# EVALUATION OF RECLAIMED ASPHALT PAVEMENT INCORPORATION IN ASPHA-MIN MODIFIED WARM MIX ASPHALT

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## ABSTRACT

Reclaimed Asphalt Pavement (RAP) can reduce the demand for virgin aggregates and binder in asphalt mixtures, but its performance depends on the behavior of aged binder-coated particles and their interaction with production temperature. This study evaluated RAP incorporation in Aspha-min modified Warm Mix Asphalt (WMA) and compared it with corresponding Hot Mix Asphalt (HMA) mixtures under local material and specification conditions. RAP was incorporated at 20%, 40%, and 60% replacement levels. The mixtures were assessed using volumetric properties, Marshall stability and flow, Indirect Tensile Strength (ITS), and Tensile Strength Ratio (TSR). A practical blending evaluation indicated very low RAP binder activation; therefore, RAP was treated mainly as a stiff coated aggregate, and the 60% RAP mixture was redesigned separately. Results showed that increasing RAP content increased Marshall stability and reduced flow, while air voids generally increased, particularly in WMA. ITS and TSR also improved with RAP content, and all RAP-incorporated mixtures satisfied the relevant wearing course criteria. The simplified environmental assessment showed increasing benefit with RAP content, reaching 54.95 MJ/t total energy saving and 3.98 kg $CO_2$/t reduction for WMA with 60% RAP. The findings confirm that RAP can be incorporated in Aspha-min modified WMA when binder activity and volumetric control are properly considered.

**Keywords:** reclaimed asphalt pavement, warm mix asphalt, Aspha-min, sustainability

## 1. INTRODUCTION

The reuse of Reclaimed Asphalt Pavement (RAP) is an important strategy for improving the sustainability of asphalt pavement construction. RAP consists of milled or removed asphalt mixture containing aggregates coated with aged bituminous binder. Its use can reduce virgin aggregate extraction, fresh binder demand, construction waste, and material cost. These benefits are highly relevant to local road construction, where asphalt production depends heavily on natural aggregates and energy-intensive production processes.

Despite these advantages, RAP incorporation is not a simple replacement process. During service life, RAP binder undergoes oxidation and volatilization, which increases stiffness and reduces ductility. In Hot Mix Asphalt (HMA), this aged binder can improve rutting resistance, but it may also reduce workability and increase cracking susceptibility. High production temperatures may further age the RAP binder. Warm Mix Asphalt (WMA) offers a potential solution because it enables lower production temperatures, which can reduce secondary aging. However, lower temperatures may also limit the activation and diffusion of RAP binder. Therefore, the effect of RAP in WMA must be evaluated using source-specific material characterization and local performance criteria.

The objective of this study is to investigate the influence of RAP replacement level on the volumetric, strength, and moisture susceptibility performance of Aspha-min modified WMA, while comparing the response with corresponding RAP-HMA mixtures.

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## 2. LITERATURE REVIEW

RAP is widely recognized as a valuable recycled material because it contains reusable aggregate and aged binder. Tarsi et al. (2020) noted that RAP use reduces the environmental burden associated with aggregate extraction and binder production. However, RAP performance is controlled by binder aging, aggregate gradation, source variability, and stockpile consistency. Hettiarachchi et al. (2019) and Zhao et al. (2013) reported that RAP generally improves stiffness and rutting resistance, but high RAP contents may reduce workability and cracking resistance.

The combination of RAP and WMA is governed by competing mechanisms. Guo et al. (2020) explained that WMA can limit additional binder aging and support higher RAP use, but reduced temperature can restrict aged binder mobilization. Therefore, assuming full blending between aged RAP binder and virgin binder may be inappropriate, especially for high-RAP WMA mixtures. Previous studies have shown that RAP-WMA can perform satisfactorily, but most findings are based on foreign materials, binder grades, climatic conditions, and specification frameworks. Hence, local evaluation is needed before RAP-incorporated Aspha-min WMA can be recommended for practical use.

## 3. METHOD

RAP used in this study was obtained from milled asphalt layers collected from an expressway road section in Kaduwela. A single RAP source was used to minimize variability. The material was air-dried, mechanically sieved, and separated into size fractions. RAP and virgin aggregates were blended to satisfy the Standard Specifications for Construction and Maintenance of Roads and Bridges wearing course Type II gradation.

Three RAP replacement levels were evaluated: 20%, 40%, and 60% by aggregate mass. The 20% level represented moderate RAP incorporation, 40% represented high RAP incorporation, and 60% represented a very high RAP condition. RAP-HMA mixtures and RAP-WMA mixtures were prepared for each RAP level, with the WMA mixtures produced using the selected Aspha-min WMA condition. RAP aggregates were heated to 15 °C below the target mixing temperature to reduce additional secondary aging while maintaining workability during mixing.

