



Sustainable Road Construction Using Recycled Asphalt Pavement

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Abstract

Rapid urbanization and the continuous growth of transportation infrastructure have increased the demand for road construction materials worldwide. Conventional pavement construction depends heavily on virgin aggregates and bitumen, resulting in excessive resource consumption, environmental degradation, high energy usage, and increased greenhouse gas emissions. In recent years, Recycled Asphalt Pavement (RAP) has gained significant attention as a sustainable and cost-effective solution in highway engineering. RAP is produced by reclaiming and processing old asphalt pavements for reuse in new pavement construction. The reuse of RAP helps reduce construction waste, conserve natural resources, and minimize the environmental impact associated with road development. This study examines the importance of RAP in sustainable road construction by analysing its composition, production methods, engineering properties, environmental benefits, and recent technological developments. It also discusses different recycling techniques such as hot and cold recycling, along with the challenges related to aged binder stiffness, moisture susceptibility, and quality control. Recent advancements including rejuvenators, warm mix asphalt technology, and AI-based pavement analysis have further improved RAP performance and durability. The study concludes that RAP is an effective sustainable

pavement material that can reduce construction costs and carbon emissions while maintaining satisfactory structural and functional pavement performance when proper mix design and quality control practices are adopted.

Keywords— Recycled Asphalt Pavement (RAP), Sustainable Road Construction, Asphalt Recycling, Flexible Pavement. Sustainable Pavement Materials. Green Highway Technology



I. INTRODUCTION

Transportation infrastructure plays a major role in economic development, but conventional road construction practices consume enormous quantities of natural materials and energy. The extraction of aggregates and production of asphalt binder contribute heavily to environmental pollution and greenhouse gas emissions. As a result, sustainable pavement technologies have become increasingly important in modern civil engineering. Recycled Asphalt Pavement (RAP) is considered one of the most effective sustainable solutions for pavement construction and rehabilitation. RAP is generated when existing asphalt pavements are removed during maintenance, rehabilitation, or reconstruction activities. Instead of disposing of this material in landfills, it can be processed and reused in new pavement layers. The reuse of reclaimed asphalt materials supports the concept of a circular economy by minimizing waste generation and reducing dependence on virgin materials. In recent years, highway agencies and researchers have focused on increasing RAP utilization because of its environmental and economic advantages. Studies have shown that RAP can provide comparable structural performance to conventional asphalt mixtures when appropriate recycling techniques and rejuvenators are used.

II. LITERATURE REVIEW

Recent research on sustainable asphalt mixtures highlighted the importance of recycling technologies and low-temperature asphalt production methods. The study reported that recycled asphalt materials, steel slag aggregates, recycled concrete aggregates, and waste-derived materials can successfully replace conventional pavement materials. The authors observed that RAP mixtures containing 20–50% recycled content exhibited satisfactory rutting resistance, stiffness, and durability when proper rejuvenation techniques were applied. The research also emphasized the role of circular economy principles in modern pavement engineering.

III. METHODOLOGY

This study adopted an experimental and analytical research design to evaluate the suitability of Recycled Asphalt Pavement (RAP) for sustainable road construction. The research focused on investigating the engineering, environmental, and economic performance of RAP mixtures compared with conventional asphalt mixtures. Both laboratory experimentation and comparative performance analysis were carried out to determine the effectiveness of RAP in flexible pavement applications. The study employed a mixed research approach involving quantitative laboratory testing and qualitative evaluation of sustainability benefits. Different RAP replacement percentages were considered to identify the optimum mix proportion that provides satisfactory pavement performance while reducing environmental impact.

MATERIALS

Recycled Asphalt Pavement (RAP), Virgin coarse aggregates, Virgin fine aggregates, Bitumen binder (VG-30 grade), Mineral filler, Rejuvenating agent (if required) RAP materials were collected from existing deteriorated asphalt pavements obtained from nearby road rehabilitation projects. The reclaimed material was processed by crushing and screening before laboratory use.

COLLECTION OF RAP MATERIALS

The RAP samples were collected from milled asphalt pavements during road maintenance operations. The collected materials were transported to the laboratory for further processing and testing.

Laboratory Preparation

The RAP materials were crushed and sieved according to standard aggregate gradation requirements. Different asphalt mixtures were prepared with varying RAP contents such as:



1. 0% RAP (Control Mix)
2. 20% RAP
3. 40% RAP
4. 60% RAP

Fresh aggregates and bitumen were added to maintain the required mix properties.

