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Analysis Engineering Material Feasibility of RAP & RAS Modified Hot Mix Asphalt for Bahadurganj–Araria Section of NH-327E

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Abstract — The use of reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) can support material circularity in highway construction by returning aged aggregate and binder to productive use. This study evaluates the resource-substitution potential and engineering feasibility of a dense-graded hot mix asphalt containing a combined 31.53% RAP and tear-off RAS. The mixture incorporated 19.89% virgin 13.2 mm aggregate, 43.66% virgin 6 mm aggregate, 1.94% hydrated lime, 2.48% VG-30 virgin bitumen, and 0.50% rejuvenator. A material-flow assessment was combined with gradation compliance and Marshall design results. Recycled binder supplied 3.33 percentage points of the 5.80% total binder content, corresponding to 57.4% of the binder system; RAS alone supplied 1.88 percentage points. All sieve results remained within the adopted Ministry of Road Transport and Highways limits. At the selected 5.8% binder content, the mixture achieved 1232.70 kg Marshall stability, 3.27 mm flow, bulk specific gravity of 2.443, 3.99% air voids, 14.19% VMA, and 71.89% VFB. These results demonstrate that substantial recycled-material and recycled-binder contributions can be achieved without losing basic Marshall and volumetric compliance. The design offers a technically credible pathway for reducing dependence on virgin pavement materials. However, project-specific cost, energy, emissions, leaching, durability, and field-performance data are required before claiming quantified environmental or economic benefits.

Keywords— material circularity; recycled asphalt shingles; reclaimed asphalt pavement; recycled binder; sustainable pavements; Bahadurganj–Araria section of NH-327E

I. INTRODUCTION

Highway construction depends on large and continuous supplies of aggregates and bitumen. Aggregate extraction alters land, consumes energy, generates dust, and requires transport from quarries to mixing plants. Bitumen production relies on petroleum refining and is sensitive to price and supply variability. As road networks expand, these material demands make resource efficiency a practical engineering concern rather than only an environmental objective.

RAP is generated during milling or removal of asphalt pavement, whereas RAS originates from manufacturing scrap or discarded roofing shingles. Both materials contain mineral particles and aged asphalt binder. Returning them to hot mix asphalt can reduce disposal demand and partially substitute virgin resources. RAS is especially binder-rich, but its binder is highly oxidized and stiff. High recycled content can therefore improve deformation resistance while making mixing, compaction, and cracking performance more difficult. A technically acceptable circular mixture must show not only a high recycled percentage but also adequate gradation, density, void structure, stability, and deformation response (Ghabchi et al., 2016; Ozer et al., 2013).

Many sustainability claims for recycled asphalt are based on the intuitive assumption that less virgin material automatically produces lower cost and lower environmental impact. The direction of benefit is reasonable, but its magnitude depends on local conditions. Collection, sorting, grinding, stockpile management, hauling distance, moisture, plant temperature, rejuvenator production, and the service life of the final pavement can offset part of the avoided virgin-material burden. Consequently, mass substitution should be distinguished from a complete life-cycle or cost assessment (Pouranian & Shishehbor, 2019; de Bortoli, 2023).

The aim of this study is to quantify the material circularity achieved by a RAP-RAS modified HMA and to determine whether that material substitution remains compatible with basic engineering requirements. The objectives are to (i) establish the mass contribution of recycled and virgin components, (ii) quantify recycled binder replacement, (iii) verify grading compliance, (iv) use measured Marshall and volumetric properties as a technical feasibility screen, and (v) identify the additional evidence needed for highway implementation in India.

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II. LITERETURE REVIEW

1. RAP and RAS as Secondary Pavement Resources
RAP is one of the most reusable products generated by road maintenance because its aggregate and binder were originally selected for pavement service. RAS also contains recoverable asphalt and mineral matter, but shingle construction introduces fibres, fine mineral granules, and greater binder ageing. Research has shown that RAS source, processing, and dosage substantially affect mixture response. Controlled grinding and source separation improve uniformity, while contamination and moisture can compromise production consistency (Zhou et al., 2012; Zieliński, 2022).

The principal circularity advantage of RAP and RAS is the simultaneous recovery of mineral and binder resources. Unlike inert recycled filler, these materials can reduce both virgin aggregate demand and virgin asphalt demand. Their aged binder may not blend completely with virgin binder, however, and therefore total binder replacement is not identical to effective binder replacement. Binder accounting remains useful as a transparent material-flow indicator, provided it is not represented as proof of complete blending.

