Exploring The Effectiveness of Crumb Rubber Modified Asphalt (CRMA): A Comprehensive Overview On Submerged Roads In Malaysia

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Abstract. As Malaysia is located within the equatorial region, heavy rainfalls and thunderstorms are common occurrences, often leading to flooding that affects the extensive road network in the East Coast of the Malaysian Peninsular. Some flooding involves stagnant water that may remain for several days before subsiding. The impact of moisture on the pavement surface is extensively documented with damages often includes stripping of the asphalt due to the compromised properties of the bitumen. This study aims to evaluate the effectiveness of the "special mix" bitumen known as Crumb Rubber Modified Bitumen, CRMB, as a replacement for the existing bitumen grade against moisture induced damages. Test samples were collected from flooded affected areas namely Federal Road FT 02 Sec 321, Sec 331 and FT 62 Sec 0 with two of the areas flooded twice within the same year. Core samples from FT 222, Sec 0, using conventional bitumen, were also tested as a control sample. The roads were maintained using two methods, Mill & Pave (MP) 50mm and Overlay 50mm. Maintenance work was conducted in different years to ensure a more comprehensive analysis. The moisture susceptibility test (AASHTO T283) was used to compare the performance of CRMB against conventional bitumen. The findings indicate that the CRMA with Mill and Pave 50mm (Section 331) shows the highest moisture resistance with a TSR % of 92.6%, making it the most effective for flood-prone areas. In contrast, the CRMA overlay and AC 14 with Mill & Pave 50mm treatments perform poorly, with TSR % values of 45.4% and 45.2%, respectively. This highlights the benefits of CRMB in enhancing road durability in areas prone to heavy rainfall and flooding. This improvement is critical for enhancing the longevity and safety of road networks in such regions, potentially leading to reduced maintenance costs and disruptions.

Keywords: CRMB, CRMA, indirect tensile strength, TSR, moisture resistance

1 Introduction

In regions where rain is frequent, rainwater significantly contributes to the deterioration of road performance. According to Diab et al. [1], water is well-documented for causing damage to pavement surfaces due to the loss of adhesion between the binder and the aggregate that makes up the wearing course. Roads frequently subjected to heavy rainfall and submersion consistently exhibit reduced durability and failures such as rutting, cracking, stripping, and potholes. This issue is prevalent in Malaysia, located within the Equatorial region, where heavy and frequent rainfall is the norm. The combination of heavy rainfall, high temperature, and stress from heavy traffic loading causes many roads, especially in the East Coast of the Peninsula, to suffer from these failure modes. This phenomenon is commonly known as moisture-induced damage, traceable to two main failure mechanisms of bitumen: the loss of cohesive bond strength of the bitumen itself and the reduced adhesion strength between the bitumen and aggregate.

Various test methods are widely available to measure the moisture susceptibility of pavement materials, applicable to both loose and compacted samples. According to Do et al. [2], for loose samples, the moisture susceptibility test is based on visual observation of the bitumen covering the aggregate after conditioning. In the case of compacted samples, the strength of the samples is tested before and after moisture conditioning for comparison of its tensile strength. Zhang et al. [3] conducted recent research that emphasizes the significance of assessing moisture susceptibility in relation to changing climatic patterns and heightened rainfall intensity.

For this paper, the samples tested are core samples taken from different sites in the state of Pahang Darul Makmur. The sites were chosen based on pavements that utilize Crumb Rubber Modified Bitumen (CRMB) and were exposed to stagnant flood water. Control core samples from a site utilizing conventional bitumen were also taken, and the pavement was also exposed to stagnant flood water. The test method used for assessing the moisture susceptibility of pavement material for the purpose of this paper is the AASHTO T283. This method measures both the dry and wet indirect tensile strength of the cored samples, and the results are presented as a percentage of the Tensile Strength Ratio (TSR %). The TSR percentage value is used to determine if the pavement material is resistant to moisture-induced damage after prolonged exposure to water and high temperature.

The objective of this paper is to study the effectiveness of CRMA (Crumb Rubber Modified Asphalt) pavement compared with the current conventional pavement material widely used in Malaysia when exposed to flood water, particularly in terms of moisture-induced damage leading to failures such as stripping and cracking of the pavement sur-face. The purpose of the different parameters of the chosen pavements was to obtain data that can compare the effect of pavement aging and moisture on the TSR percentage value under different pavement conditions.

