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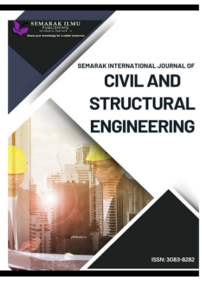

Performance Evaluation of Cold Premix Asphalt with Tire Waste Mixed on Road Pothole

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ABSTRACT

Potholes remain a critical cause of vehicle damage, accidents, and high maintenance costs, while waste tires pose environmental challenges due to limited recyclability. This study evaluates the performance of Cold Premix Asphalt (CPA) incorporating fine crumb rubber for pothole repair, with a focus on Bulk density, Void in Mineral Aggregate (VMA), Marshall stability, moisture susceptibility, bonding strength, and deformation resistance. Twelve samples were prepared under three mixture conditions and tested accordingly. Results showed that Bulk density was reduced with crumb addition due to its low density and elastic properties. The neat CPA achieved the highest Marshall stability, while crumb rubber–modified CPA recorded the lowest; however, stability improved when bitumen was added to the crumb mix. Voids in Mineral Aggregate (VMA) increased significantly with crumb rubber, but decreased with bitumen, reflecting improved compaction. Moisture susceptibility decreased in modified mixes yet remained above the 80% threshold. Field observations over three weeks confirmed that all CPA variants maintained adequate bonding and compaction under traffic conditions. Overall, the findings indicate that CPA, particularly when modified with crumb rubber and bitumen, offers a sustainable and effective alternative for pothole repair, supporting both performance and environmental benefits.

1. Introduction

Road surface damage, including bumps and potholes, not only affects the driving experience but also can cause damage to car components like tires and suspension systems, increasing the risk of accidents. [1] Potholes are the most common bowl-shaped holes on roadways, with various dimensions on pavement surfaces [2]. A pothole is quite a big structural road collapse. It is produced by the combination of water and transportation [3]. Regular inspections, repairs, and maintenance of roads and highways are necessary to protect them from wear and tear from traffic, weather, and other causes. Improper road maintenance leads to fast degradation, including potholes, bumps, and

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cracks. Traditional repair methods rely on harmful materials and require frequent upkeep. The present research examines the viability of using waste tire crumb in cold premix asphalt (CPA) as a greener alternative. Typically, crumb rubber is made from discarded tires. Recycling tires is an eco-friendly technique to reduce environmental concerns. Incorporating crumb rubber in asphalt mixes is a sustainable technique to reuse used tires in road building [4]. Tires can be burned, recycled into bituminous mixtures (dry or wet), used as aggregate in pavement and cement concrete [4], reprocessed into fuel gas, oils, solid residue (char), and low-grade carbon black, or devulcanized [5]. Then, CPA is environmentally friendly, with low-temperature and easy-to-apply material for pothole repair. CPA is ready-made asphalt that was produced through the cold mix asphalt (CMA) procedure. CMA is a more ecologically friendly alternative to hot mix asphalt (HMA). Cold mixes are made using aggregates, asphalt emulsion, and water at ambient temperature [6][7]. CMA patching materials may be quickly manufactured to fill potholes on a pavement surface [6] and the micro-surfacing does not require a rolling compaction process. Several factors affect the mechanical and durability properties of CMA, such as aggregate gradation, binder (residue) grade, binder content, water content, void content, curing condition, curing time, and active fillers. etc [8].

According to Wulandari and Tjandra [9], the voids in mineral aggregate (VMA) increase with higher bitumen content, ensuring that mixtures retain sufficient voids for asphalt binder, thereby promoting durability and meeting the general requirements for asphalt mixtures. In a related study, Wulandari and Tjandra [9,10] also reported that crumb rubber can serve as a suitable substitute for fine aggregates in cold mix asphalt (CMA), where the incorporation of finer crumb rubber particles improved mixture stability while still satisfying the specified Void in Mixture (VIM) requirements. Similarly, Khaled et al. [11] observed that bulk density decreases with increasing crumb rubber content due to its lower density relative to conventional aggregates; for instance, a mixture with 5% crumb rubber exhibited a bulk density of 2.35 g/cm³ compared to 2.45 g/cm³ for the control mixture. Their results also indicated that VMA values increased with crumb rubber addition, suggesting improved void characteristics for binder absorption. Furthermore, another study [12] demonstrated that a mixture containing 4% crumb rubber achieved a TSR of 92.6%, reflecting strong resistance to moisture damage. However, higher crumb rubber contents were found to reduce indirect tensile strength due to increased air voids and reduced compaction, which negatively impacted cohesion. These findings suggest that while crumb rubber enhances bonding between aggregate and bitumen, its proportion must be carefully optimized to balance mechanical integrity and moisture resistance.

