide valuable insights into the potential benefits and performance characteristics of asphalt mixtures containing Crumb Rubber.

Acknowledgement

The facilities and technical support provided by the Universiti Tun Hussein Onn Malaysia's Civil Engineering and Built Environment are gratefully acknowledged by the writers. Special thanks also go out to UTHM's Advanced Highway Laboratory.

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