Comparative Study on Marshall Properties of Hot and Cold Mix Asphalt for DBM Layer Using RAP

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Abstract : The increasing demand for road construction has led to excessive consumption of natural resources such as aggregates and bitumen. Conventional Hot Mix Asphalt (HMA) requires high temperatures, resulting in increased energy consumption and environmental concerns. Cold Mix Asphalt (CMA), produced at ambient temperature using bitumen emulsion, offers a sustainable alternative. The use of Reclaimed Asphalt Pavement further enhances sustainability by reusing existing pavement materials and reducing construction costs. This study presents a comparative evaluation of Marshall properties of HMA and CMA for Dense Bituminous Macadam layer using RAP. Mixes were prepared with different RAP contents along with a control mix using virgin aggregates. The performance of the mixes was evaluated through Marshall Stability, Flow, and volumetric properties. The results indicate that both HMA and CMA mixes satisfy the required specifications, with HMA exhibiting comparatively higher stability. The study highlights the potential of RAP-based cold mix asphalt as a sustainable and cost-effective alternative for pavement construction.

***Index Terms* - Cold mix Asphalt, Hot Mix Asphalt, Recycling Asphalt Pavement**

I.INTRODUCTION

The increasing pace of urbanization and road network expansion has shifted the focus toward sustainable yet high-performance pavement solutions, particularly in heavily trafficked corridors. Dense Bituminous Macadam (DBM) plays a central structural role in flexible pavements by distributing vertical stresses and resisting fatigue cracking, rutting, and shear deformation. Traditionally, Hot Mix Asphalt (HMA) has dominated DBM construction due to its excellent strength, cohesion, and field-proven durability under repeated loading. However, the high-temperature production regime of HMA not only escalates energy and fuel costs but also amplifies carbon emissions and accelerates binder aging, making it less compatible with modern sustainability targets and climate-resilient infrastructure goals.

Against this backdrop, Cold Mix Asphalt (CMA) produced using bitumen emulsion at ambient temperature is gaining attention as a viable, low-energy alternative for binder and maintenance layers. CMA reduces onsite energy use, lowers emissions, and enables stockpiling and construction under marginal weather conditions, while Reclaimed Asphalt Pavement (RAP) from resurfacing and rehabilitation helps conserve virgin aggregates and reduce landfill waste. Optimizing RAP content and choosing between HMA and CMA are critical to ensure DBM meets strength, durability, and volumetric requirements without compromising workability. A focused comparison of Marshall properties for HMA and CMA DBM mixes with varying RAP proportions therefore supports the adoption of RAP-based technologies that balance structural performance with environmental responsibility in modern pavement construction.

II. NEED OF THE STUDY

The rapid expansion of road networks and traffic intensities has increased demand for Dense Bituminous Macadam layers, raising consumption of virgin aggregates and bitumen along with energy use and greenhouse gas emissions. Conventional Hot Mix Asphalt for DBM offers high strength but conflicts with sustainable development and climate-action goals focused on resource conservation and low-carbon construction. Cold Mix Asphalt, prepared with bitumen emulsion at ambient temperature, reduces fuel use and emissions, supporting eco-friendly and circular-economy objectives. Large quantities of Reclaimed Asphalt Pavement from rehabilitation remain underutilized, despite their potential to conserve natural resources and reduce landfill waste. A comparative study of Marshall properties for HMA and CMA DBM mixes with varying RAP content is therefore needed to optimize sustainable, cost-effective pavement solutions that align with long-term environmental and infrastructure-resilience goals.

III. OBJECTIVES OF THE STUDY

- To design Dense Bituminous Macadam mixes using Hot Mix Asphalt and Cold Mix Asphalt by incorporating different proportions of Reclaimed Asphalt Pavement.
- To evaluate the performance of the mixes based on Marshall properties, including Stability, Flow value, Bulk Density, Air Voids, Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB).
- To compare the mechanical and volumetric behavior of HMA and CMA mixes prepared with 0%, 50%, and 70% RAP content under similar gradation and binder conditions.
- To determine the optimum RAP content that satisfies DBM specifications while ensuring adequate strength, workability, and overall performance.

