SUSTAINABLE ASPHALT PRODUCTION USING RECLAIMED ASPHALT PAVEMENT (RAP) WITH WASTE ENGINE OIL (WEO) AS CHEMICAL REJUVENATOR: ENVIRONMENTAL AND ECONOMIC BENEFITS FOR SRI LANKA'S ROAD TRANSPORTATION

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ABSTRACT

Reclaimed Asphalt Pavement (RAP), also known as milling asphalt, is generated in large quantities in Sri Lanka as roads deteriorate rapidly due to heavy traffic and harsh weather conditions. This results in massive wastage of bitumen and aggregates, accelerating the depletion of natural aggregate sources through overexploited quarries and heavy reliance on imported bitumen (over 90% of demand). Currently, the common practice of complete pavement removal and relaying leads to enormous waste of aggregates, bitumen, machinery, and labor, with virtually no recycling processes existing in the road construction industry. This study investigates sustainable asphalt production by developing an optimized hot mix incorporating 30% RAP using Waste Engine Oil (WEO) as a chemical rejuvenator. Laboratory results confirmed a well-balanced combined gradation within the job mix formula limits. Marshall stability and volumetric properties of the 30% RAP mix were highly comparable to the conventional virgin asphalt mix. Waste Engine Oil (WEO) was effectively used as the chemical rejuvenator. Due to its rich content of aromatic hydrocarbons, saturates, and maltene fractions, WEO restores the colloidal balance in aged bitumen by peptizing and redispersing asphaltenes, which reduces viscosity, improves ductility and workability, and recovers the original rheological and mechanical properties of the binder. This 30% RAP approach offers approximately 30-40% savings in asphalt production costs, reduces carbon emissions by up to 30%, alleviates landfill pressure, and minimizes ecosystem damage (e.g., deforestation in the Central Highlands). It will strongly support Sri Lanka's resource conservation, economic recovery and infrastructure growth (including Colombo's smart city projects), and Paris Agreement commitment to carbon neutrality by 2050.

Keywords: Reclaimed Asphalt Pavement (RAP), Waste Engine Oil (WEO), chemical rejuvenators, sustainable asphalt

1. INTRODUCTION

The road construction industry in Sri Lanka is a significant contributor to environmental degradation, due to the rapid deterioration of road pavements caused by heavy traffic loads, intense rainfall, and tropical climatic conditions. This frequent deterioration leads to large-scale milling operations that generate substantial amounts of Reclaimed Asphalt Pavement (RAP), commonly referred to as milling asphalt. Currently, this valuable material, which contains reusable aggregates and aged bitumen, is largely wasted, exacerbating the depletion of natural aggregate sources. Traditional road rehabilitation practices in Sri Lanka predominantly follow a "remove and replace" approach - completely discarding old pavement and constructing new layers with virgin materials. causes enormous wastage of aggregates, bitumen, machinery, and labor, while placing severe pressure on already overexploited quarries and overburdened landfills. With Sri Lanka facing economic recovery challenges post-2022 and committed to achieving carbon neutrality by 2050 under the Paris Agreement, the adoption of circular economy principles in the road infrastructure sector has become imperative. Recycling RAP offers a strategic solution for resource conservation, cost efficiency, and environmental

sustainability. However, the aged and oxidized bitumen in RAP makes it brittle and less workable, necessitating the use of effective chemical rejuvenators. This study investigates the technical feasibility of incorporating 30% Reclaimed Asphalt Pavement (RAP) into new hot mix asphalt using Waste Engine Oil (WEO) as a chemical rejuvenator. The primary objective is to develop an optimized, sustainable asphalt mix that performs comparably to conventional virgin mixes while delivering significant economic and environmental benefits.