CRMA pavements are produced using CRMB, which has a higher viscosity compared to conventional bitumen. According to Behiry [4], the thickness or viscosity of the bitumen or asphalt film impacts the durability of the bitumen and, consequently, the durability of the pavement. Moreover, the latest research conducted by Wang et al. [5] indicates that CRMA has the potential to greatly enhance resistance against moisture-induced damage owing to its superior viscoelastic characteristics. Ambient environmental conditions, such as temperature and rain, will also affect the overall durability of the pavement material. Traffic conditions of the road also affect pavement durability due to the vertical loading of the vehicle on the pavement. The core samples taken for this paper are from pavements maintained in different years with different types of treatment methods and on different classifications of roads with varying traffic conditions.

A study conducted by Liu et al. [6] suggests that the deterioration of pavement components due to aging can worsen their susceptibility to moisture, thus requiring frequent monitoring and repair. Additionally, Ahmad et al. [7] discovered that the utilization of CRMB can extend the lifespan of pavements in tropical regions by mitigating moisture damage and enhancing flexibility. Xiao et al. [8] documented that CRMA has enhanced performance in terms of moisture resistance and structural integrity during intense rainfall conditions. A study conducted by Lee et al. [9] has shown that CRMA is able to improve pavement performance in flood-prone regions by enhancing structural cohesiveness and minimizing cracking. Furthermore, research conducted by Kim et al. [10] highlights the significance of CRMA in reducing environmental consequences through the recycling of rubber waste and enhancing the longevity of roads. The use of CRMA mixes in flood-prone regions of Malaysia may improve the sustainability of road infrastructure by prolonging pavement life, reducing maintenance needs, and contributing to environ-mental sustainability.

Additional research is necessary to analyze the long-term performance and durability of CRMA under different weather conditions and traffic loads to confirm and verify these findings.

2 Materials and Methodology

2.1 Field cores

A total of five road locations were selected to conduct this study. Samples were collected from several areas that were significantly impacted by flooding. These areas include Federal Road FT 02 at Sections 312 and 333, FT 62 at Section 0, and FT 08 at Section 67. It is important to note that two of these locations experienced flooding twice within the same year, indicating repeated exposure to severe weather conditions. For comparative analysis, core samples were also taken from Federal Road FT 222 at Section 0. Unlike the other samples, this section used conventional bitumen, which serves as a control sample. This allows for a comparison between the performance of conventional bitumen and the materials used in the flood-affected areas, providing insights into how different mate-rials withstand flooding and other environmental stresses. The roads were maintained using two methods: Mill & Pave (MP) 50mm and Overlay 50mm. Maintenance work was conducted in different years to ensure a more comprehensive analysis. The details of the road segments and their respective maintenance activities are summarized in Table 1.

Table 1. Road Segments and Maintenance Details

No	Treat-ment	District	Road	Sec	Road Classification	Type of Treatment	Year of Maintenance	Year of Flooding
1	CRMA	Maran	FT 62	0	Secondary	Overlay	2019	Early and Late 2021
2	CRMA	Kuantan	FT 02	321	Main	Mill & Pave 50mm	2020	Early and Late 2021
3	CRMA	Raub	FT 08	67	Main	Mill & Pave 50mm	2020	Early and Late 2021
4	CRMA	Kuantan	FT 02	333	Main	Mill & Pave 50mm	2021	Late 2021
5	AC 14	Kuantan	FT 222	0	Secondary	Mill & Pave 50mm	2021	Late 2021

The moisture susceptibility test (AASHTO T283) was used to compare the performance of CRMB against conventional bitumen. The following properties were measured for each core: the theoretical maximum specific gravity of each mixture was determined in accordance with AASHTO T 209, while the bulk specific gravity was determined in accordance with ASTM D2726 and ASTM D2041. The size distribution (gradation) of the recovered aggregate was determined according to ASTM D422. The asphalt binder content of each mixture was determined using the ignition method according to ASTM D6307. The moisture susceptibility test was conducted using the Modified Lottman Test (AASHTO T283).

2.2 Volumetric Properties Test and Aggregate Gradations of Mixtures

The properties of each mixture were determined in accordance with the related standard procedures. The size distribution (gradation) of the recovered aggregate was determined in accordance with ASTM D422. The asphalt binder content of each mixture was determined using the ignition method according to ASTM D6307, which allows for the asphalt binder in an HMA sample to be burned off in an ignition furnace at 600°C. The degree of compaction/density analysis was determined by comparing the bulk density with the theoretical maximum specific gravity. The theoretical maximum specific gravity of each mixture was determined using AASHTO T209, while the bulk specific gravity was determined in accordance with ASTM D2726 and ASTM D2041.

