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Utilization of Reprocessed Pavement Materials

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***Abstract* –** The utilization of Reclaimed Asphalt Pavement (RAP) in pavement construction presents a promising avenue for sustainable infrastructure development. This study investigates the feasibility of RAP materials, aligning with National Highway Authority (NHA) Class B specifications, through a comprehensive analysis of physical and mechanical properties. Physical tests including sieve analysis and abrasion testing, alongside mechanical assessments like penetration tests, inform the potential of RAP to meet pavement construction requirements while reducing reliance on virgin materials. The rejuvenation process, blending RAP bitumen with virgin bitumen, is optimized to balance mechanical properties and sustainability objectives. Through optimized rejuvenation processes, blending RAP bitumen with virgin bitumen achieves a 60/70 penetration grade, showcasing a reduction in virgin material usage and enhancement in pavement durability. This approach highlights a qualitative shift towards eco-friendly practices in pavement engineering, ensuring long-term environmental benefits while maintaining optimal performance standards.

Keywords – Reclaimed Asphalt Pavement, National Highway Authority, Sustainable Infrastructure, Pavement Construction, Rejuvenation Process.

I. INTRODUCTION

Reclaimed Asphalt Pavement (RAP) has become an essential component in modern road construction, significantly contributing to sustainability [1]. The practice of reusing asphalt began in the early 20th century, with systematic efforts gaining traction in the mid-20th century [2]. The oil crisis of the 1970s, combined with rising environmental concerns and the increasing cost of virgin materials, accelerated the development of asphalt recycling technologies [2]. Today, RAP plays a crucial role in reducing the environmental impact of road construction while conserving natural resources [3-4]. The process involves milling or grinding old pavement, processing the material, and incorporating it into new asphalt mixes, maintaining both structural integrity and performance characteristics [5-12].

While RAP offers numerous benefits, such as reduced energy consumption, lower greenhouse gas emissions, and improved pavement performance, its widespread adoption is hindered by several challenges. These include material variability, lack of standardized guidelines, and limited emphasis on optimizing material properties [13-14]. Addressing these issues is crucial to enhancing RAP utilization and promoting sustainability in road construction [1,15].

This research aims to investigate the physical properties of RAP materials to better understand their suitability and performance in road construction [1, 5-12]. The study focuses on characterizing RAP and analyzing its performance to optimize its use in asphalt mixes. By determining the appropriate balance of virgin materials and RAP, this research will provide insights into creating high-quality, sustainable road surfaces [16-17].

The methodology involves obtaining RAP samples and separating the components through chemical processes. Once separated, individual tests on bitumen and aggregates are conducted to assess their properties, including penetration, softening points, gradation, and strength [18-21]. After characterizing the reclaimed materials, a Job Mix Formula (JMF) is prepared and tested to evaluate performance against national standards [22].

The findings from this research will help optimize the use of RAP by determining how much virgin material is necessary to meet the required standards for asphalt mixes. By conducting fatigue and strength tests, this study aims to establish a practical framework for using RAP effectively in road construction, contributing to the overall sustainability and performance of infrastructure projects.

II. MATERIALS AND METHOD

To achieve the objectives of this project, a two-step approach was employed. The first step involved obtaining Reclaimed Asphalt Pavement (RAP) samples, followed by separating the constituent materials. This separation was achieved using carbon tetrachloride (CCl_4). The second phase focused on conducting individual tests on the asphalt components—aggregates and bitumen. A Job Mix Formula (JMF) was developed using the reclaimed material and compared to the specifications for NHA Class-B Asphalt. Based on the results, a new JMF was formulated by adjusting the proportions of RAP and adding the necessary amount of virgin material to achieve the desired performance parameters.