EXPERIMENTAL METHODOLOGY

The physical properties of virgin aggregates and Recycled Asphalt Pavement (RAP) aggregates were evaluated using standard laboratory tests conducted according to IRC and ASTM standards.

Aggregate Impact Value Test

It measures the percentage of fines (smaller particles) produced when a sample of aggregate is subjected to a standard impact load.

$$\text{Formula: } AIV = \frac{\text{Weight of fines passing 2.36 mm sieve}}{\text{Total weight of sample}} \times 100$$

SAMPLES	Virgin Aggregate	RAP Aggregate
1	18.2	21
2	18.7	21.5
3	18.6	21.1
Average	18.5	21.2

Permissible Limit: <30%

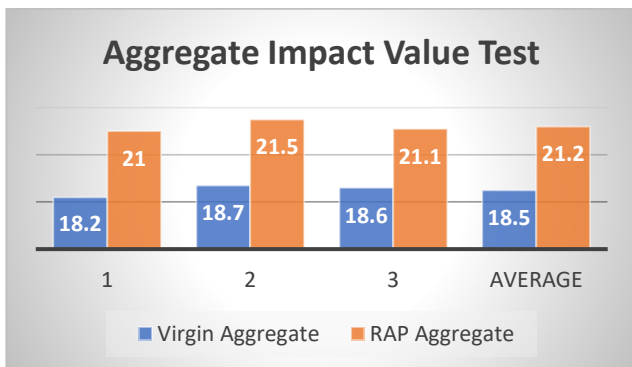


Figure 1: Comparative analysis of Aggregate Impact Value Test.

Los Angeles Abrasion Test

The Los Angeles Abrasion Test is conducted to evaluate the hardness and abrasion resistance of aggregates used in pavement construction. In this test, aggregates are placed in a rotating steel drum along with steel balls to determine their resistance to wear and impact. The percentage loss in weight after

the test is termed as the Los Angeles Abrasion Value. Lower abrasion values indicate better quality and more durable aggregates suitable for road works.

Permissible Limit: <35%

Trial No.	Virgin Aggregate	RAP Aggregate
1	23.8	27.2
2	24.1	27.8
3	24.2	27.5
Average	24	27.5

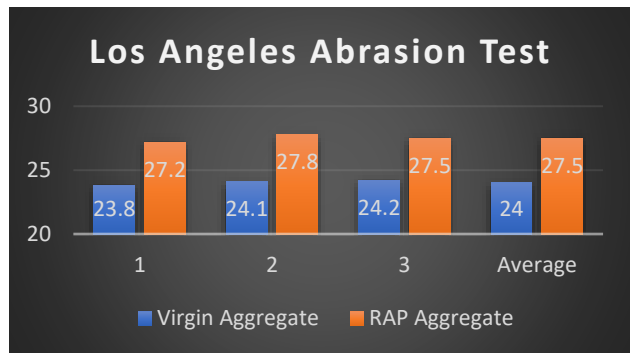


Figure 2: Comparative analysis of Los Angeles Abrasion Test.

Specific Gravity Test

The Specific Gravity Test is conducted to determine the density and strength characteristics of aggregates used in pavement construction. Specific gravity indicates the ratio of the weight of aggregate to the weight of an equal volume of water. Higher specific gravity values generally indicate stronger and more durable aggregates. The test is important for mix design and quality control in road construction.

Trial No.	Virgin Aggregate	RAP Aggregate
1	2.71	2.6
2	2.73	2.62
3	2.72	2.61
Average	2.72	2.61

Permissible Limit: 2.5–3.0

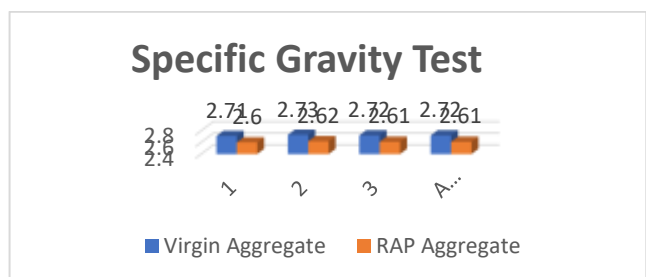


Figure 3: Comparative analysis of Specific Gravity Test.



1. Water Absorption Test

The Water Absorption Test is conducted to determine the amount of water absorbed by aggregates, which indicates their porosity and durability. Aggregates with lower water absorption values are considered stronger and more resistant to weathering effects. This test is important for assessing the quality and suitability of aggregates for pavement and concrete construction.

