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Assessment of the Suitability of Reclaimed Asphalt Pavement (RAP) for Use as a Base Course Material in Road Construction

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ABSTRACT

This study investigates the compaction characteristics, mechanical strength, and suitability of Reclaimed Asphalt Pavement (RAP) blended with crushed stone base (CSB) for potential use in pavement structures. The stone base exhibited the lowest Optimum Moisture Content (OMC) of 7.76% and a relatively low Maximum Dry Density (MDD) of 2.21 g/cm³, typical of clean granular materials. In contrast, 100% RAP showed the highest OMC (10.70%) and MDD (2.46 g/cm³), attributed to the presence of bituminous binder enhancing particle cohesion. OMC increased with RAP content up to 20% but declined beyond 40%, suggesting interaction effects that enhance compaction efficiency at intermediate blends. MDD values consistently increased with RAP content, indicating improved packing density. Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV) tests confirmed that all material combinations complied with the Federal Ministry of Works (1997) specifications. CBR results revealed that 100% stone base achieved the highest strength (100.6%), while 100% RAP had the lowest (22%). Mixtures with 20–40% RAP demonstrated significantly improved CBR values (97% and 75%, respectively), approaching the performance of the virgin stone base. These findings suggest that incorporating up to 40% RAP into stone base can achieve acceptable strength for base layer applications, supporting material reuse while maintaining structural integrity and sustainability.

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INTRODUCTION

As many highways transition from the initial construction phase to maintenance and rehabilitation, recycling has emerged as a key strategy for sustainable pavement management. The growing demands on existing infrastructure, driven by increased traffic volumes and aging road networks, necessitate efficient and environmentally responsible methods for pavement preservation and rehabilitation. Among these methods, the recycling of asphalt pavement particularly through the use of Reclaimed Asphalt Pavement (RAP) has gained widespread acceptance (National Asphalt Pavement Association, 2021).

RAP, typically generated through milling or full-depth removal of existing asphalt layers, consists of aged asphalt binder and aggregates. Its incorporation into new asphalt mixtures or other structural layers of pavement offers a host of benefits, including economic savings, resource conservation, and reduced environmental impacts (Hamzah et al., 2012). As highlighted by Lo Presti et al. (2023), the advantages of using RAP include a reduction in the consumption of virgin materials (both aggregates and binder), decreased energy usage, lower greenhouse gas emissions, and diminished reliance on landfilling construction waste.

The aging of asphalt materials—characterized by oxidative hardening and increased brittleness—means that RAP typically contains a stiffer binder. This aged binder can affect the mechanical properties of the recycled

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mix, particularly in terms of cracking susceptibility. However, with proper mix design and processing techniques, such challenges can be mitigated to ensure performance meets modern standards (Zhou et al., 2015).

In addition to its use in hot mix asphalt (HMA) production, RAP can be repurposed as a component in stabilized base and subbase layers, embankments, or even granular fill material. These versatile applications enhance its value as a recyclable material. As Zaumanis et al., (2022) notes, the primary motivations behind RAP utilization are both economic through reduced material acquisition and hauling costs and environmental through minimized energy consumption and resource depletion.

Despite the numerous benefits, a significant portion of RAP still remains underutilized. While RAP has been incorporated into surface and base courses, opportunities exist to increase its use across all pavement layers. With thousands of miles of roadways approaching or exceeding their service life, recycling existing materials from these roads provides a logical and sustainable means of maintaining and reconstructing the highway system. Reusing materials that were originally employed in construction aligns with sound engineering practice, conserves natural resources, and reduces costs, thereby reinforcing RAP's role as a cornerstone of sustainable pavement engineering (Costa et al., 2025).

To ensure the long-term success of RAP implementation, it is essential that recycled materials not only provide environmental and economic benefits but also maintain high performance standards. When used correctly, RAP contributes significantly to a circular economy in the asphalt industry an approach that optimizes the use of natural resources while reducing the industry's ecological footprint.

Materials and Method

Reclaimed Asphalt Pavement (RAP)

The Reclaimed Asphalt Pavement (RAP) material utilized in this study was sourced from the ongoing rehabilitation works along the Maiduguri-Monguno Road in Borno State, Nigeria. 25 kilograms of the material were collected and transported to the Soil Mechanics Laboratory at the University of Maiduguri for experimental investigation.