2.1 Materials

This study utilized Reclaimed Asphalt Pavement (RAP), aggregates, and bitumen sourced from various locations. The RAP was obtained from DHA Phase V, Islamabad, in compliance with National Highway Authority (NHA) Class-B specifications for the wearing course. Aggregates were procured from the Margalla Crush Stone office in Taxila, Rawalpindi, known for producing high-quality Margalla Crush, ensuring reliability for construction purposes. The bitumen used was of grade 80/100, sourced from the Attock Oil Refinery (ARL) near Morgah, Rawalpindi, a standard penetration grade suitable for road paving.

2.2 Reclaimed Asphalt Separation and Testing Process

The separation of Reclaimed Asphalt Pavement (RAP) involves breaking down the material into smaller chunks and extracting its components.

2.3 Extraction of Reclaimed Asphalt Material (RAP)

After collecting the RAP from the site, it is transported to the laboratory, where larger pieces are mechanically broken into smaller chunks without damaging the aggregates. The reduced RAP is then mixed with carbon tetrachloride (CCl_4) and heated to facilitate separation.

Once cooled, the solvent dissolves the bitumen, allowing the aggregates to settle at the bottom of the extractor for collection. The CCl_4 is then evaporated, leaving behind the extracted bitumen. It is important to note that the extracted aggregates may lack fine particles, while the bitumen tends to be harder with a lower penetration value due to these fine particles being absorbed.

2.4 Tests on Aggregates

In evaluating aggregates, key parameters such as particle sizes and strength are assessed through gradation and the Los Angeles Abrasion Test [20-21].

A representative sample of aggregates is dried and passed through a series of sieves (37.5 mm to No. 200) arranged in descending order. The sample is weighed before sieving and subjected to shaking until no

more than 1% of the material passes through each sieve within one minute. The retained material on each sieve is weighed.
The percentage of total weight retained is calculated and compared to National Highway Authority (NHA) Class-B specifications. Discrepancies are noted, and a report is generated detailing initial and retained weights, calculated percentages, and recommendations for adjustments.

Table 1: Sieve Analysis Test Results with Passing Percentages

Sieve Size (mm)	Retained Weight (g)	Cumulative Retained Weight (g)	Passing Weight (g)	Passing Percentage (%)
19.0	0	0	966.1	100
12.5	136.5	136.5	829.6	85.87
9.5	85.8	222.3	743.8	76.99
4.75	277.6	499.9	466.2	48.26
2.36	187.7	687.6	278.5	28.83
1.18	207.4	895.0	71.1	7.36
0.075	36.2	931.2	34.9	3.61
Pan	34.9	966.1	0	0

The Los Angeles Abrasion Test, following ASTM C131-01, measures the percentage loss in strength of aggregates. Steel balls were added to aggregates in a rotating drum, spun at 30 to 33 rev/min for 500 revolutions.
Post-rotation, aggregates were separated on a sieve (1.70 mm, No. 12) and oven-dried. Weights of the original sample (W_1) and retained material (W_2) were recorded, with abrasion value calculated as:
The abrasion value will be calculated by:

$$Abrasion\ Value = \frac{W_1 - W_2}{W_1} \text{ x } 100$$

$$\%\ Loss = \frac{Change\ in\ Wt.\ retained\ on\ \#\ 12\ sieve}{Original\ Wt. retained\ on\ \#\ 12\ sieve} \text{ x } 100$$

For aggregates passing through the 4.75 mm sieve and retained on the 2.36 mm sieve, Class D Gradation was used. Results:

- W1=5000 g $W_1 = 5000$
- W2=1640 g $W_2 = 1640$
- **Abrasion Value = 32.80%**

2.5 Tests on Bitumen

The assessment of bitumen focuses on determining its grade, flow, and softening characteristics through two key tests: the penetration test and the softening point test [18-19].
After extracting bitumen from the RAP material, it is heated for 30 minutes and then cooled for 1 to 1.5 hours in a container. The sample is placed in a water bath at 25 ºC, after which it is tested using a penetrometer to measure penetration. This value is used to assess the grade of the bitumen.
Table 2.2 presents the results of the penetration grade of bitumen.