IV. METHODOLOGY

The study follows an experimental methodology to evaluate the performance of RAP-based hot mix asphalt (HMA) and cold mix asphalt (CMA) for DBM layer. Reclaimed Asphalt Pavement (RAP) material was collected and tested to determine the binder content, which was found to be 3%. Mixes were prepared with RAP proportions of 0%, 50%, 70%, and 100%, and the remaining portion was replaced with virgin aggregates to achieve the required gradation. The total binder requirement was determined from the optimum binder content, and the binder already present in RAP was considered while calculating the additional binder to be added.

For hot mix asphalt, the aggregates and RAP were heated to the required temperature (about 150–160°C), after which the calculated quantity of bitumen was added and thoroughly mixed to ensure proper coating. The mix was then placed in Marshall moulds and compacted using standard compaction procedures. For cold mix asphalt, the mixing was carried out at ambient temperature without heating, where RAP and virgin aggregates were blended with bitumen emulsion based on the required binder content. The mixture was properly mixed until uniform coating was achieved, and specimens were prepared and allowed to cure for emulsion breaking before testing.

Marshall specimens were tested for stability, flow value, and volumetric properties such as air voids, VMA, and VFB. The results were used to compare the performance of HMA and CMA mixes and to assess the suitability of RAP in pavement construction.