Stone Base

The stone base material used in this study was sourced from the Qumecs Nigeria Limited yard, along Baga Road Maiduguri, originating from Shira Quarry site in Bauchi State, Nigeria. A sample weighing approximately 25 kilograms was transported to the Soil Mechanics Laboratory at the University of Maiduguri for testing and analysis.

METHODS

Milling of RAP

The RAP sample was milled using the milling machine at the Qumecs yard. The RAP produced is milled to 38 mm or less with a maximum allowable top size of 51 mm.

Dosage

The dosages for the various combination of RAP-stone base materials are presented in Table 1.

Table 1: The dosages for the various combination of RAP-stone

S/N	RAP (%)	Aggregate (%)
1.	100	0
2.	80	20
3.	60	40
4.	40	60
5.	20	80

Particle Size Distribution

The particle size distribution analysis was conducted in accordance with the procedure outline in BS812: Part103: 1990 for BS heavy.

Compaction Characteristics

A specified amount of water, ranging between 3% and 12%, was mixed into the aggregate and allowed to soak for at least 24 hours before compaction. Each sample was sealed in a polythene bag to prevent the evaporation of moisture from the aggregate. The

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mould and base plate were cleaned thoroughly, and grease was applied to their inner surfaces. The mould, with its base plate attached, was weighed and fitted with an extension collar. The wet soil was then compacted in five equal layers using a rammer weighing 4.5 kg with a free fall of 30 cm. Each layer received 56 evenly distributed blows within a 15 cm diameter mould.

After compaction, the collar was removed and excess soil was trimmed flush with the top of the mould. The outside of the mould and base plate was cleaned, and the assembly was weighed again with the compacted soil. A representative soil sample was taken from each specimen to determine moisture content. The height and weight of each compacted specimen were measured, and moisture content was determined by oven drying the samples at for 24 hours. Moisture-density curves were subsequently prepared for each material, from which the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) values were visually determined (BS 1377 Part 4, 1990).

California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test was conducted in accordance with BS 1377: Part 9: 1990, which specifies procedures for assessing the strength of subgrade, sub-base, and base course materials through penetration resistance. RAP and stone base materials were used for the test. Each sample was compacted into a CBR mould (with a diameter of 152 mm and a height of 127 mm) using the modified Proctor method, which involved compacting the soil in three equal layers. Each layer received 55 blows from a 2.5 kg rammer dropped from a height of 310 mm. The collar was fixed to the top of the mould during compaction, and a spacer disc was used at the bottom to ensure uniformity.

The specimen was then placed under a CBR testing machine. The surcharge weights were kept in place during testing. A cylindrical plunger with a diameter of 50 mm was penetrated into the sample at a constant rate of 1.0 mm/min. The load readings were recorded at penetration depths of 0.25 mm intervals up to 7.5 mm. The corresponding CBR values at 2.5 mm and 5.0 mm penetration were calculated by comparing the measured load with the standard load values (13.2 kN and 19.96 kN respectively).

The CBR value was calculated using the following formula:

$$CBR = \left(\frac{Measured\ Load}{Standard\ Load}\right) \times 100\% \qquad (1)$$

Aggregate Crushing Value (ACV)

The Aggregate Crushing Value (ACV) test was conducted to determine the resistance of aggregates to crushing under gradually applied compressive load. The cylindrical steel mould (with an internal diameter of 150 mm and a height of 130 mm) was filled in three layers with the prepared aggregate sample. Each layer was tamped 25 times using a tamping rod. The surface was then leveled, and the plunger was placed on top of the aggregate.