Table 1: Penetration Grade of Bitumen

Sr. #	PenetrationValue	Grade of bitumen
1	18.7	20
2	21.3	

The softening point test assesses the flow characteristics of bitumen. Heated bitumen is placed in two brass rings with steel balls and submerged in a water bath. The softening point is the average temperature at which both disks soften enough for the balls to drop 25 mm (1.0 in.).
After evaluating the properties of the Reclaimed Asphalt mix, a comparison with NHA Class-B asphalt is made to develop a new Job Mix Formula (JMF) aiming for similar performance. The softening point was found to be 58°C, within the acceptable range of 50°C - 75°C.
This initiates the second phase of the research, focusing on formulating the JMF using reclaimed and virgin materials to achieve the desired performance

2.6 Formulating JMF with Reclaimed & Virgin Materials

The main objective of this research is the complete utilization of reclaimed material, supplemented with the necessary percentages of virgin materials to meet NHA specifications. Data from testing individual constituents, aggregates and bitumen, will guide this process. New aggregates will be sourced from the Margalla Crushing Plant, while virgin bitumen will be obtained from Attock Oil Refinery Limited (ARL). A hit-and-trial approach will determine the required quantity of virgin materials to adjust the asphalt mix properties to conform to NHA Class-B asphalt specifications.
Sieve analysis data reveals the missing aggregate sizes relative to NHA Class-B gradation. To achieve compliance, the percentage by weight of the missing aggregate particles will be added to the existing mix. Following the addition of new aggregates, the increase in strength will be assessed using the Los Angeles Abrasion Test.

Table 3: Modification in Aggregates Extracted from the RAP Sample to align with NHA Class-B Specifications

Sieve Size (mm)	JMF Percentages (%)	RAP Materials (gm)	Virgin Material Adjustment (gm)	New RAP Material (gm)	RAP Percentages (%)	Actual Material to be used in Mix Design (gm)
19.0	100	0	0	0	0	0
12.5	82.1	651.9	243.0	894.9	18.77	216.1
9.5	70.0	545.6	59.5	605.1	12.69	146.1
4.75	49.9	1527.7	-522.5	1005.2	21.09	242.7
2.36	34.4	943.7	-170.0	773.7	16.23	186.8
1.18	9.6	968.0	273.0	1241.0	26.04	299.7
0.075	4.7	255.3	-9.7	245.6	5.13	59.3
Pan	0	107.3	-107.3	0	0	0

The extracted bitumen tends to be harder, exhibiting low penetration values due to the absorption of fine aggregate particles. To address this, virgin bitumen from Attock Oil Refinery Limited will be added to the extracted bitumen. An Equation for the blended penetration value P is:

$$P = x \, . \, P_1 + (1 - x) \, . \, P_2$$

Where P_1 = Penetration of the harder bitumen, P_2 = Penetration of the softer bitumen and x = Fraction of the harder bitumen

To meet NHA Class-B specifications, a blend ratio of 35.7% was utilized for Grade 20 (RAP sample) and 64.3% for Grade 80/100 (virgin bitumen).

2.7 Formulation of a Job Mix Formula

A new Job Mix Formula (JMF) is prepared using the modified aggregates and bitumen [22]. The properties of this JMF will be evaluated and compared with NHA Class-B asphalt specifications.

In this step, heated bitumen is mixed with aggregates to create three samples. One sample is left loose to dry in a container, while the other two are compacted. Compaction involves placing the mixture in a specimen mold, covering it with a collar, and applying 75 blows with a hammer raised to a height of 18 inches. After compacting one end, the mold is inverted, and the same compaction process is applied to the other end. The samples are then extracted using a sample extractor.