The Marshall stability and flow tests were performed to assess the volumetric characteristics of the asphalt mixture, including stability (kN), flow (mm), stiffness (kN/mm), and air void content (percent) to ensure the quality of the asphalt mixture. The procedure for the Marshall stability and flow test follows ASTM D6927, starting with immersing the test samples in a water bath for 30 minutes at a steady temperature of 60°C or by placement in an oven. The test samples were then placed in the loading head of the Marshall stability testing machine, and the flow meter was calibrated to zero by inserting a 101.6 mm cylindrical metal piece into the loading head. The test load was applied to the samples at a constant deformation rate of 50 mm per minute until the maximum capacity or peak resistance load was achieved. The stability value is determined by measuring the maximum load that the samples can sustain before failure. During the stability test, the flow meter stayed firmly in place over the guide rod and was removed as the load began to diminish. The flow value of the sample is defined by the deformation at the peak load. The stiffness value for each sample was calculated as the average of the stability and flow test results. The percentage of air voids was calculated based on the bulk specific gravity and theoretical maximum specific gravity of the mixture as determined in the density test section. Stiffness is calculated using the stability and flow values, while the void in the total mix is calculated using bulk specific gravity and theoretical maximum specific gravity, respectively.

2.3 Moisture Susceptibility Test

The Modified Lottman Test (AASHTO T283) was utilized to assess whether the formulated design test mixture was prone to moisture damage in the pavement. This test measures the reduction in strength or stiffness of an asphalt mix due to moisture-induced damage. This test is crucial as it simulates the conditions that asphalt pavements experience in the field, particularly the effects of water infiltration. Water can weaken the bond between the asphalt binder and the aggregate, leading to a reduction in the pavement's strength and durability. By subjecting the samples to water conditioning, the test can accurately measure how well the asphalt mixture can withstand these detrimental effects.

The Modified Lottman Test (AASHTO T283) is performed by compacting samples with 7 ± 0.5% air voids. Three samples are used as controls (tested without moisture conditioning), while three additional samples are conditioned by saturating them with water at 70-80%, followed by a 24-hour immersion in water at 60°C. The samples are then tested for indirect tensile strength (ITS) by loading them at a constant head rate of 50 mm/minute at 25°C using an ITS machine and recording the maximum compressive force needed to break the samples. The potential for moisture damage is indicated by the Tensile Strength Ratio (TSR) values obtained in the test. TSR is calculated as the ratio of the ITS of the conditioned samples to the ITS of the unconditioned control samples. A higher TSR value indicates that the mix is more resistant to moisture damage as it retains more of its strength after being exposed to water. Generally, a TSR value of 80% or higher is considered acceptable, indicating that the mixture has good resistance to moisture damage. TSR results are critical for determining the durability and longevity of the pavement, helping engineers make informed decisions about the suitability of the asphalt mixture for use in various environmental conditions.

3 Results & Discussion

3.1 Volumetric Properties

The volumetric properties tests were conducted immediately once the projects were completed on-site. This is in accordance with the procedure set by the road authority for all maintenance works carried out on site. Core samples were taken from the project site and tested for the volumetric properties as per the outlined methodology. The obtained results from the core samples were then tabulated in Table 2. From the results, it was determined that the pavement materials at the site met the performance requirements set by the road authorities. The results also indicated that the pavement materials from different quarries used for the different sites are all in compliance with the specifications set by the road authority. For CRMA (Crumb Rubber Modified Asphalt) pavement material, the stiffness test is not required by the road authority's specifications and a Gap Graded design mix is used while a Dense mix is used for the AC 14 (Asphalt Concrete 14) pavement material. The different design mixes accommodate the expansion of CRMB (Crumb Rubber Modified Bitumen) under high temperatures, reflected in the higher Air Void in Mix percentage requirement for CRMA compared to AC 14. This immediate testing ensures that materials are evaluated under realistic conditions, enhancing the reliability of the results and ensuring the longevity and performance of the pavements.

The analysis of volumetric properties for both CRMA and AC14 mixes across various road segments indicates excellent performance in terms of stability, flow, and air void content. All CRMA sections (FT 62 Sec 0, FT 02 Sec 312, FT 08 Sec 67, and FT 02 Sec 333) exhibit stability values well above the minimum requirement of 6000 N, with values ranging from 9935.6 to 12702.2 N, demonstrating high resistance to deformation. Flow values for CRMA (2.8 to 3.3 mm) and air void contents (4.74% to 5.87%) are within the specified limits, indicating balanced flexibility and good compaction. Similarly, the AC14 mix in FT 222 Sec 0 shows a stability value of 11179.7 N, a flow of 3.0 mm, and an air void content of 4.92%, all within the required ranges, along with a high stiffness value of 3685.6 N/mm, reflecting strong load-bearing capacity and structural integrity. Overall, both mixes meet and exceed standard specifications, ensuring durability and excellent performance for flexible pavements.