The assembly was then placed in a compression testing machine, and a load of 400 kN was applied gradually over 10 minutes. After the test, the crushed aggregate was sieved through a 2.36 mm sieve. The weight of the fraction passing the sieve was recorded as W_2, and the original weight of the sample was recorded as W_1(BS 812: Part 110: 1990).

$$ACV(\%) = \frac{W_2}{W_1} \times 100\% \qquad (2)$$

Aggregate Impact Value (AIV)

The Aggregate Impact Value (AIV) test was conducted to determine the toughness of aggregates or their resistance to sudden shock or impact. The cylindrical mould (with a diameter of 102 mm and height of 50 mm) was filled with the prepared aggregate in three layers. Each layer was tamped 25 times using a tamping rod. The mould was then fixed to the base of the impact testing machine, and the hammer (weighing 13.5 to 14.0 kg) was allowed to fall freely from a height of 380 mm onto the sample 15 times. After the test, the sample was sieved through a 2.36 mm sieve, and the weight of the material passing through the sieve was recorded as W_2. The original weight of the sample before testing was W_1.

$$AIV(\%) = \frac{W_2}{W_1} \times 100\% \qquad (3)$$

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RESULTS AND DISCUSSION

Particle Size Distribution analysis

Mechanical analysis was carried out to determine the particle size distribution of both Reclaimed Asphalt Pavement (RAP) and crushed stone base samples using standard sieve analysis procedures. The objective was to evaluate the gradation and assess their suitability for use as base course materials. The RAP material, which originated from previously milled asphalt concrete layers, exhibited a gradation influenced by the characteristics of the parent asphalt mix as well as the milling and stockpiling processes. Due to these factors, RAP typically contains a blend of coarse and fine aggregates bound with residual asphalt binder. The sieve analysis of the RAP sample revealed that it comprised a combination of gravel, sand, and fine particles. After washing and sieving, the particle size distribution was observed to fall within the specified range of 5 mm to 50 mm (Federal Ministry of Works Nigeria Specification,1997).

Table 1: Particle Size Distribution of the Stone Base Materials.

Sieve size	Weight retained (g)	% Retained	Cumulative % Retained	% Passing
4.75	305	10.2	0.75	99.25
2.36	458.5	15.3	0.62	99.38
1.18	380.5	12.7	0.95	99.05
0.6	582.5	19.4	0.45	99.55
0.425	275.5	9.2	0.21	99.79
0.300	125	4.2	0.24	99.76
0.15	145.5	4.9	0.12	99.88
0.075	75	2.5		

Table 2: Percentage of size of RAP material

Sieve size	Weight retained (g)	% Retained	Cumulative % Retained	% Passing
4.75	215	4.76	0.90	99.10
2.36	930	25.01	1.53	98.47
1.18	705	42.61	0.51	99.49
0.6	603	14.28	0.17	99.83
0.425	210	4.65	0.08	99.92
0.300	72	2.1	0.05	99.95
0.15	60	1.33	0.16	99.84
0.075	205	4.55		

Similarly, the crushed stone base sample also met the specified gradation requirements. Both materials demonstrated comparable grading characteristics; however, the RAP sample was found to contain a relatively higher proportion of coarse particles and fine materials (also referred to as mineral dust or "fines") than typically observed in conventional base course aggregates. These fines are generally bound to the asphalt matrix during the milling or crushing process, contributing to the fine content of the RAP.

The gradation of both the crushed stone base and the RAP samples complied with the standard specifications for base course materials, indicating their potential suitability for use in pavement construction applications, particularly when proper blending and processing are undertaken.

Compaction Characteristics

The stone base has the lowest OMC (7.76%) and a relatively low MDD (2.21 g/cm³). This is expected for clean, angular, granular

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materials, which require less moisture to reach compaction and have higher interlocking potential but may not achieve the highest densities due to the absence of finer binder materials. The standalone RAP has the highest OMC (10.70%) and the highest MDD (2.46 g/cm³). This may seem counterintuitive since RAP typically has a lower specific gravity, but the presence of bituminous binder likely fills voids between particles and enhances cohesion during compaction, thereby achieving higher density. However, RAP also retains more moisture due to the binder, which explains the elevated OMC (Nunez and Perez, 2023).