2.8 Volumetric Analysis

To evaluate the qualities of the asphalt, several tests are conducted, focusing on density and void calculations. Key parameters include the Bulk Specific Gravity of Aggregates (Gsb), Maximum Specific Gravity of Loose Asphalt Mix (Gmm), Bulk Specific Gravity of Compacted Asphalt Mixture (Gmb), Specific Gravity of Asphalt (Gb), and Effective Asphalt (Pbe). The Rice Test method is used to determine Gmm by weighing the loose asphalt sample and measuring the volume of displaced water. Gsb is calculated by comparing the mass of a permeable material to an equivalent volume of distilled water, while Gmb is determined by weighing compacted cylindrical samples in both air and water.

Additional parameters such as Voids in Mineral Aggregates (VMA), Air Voids (Va), and Voids filled with Asphalt (VFA) are critical for assessing asphalt properties and its Optimum Asphalt Content (OAC). VMA represents the percentage of the total sample volume that signifies the intergranular void space between aggregate particles, including air voids and effective asphalt. Va indicates the percentage of total volume corresponding to air spaces between coated aggregate particles, whereas VFA is the percentage of voids in the aggregates filled with asphalt, calculated as the ratio of (VMA - Va) to VMA. These metrics collectively inform the characteristics and optimal composition of asphalt for efficient paving performance.

Table 2.4 shows the volumetric analysis done for the asphalt mix sample prepared by using the rejuvenated RAP sample.

Table 2.4: Volumetric Analysis of Rejuvenated RAP Sample

Binder Content (%)	4.1
G_{sb}	2.665
G_{mb}	2.306
P_s	95.9
G_{mm}	2.359
VMA	17
V_a	2.22
VFA	63
Stability (kg)	1487.3
Flow (mm)	8.7

Table 2.5 shows the volumetric analysis for the NHA Class-B specified sample.

Table 2.5: Volumetric Analysis for NHA Class-B Specified Sample

Binder Content (%)	4.1
G_{sb}	2.629
G_{mb}	2.348
P_s	95.9
G_{mm}	2.482
VMA	14.5
V_a	3.21
VFA	57.9
Stability (kg)	1470
Flow (mm)	10.5

Table 2.6 shows the weights and bulk specific gravity of the asphalt mix samples.

Table 2.6: Weights and Bulk Specific Gravity of Asphalt Mix Samples

Bitumen Content (%)	4.10	
Sample	1	2
Weight of Sample (gm)	1193.6	1181.8
Weight in Water (gm)	688.3	676.6
SSD Weight (gm)	1204.3	1190.5
G_{mb}	2.313	2.300
Wt. of Loose Sample (gm)	1212.6	
Wt. of Cont. + Water (gm)	10978.0	
Wt. of Cont. + Water + Sample (gm)	11676.5	
G_{mm}	2.359	
Unit Weight (kg/m^3)	2282.4	2259.8
Stability (kN)	665.0	
Stability (kg)	1487.3	
Flow (mm)	8.7	

2.9 Marshall Stability Test

The Marshall Stability Test evaluates the flow properties and stability of asphalt mixtures, measuring their resistance to cracking and deformation under loads. The stability value, in kilonewtons (kN), indicates how well the asphalt can withstand stress.

Cylindrical specimens are compacted using a Marshall compactor and then conditioned. They are subjected to vertical load in the testing apparatus, where the maximum load indicates stability. Results are compared to NHA Class-B specifications to assess the impact of added virgin materials.

2.10 Semi-Circular Bending Test

The Semi-Circular Bending Test assesses the fatigue resistance of asphalt concrete under repeated loading, simulating real traffic conditions. This test determines how many cycles a specimen can endure before failure [23].

Semi-circular specimens undergo cyclic loading with defined parameters. Load and vertical deformation are recorded until failure occurs. The test measures axial deformation and concludes upon cracking.

The load-bearing capacity is key to evaluating performance. The control sample, following NHA Class B specifications, reached 51 kN, while the rejuvenated RAP sample achieved 44 kN.