2. Role of Rejuvenators
A rejuvenator is introduced to improve the mobility and compatibility of aged binder. Studies of high-RAP and high-RAS mixtures report that an appropriately selected recycling agent can improve workability and cracking-related properties, but excessive dosage may lower rutting resistance or increase moisture sensitivity (Arámbula-Mercado et al., 2018; Tran et al., 2017). The required dosage depends on recycled-binder stiffness, virgin grade, processing conditions, and target performance. In the present mixture, 0.50% rejuvenator was used as a modest adjustment rather than as a substitute for performance verification.

3. Sustainability Assessment Boundaries
Three levels of evidence should be separated. First, material circularity can be quantified directly from mixture composition and binder mass balance. Second, engineering feasibility can be screened using grading, volumetric, and Marshall data. Third, environmental and economic performance requires a defined functional unit and system boundary, supported by project-specific inventory data. This study completes the first two levels. It identifies the third level as future work so that potential benefits are not overstated (Zieliński, 2022).

III. MATERIALS AND METHODS

1. Mixture Composition and Binder Accounting
The proposed HMA combined recycled RAP and tear-off RAS with two virgin aggregate fractions, hydrated lime, VG-30 binder, and rejuvenator. Component proportions were calculated on the total mixture mass. Binder extraction records identified 1.45% binder from RAP, 1.88% from RAS, and 2.48% virgin binder. The reported total binder content was 5.80%; minor rounding explains the 0.01 percentage-point difference between the summed component values and the stated total.

Table 1: Material composition of the proposed mixture

Material	Mass fraction (%)	Resource category	Primary role
RAP and RAS combined	31.53	Secondary material	Recycled aggregate and aged binder
Virgin aggregate 13.2 mm	19.89	Virgin material	Coarse aggregate
Virgin aggregate 6 mm	43.66	Virgin material	Fine aggregate
Hydrated lime	1.94	Virgin additive	Filler and adhesion support
VG-30 bitumen	2.48	Virgin material	Binder
Rejuvenator	0.50	Additive	Aged-binder conditioning

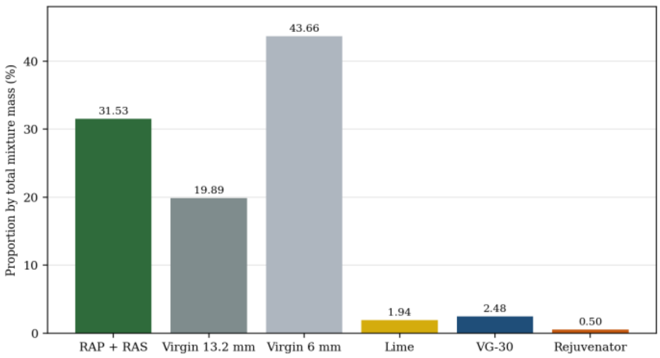

Figure 1: Mass composition of the RAP RAS modified mixture

3.2 Circularity Indicators

The recycled-material fraction was defined as the combined RAP-RAS mass divided by total mixture mass. The recycled-binder share was calculated as the sum of RAP and RAS binder divided by total binder content. Virgin-binder dependence was calculated from the VG-30 contribution. These indicators describe input substitution only; they do not include end-of-life recyclability, transport, plant energy, or service-life extension.

Table 2: Material circularity indicators

Indicator	Calculation	Result	Interpretation
Recycled material in total mix	31.53 / 100	31.53%	Direct secondary-material input
Recycled binder contribution	1.45 + 1.88	3.33% of total mix	Binder supplied by RAP and RAS
Recycled share of binder system	3.33 / 5.80	57.4%	Nominal binder substitution
RAS share of binder system	1.88 / 5.80	32.4%	Binder contribution from shingles
RAP share of binder system	1.45 / 5.80	25.0%	Binder contribution from pavement
Virgin share of binder system	2.48 / 5.80	42.8%	Remaining virgin-binder dependence

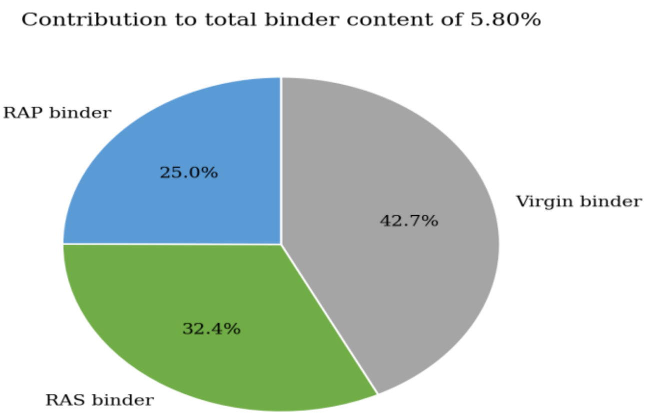

Figure 2: Source contribution to the total binder system

3. Engineering Feasibility Screen

Engineering feasibility was assessed in two stages. First, the combined aggregate grading was compared with the adopted MoRTH envelope at ten sieve sizes. Second, the selected mixture was evaluated using directly measured Marshall stability, flow, bulk and maximum specific gravity, air voids, VMA, and VFB. The measured data were used only as a screening basis; literature-derived rutting, fatigue, and moisture values were excluded from the experimental findings.