Building on these insights, the present study investigates the effects of Cold Premix Asphalt (CPA) under three mixture conditions on mechanical performance, volumetric properties, density, and moisture susceptibility, as well as evaluates the durability of pothole repairs with respect to bonding and deformation behavior. This study is significant as it evaluates the potential of Cold Premix Asphalt (CPA) and its modified forms as sustainable alternatives for road maintenance and repair. Pothole damage remains a critical issue affecting road safety, serviceability, and maintenance costs, particularly under high moisture and traffic conditions. Unlike conventional hot mix asphalt, CPA requires no heating during preparation or application, thereby reducing energy consumption, emissions, and operational costs. By incorporating waste materials such as crumb rubber, CPA further supports circular economy practices while enhancing mechanical performance and durability. The findings of this research contribute to identifying cost-effective, environmentally responsible, and technically reliable solutions for extending pavement service life, ultimately promoting more resilient and sustainable road infrastructure.

2. Experimental Procedure

2.1 Samples Preparation and Testing

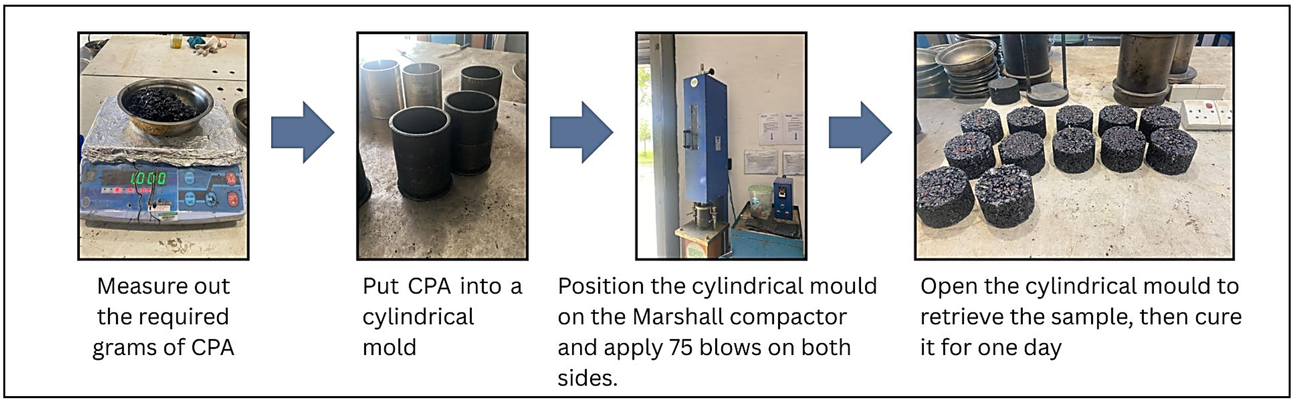

Fig. 1. Sample preparation procedure

Figure 1 shows the proses experimental procedure, three materials data were prepared for Cold Premix Asphalt (1000g); Cold Premix Asphalt mixed with crumb rubber (1050g) in proportion 20:1 and Cold Premix Asphalt mixed with bitumen and crumb rubber (1100g) in proportion 20:1:1. The materials are weighed and mixed to a desired consistency for each setup. Three specimens are prepared from each material, allowing for reliable and accurate results. These samples are subsequently tested for performance and properties such as Volumetric analysis, Marshall stability, and moisture susceptibility. There were three different additive levels tested in the 12 samples. The steel cylindrical mold was positioned on the automatically operated compaction equipment for 75 blows. The specimen, 100 mm in diameter and 63.5 mm in height, was removed from the mold and allowed to cool for one day before testing. Bitumen and crumb rubber were mixed in a mechanical mixer for 3–5 min at 160°C before the asphalt mixture was cast in molds for tests.