2.11 Total Immersion Test

The Total Immersion Test evaluates the moisture susceptibility of asphalt mixes, focusing on their resistance to moisture damage, which can cause stripping between the asphalt binder and aggregates [24]. Asphalt specimens are compacted into cylindrical shapes, conditioned (either at room temperature or in an oven), and then fully immersed in water at approximately 60°C (140°F) for about 24 hours. After immersion, visual inspections are conducted to check for signs of moisture damage, including stripping.
Key parameters include maintaining a water temperature of around 60°C and a 24-hour immersion period, though these can vary based on specific protocols. This test is crucial for determining the durability of asphalt mixes under moist conditions, helping to guide material selection and the use of additives to enhance moisture resistance. By assessing the performance of the asphalt mix, engineers can make informed decisions that improve the quality and longevity of pavements.

III. RESULTS

3.1. Performance Comparison Between RAP & NHA Class-B Sample:

(a) Mechanical Properties Comparison:

The comparison between the RAP and NHA Class-B samples shows similar binder content, while the RAP sample has higher bulk specific gravity (Gsb), voids in mineral aggregates (VMA), and voids filled with asphalt (VFA), indicating better compaction. The RAP sample also exhibits slightly higher stability and lower flow, confirming its suitability for pavement construction. All measured parameters are within acceptable limits, demonstrating the rejuvenated RAP's performance is comparable to the NHA Class-B standard.

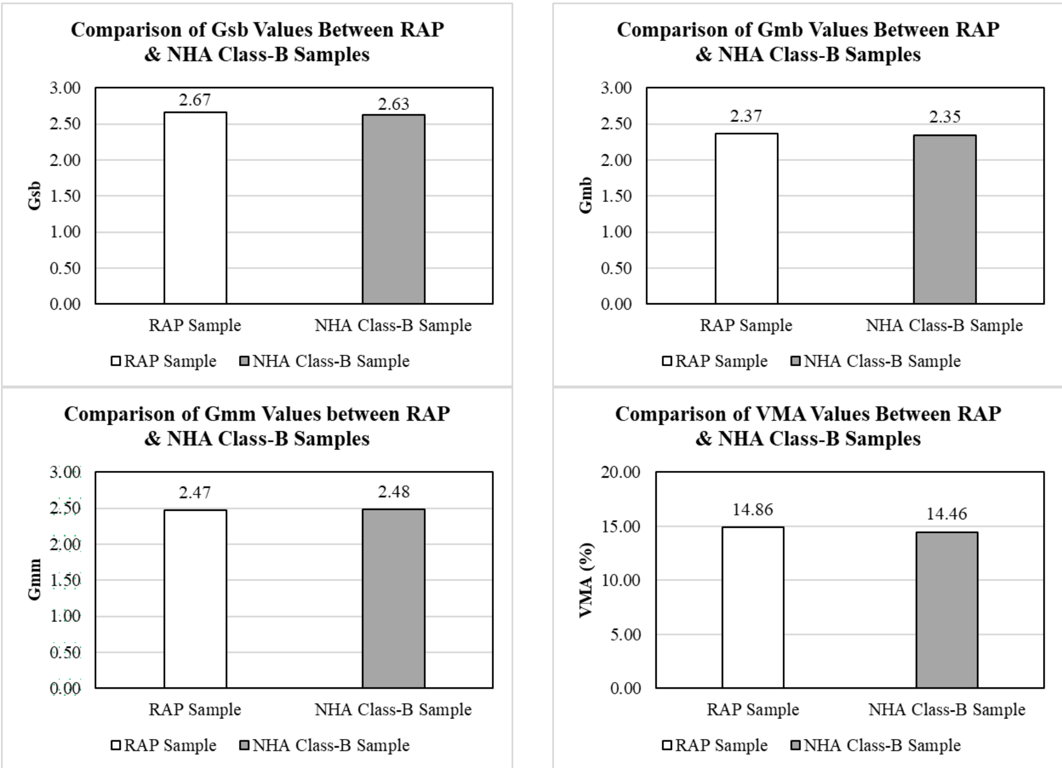

Fig 1: Mechanical Properties Comparison Bar Charts

(b) Performance Metrics Comparison:

The comparison shows that RAP samples have fewer air voids and higher voids filled with asphalt, indicating better compaction and asphalt distribution. RAP samples also exhibit slightly higher stability and lower flow, suggesting improved load-bearing capacity with less deformation. These results confirm that when properly blended with fresh asphalt, RAP material performs comparably to NHA Class-B standards, ensuring the mix's effectiveness.