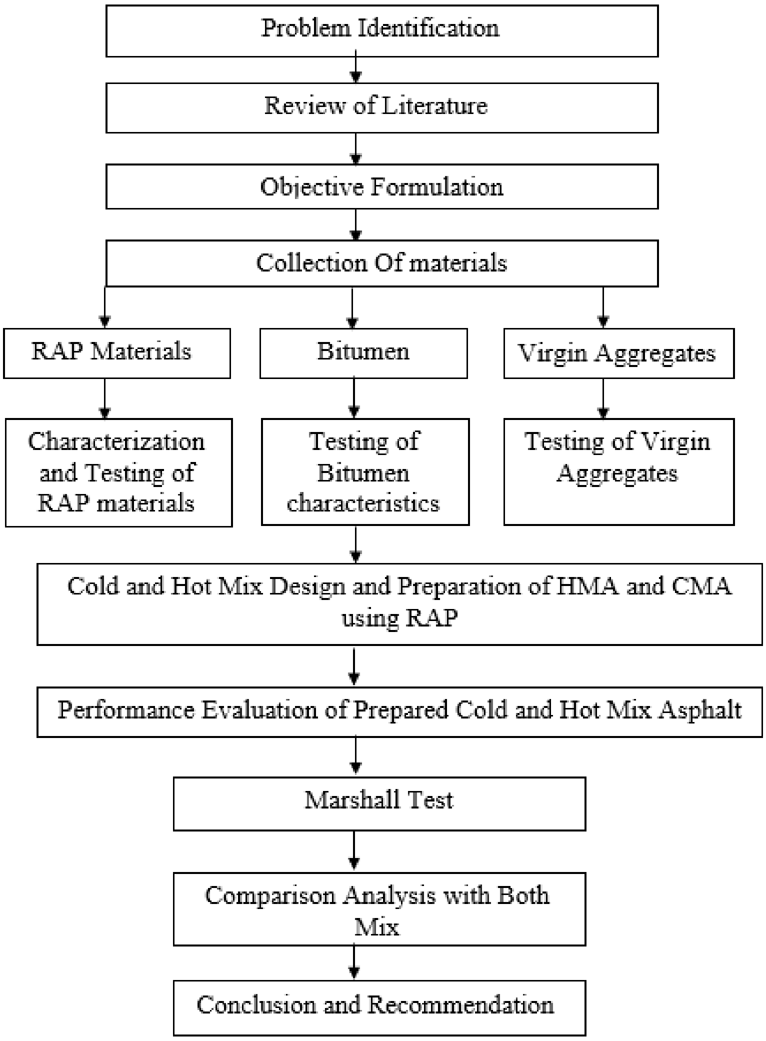

Fig -1: Methodology

V. RESULTS AND DISCUSSION

The experimental program involved the preparation and testing of Dense Bituminous Macadam (DBM) mixes using both Hot Mix Asphalt (HMA) and Cold Mix Asphalt (CMA) with 0%, 50%, and 70% Reclaimed Asphalt Pavement (RAP) by mass of aggregates. Marshall mix design was adopted to determine the optimum binder content, and each mix was evaluated for stability, flow value, bulk density, air voids, voids in mineral aggregate (VMA), and voids filled with bitumen (VFB). The results show that HMA consistently yields higher Marshall stability and lower flow values, indicating a stiffer, more compact structure, whereas CMA offers slightly lower strength but acceptable workability and volumetric parameters within the permissible DBM range. The incorporation of RAP in both HMA and CMA influences the stiffness–ductility balance and volumetric characteristics, with 50% RAP emerging as the most balanced proportion in terms of performance and mix stability.

5.1 Results of Hot Mix Asphalt (HMA)

Hot Mix Asphalt (HMA) DBM mixes showed higher Marshall stability and lower flow values compared to CMA, reflecting the improved binder–aggregate bonding achieved at elevated mixing and compaction temperatures. The control mix with 100% virgin aggregates typically achieved stability values above 12 kN, with flow in the range of 2.8–3.2 mm which is given in the table 1, air voids around 4%, and VMA and VFB satisfying standard DBM specifications. As RAP content increased to 50% and 70%, HMA demonstrated a rise or sustained high stability (13–14 kN), along with reduced air voids and higher VFB, indicating denser packing and enhanced stone-on-stone contact. The aged binder in RAP contributed to mix stiffness, improving rut resistance while maintaining volumetric acceptability. Overall, HMA-DBM with RAP up to 70% exhibited strong structural performance, making it suitable for high-traffic binder course applications when properly balanced with fresh binder content

Table -1: Marshall and Volumetric Properties of HMA

Mix (%)	Marshall Stability (kN)	Marshall Flow (mm)	Bulk Density (g/cm³)	V_v (%)	V_{MA}(%)	V_{FB} (%)
100 %VA	12.5	3.2	2.42	4.0	14.8	73
50%RAP	13.8	2.8	2.44	3.6	15.2	75
70%RAP	13.2	2.5	2.45	3.4	15.8	77

5.2 Results of Cold Mix Asphalt (CMA)

Cold Mix Asphalt (CMA) DBM mixes prepared at ambient temperature using bitumen emulsion exhibited lower Marshall stability compared to HMA across all RAP levels. For 100%virgin aggregates, CMA recorded a stability in the range of 9–10 kN with flow values around 3.5–3.7 mm, indicating acceptable deformability and workability under standard compaction tabulated in above table 2. When 50% RAP was incorporated, stability increased slightly (around 9.5–10 kN), air voids reduced, and voids filled with bitumen (VFB) improved, suggesting better aggregate packing and binder effectiveness. At 70% RAP, however, stability decreased marginally while air voids increased, indicating that excessive RAP content may reduce effective coating and homogeneity in CMA. Volumetric properties such as VMA and VFB remained within typical DBM limits, confirming that CMA-DBM with moderate RAP (up to 50%) can meet structural and durability requirements for low- to medium-traffic applications.