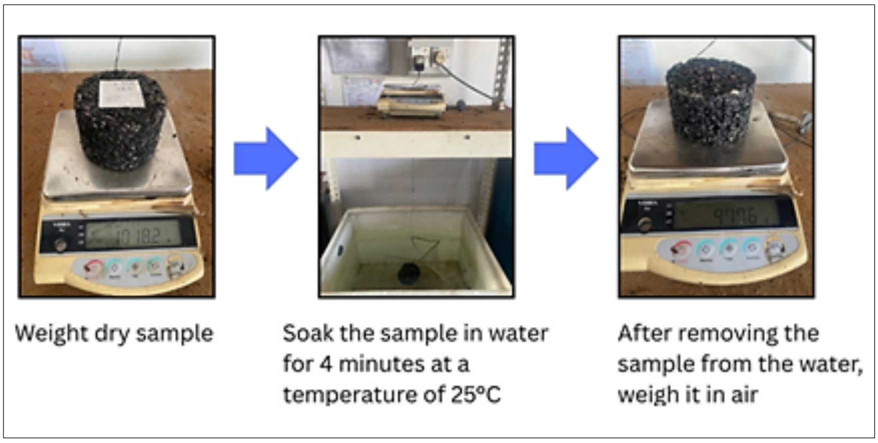

Fig. 2. Bulk density measurement

Figure 2 shows the preparation of samples for bulk density. For the bulk density measurement, the samples were cooled down in a water bath (25°C ± 1°C) for at least 4 minutes for a temperature balance, then the submerged weight was measured as in Eq. (1).

$$Bulk\ Density, Gmb = \frac{MDry}{MSSD - MSub} \quad (1)$$

Where;

M_{Dry} = dry mass in air

M_{SSD} = saturated surface dry mass
M_{sub} = mass of specimen in wate

The VMA is calculated by the measurement of the average bulk specific gravity of the mix (Avg) with compacted asphalt specimens and using standard test procedures. Then the P_s value in the mix (percentage stone) can be calculated by the proportion of the weight of the aggregate. Then, determine the bulk specific gravity of the aggregate G_{sb} through the method of specific gravity tests. This number represents the empty space between aggregates in the mixture to allow for the binder to improve on durability. The equation for VMA as in Eq. (2):

$$VMA = \left(1 - \frac{G_{MBxPs}}{G_{SB}}\right) \times 100 \quad (2)$$

Where;

VMA = Voids in Mineral Aggregate (%)
G_{mb} = Bulk specific gravity of the compacted mix
P_s = Aggregate portion by weight of total mix (%)
G_{sb} = Bulk specific gravity of the aggregate

Marshall Stability test in accordance with ASTM D6927 was conducted by placing the asphalt specimen into the Marshall Stability Testing Machine, ensuring proper alignment of the loading head. Gradually apply the load at a rate of 50.8 mm per minute and record the maximum load before specimen failure (stability value, measured in kN). Then, to assess the Moisture Susceptibility of CPA, prepare cylindrical specimens and first conduct the dry Indirect Tensile Strength (ITS) test by allowing the specimens to cure for 24 hours at 25ºC, then applying a load using a Marshall testing machine at a rate of 50.8mm/min across the vertical diametrical plane. Record the peak load at failure to calculate the dry ITS using the formula where L is the peak load, D is the specimen's diameter, and H is its height.

$$ITS = \frac{2L}{\pi DH} \quad (3)$$

Next, soak the specimens in water at 25°C for 24 hours. After conditioning, perform the wet ITS test using the same loading procedure and record the peak load to determine the wet ITS. Finally, calculate the TSR as Eq. (4) by comparing the wet ITS to the dry ITS using the formula TSR. TSR of 80% or higher, indicating good moisture resistance.

$$TSR\ (\%) = \frac{Indirect\ Tensile\ Strength\ (Conditioned)}{Indirect\ Tensile\ Strength\ (Unconditioned)} \times 100 \quad (4)$$