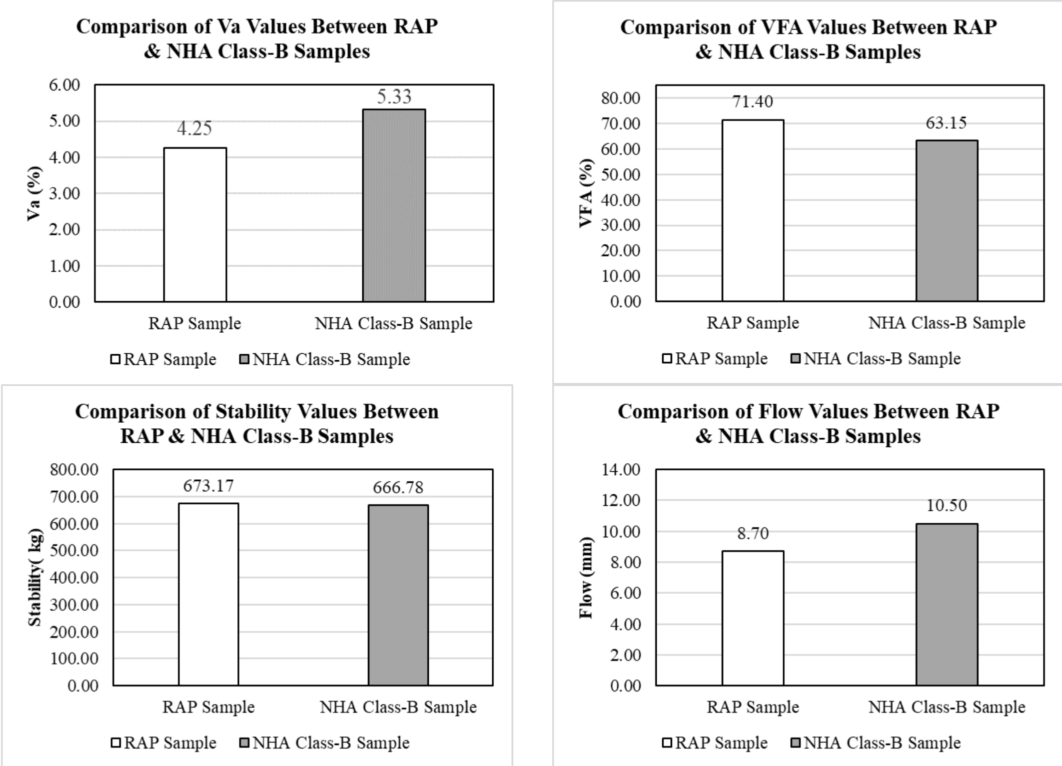

Fig 2: Performance Metrics Comparison Bar Charts

3.2. Fatigue Comparison Between RAP & NHA Class-B Sample:

The fatigue comparison shows that the NHA Class-B sample has a higher load-bearing capacity of 51 kN, while the rejuvenated RAP sample bears 44 kN before cracking. This suggests that the NHA sample is more resistant to deformation. The lower capacity of the RAP sample highlights the need for efficiency improvements to meet NHA load-bearing standards, despite the potential benefits of using reclaimed materials.