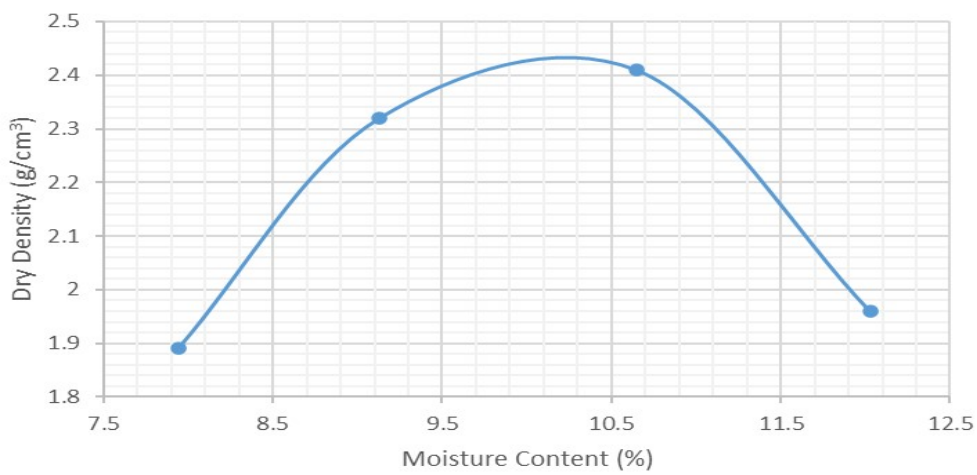

Figure 2.1: Compaction Characteristics of standalone RAP

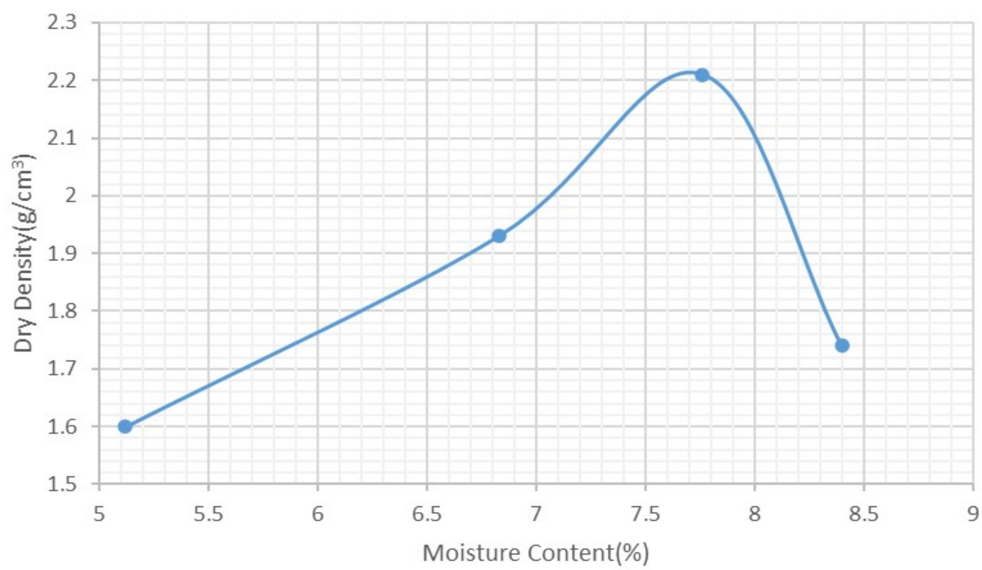

Figure 2.2: Compaction Characteristics of standalone stone base material

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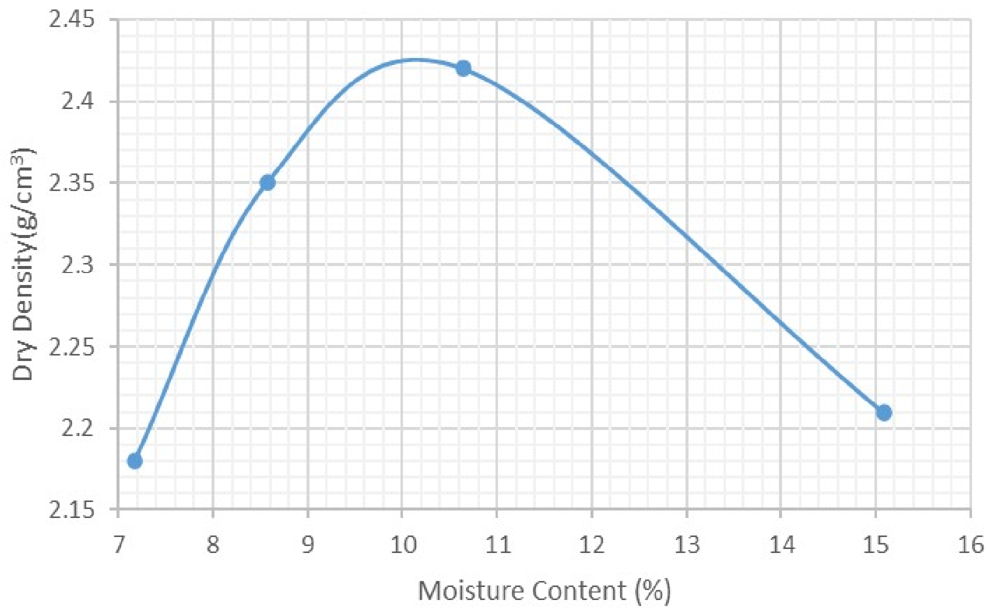