These findings align with previous studies such as Shafabakhsh and Ani [11], which discussed the enhanced stability and durability of asphalt mixtures modified with nanomaterials, showing improvements in stability and flow values similar to those observed in CRMA mixes. Zhao and Guo [12] also evaluated the volumetric properties of warm mix asphalt, highlighting the benefits of modifiers in improving stability, flow, and air voids akin to the findings in the AC14 mix. Additionally, Yildirim [13] reviewed the performance enhancements in asphalt binders due to polymer modification, aligning with the superior stability and flow characteristics seen in CRMA and AC14 mixes. Furthermore, Hossain et al. [14] examined the rutting resistance and overall stability improvements in modified hot mix asphalt, supporting the high stability values found in the CRMA and AC14 mixes. Finally, Mogawer et al. [15] investigated the benefits of adding hydrated lime to asphalt mixtures, enhancing stability and reducing air voids, which parallels the findings in both CRMA and AC14 mixtures.

Table 2. Result of Volumetric Properties of AC14 and CRMA Mixes

Sample			Stability (N)	Flow (mm)	Stiffness (N/mm)	Air Void in Mix (%)
CRMA	Road Segment	FT 62 Sec 0	12244.4	3.3	NA	4.74
		FT 02 Sec 312	12702.2	2.8	NA	5.87
		FT 08 Sec 67	9935.6	3.3	NA	5.50
		FT 02 Sec 333	11331.1	2.9	NA	5.16
Standard Specification For Road-works: Section 4: Flexible Pave-ment - CRMA			≥ 6000	2.0 -5.0	Non Applicable	4.5 - 6.5
AC14	Road Segment	FT 222 Sec 0	11179.7	3.0	3685.6	4.92
Standard Specification For Road-works: Section 4: Flexible Pave-ment - AC 14			> 8000	2.0 - 4.0	> 2000	3.0 - 5.0

3.2 Moisture Susceptibility

Pavement damage is a multifaceted issue influenced by various factors, among which moisture-induced damage is notably significant, especially in regions with high rainfall like Malaysia. The high precipitation levels in Malaysia can exacerbate moisture-related issues in pavement structures, leading to a reduction in their lifespan and performance. Previous studies have shown that moisture can significantly affect the adhesion mechanism between binder and aggregate, altering both chemical and mechanical binding properties and weakening the binding strength at the molecular level [16,17]. This paper aims to explore these factors in detail and analyse the results obtained from core samples tested for moisture susceptibility, specifically focusing on the tensile strength ratio (TSR) of various road segments treated with CRMA and AC14 mixes. By understanding the impact of moisture on pavement performance, this study seeks to contribute to the development of more resilient pavement materials and maintenance strategies.

Core samples of the CRMA sites were taken from the sites that were flooded during two major flooding incidents in the State of Pahang, one in early 2021 and the other in late 2021. Using the moisture susceptibility test, the core samples were tested for the tensile strength ratio (TSR), and the results are presented in Table 3. From the results, the TSR values vary from site to site for the CRMA pavement. Different types of maintenance treatments and different timings of these works influenced the TSR values. The lowest TSR result is at FT 62 Sec 0, where the maintenance method was a 50mm overlay. This site, treated with CRMA in 2019 and flooded twice in 2021, showed a TSR of 45.4%. The next lowest TSR value is at FT 02 Sec 312 with a TSR of 52.0%; this site, a main arterial road with higher traffic volume, was also flooded twice in 2021. FT 08 Sec 67, another major road, displayed a higher TSR value of 68.0% compared to FT 02 Sec 312. Maintenance works for FT 02 Sec 312 and FT 08 Sec 67 were completed in mid-2020 and late 2020, respectively, and both sites were flooded twice in 2021. FT 02 Sec 333 exhibited the highest TSR value among the tested samples, including the normal AC 14 pavement, with a TSR of 92.6%. Maintenance work for FT 02 Sec 333 was carried out in September 2021, while for the control site using the dense mix AC 14 material, maintenance was conducted in July 2021. Since FT 02 Sec 333 and FT 222 Sec 0 were flooded simultaneously and the two sites are within the same area affected by the flooding, the two sites provide a comparison of CRMA and AC 14 pavement performance when exposed to stagnant floodwater.

