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Investigating the Viability of Reclaimed Asphalt Pavement as Backfill Material for Sustainable Material Management

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ABSTRACT: This study examines the feasibility of using Reclaimed Asphalt Pavement (RAP) as a replacement for embankment and backfill materials in roads in Saudi Arabia. The research addresses the demand for sustainable material-management practices and reduced reliance on virgin materials with the increasing generation of construction and demolition waste. An experimental method was followed using RAP and natural fine aggregate from a construction site in the Tabuk region. The RAP was crushed, screened, and mixed with various proportions of natural material before laboratory evaluation. The experimental programme involved particle-size distribution using sieve analysis, Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) using the Modified Proctor compaction test, and the California Bearing Ratio (CBR) test. The results showed differences in the gradation, compaction, and bearing properties of the tested materials. The OMC values ranged from 7.1% to 7.3%, while MDD ranged from 2.080 to 2.240 g/cm³. CBR values at 100% MDD ranged from 34% to 83%. Among the five samples, Sample D showed the best performance, with an OMC of 7.1%, MDD of 2.240 g/cm³, and CBR of 83%. The results indicate that appropriately processed RAP has potential for use in embankment and backfill applications, subject to field validation and project-specific requirements in future.

1. INTRODUCTION

Road embankments are critical components of road construction because failure of the foundation layer can affect the stability and performance of the entire road. Road construction and maintenance therefore require materials that are effective and economical while conserving natural resources and reducing environmental impacts (Jiang et al., 2018). Reclaimed Asphalt Pavement (RAP), containing crushed stones, bitumen, sand, and gravel, is a potentially valuable material that can be recycled and reused in road construction (Mariyappan et al., 2023). Its reuse as embankment or backfill material may reduce construction costs, minimise waste, and reduce dependence on virgin materials. The use of construction waste in asphalt pavement has also demonstrated Saudi Arabia's efforts towards a circular economy focused on waste reduction and environmental conservation (Alharbi et al., 2025).

Rapid urbanisation and infrastructure development in Saudi Arabia have resulted in increasing quantities of construction and demolition (C&D) waste. Al-Ghamdi et al. (2017) and Yang et al. (2017) reported that the volume of C&D waste is substantial due to population growth, urban development, and the construction of new facilities. This has created environmental and waste-management challenges and increased the need for appropriate reduction, reuse, and recycling practices. Saudi Arabia generates more than 120 million tonnes of C&D waste annually, placing considerable pressure on existing waste-management systems (Haider, 2022). The large quantity of construction and demolition debris highlights the importance of sustainable recycling and reuse strategies to reduce landfill disposal and conserve natural resources (Bonifazi et al., 2025). These efforts are also associated with Saudi Vision 2030, which promotes environmental protection, economic development, infrastructure improvement, and sustainable resource management.

Asphalt pavement has a finite service life, with properly designed and constructed pavements typically lasting approximately 15–20 years before major rehabilitation or replacement (Xin et al., 2026). Consequently, continuous road rehabilitation generates substantial quantities of RAP and increases the need for sustainable reuse strategies. The recycling and reuse of asphalt materials can reduce the amount of demolition waste disposed of in landfills while decreasing the demand for raw materials in new construction (Rahman et al., 2020). Saudi Arabia has therefore adopted recycling mechanisms to encourage the reuse of asphalt materials, including their potential application in road construction as embankment or backfill material. The reuse of RAP is consistent with the transition towards a circular economy and the broader objective of reducing waste and conserving resources (Satar et al., 2025).