Figure 2.3: Compaction Characteristics of the stone base material with 20% RAP

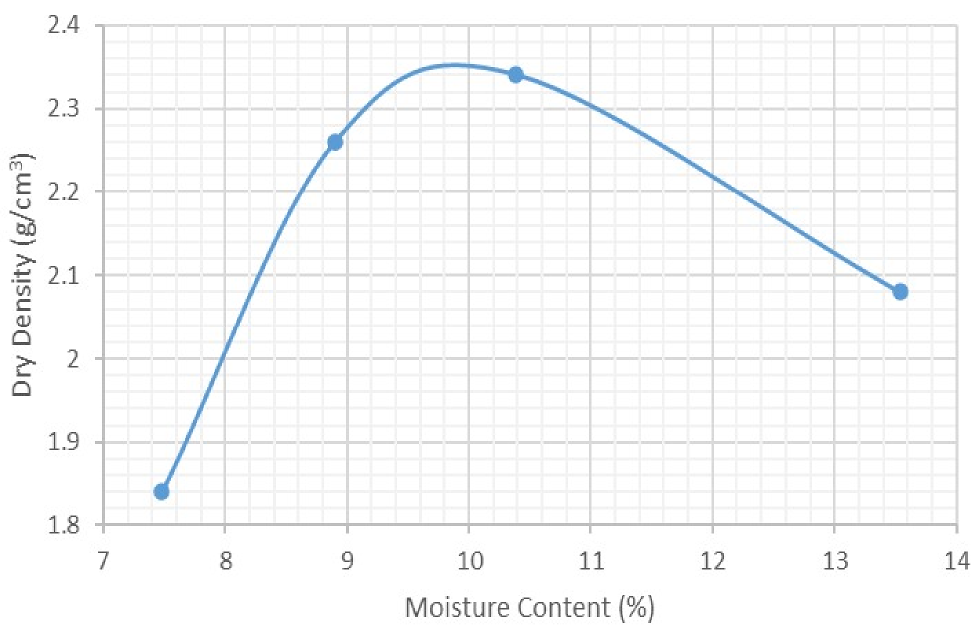

Figure 2.4: Compaction Characteristics of the stone base material with 40% RAP

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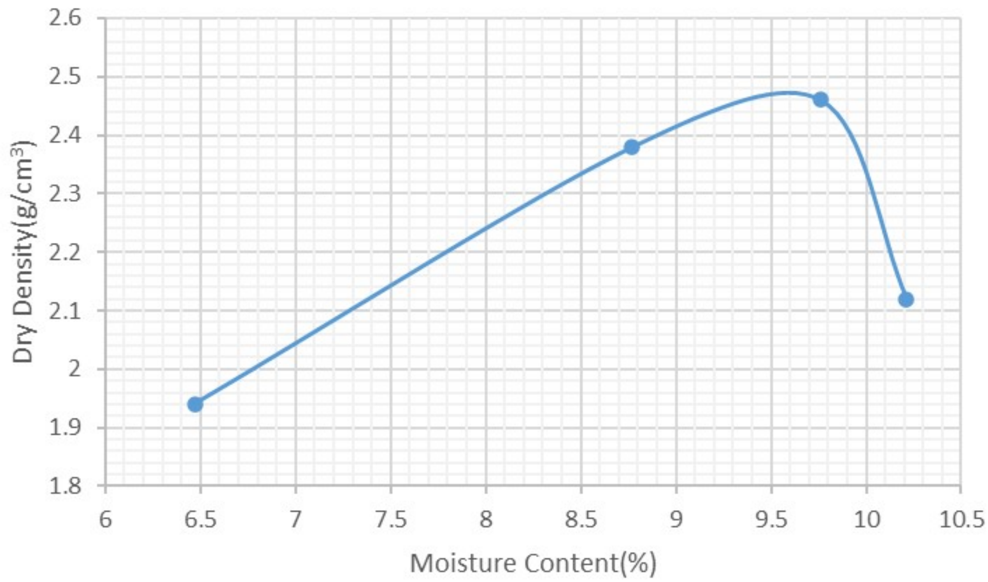