2.2 Procedure Patching Potholes

The next procedure involves observing the durability of pothole repairs using three different conditions of CPA in terms of bonding and deformation after testing. The procedure for patching potholes is as follows: Clean the pothole to remove debris, loose material, dirt, and water. Then, put and spread the CPA evenly across the pothole. Next, compact the CPA using the hand tamper and inspect the repaired area for defects such as air voids or improper compaction**.** The potholes will be inspected weekly to assess whether the CPA remains intact or has deteriorated**.**

3. Results and Discussions

Table 1 compares the performance of CPA and its modified mixtures. Pure CPA exhibited the highest bulk density (2.198–2.217 g/cm³), high Marshall stability (17.131–17.94kN), moderate VMA (9.85–12.12%), and excellent moisture resistance (TSR >112%), confirming its suitability as a strong, durable pavement material [13,14]. The incorporation of crumb rubber reduced density (1.862–1.867 g/cm³) and stability (5.566–5.749kN), while significantly increasing VMA (24.24–25.00%). Although moisture resistance declined (TSR 81.88–81.99%), values remained within acceptable limits (>80%), meeting the standard for medium-volume roads [13,14]. When bitumen was added with crumb rubber, Marshall stability improved markedly (17.135–20.223kN), often surpassing pure CPA, while density slightly decreased (1.740–1.787 g/cm³) and VMA was reduced (21.21–22.35%) as the bitumen partially filled rubber-induced voids. Moisture resistance remained acceptable (TSR 81.89–81.99%), though lower than that of pure CPA [14]. Collectively, these results show that while crumb rubber alone compromises density and stability, its combination with bitumen produces a dense, stable, and durable mix with enhanced strength, supporting its potential as a sustainable material for road maintenance [13,14].

Table 1
Cold Premix Asphalt + Crumb

CPA	Trial	Bulk Density (g/cm³)	VMA (%)	Marshall (kN)	TSR (%)
CPA	Sample 1	2.198	9.85	17.131	112.31
	Sample 2	2.217	11.36	17.132	113.12
	Sample 3	2.218	12.12	17.135	113.60
CPA + Crumb	Sample 1	1.862	24.24	5.566	-
	Sample 2	1.867	24.62	5.630	-
	Sample 3	1.867	25	5.749	-
CPA + Crumb + Bitumen	Sample 1	1.740	21.21	17.949	81.88
	Sample 2	1.743	21.59	18.277	81.89
	Sample 3	1.787	22.35	20.223	81.99

3.1 Bulk Density

Figure 3 shows the test results for the weight/volume per mass unit of the cold premix asphalt samples, which are screening tests that exhibit an exponentially decreasing value once a few materials are added. With an average g/cm³ between the three samples, the CPA also had the highest bulk density. The size of CPA aggregates was neither too small nor very large, but there were visual spaces or voids that appeared in the specimen after compaction, which meant poor packing, but because of the larger bulk density and good fit of the aggregates in CPA, the Marshall stability became better [1]. In addition to Crumb (CPA + Crumb), the bulk density reduced to 1.9g/cm^3, because there was not enough bitumen to hold the materials together properly. As a result, the mix became less compact, and the bulk density decreased. The bulk density of CPA + Crumb mix, even with the addition of bitumen, has shown a decrease. This is on account of the 0.43 mm crumb particles that are light and springy, which means they lower the overall mix weight. Their smallness can also result in more air space between particles, so the mix is less dense. When the amount of bitumen is insufficient to completely coat all aggregates, then a voider mixture and thus lower bulk density would be the result.