Because RAP binder activity strongly affects mixture design, a practical blending evaluation was conducted for 40% and 60% RAP. Since the blending test results indicated very limited active binder contribution, RAP was considered mainly as a stiff binder-coated aggregate. The prepared mixtures were evaluated using bulk specific gravity, air voids, Voids in Mineral Aggregate (VMA), Marshall stability, flow, ITS, and TSR. These parameters were selected because they are directly relevant to local wearing course specification compliance. A simplified environmental assessment was also performed using the combined effect of reduced production temperature and avoided virgin aggregate production.

## 4. RESULTS AND DISCUSSION

The RAP-incorporated mixtures were evaluated by comparing RAP-HMA and RAP-WMA at 20%, 40%, and 60% RAP with the corresponding zero-RAP control mixtures. The results showed that RAP content had a clear influence on Marshall response, volumetric behavior, tensile strength, moisture resistance, and environmental performance. A concise summary of the results and their engineering interpretation is presented in Table 1.

**Table 1.** Summary of RAP Evaluation Results and Interpretation

| RAP level | Mixture design approach | Main performance response | Environmental outcome for WMA |
|---|---|---|---|
| 20% | Control optimum binder content was used for direct comparison. | Compared with 0% RAP-WMA, Marshall stability increased by 19.8%, flow reduced by 5.5%, ITS increased by 31.1%, and TSR increased by 0.6%. The response indicates improved stiffness and tensile resistance while maintaining SSCM Wearing Course Type II compliance. | Total estimated energy saving: 38.32 MJ/t; total $CO_2$ reduction: 2.87 kg/t. |
| 40% | Control optimum binder content was used with correction for limited RAP binder contribution. | Compared with 0% RAP-WMA, Marshall stability increased by 25.3%, flow reduced by 11.7%, ITS increased by 35.8%, and TSR increased by 1.2%. Air voids increased, indicating reduced aggregate mobility during compaction, particularly under WMA production temperature. | Total estimated energy saving: 46.63 MJ/t; total $CO_2$ reduction: 3.42 kg/t. |
| 60% | A separate Marshall mix design was carried out; added virgin binder content was reduced from 5.5% to 4.95%. | Compared with 0% RAP-WMA, Marshall stability increased by 42.9%, flow reduced by 15.2%, ITS increased by 38.8%, and TSR increased by 5.3%. This confirms the highest stiffness-related response, but the mixture should be interpreted as a redesigned high-RAP condition rather than a direct continuation of lower RAP levels. | Total estimated energy saving: 54.95 MJ/t; total $CO_2$ reduction: 3.98 kg/t. |

Overall, the increase in RAP content shifted both HMA and WMA mixtures towards a stiffer and more skeleton-controlled response. Marshall stability increased and flow decreased because RAP introduced aged binder-coated particles with higher internal friction. At the same time, bulk specific gravity generally decreased, and air voids increased because the stiff RAP particles reduced aggregate rearrangement during compaction, particularly under the reduced WMA production temperature.

The ITS and TSR results also improved with RAP content, indicating that RAP contributed to load transfer and retained moisture resistance under the adopted conditioning procedure. However, the 60% RAP mixture should be interpreted as a redesigned high-RAP mixture rather than a direct continuation of the lower RAP levels. The environmental assessment further confirmed that the benefit increased with RAP content, with the highest estimated saving obtained for WMA with 60% RAP.

## 5. CONCLUSION

The RAP evaluation confirmed that RAP can be incorporated into Aspha-min modified WMA under local material conditions while maintaining acceptable laboratory performance.

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Increasing RAP content improved Marshall stability, reduced flow, and increased ITS and TSR. However, higher RAP contents also reduced compaction efficiency, especially in WMA, because RAP behaved mainly as a stiff coated aggregate with limited binder activation. The 60% RAP mixture required a separate Marshall mix design because the mixture structure and binder demand changed significantly at very high RAP content.

The study demonstrates that RAP incorporation can enhance the sustainability of Aspha-min modified WMA by reducing virgin aggregate demand and increasing energy and $CO_2$ savings. Nevertheless, RAP-WMA mixture design should not assume full RAP binder blending. Future research should include long-term rutting, fatigue cracking, stiffness, and field compaction evaluations, particularly for high-RAP mixtures, to confirm laboratory feasibility under construction conditions.

## 6. REFERENCES


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