Figure 2.5: Compaction Characteristics of the stone base material with 60% RAP

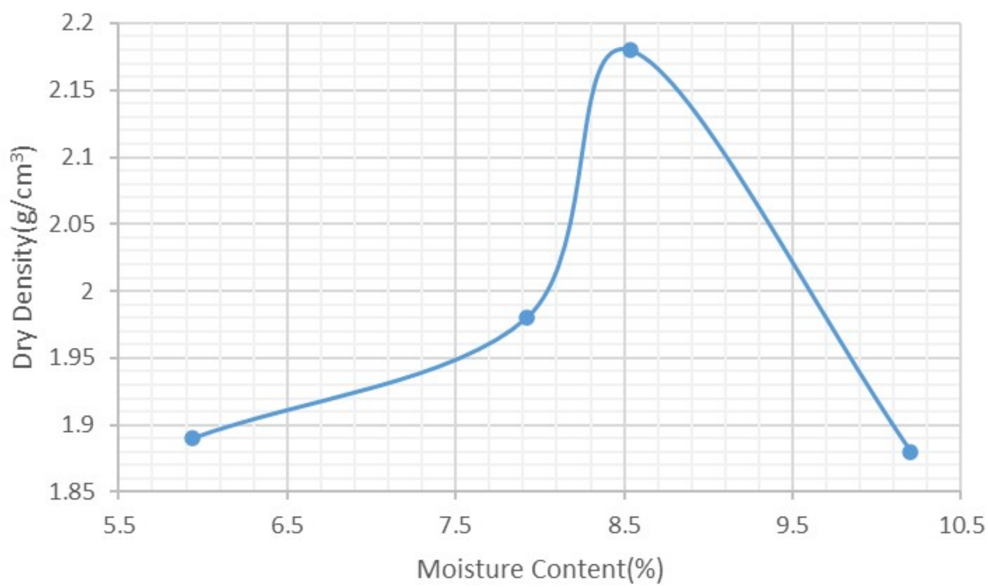

Figure 2.6: Compaction Characteristics of the stone base material with 80% RAP

As RAP content increases from 0% to 20%, OMC rises significantly (from 7.76% to 10.52%), likely due to increased moisture absorption by the aged binder in RAP. Surprisingly, OMC starts to decrease beyond 40% RAP (down to 8.54% at 80%), before peaking

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again at 100%. This could indicate interaction effects between RAP and stone base, where intermediate blends allow better moisture retention and compaction efficiency (Alotaibi and Al-Mutairi, 2025).

The MDD increases steadily with RAP content—from 2.21 g/cm³ for stone base to 2.46 g/cm³ for 100% RAP. This implies that RAP contributes positively to compaction density, possibly due to the finer particles filling voids, bitumen acting as a binder to enhance cohesion and a denser packing structure due to the combined gradation of RAP and stone base (Alhassan and Mohammed, 2021).

Aggregate Impact Value

The result of AIV values revealed that both standalone RAP and stone base as well as the various combination are within the specified limit (Federal Ministry of Work Nigeria, 1997). The result is presented in Table 3 and 4.