Figure 3: Study methodology and evaluation sequence

IV. RESULTS AND DISCUSSION

1. Resource Substitution

The mixture incorporated 31.53% combined RAP and RAS by total mass. This is a substantial direct recovery of secondary material, although it should not be interpreted as a 31.53% reduction in all virgin inputs because the recycled blend contains both aggregate and binder and because additives remain necessary. The two virgin aggregate fractions together accounted for 63.55% of mixture mass, showing that recycled materials complemented rather than fully replaced conventional aggregate supply.

The binder mass balance provides the more informative result. RAP and RAS jointly supplied 3.33 percentage points of a 5.80% binder system. On a nominal basis, recycled sources therefore represented 57.4% of total binder, while virgin VG-30 represented 42.8%. RAS supplied the largest individual binder contribution at 32.4% of total binder, followed by RAP at 25.0%. These values show why even a moderate shingle mass can materially reduce virgin-binder demand. They also explain the need for rejuvenation and performance checks because more than half of the nominal binder originated from aged material.

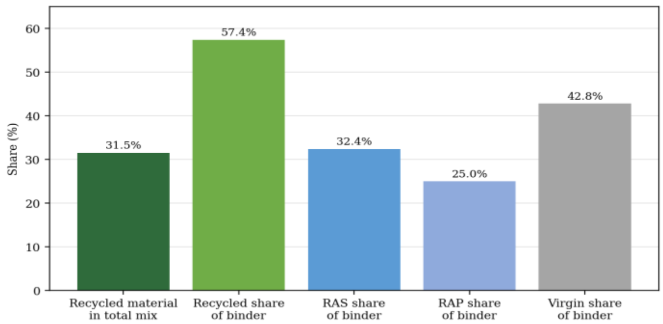

Figure 4: Comparison of calculated material circularity indicators

2. Grading Compliance

Table 3: Combined grading and adopted limits

Sieve (mm)	Passing (%)	MoRTH limit (%)	Status
19.0	100.00	100	Complies
13.2	94.63	90-100	Complies
9.50	80.90	70-88	Complies
4.75	62.49	53-71	Complies
2.36	49.47	42-58	Complies
1.18	40.93	34-48	Complies
0.600	33.73	26-38	Complies
0.300	22.34	18-28	Complies
0.150	16.63	12-20	Complies
0.075	6.71	4-10	Complies

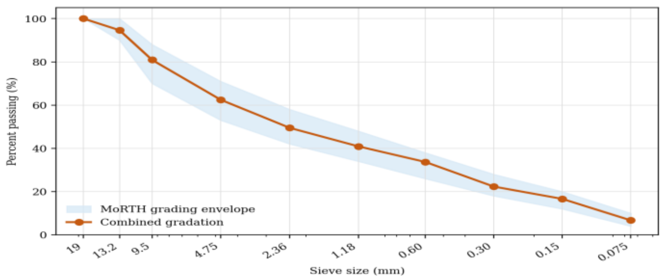

Figure 5: Combined aggregate gradation within the MoRTH grading System

All ten sieve results complied with the adopted grading envelope. The blend closely followed the midpoint of the limits, with a maximum positive midpoint deviation of 1.90 percentage points at 9.50 mm and a maximum negative deviation of 0.66 percentage points at 0.300 mm. This result demonstrates that use of a secondary material did not prevent formation of a controlled aggregate structure. Gradation control is essential because variability in RAP and tear-off RAS can otherwise create inconsistent voids and binder demand.