Despite the potential environmental and economic benefits of RAP reuse, its suitability as an embankment or backfill material depends on its engineering performance. In particular, the compaction characteristics, particle-size distribution, and bearing capacity of RAP and RAP–virgin aggregate mixtures need to be evaluated before wider application. Therefore, this study investigates the feasibility of using RAP as an alternative embankment or backfill material after appropriate crushing and screening. The study evaluates RAP–fine aggregate mixtures to assess their particle-size distribution, compaction characteristics, and bearing performance under laboratory conditions. The different materials were compared to assess their engineering performance and potential suitability for road embankment and backfill applications. In this study, RAP and virgin fine aggregate obtained from a construction project in the Tabuk region of Saudi Arabia were processed and blended at different proportions. The laboratory investigation included sieve analysis to determine particle-size distribution, Modified Proctor compaction testing to determine Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), and California Bearing Ratio (CBR) testing to evaluate bearing performance. The different materials were compared to assess their engineering properties and potential suitability for road embankment and backfill applications. The study also considers the potential environmental benefits of RAP reuse, particularly the reduction of construction waste sent to landfills and the conservation of virgin aggregate resources. The investigation was conducted at laboratory scale and did not include field performance or long-term monitoring of RAP embankments.

2. MATERIALS AND METHODS

2.1 Materials and Experimental Design

The experimental investigation used Reclaimed Asphalt Pavement (RAP), natural fine aggregate, and clean tap water. The RAP was obtained from an asphalt pavement construction project in the Tabuk region of Saudi Arabia. The collected RAP was broken, crushed, and graded to obtain the desired particle-size distribution before being blended with natural fine aggregate. The fine aggregate was obtained from the same construction project and was used as the virgin material for blending. Clean tap water was used to adjust the moisture content during compaction testing. The Optimum Moisture Content (OMC) obtained from the Modified Proctor test was subsequently used for preparation of the California Bearing Ratio (CBR) specimens. The experimental programme comprised a natural material control and RAP–fine aggregate blends prepared on a mass basis. The RAP contents investigated were 25%, 50%, 70%, 75%, and 100%, corresponding to fine aggregate contents of 75%, 50%, 30%, 25%, and 0%, respectively. The mixtures were evaluated to determine changes in particle-size distribution, compaction characteristics, and bearing performance with different proportions of RAP.

2.2 Laboratory Testing

Three principal laboratory tests were conducted: sieve analysis, Modified Proctor compaction, and CBR testing. These tests were selected to characterise the particle-size distribution, moisture–density relationship, and bearing capacity of the RAP-based materials.

2.2.1 Sieve Analysis

Particle-size distribution was determined in accordance with ASTM C136/C136M and ASTM C117. The samples were oven-dried at 110 ± 5°C until a constant mass was obtained. A suitable series of sieves was arranged from the largest to the smallest opening, and the dried sample was placed on the upper sieve and mechanically or manually sieved. The material retained on each sieve was weighed to an accuracy of 0.1% of the total dry sample mass. The percentage retained and percentage passing were then calculated to determine the particle-size distribution of each material. The percentage retained was calculated as:

$$\text{Percentage Retained (\%)} = \frac{\text{Weight retained on each sieve}}{\text{Total weight of sample}} \times 100$$

The percentage passing was subsequently determined from the cumulative percentage retained.

2.2.2 Modified Proctor Compaction Test

The Modified Proctor compaction test was conducted in accordance with ASTM D1557 to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). The prepared material was mixed with controlled amounts of water and compacted in five layers using a 10-lbf (44.5 N) rammer with an 18-inch drop. Depending on the particle-size characteristics of the material, the applicable mould and compaction method were selected. Method A used a 4-inch mould with material passing the No. 4 sieve and 25 blows per layer; Method B used a 4-inch mould with material passing the 3/8-inch (9.5 mm) sieve and 25 blows per layer; and Method C used a 6-inch mould with material passing the 3/4-inch (19 mm) sieve and 56 blows per layer.

After compaction, the bulk density and moisture content were determined, and the dry density was calculated. The procedure was repeated at different moisture contents, and dry density was plotted against moisture content to obtain the MDD and OMC.

The bulk density was calculated as:

$$\text{Bulk Density} = \frac{Wmould+soil-Wmould}{Vmould}$$

The moisture content was calculated as:

$$\text{Moisture Content (\%)} = \frac{Wwet-Wdry}{Wdry} \times 100$$

The dry density was calculated as:

$$\text{Dry Density} = \frac{Bulk\ Density}{1+Moisture\ Content}$$

where the moisture content is expressed as a decimal in the dry-density calculation. The resulting compaction curves were used to determine the OMC and MDD for the tested materials.