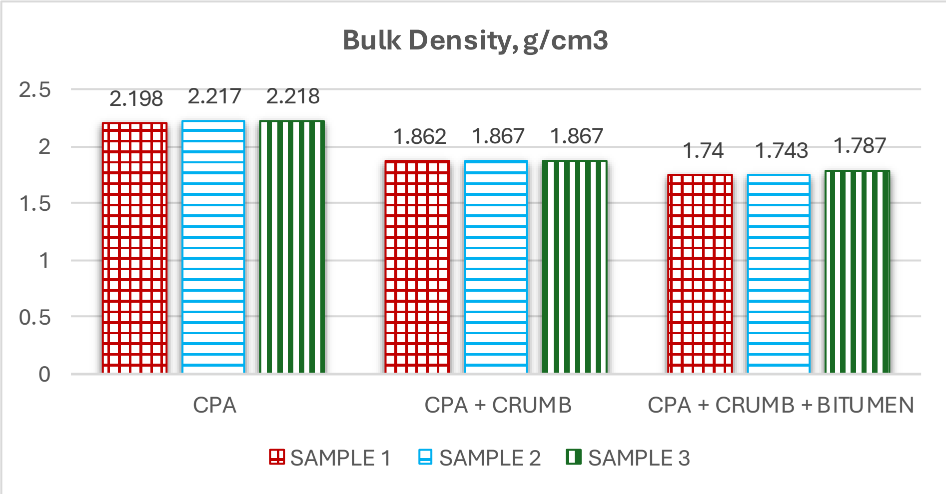

Fig. 3. Results of bulk density

3.2 Void in Mineral Aggregate

Figure 4 shows a clear pattern in Void in Mineral Aggregate (VMA) values across three different combinations. CPA has low VMA values, between 9.85% and 12.12%. This suggests a thick and well-compacted mix. When 50g of crumb rubber was added to the CPA, VMA increased significantly in all samples, ranging from 24.24% to 25%. This sharp rise is due to the elastic and low-density nature of crumb rubber, which increases volume without strengthening the aggregate interlock. This results in more internal voids. In the third mix, which included 50g of bitumen, VMA slightly decreased to between 21.21% and 22.35%. The added bitumen partially filled the gaps left by the crumb rubber, improving the coverage and compatibility of the mix. Overall, the data indicate that crumb rubber greatly increases VMA, and while extra bitumen can reduce it, the values remain higher than those of the initial CPA. The previous results [9] indicate that VMA improves as bitumen content increases, and more air voids for better binder coating and durability [9]. On the other hand, in the present study, VMA values with crumb rubber were, in general, higher, and the lowest values were 21.21%–22.35% also when 50g of bitumen was added. The introduced binder filled voids that were formed by crumb rubber to some extent, leading to better coverage and mixture compatibility. Although the trend is different, the findings are consistent, with crumb rubber increasing VMA and additional bitumen improving the mixture to provide satisfactory durability and meet the general requirements of asphalt.

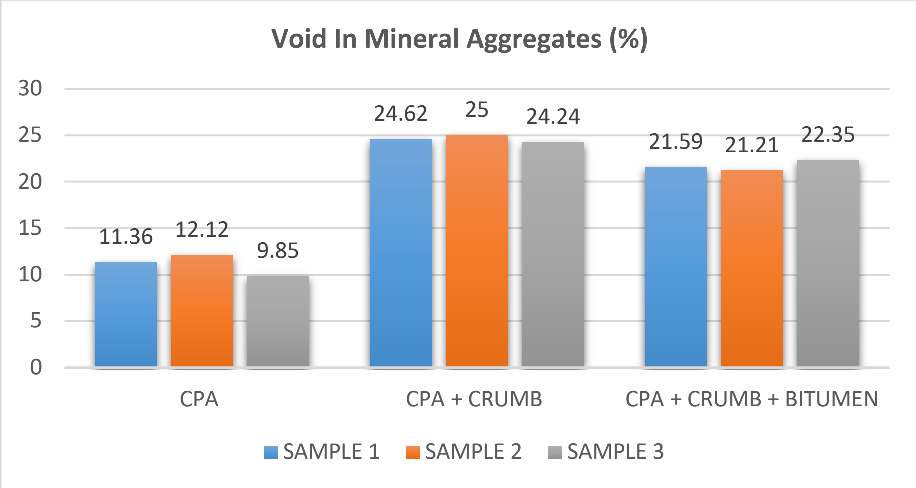

Fig. 4. Results of VMA

3.3 Marshall Stability

Figure 5 shows Marshall Stability values of the CPA specimens, which show an obvious variation in the strength of the materials when modified. The stability of all the unmodified CPA samples is high, with a value of about 17kN, which demonstrates a high load-carrying capacity. With 50g of ground rubber (CPA + G.R.) MSS is reduced to about 5-6kn for all the samples, which proves that only crumb rubber affects the internal structure, and it is due to worse bonding and elastic properties, which are not adequately covered by the binder. Even though there was a reduction in the values of Marshall stability of CPA + crumb rubber mix, they were still far above the minimum required value of 2.0kN for medium volume traffic roads (MVTR) [13].