Trial No.	Virgin Aggregate	RAP Aggregate
1	1.1	2
2	1.3	2.2
3	1.2	2.1
Average	1.2	2.1

Permissible Limit: <2%

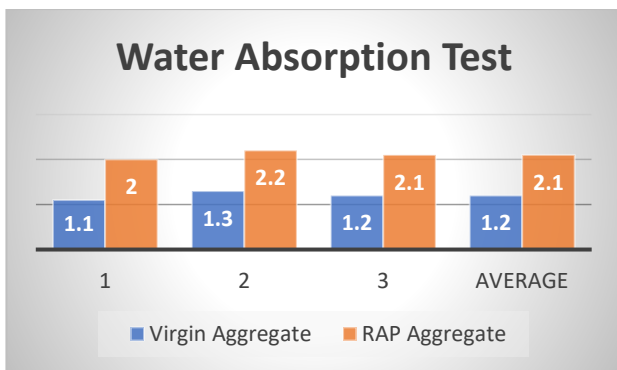


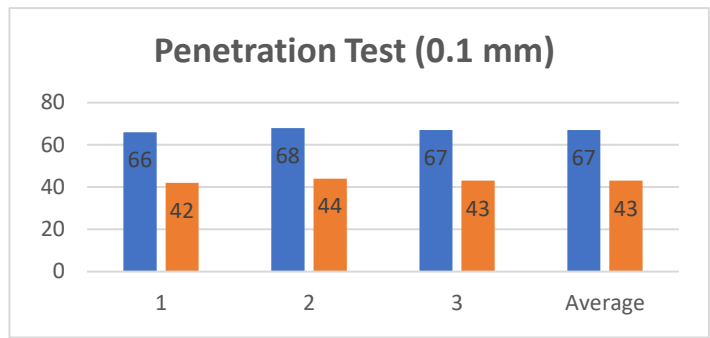
Figure 4: Comparative analysis of Water Absorption Test.

2. Bitumen Testing

Bitumen properties were evaluated to determine the suitability of virgin and RAP binders for sustainable pavement construction.

Penetration Test (0.1 mm)

The Penetration Test is conducted to determine the consistency and hardness of bitumen by measuring the depth of penetration of a standard needle under specified conditions. Higher penetration values indicate softer binders, while lower values indicate harder and stiffer binders. This test helps in selecting suitable bitumen for pavement construction under varying climatic and loading conditions.



Trial	Virgin Binder	RAP Binder
1	66	42
2	68	44
3	67	43
Average	67	43

Figure 5: Comparative analysis of Penetration Test (0.1 mm)

Ductility Test (cm)

It measures the distance in centimeters that a bitumen sample can stretch under standard conditions. Higher ductility values indicate better flexibility and adhesive properties, which are important for pavement durability and crack resistance.

Trial	Virgin Binder	RAP Binder
1	82	48
2	84	50
3	83	49
Average	83	49

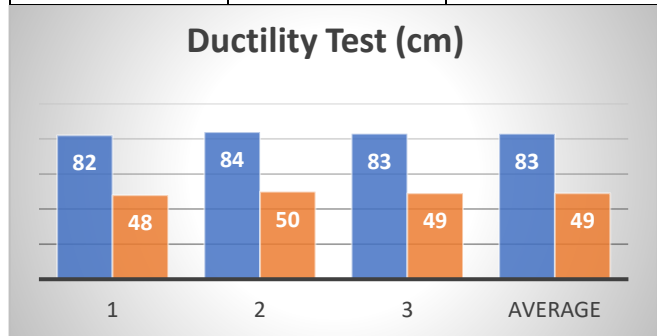


Figure 6: Comparative analysis of Ductility Test (cm)

Softening Point Test (°C)

The Softening Point Test is conducted to determine the temperature at which bitumen softens under standard heating conditions. This test indicates the temperature susceptibility of the binder and its suitability for different climatic conditions. Higher softening point values indicate harder binders with better resistance to deformation at high temperatures.



Trial	Virgin Binder	RAP Binder
1	46	55
2	47	56
3	46.5	55.5
Average	46.5	55.5

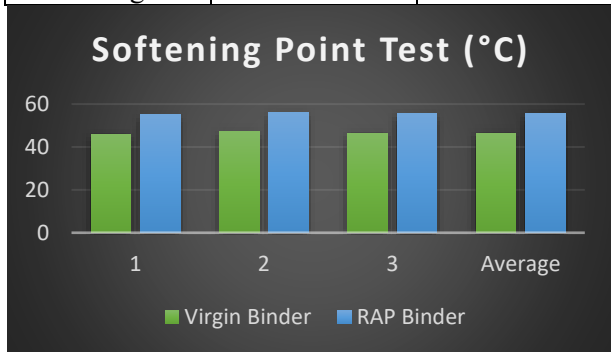


Figure 7: Comparative analysis of Softening Point Test (°C)

Viscosity Test (Poise)

The Viscosity Test is conducted to determine the flow characteristics and consistency of bitumen at a specified temperature. Viscosity indicates the resistance of the binder to flow, which affects mixing, compaction, and coating of aggregates during pavement construction. Higher viscosity values indicate stiffer binders, while lower values indicate more fluid binders suitable for easy workability.