2.2.3 California Bearing Ratio Test

The CBR test was conducted to evaluate the bearing resistance of the tested materials following the ASTM D1883 procedure. Specimens were prepared in a 6-inch (152.4 mm) diameter mould, with preliminary compaction performed to establish the required moisture and density conditions. Three specimens were prepared at the OMC or within 0.5% of the OMC to achieve the specified density. Moisture content was determined in accordance with ASTM D2216. A spacer disc and filter paper were placed in the mould before compaction, and a surcharge weight of at least 10 lbf (4.54 kg) was applied during testing.

For soaked CBR testing, the specimens were immersed in water for 96 ± 2 h, after which excess surface water was removed and the specimens were allowed to dry for approximately 15 min. The penetration test was then conducted at a constant loading rate while recording the applied load against penetration. The loads corresponding to penetrations of 2.5 and 5.0 mm were used to calculate the CBR.

The CBR was calculated as:

$$\text{CBR (\%)} = \frac{Measured\ Load}{Standard\ Load} \times 100$$

where the standard loads were 13.24 kN at 2.5 mm penetration and 19.96 kN at 5.0 mm penetration. The larger calculated CBR value was taken as the final CBR value.

2.3 Data Analysis

The experimental data were organised and analysed using Microsoft Excel. For sieve analysis, percentage retained and percentage passing were calculated to characterise particle-size distribution. Modified Proctor data were used to determine OMC and MDD, while CBR data were used to evaluate the bearing capacity of the tested materials. Tables, graphs, and

comparative analyses were used to assess differences in gradation, compaction behaviour, and bearing performance among the RAP–fine aggregate materials.

3.0 RESULTS AND DISCUSSION

The particle-size distribution of the natural fine aggregate and RAP–fine aggregate mixtures showed clear differences with changes in RAP content (Table 1). The tested materials included natural material (0% RAP), 25%, 50%, 70%, 75%, and 100% RAP. In general, increasing the RAP content reduced the percentage of material passing the finer sieve sizes. For example, the percentage passing the No. 4 (4.75 mm) sieve decreased from 69.1% for the natural material to 62.3%, 55.6%, 53.0%, 49.0%, and 42.1% for the 25%, 50%, 70%, 75%, and 100% RAP materials, respectively. A similar pattern was observed for the No. 200 (0.075 mm) sieve, where the percentage passing decreased from 17.2% for the natural material to 13.8%, 10.4%, 0.9%, 7.1%, and 3.8% for the corresponding RAP materials. The results indicate that the RAP material contained a lower proportion of fine particles than the natural fine aggregate.

The observed gradation indicates that blending RAP with fine aggregate provides a means of modifying the particle-size distribution of the material. The higher proportion of fine aggregate contributes more fine particles and produces a more continuous particle-size distribution, whereas the higher RAP contents generally result in a lower fine fraction. This is consistent with previous studies showing that RAP gradation and the properties and proportion of natural aggregate used in blending can influence the engineering behaviour of RAP-based unbound materials (Ok et al., 2020; de Almeida Silva et al., 2024).

This is relevant to embankment and backfill applications because particle-size distribution influences particle packing, compaction behaviour, and the resulting structure of the compacted material (Dager et al., 2023; Rout et al., 2023). However, satisfactory gradation alone does not establish engineering suitability; the gradation results therefore need to be considered together with the compaction and CBR results.