2. LITERATURE REVIEW

The use of Reclaimed Asphalt Pavement (RAP) in new asphalt mixtures has gained global attention as a sustainable practice. Numerous studies have demonstrated that incorporating 15-50% RAP can significantly reduce the demand for virgin aggregates and bitumen while lowering greenhouse gas emissions. However, the main challenge lies in the aged bitumen within RAP, which undergoes oxidative hardening, resulting in increased stiffness, reduced ductility, and poor workability. Numerous international studies have established that incorporating RAP into new asphalt mixtures is an effective strategy for promoting sustainability in road construction. Research conducted in the United States and Europe has shown that RAP contents ranging from 20% to 50%[1] can significantly reduce the consumption of virgin aggregates and bitumen while lowering greenhouse gas emissions by 15-35%)[1]. Most studies employed the Marshall or Superpave mix design methods and reported acceptable mechanical performance when proper rejuvenation techniques were applied. However, many of these investigations primarily focused on low to medium RAP percentages (as below 25%), with limited exploration of higher RAP contents under tropical climatic conditions like Sri Lanka. The primary challenge in using high RAP content is the oxidative aging of bitumen, which increases stiffness and reduces ductility. To counteract this, studies indicate that aromatic rich rejuvenators are most effective in restoring the maltene-asphaltene balance in aged binders[2]. Common rejuvenators include bio-based oils, tall oil, and commercial recycling agents. While these agents have shown promising results in restoring rheological properties, several researchers have highlighted concerns regarding long-term durability and moisture susceptibility. Waste Engine Oil has recently gained attention as a sustainable and economical alternative rejuvenator. Several studies have demonstrated that WEO, rich in aromatic hydrocarbons and light maltene fractions, effectively reduces the viscosity of aged bitumen and improves workability[4]. Laboratory evaluations using Marshall stability, resilient modulus, and dynamic shear rheometer tests revealed that WEO-rejuvenated RAP mixes can achieve performance comparable to virgin mixtures at dosages between 5-15% by weight of total binder.

3. METHOD

This experimental study was conducted in a controlled laboratory environment. Reclaimed Asphalt Pavement (RAP) was collected from milled road sections in Sri Lanka. The RAP material was processed and blended with virgin aggregates to achieve a target of 30% RAP content in the total mix. Waste Engine Oil (WEO) was added as a chemical rejuvenator at an optimized dosage to restore the properties of the aged bitumen. The combined aggregate gradation for the total mix was designed to meet the Job Mix Formula (JMF) requirements, as verified through sieve analysis. Marshall mix design procedure was followed to determine optimum bitumen content. Key tests performed included: Gradation analysis (sieve analysis), Marshall stability and flow test, Volumetric analysis (density, air voids - Va, voids in mineral aggregate - VMA), etc. A control mix using 100% virgin aggregates and fresh bitumen was prepared for comparison. All specimens were compacted and tested under standard conditions to evaluate mechanical and volumetric performance.

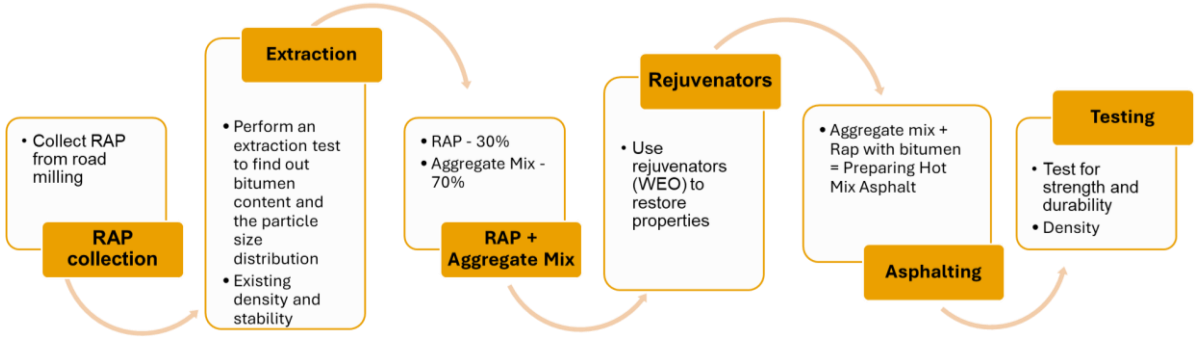

Figure 1. Modification process flow of RAP mix asphalt

4. RESULTS AND DISCUSSION

Laboratory results confirmed that the combined gradation of the 30% RAP mix fell well within the specified upper and lower limits of the Job Mix Formula.