Table 3: AIV Result for RAP and Stone Base Material

Sample	Wt of sample passing	Wt of sample retained	AIV%	Specification
Rap	346.5	138.3	21.68	
Csb	340	43.7	12.85	≤35%

Table 4: AIV Result for Mixed RAP and Stone Base Materials

% Replacement	Net Wt of sample oven dried	Wt of sample fraction passing 2.36 sieve after test	AIV %	Specification
100%	346.4g	75.1	21.68	
80%	347.4g	70.6	20.32	
60%	342.9	64.24	18.73	≤35%
40%	344.6	47.3	13.73	
20%	342.8	33.6	9.80	

Aggregate Crushing Value

The Aggregate Crushing Value (ACV) results indicated that the standalone RAP, the stone base, and all their various combinations comply with the specified limits set by the Federal Ministry of Works, Nigeria (1997). The results are presented in Tables 5 and 6.

Table 5: ACV Result for RAP and Stone Base Materials

Sample	ACV%	Specification
Stone base	19.67	
Rap	27.33	**≤30%**

Table 6: ACV Result for Mixed RAP and Stone Base Materials

%Replacement	Wt of sample	Wt of sample passing 2.36mm sieve	ACV %	Specification
100%	3000	820	27.33	
80%	3000	765	26.50	
60%	3000	740	24.67	**≤30%**
40%	3000	690	23.0	
20%	3000	678	22.60	
Stone Base	3000	590	19.67	

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CBR Results

The CBR results for all the materials are presented in Table 7. The standalone stone base material recorded the highest CBR value, indicating excellent strength and load-bearing capacity, well-suited for use in base or subbase layers of pavement structures. A value exceeding 100% suggests a very dense, well-graded aggregate with excellent interlocking characteristics.

In contrast, the standalone RAP recorded the lowest CBR value (22%), which is unsuitable for direct use as a base material without stabilization. This low strength is attributed to the presence of aged bitumen coating, which reduces friction and interlocking between particles, the finer and less angular nature of RAP particles and potential moisture sensitivity.

Table 7: CBR results for different dosages of the materials

Sample	CBR Value
Stone Base	100.6%
Rap 100%	22%
Rap 80%	38%
Rap 60%	49%
Rap 40%	75%
Rap 20%	97%

A clear trend of increasing CBR values is observed as the percentage of stone base material increases in the RAP mixture:

RAP 80% (CBR = 38%) and RAP 60% (CBR = 49%). These mixtures show moderate strength improvement compared to 100% RAP but still fall below acceptable thresholds for high-traffic base layer applications. However, they might be suitable for light-duty or subgrade improvement with proper design considerations *RAP 40% (CBR = 75%).* At this blend ratio, the material achieves a substantial strength increase. While still below 100%, it approaches the strength range required for use in secondary base courses or rural roads.

RAP 20% (CBR = 97%)

This mix provides a near-equivalent performance to the standalone stone base, indicating a highly suitable balance for base layer use. The stone base's strength-dominant nature offsets the weaker RAP properties, producing a structurally sound material with reduced dependency on virgin aggregates. Using up to 20–40% RAP allows for significant reuse of reclaimed materials while maintaining adequate strength, contributing to cost savings and environmental sustainability. However, RAP above 60% may require stabilization for structural applications.

CONCLUSION

The study demonstrates the potential of incorporating Reclaimed Asphalt Pavement (RAP) into crushed stone base (CSB) materials for use in road construction. The results indicated that while standalone RAP has higher moisture demand and density due to the presence of bituminous binder, while its strength properties—especially California Bearing Ratio (CBR)—are significantly lower compared to natural stone base. However, blending RAP with stone base in varying proportions improves both compaction and mechanical performance. The optimum performance in terms of strength and compaction was observed at RAP replacement levels between 20% and 40%. At 20% RAP, the CBR value reached 97%, closely matching that of the virgin stone base (100.6%), suggesting that such a blend is suitable for base layer applications. All mixtures met the specified limits for Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV), confirming their durability and resistance to fragmentation.

These findings support the partial replacement of natural aggregates with RAP, particularly up to 40%, as a sustainable and cost-effective solution for pavement construction. Higher RAP contents (above 60%) may require additional stabilization to meet structural performance requirements. Ultimately, the controlled use of RAP in pavement layers can contribute to environmental conservation, reduced reliance on virgin materials, and improved construction economy without compromising performance.

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