Table 1. Particle-size distribution of the tested materials

Sieve	Opening (mm)	Natural	25% RAP	50% RAP	70% RAP	75% RAP	100% RAP
2"	50.0	100.0	100.0	100.0	100.0	100.0	100.0
1½"	37.5	91.1	92.6	94.2	96.5	95.7	97.3
1"	25.0	88.4	89.5	90.6	92.4	91.7	92.8
¾"	19.0	83.7	83.7	83.8	86.5	84.0	83.7
½"	12.5	78.1	75.6	73.2	77.5	71.0	68.3
⅜"	9.5	75.1	71.0	67.0	70.8	63.0	59.0
No. 4	4.75	69.1	62.3	55.6	53.0	49.0	42.1
No. 10	2.00	62.1	53.0	44.0	38.4	34.8	25.8
No. 16	1.18	55.8	46.5	37.2	—	27.9	18.6
No. 30	0.600	46.7	38.1	30.0	—	21.0	12.5
No. 40	0.425	38.2	31.0	23.7	16.6	16.4	9.2
No. 100	0.150	19.3	15.6	12.0	—	8.2	4.6
No. 200	0.075	17.2	13.8	10.4	0.9	7.1	3.8

The Modified Proctor results showed relatively little variation in Optimum Moisture Content (OMC), whereas greater variation was observed in Maximum Dry Density (MDD) (Table 2). The OMC values ranged from 7.1% to 7.3%, while MDD ranged from 2.080 to 2.240 g/cm³ (Table 2). Sample D recorded the lowest OMC (7.1%) and the highest MDD (2.240 g/cm³), while Sample E had an OMC of 7.3% and the lowest MDD of 2.080 g/cm³. Samples A and C also recorded an OMC of 7.3%, while Sample B recorded 7.2%.

Table 2. Modified Proctor compaction characteristics of the tested samples

Sample	OMC (%)	MDD (g/cm³)
A	7.3	2.123
B	7.2	2.162
C	7.3	2.205
D	7.1	2.240
E	7.3	2.080

The narrow OMC range suggests that the tested materials required broadly similar moisture conditions to achieve their respective maximum dry densities. This is consistent with previous studies indicating that moisture content, RAP characteristics and compaction conditions influence the moisture–density response of RAP-based materials (Palammal, 2025; Kamboj & Debbarma, 2026). From a practical perspective, this relatively uniform moisture requirement may facilitate moisture control during field compaction. In contrast, the MDD values showed a wider range, indicating greater differences in the ability of the tested materials to achieve dense packing under the applied compactive effort.

Differences in material composition and particle arrangement may have contributed to the variation in achievable dry density, as RAP geotechnical behaviour is influenced by particle characteristics, gradation and processing (Bodapati & Chappidl, 2026; Dager et al., 2023). The results are consistent with the importance of compaction characteristics when RAP is considered for use as an unbound embankment or backfill material. However, because the available laboratory information does not establish a reliable relationship between Samples A–E and the RAP percentages used in the sieve-analysis programme, the MDD trend should not be interpreted directly as an increase or decrease in MDD with increasing RAP content.

The CBR results showed greater variation among the tested samples than the OMC values (Table 3). At 100% MDD, CBR values ranged from 34% to 83% (Table 3). Sample A recorded a CBR of 44%, followed by Sample B at 58%, Sample C at 70%, Sample D at 83%, and Sample E at 34%. Based on the classification adopted in the study, CBR values between 30% and 60% were classified as Good, while values greater than 60% were classified as Excellent. Accordingly, Samples A, B, and E were classified as Good, whereas Samples C and D were classified as Excellent.

Table 3: CBR performance of the tested samples at 100% MDD

Sample	MDD (g/cm³)	OMC (%)	CBR at 100% MDD (%)	Classification
A	2.123	7.3	44	Good
B	2.162	7.2	58	Good
C	2.205	7.3	70	Excellent
D	2.240	7.1	83	Excellent
E	2.080	7.3	34	Good

A clear difference in bearing performance was observed among the tested samples. From Sample A to Sample D, CBR increased from 44% to 83%, representing an increase of approximately 88.6% relative to Sample A, whereas Sample E recorded a CBR approximately 22.7% lower than Sample A. Sample D therefore achieved the highest CBR of the tested samples, while Sample E recorded the lowest. The CBR results are generally consistent with previous studies reporting that RAP and RAP–aggregate mixtures can provide suitable bearing performance when appropriate gradation, moisture content and compaction are achieved (Pradhan and Biswal, 2022). The CBR pattern broadly corresponded with the MDD results. Sample D had both the highest MDD (2.240 g/cm³) and highest CBR (83%), whereas Sample E had both the lowest MDD (2.080 g/cm³) and lowest CBR (34%). This pattern indicates an association between the achieved dry density and bearing resistance within the tested materials. The association between density and bearing performance is also supported by previous research indicating that the engineering behaviour of RAP mixtures is sensitive to density, gradation and compaction conditions (Marcobal et al., 2019; de Almeida Silva et al., 2024). However, the observed pattern alone does not establish a causal relationship between MDD and CBR. Higher compaction may contribute to improved particle interlock and penetration resistance, but additional testing would be required to establish such a relationship quantitatively.