Trial	Virgin Binder	RAP Binder
1	310	420
2	315	425
3	312	423
Average	312	423

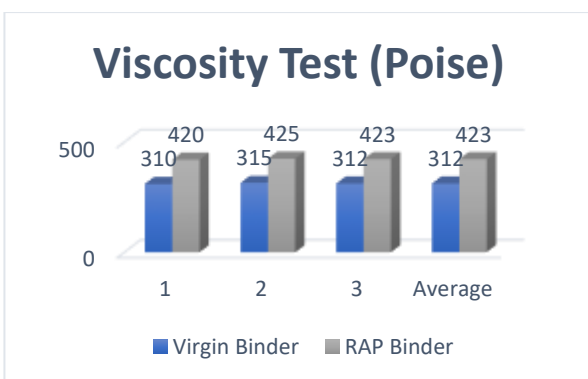


Figure 8: Comparative analysis of Viscosity Test (Poise)

3. Marshall Mix Design

Marshall Stability testing was performed to evaluate the strength and performance characteristics of asphalt mixtures containing different percentages of Reclaimed Asphalt Pavement (RAP). The test helps in determining the optimum binder content and assesses the stability, flow value, density, and air voids of the bituminous mix. Higher stability values indicate better load-bearing capacity and resistance to deformation under traffic loads.

RAP %	Marshall Stability (kN)	Flow Value (mm)	Air Voids (%)	VMA (%)	Bulk Density (g/cc)
0	12.5	3.2	4.2	15.1	2.32
20	13.8	3.4	4	15.5	2.35
40	14.6	3.6	3.8	16	2.38
60	13.9	3.9	3.6	16.4	2.36

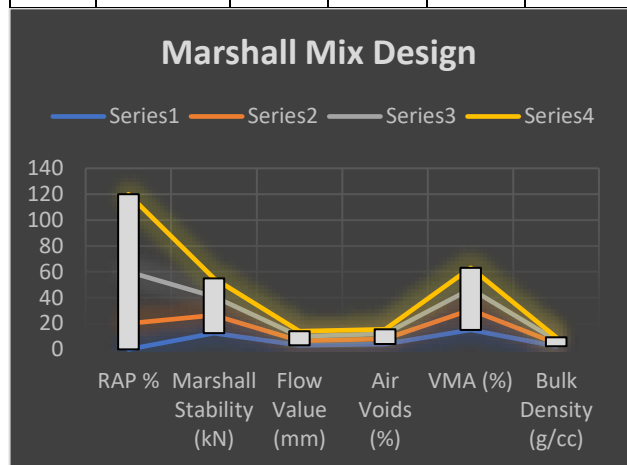


Figure 9: Comparative analysis of Marshall Mix Design

4. Performance Evaluation Tests

Additional performance tests were conducted to evaluate durability, cracking resistance, and long-term pavement performance.



Indirect Tensile Strength (MPa)

RAP Percentage	Indirect Tensile Strength (MPa)
0	0.82
20	0.88
40	0.91
60	0.86

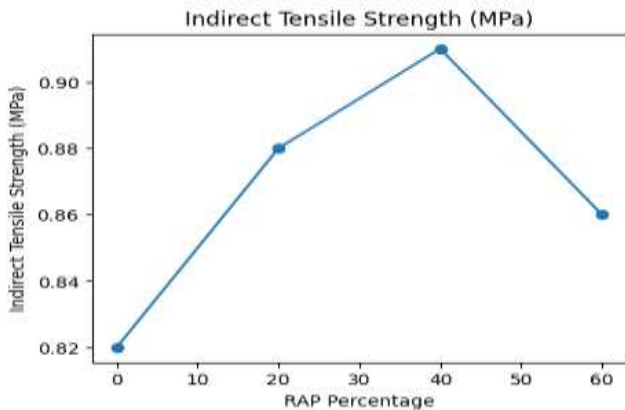


Figure 10: Comparative analysis of Performance Evaluation Tests

Rutting Resistance (mm)