Table -2: Marshall and Volumetric Properties of CMA

Mix (%)	Marshall Stability (kN)	Marshall Flow (mm)	Bulk Density (g/cm³)	V_v (%)	V_{MA} (%)	V_{FB} (%)
100%VA	9.4	3.7	2.38	4.8	14.5	68
50%RAP	9.8	3.5	2.40	4.2	15.1	72
70%RAP	8.6	3.2	2.39	4.6	15.3	70

5.3 Comparative Analysis of Marshall and Volumetric Properties of HMA and CMA

The combined analysis of Marshall and volumetric properties clearly reflects the performance of HMA and CMA mixes across different RAP contents in the DBM layer. The Marshall Stability of HMA increases from 12.5 kN at 100% virgin mix to a maximum of 13.8 kN at 50% RAP, and then slightly decreases to 13.2 kN at 70% RAP. In contrast, CMA shows lower stability values, increasing from 9.4 kN to 9.8 kN at 50% RAP, followed by a reduction to 8.6 kN at 70% RAP. Flow values for HMA decrease from 3.2 mm to 2.8 mm and further to 2.5 mm with increasing RAP, indicating increased stiffness, while CMA shows a similar decreasing trend from 3.7 mm to 3.5 mm and 3.2 mm.

From the volumetric properties, air voids (Vv) for HMA decrease from 4.0% at 100% virgin mix to 3.6% at 50% RAP and 3.4% at 70% RAP, indicating better compaction and densification. For CMA, air voids reduce from 4.8% to 4.2% at50% RAP but increase to 4.6% at 70% RAP, suggesting reduced compaction efficiency at higher RAP content. The VMA values increase slightly with RAP for both mixes, maintaining adequate void space for binder, while VFB values also increase, indicating improved binder filling, especially in HMA.

Overall, at 50% RAP, both HMA and CMA exhibit optimum performance with higher stability (13.8 kN for HMA and 9.8 kN for CMA), moderate flow values (2.8 mm and 3.5 mm), and acceptable air voids (3.6% and 4.2%), satisfying DBM requirements. At 70% RAP, although HMA maintains relatively high stability (13.2 kN), CMA shows a noticeable reduction in stability (8.6 kN) and an increase in air voids (4.6%), indicating performance limitations. Hence, based on both Marshall and volumetric properties, 50% RAP is identified as the optimum replacement level for DBM layer, with HMA showing superior performance while CMA remains a feasible and economical alternative.

Figure 1 shows the variation of volumetric properties with increasing RAP content. It can be observed that VMA and VFB values increase with RAP percentage for both HMA and CMA, indicating higher void space and improved binder filling due to the presence of aged binder. The air voids (Vv) show a slight decreasing trend in HMA, which indicates better compaction and denser mix formation, while CMA shows relatively stable values. Overall, all volumetric properties remain within permissible limits, confirming that increasing RAP does not adversely affect mix design requirements.