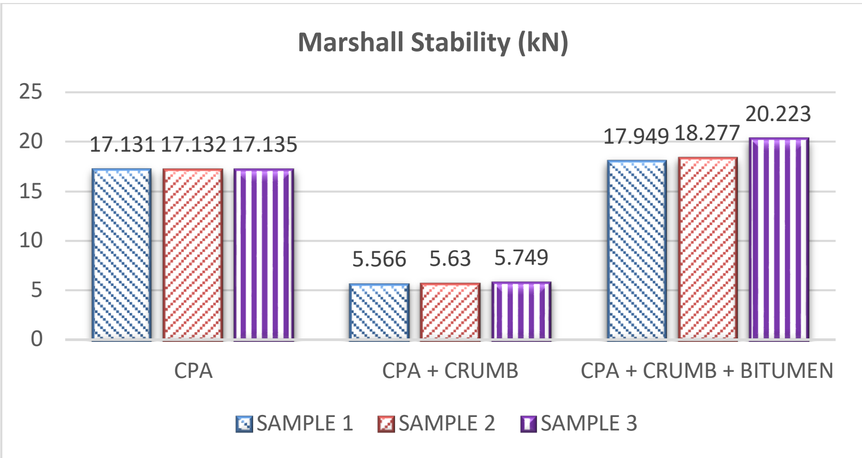

Fig.5. Results of Marshall stability

The incorporation of bitumen into the crumb rubber–modified mix (CPA + Crumb + Bitumen) produced a notable increase in Marshall stability, exceeding that of the unmodified CPA, with values ranging from approximately 18kN to slightly above 20kN. This enhancement in stiffness can be attributed to the interaction between bitumen and rubber particles, which strengthens the rubberized binder and results in higher Marshall stability [15]. These findings indicate that bitumen serves as an effective bonding agent between aggregates and crumb rubber, thereby improving the tensile bond strength and overall structural performance after repair. Given that all samples tested in this study exhibited stability values above the baseline requirement, the proposed mix demonstrates promising potential with respect to MVTR. Similar beneficial effects of waste rubber on the mechanical properties of asphalt mixes, particularly in enhancing Marshall stability, have also been reported in previous studies [15].

3.4 Moisture Susceptibility

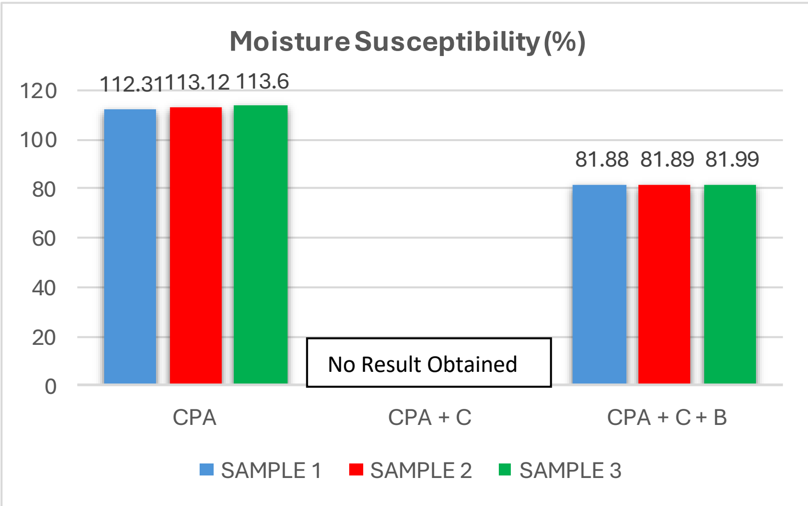

Fig. 6. Results of moisture susceptibility

Figure 6 presents the moisture susceptibility results for Cold Premix Asphalt (CPA) and the modified CPA mixes. The CPA samples recorded very high values (112.31–113.60%), indicating excellent resistance to moisture damage and strong cohesion, well above the 80% TSR benchmark for acceptable performance [6,14]. This suggests that CPA is highly suitable for wet conditions. By contrast, the CPA + C mix failed during the Marshall stability test due to its brittle nature, while the addition of crumb rubber and bitumen reduced the values to 81.88–81.99%. Although still above the minimum threshold, this reduction indicates a greater susceptibility to moisture damage, likely due to the hydrophobic properties of crumb rubber, which hinder bitumen–aggregate bonding. Higher VMA values observed in earlier tests may also have contributed to increased air voids and moisture penetration. Overall, the modified mix shows reduced moisture resistance compared to the original CPA