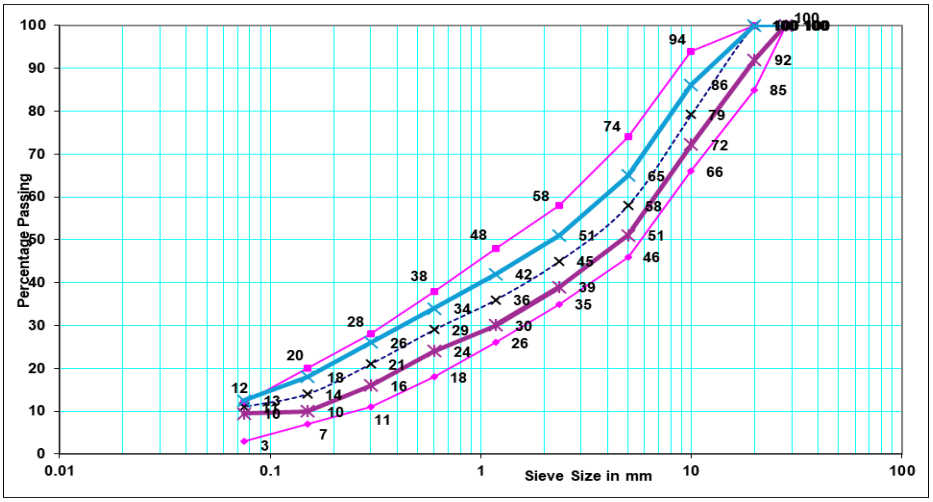

Figure 2. Job Mix Formula according to the combined gradation

Table 1. Comparison RAP mix vs virgin mix

Mix Type	RAP 30% + Aggregate Mix 70%	Aggregate Mix 100% (Usual Asphalt)
Stability	9.6	11.0
Flow	11.3	10.7
Binder Content	4.5 + 0.51 = 5.0	5.0
Density	2.443	2.438
Gmm (Rice method)	2.524	2.523
Va	3.2	3.4

The 30% RAP mix exhibited only marginally lower stability while maintaining acceptable flow and excellent volumetric properties. These results indicate that Waste Engine Oil successfully rejuvenated the aged bitumen in RAP, restoring its workability and binding characteristics. The close similarity in density and air voids further confirms the technical viability of the mix for practical road applications. From an economic perspective, incorporating 30% RAP can

potentially reduce material costs by 30-40%. Environmentally, this approach significantly lowers the demand for virgin aggregates and imported bitumen, reduces landfill waste, and cuts carbon emissions by up to 30%. These benefits align strongly with Sri Lanka's national sustainability targets and post-economic crisis recovery needs.

Figure 3. Marshall specimens cast with RAP mix and usual aggregate mix

5. CONCLUSION

This study successfully demonstrates that sustainable hot mix asphalt can be produced using 30% Reclaimed Asphalt Pavement (RAP) rejuvenated with Waste Engine Oil (WEO). The laboratory performance of the RAP mix was comparable to conventional virgin asphalt, validating the effectiveness of WEO as a chemical rejuvenator. The adoption of this technology offers substantial economic savings, resource conservation, and environmental protection, making it a practical and timely solution for Sri Lanka's road infrastructure challenges. It is recommended that further field trials and long-term performance studies be conducted to facilitate wider implementation. This research provides a strong foundation for initiating large-scale RAP recycling practices in Sri Lanka, supporting the transition toward greener and more sustainable transportation infrastructure.

6. REFERENCES

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