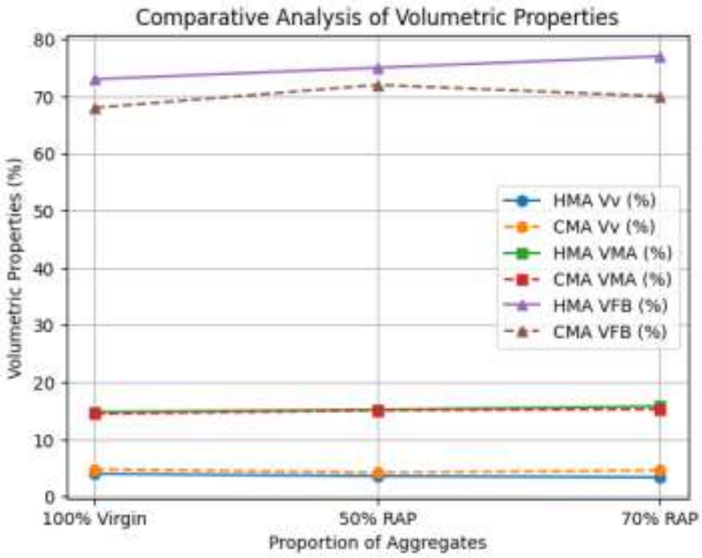

Fig -2: Comparative Analysis of Volumetric Properties CMA and HMA

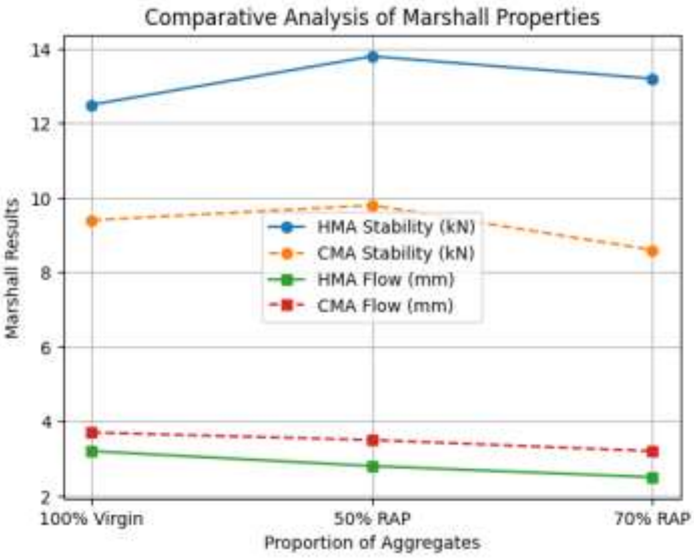

Fig -3: Comparative Analysis of Marshall Properties of CMA and HMA

Figure 2 illustrates the Marshall Stability and Flow values for different RAP contents. It is observed that stability increases at 50% RAP and slightly decreases at 70% RAP, indicating that 50% RAP provides optimum strength due to proper blending of aged and new binder. HMA exhibits higher stability compared to CMA. The flow values decrease with increasing RAP, showing that the mix becomes stiffer due to aged binder presence. Despite this trend, all values fall within acceptable limits, demonstrating that RAP can be effectively used in both HMA and CMA mixes.

VI. CONCLUSIONS

- HMA shows higher Marshall Stability (12.5–13.8–13.2 kN) than CMA (9.4–9.8–8.6 kN) with lower flow values, indicating greater strength and stiffness, while CMA provides comparatively moderate strength.

- In volumetric properties, HMA has lower air voids (4.0%–3.4%) and higher VFB (73%–77%) than CMA (4.8%–4.6% and 68%–70%), whereas CMA still maintains acceptable compaction and binder distribution.

- Overall, while HMA performs superior, CMA demonstrates satisfactory performance with the added advantage of being a more economical and sustainable alternative, especially at 50% RAP.

REFERENCES

[1]Ameri, M., Mohammadi, M.H., Motevalizadeh, S.M. and Mousavi, A., 2019. Experimental study to investigate the performance of cold in-place recycling asphalt mixes. Proceedings of the Institution of Civil Engineers – Transport, 172(6), pp.360–370.
[2]Eloufy, A. M. “Evaluating the Performance of Half-Warm Asphalt Mixtures Using Reclaimed Asphalt Pavement (RAP).” Periodica Polytechnica Civil Engineering, 2022.
[3]Flores, G., Gallego, J., Miranda, L. and Marcobal, J.R., 2020. Cold asphalt mix with emulsion and 100% RAP: Compaction energy and influence of emulsion and cement content. Construction and Building Materials, 250, p.118804.
[4]Hu, G., Yang, Q., Qiu, X., Zhang, D., Zhang, W., Xiao, S. and Xu, J., 2022. Use of DIC and AE for investigating fracture behaviors of cold recycled asphalt emulsion mixtures with 100% RAP. Construction and Building Materials, 344, p.128278.)
[5]Siddagangaiah, A.K., 2024. Effect of RAP fractionation and dosage on design and mechanical behaviour of cold asphalt mixes. Construction and Building Materials, 422, p.135773.
[6] Yao, X., Xu, H. and Xu, T., 2022. Mechanical properties and enhancement mechanisms of cold recycled mixture using waterborne epoxy resin/styrene–butadiene rubber latex modified emulsified asphalt. Construction and Building Materials, 352, p.129021.