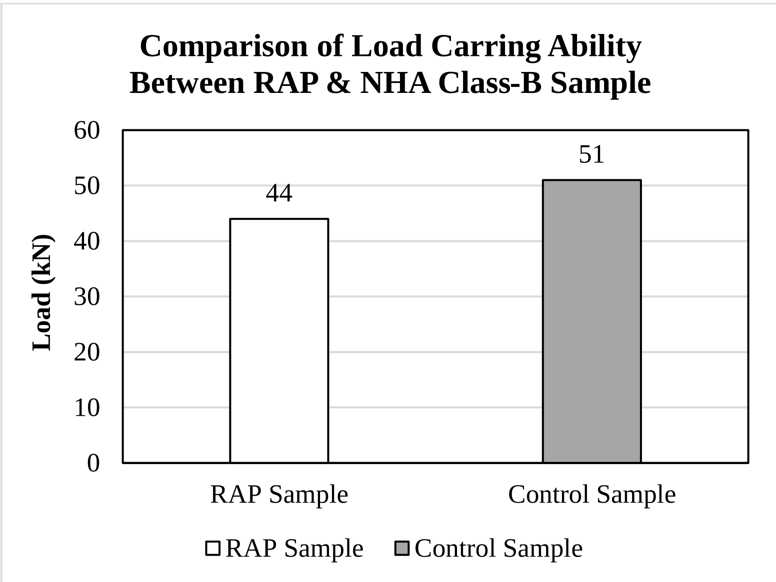

Fig 3: Load Carrying Ability Comparison Bar Chart

3.3. Moisture Damage Assessment for RAP and NHA Class-B Samples

The total immersion test indicated that the NHA Class-B sample retained 90-95% integrity, while the rejuvenated RAP sample showed a reduction to 85-90% after one day in water. Both samples exhibit moisture susceptibility, suggesting that enhancements in the rejuvenation process are needed for better resistance to moisture-induced distress.

IV. DISCUSSION

This discussion examines the mechanical performance, fatigue resistance, and moisture susceptibility of RAP compared to NHA Class-B samples, assessing RAP's potential and areas for improvement in pavement construction.

- Compare and discuss the mechanical properties (Gsb, VMA, VFA, stability, and flow) of RAP and NHA Class-B samples, explaining how RAP's compaction and load-bearing capacity meet the standards.

- Analyze the higher stability and better compaction of RAP material, discussing its implications for pavement durability and performance over time.

- Evaluate the difference in fatigue resistance between RAP and NHA Class-B, discussing potential improvements needed in RAP to enhance its load-bearing capacity.

- Discuss the moisture damage results, exploring potential adjustments in RAP rejuvenation techniques to improve resistance to water-induced distress.

- Discuss the environmental and economic benefits of utilizing RAP materials in pavement construction, particularly in terms of resource conservation and lifecycle costs.

- Provide insights on how the rejuvenation process can be improved for better fatigue resistance and moisture damage mitigation, aligning RAP materials more closely with NHA standards.

- Reflect on the limitations of your research, including sample size, test conditions, and any external factors that may influence the generalizability of the findings.

- Suggest areas for future research, such as long-term field performance studies of RAP in different environmental conditions or testing with alternative rejuvenating agents.

V. CONCLUSION

The conclusions drawn from the above conducted study are as follows:

1. Both RAP and control samples showed potential for pavement construction, but the control sample aligned more closely with NHA Class B gradation specifications, while RAP had a passing percentage of 48.26% for the 4.75 mm sieve.
2. The optimized blend of 35.7% RAP and 64.3% virgin bitumen met the 60/70 penetration grade requirements, making RAP comparable to standard mixtures in terms of bitumen performance.
3. RAP exhibited a moderate abrasion value of 32.8%, while the control sample showed better durability under mechanical stress.
4. The control sample outperformed RAP, with a load-bearing capacity of 51 kN compared to RAP's 44 kN, making the control sample stronger against deformation.
5. The rejuvenated RAP sample demonstrated slightly better stability (673.17 kg) and a higher VMA (14.86%) than the control sample, indicating better compaction and binder distribution.

6. RAP shows potential in pavement construction, but further testing and optimization are needed to ensure it meets durability and performance standards before widespread use.

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