When the gradation, compaction, and bearing results were considered together, Sample D showed the strongest overall engineering performance under the laboratory conditions, with an OMC of 7.1%, MDD of 2.240 g/cm³, and CBR of 83%. Sample C also showed relatively high performance, with an MDD of 2.205 g/cm³ and CBR of 70%, while Sample E recorded the lowest MDD and CBR values. Based on these results, Sample D was considered the best-performing tested sample. However, the available data do not provide a clear correspondence between Samples A–E and the RAP percentages used in the sieve analysis. Therefore, the specific RAP content represented by Sample D cannot be determined from the available results, and no optimum RAP percentage is proposed.

The overall findings indicate that appropriately processed and blended RAP has potential for use in road embankment and backfill applications. This finding is consistent with previous studies indicating that properly processed RAP can be used as a recycled granular material in unbound infrastructure applications when gradation, compaction, density and bearing requirements are adequately controlled (Akbas & Iyisan, 2025; Zhang et al., 2022). The sieve-analysis results demonstrate that RAP and fine aggregate can be blended to modify particle-size distribution, while the Modified Proctor and CBR results demonstrate that the tested materials can achieve measurable compaction and bearing performance. Nevertheless, suitability for field application should not be judged solely on RAP content. Gradation, moisture condition, achievable density, bearing capacity, material variability, field compaction and compliance with project specifications should be considered before implementation. Previous studies similarly emphasise processing, gradation control, compaction and quality assurance when RAP is incorporated into engineered road materials (Sukhija & Coleri, 2025). The laboratory findings therefore provide evidence of potential feasibility rather than confirmation of long-term field performance.

From a sustainability perspective, the reuse of RAP can potentially reduce the quantity of asphalt waste requiring disposal and reduce dependence on virgin aggregate materials (Jasim et al., 2024; Antunes et al., 2019). Previous sustainability and life-cycle studies have reported environmental benefits associated with recycling asphalt materials and reducing the demand for virgin materials and associated transportation (Alharbi et al., 2022; Hasan & Akbarnezhad, 2022). Such reuse is consistent with circular-economy principles and the broader sustainability objectives for Saudi Arabia. However, the present study did not quantify landfill reduction, virgin aggregate savings, carbon emissions, energy savings or economic benefits. Therefore, these environmental benefits should be considered potential advantages of RAP reuse rather than quantified outcomes of the present experimental study. Field trials and longer-term monitoring are also required to evaluate settlement, density, strength, environmental effects and performance under actual traffic and climatic conditions. Further laboratory investigations, including soaked CBR, permeability, drainage, durability and repeated-load testing, together with wider RAP–fine aggregate proportions and RAP sources from different regions of Saudi Arabia, would strengthen the assessment of RAP for wider road-construction applications.

5. CONCLUSION

Overall, the results indicate that processed RAP has potential for use as an embankment or backfill material in road construction. The tested samples showed satisfactory compaction and bearing performance, with OMC values of 7.1–7.3%, MDD values of 2.080–2.240 g/cm³, and CBR values of 34–83%. Sample D showed the best overall performance under the laboratory

conditions. However, further field trials and long-term testing are needed to confirm its suitability and performance under actual road construction conditions.

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AUTHOR CONTRIBUTIONS

Abdullah Adnan Arif: Conceptualization, Investigation, Methodology, Data Curation, Formal Analysis, and Writing

Aiman Al-Odaini: Supervision, Review & Editing.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

Ethical approval was not required for this study.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

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