3. Technical Validation at the Selected Binder Content

Table 4: Engineering properties at 5.8 percent total binder

Property	Measured value	Engineering interpretation
Bulk specific gravity Gmb	2.443	Maximum measured compacted density
Maximum specific gravity Gmm	2.545	Consistent with 3.99% air voids
Air voids	3.99%	Approximately 4% design target
VMA	14.19%	Adequate aggregate-binder void structure
VFB	71.89%	Balanced filling of available VMA
Marshall stability	1232.70 kg	Maximum measured stability
Flow	3.27 mm	Moderate deformation at peak stability
Marshall quotient	3.77	Balanced strength-flow response

The 5.8% binder mixture combined maximum Marshall stability and maximum compacted density with approximately 4% air voids. Stability was 1232.70 kg and flow was 3.27 mm. These values support basic structural and volumetric feasibility despite the high nominal recycled-binder share. At 6.0 and 6.2% binder, flow increased and stability declined, indicating that additional binder did not improve the mixture. The selected design therefore represents a controlled balance rather than a simple attempt to maximize recycled or total binder content.
The result is consistent with studies reporting that RAS and RAP can improve stiffness and rutting-related resistance, while rejuvenators can support workability and flexibility when carefully dosed (Ghabchi et al., 2016; Mokhtari et al., 2020). Nevertheless, Marshall stability is not a direct measure of fatigue life, fracture resistance, thermal cracking, or moisture durability. The mixture should therefore advance to balanced performance tests before field use.

4. Environmental and Economic Interpretation

The verified benefit of the design is reduced demand for virgin inputs at the mixture gate: 31.53% of total mixture mass came from RAP and RAS, and 57.4% of the nominal binder system came from recycled sources. These indicators support resource conservation and waste diversion. They do not, by themselves, quantify greenhouse-gas reduction, energy savings, or financial savings. Such outcomes depend on local shingle availability, preprocessing cost, haul distance, avoided disposal charges, virgin material prices, plant modifications, and pavement service life.

A defensible environmental assessment should use one tonne of produced HMA or one lane-kilometre of pavement over a defined design life as the functional unit. It should include collection and transport of RAP and RAS, sorting and grinding, moisture management, heating and mixing, rejuvenator production, paving, maintenance, and end-of-life recovery. A cost assessment should use the same system boundary and include quality-control and risk costs. If the recycled mixture requires shorter maintenance intervals, initial material savings may not translate into life-cycle benefit; if durability is equivalent or better, the avoided virgin binder and disposal burdens become more valuable.

5. Framework for Highway Implementation

Table 5: Recommended implementation controls

Control area	Required action	Purpose
Source acceptance	Separate shingle sources and screen contamination	Limit composition variability
Stockpile management	Control moisture and prevent segregation	Stabilize plant production
Material characterization	Measure gradation and binder content by lot	Maintain mass-balance accuracy
Binder design	Characterize recovered-binder stiffness	Select compatible VG grade and rejuvenator
Plant trial	Verify coating, temperature, and compaction	Transfer laboratory design to production
Balanced performance	Test rutting, cracking, and moisture resistance	Confirm durability beyond Marshall response
Field monitoring	Track density, distress, and maintenance	Validate service-life assumptions
Sustainability accounting	Collect energy, transport, cost, and waste data	Quantify life-cycle benefit

Implementation should proceed through controlled plant trials rather than immediate full-scale specification. Material characterization must be repeated because RAP and tear-off RAS properties vary by source and storage condition. The 0.50% rejuvenator dosage and 5.8% total binder content are specific to the investigated blend. Field quality control should verify total binder, gradation, temperature, density, and moisture. Balanced performance data should be linked to local traffic and climate before the recycled content is standardized for wider highway use.

Limitations

The study used one combined RAP-RAS blend and did not provide separate mixture series for RAP-only, RAS-only, and conventional control mixtures. Replicate data were unavailable, preventing statistical uncertainty analysis. The recycled-binder indicator assumes nominal accounting and does not establish complete blending or activation of aged binder. No project-specific energy, emission, transport, price, leaching, or landfill data were measured. Direct rutting, cracking, fatigue, moisture, ageing, and field-performance results were also unavailable. The conclusions are therefore limited to material circularity, gradation compliance, and Marshall-based feasibility.

VI. CONCLUSIONS

- The proposed HMA incorporated 31.53% combined RAP and tear-off RAS by total mixture mass, demonstrating substantial direct use of secondary pavement material.
- RAP and RAS supplied 3.33 percentage points of the 5.80% total binder content, corresponding to a nominal recycled-binder share of 57.4%.
- RAS contributed 32.4% and RAP contributed 25.0% of the binder system, reducing virgin VG-30 dependence to 42.8% on a mass-accounting basis.
- All combined gradation values satisfied the adopted MoRTH limits, confirming that recycled input was compatible with a controlled aggregate skeleton.
- At 5.8% binder, the mixture achieved 1232.70 kg stability, 3.27 mm flow, 3.99% air voids, 14.19% VMA, and 71.89% VFB, supporting basic engineering feasibility.
- Quantified cost and environmental benefits should be claimed only after project-specific life-cycle inventory, balanced performance testing, and field validation.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The mixture composition and engineering data supporting the findings are presented in the article. Additional records may be requested from the corresponding author.

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