RAP Percentage	Rutting Resistance (mm)
0	5.2
20	4.8
40	4.3
60	4.7

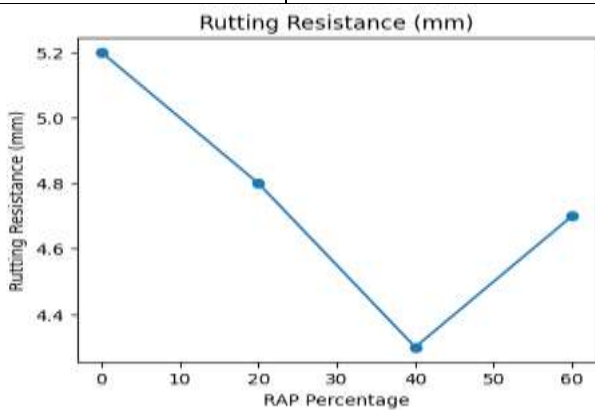


Figure 11: Comparative analysis of Rutting Resistance (mm)

Fatigue Life (Cycles)

The Fatigue Life Test is conducted to evaluate the resistance of asphalt mixtures to repeated loading and cracking under traffic conditions. It determines the number of load cycles the pavement can withstand before failure occurs. Higher fatigue life

values indicate better durability, flexibility, and longer service life of the pavement.

RAP Percentage	Fatigue Life (Cycles)
0	12000
20	13800
40	15200
60	14000

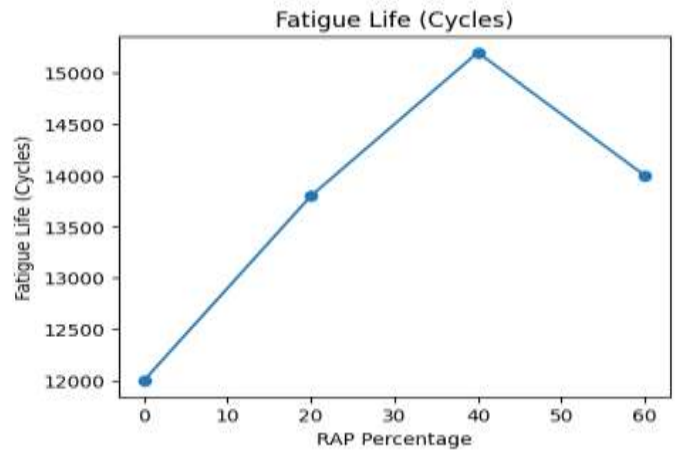


Figure 12: Comparative analysis of Rutting Resistance (mm)

Moisture Susceptibility TSR (%)

The Moisture Susceptibility Test is conducted to evaluate the resistance of asphalt mixtures to moisture-induced damage and stripping. The Tensile Strength Ratio (TSR) represents the retained strength of the mix after moisture conditioning. Higher TSR values indicate better resistance to water damage and improved durability of the pavement mixture.

RAP Percentage	Moisture Susceptibility TSR (%)
0	78
20	82
40	86
60	80

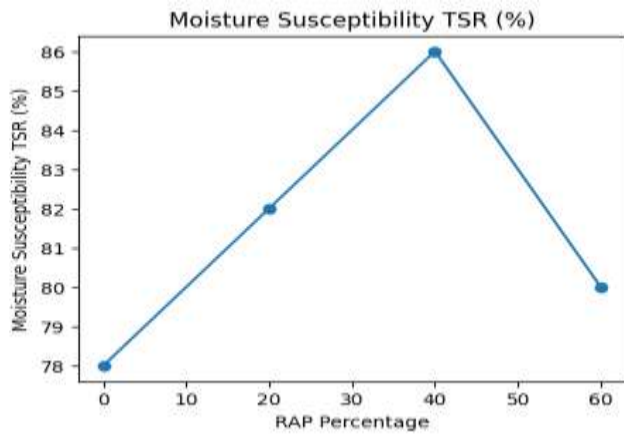


Figure 13: Comparative analysis of Rutting Resistance (mm)

Conclusion

The present study evaluated the performance of Reclaimed Asphalt Pavement (RAP) materials through various aggregate, binder, and Marshall mix design tests. The experimental results showed that RAP aggregates and binders possess acceptable engineering properties suitable for pavement applications. Although RAP materials exhibited slightly higher abrasion and water absorption values and lower penetration and ductility values compared to virgin materials, all results remained within permissible limits. Marshall Stability and other performance tests indicated that the incorporation of RAP can produce durable and economical asphalt mixtures. Therefore, the use of RAP in pavement construction can significantly reduce the consumption of natural resources, minimize environmental impacts, and promote sustainable road development.

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