The abovementioned areas were taken to inspect for visible moisture-induced damage on the pavement surface. Pavements incorporating the AC 14 mix show visible cracking on the wearing course two and a half years after the flooding incident, while all pavements incorporating the CRMA mix do not display any visible cracking. Stripping of the pavement surfaces was not observed on any of the tested sites, including the control site with the AC 14 mix. On FT 62, one road lane is affected by palm oil from a nearby processing plant, but no surface damage was observed apart from surface darkening. No potholes were observed on any of the tested sites, and no visible maintenance was conducted after the initial works. These findings align with previous studies such as Terrel and Al-Swailmi [16], which examined various test methods for assessing moisture sensitivity in asphalt-aggregate mixes, including the tensile strength ratio (TSR). Hicks [17] discussed the mechanisms of moisture damage in asphalt concrete and the effectiveness of different additives and treatments to mitigate moisture-induced damage. Tayfur et al. [18] evaluated the moisture susceptibility and rutting performance of asphalt mixtures with polymer modifiers, highlighting improvements in TSR values similar to those observed in this study. Kandhal and Rickards [19] provided case studies of premature failure in asphalt overlays due to stripping, evaluating TSR results to understand moisture susceptibility. Taherkhani [20] investigated the moisture susceptibility of warm mix asphalt mixtures using the TSR test, providing comparative data for evaluating moisture damage. Kiggundu and Roberts [21] provided a comprehensive review of the stripping phenomenon in hot mix asphalt and critically evaluated various test methods, including TSR, to assess moisture susceptibility.

Table 3. Results of Moisture Susceptibility Test for AC14 and CRMA Mixes

Mixes	AC14	CRMA			
Road Segment	FT 222 Sec 0	FT 62 Sec 0	FT 02 Sec 312	FT 08 Sec 67	FT 02 Sec 331
Flood year (occurrence flooding)	2021 (1)	2019(2)	2020(2)	2020 (2)	2021(1)
Average Dry Strength (kPa)	959	754	682	733	610
Average Wet Strength (kPa)	433	342	355	498	564
% TSR	45.2	45.4	52.0	68.0	92.6

4 Conclusion

From the results of both the Volumetric Properties and Moisture Susceptibility tests conducted on the field samples, several observations and conclusions can be derived: Subsequent paragraphs, however, are indented.

1. The volumetric testing data indicates that the CRMA and AC14 pavement materials are produced in accordance with road authority specifications. The tested core samples taken after the completion of the maintenance works show compliance with the product performance requirements. Pavement materials sourced from different quarries for various sites also comply with road authority requirements, ensuring that material quality from different quarries does not affect the pavement's performance and intended durability.

2. The moisture susceptibility test results display varying TSR values influenced by various possible factors. The lowest TSR value for the CRMA pavement was observed at FT 62 Sec 0, where maintenance was completed in 2019, while the highest TSR value was at FT 02 Sec 333, with maintenance completed in 2021 before the flooding incidents. The TSR values demonstrate a reduction as the pavement ages, possibly due to the aging of the bituminous material, which decreases the pavement's strength. Exposure to high temperatures accelerates bitumen aging, affecting its adhesion properties. Additionally, the sites FT 62 Sec 0, FT 02 Sec 312, and FT 08 Sec 67, which were flooded twice in 2021, likely experienced diminished bituminous material strength over time due to the combined effects of moisture and heat, reducing cohesion and adhesion properties. For the dense graded AC14, the TSR value is the lowest despite maintenance work being completed in 2021. The control section FT 222 Sec 0, using normal bitumen as its binder, showed the highest susceptibility to moisture damage. This indicates that while CRMA mixtures generally perform better in resisting moisture-induced damage, the AC14 mix, especially with standard bitumen, is more vulnerable under similar conditions.

3. CRMA mixtures generally offer better resistance to moisture-induced damage compared to standard AC14 mixes, highlighting the benefit of using modified binders for improved pavement performance, especially in flood-prone and high-temperature regions.

   Some recommendations for future research in this area include utilizing advanced testing methods such as dynamic modulus testing and fatigue life analysis to gain a deeper understanding of the mechanical properties and performance of CRMA and AC14 mixes. Developing climate-specific pavement design guidelines will enhance moisture resistance by considering local rainfall patterns, temperature ranges, and traffic loads. Additionally, conducting life cycle cost analysis (LCCA) will highlight the long-term economic benefits of using modified binders like CRMA over conventional materials, factoring in maintenance, durability, and performance.

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