3.5 Patching Pothole

Pothole repair work was conducted on a village road in Parit Raja, with the repaired sections inspected weekly. Figures 8 to 10 illustrate the repair process using CPA, CPA + Crumb, and CPA + Crumb + Bitumen, respectively. In each figure, (a) shows the pothole prior to treatment, (b) depicts the pothole after filling with the designated CPA material, and (c) presents the patched area following compaction. Post-repair, the sections were monitored on a weekly basis to evaluate durability, with particular attention to adhesion and surface deformation. These observations provide valuable insights into the effectiveness and long-term stability of the three CPA variants under actual field conditions.

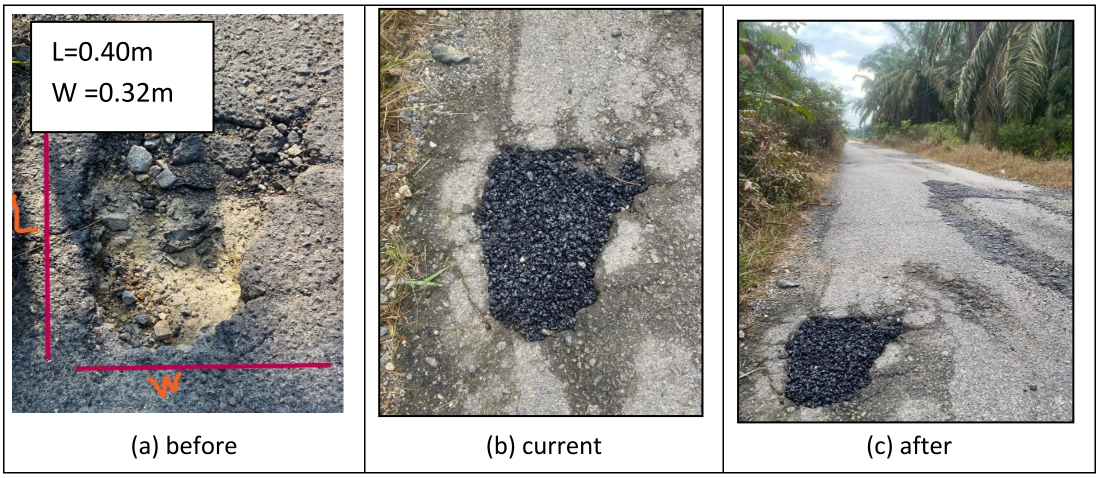

Fig. 8. Patching pothole using CPA

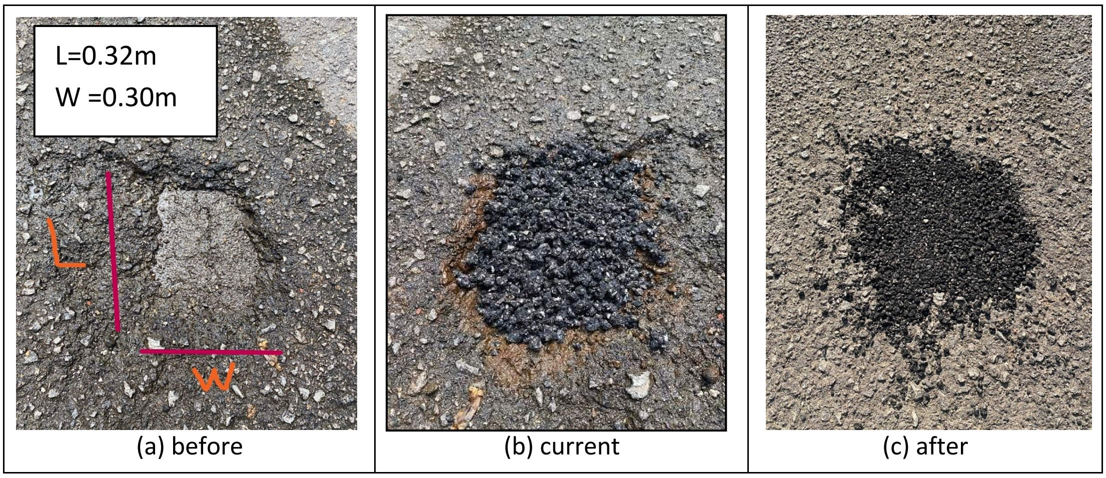

Fig. 9. Patching pothole using CPA + Crumb

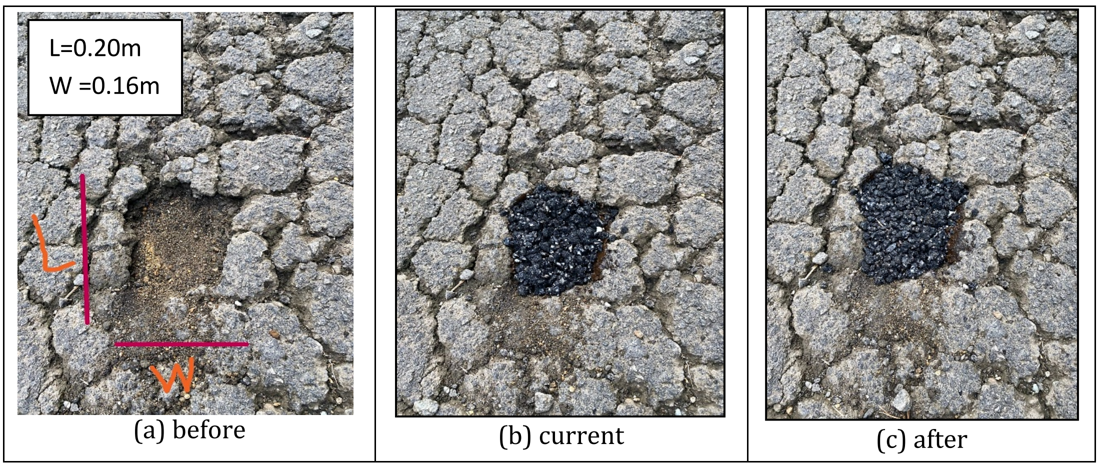

Fig. 10. Patching pothole using CPA + Crumb + Bitumen

a) CPA b) CPA + Crumb c) CPA +Crumb +Bitumen

Fig. 11. Observed image after three-week patching pothole

After three weeks of field monitoring (Figure 11), all CPA variants, including CPA, CPA + Crumb, and CPA + Crumb + Bitumen, showed good compaction and adhesion with no significant deformation under traffic loading. Despite its fragility in laboratory tests, the CPA + Crumb mix performed well in the field, indicating effective compaction under real traffic conditions. These results confirm that CPA and its modified forms meet short-term durability requirements and are suitable for medium-volume roads. Furthermore, the use of crumb rubber from waste tires provides an environmentally sustainable and cost-effective alternative to natural aggregates, with potential benefits in extending pavement service life and reducing maintenance needs. Hence, promoting recycled materials in road construction supports both performance improvement and broader sustainability goals.

4. Conclusions

This study investigated the incorporation of tire waste crumb rubber into Cold Premix Asphalt (CPA) for pothole repair, with emphasis on mechanical properties, volumetric stability, moisture susceptibility, and short-term durability. Three CPA mixtures were examined: plain CPA, CPA modified with crumb rubber, and CPA modified with crumb rubber and bitumen. The results demonstrated that crumb rubber improved Marshall stability, resistance to cracking, and water resistance of the mixtures. The modified CPA also exhibited acceptable density, satisfying both compaction and stability requirements. Field observations conducted over a three-week period revealed strong bonding and resistance to deformation, indicating satisfactory short-term performance. Overall, the utilization of waste tires in CPA offers an efficient, sustainable, and cost-effective alternative for temporary pothole repair.

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