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Review On Experimental Investigation on Use of Recycled Concrete Aggregate (RCA) in Pavement Base and Sub-Base Layers

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ABSTRACT

The increasing generation of construction and demolition waste has created a need for sustainable alternatives to natural aggregates in pavement construction. Recycled Concrete Aggregate (RCA), obtained from demolished concrete structures, has significant potential for use in pavement base and sub-base layers. This review examines experimental investigations on the physical, mechanical, and engineering properties of RCA used in pavement applications. Key parameters such as gradation, water absorption, compaction characteristics, California Bearing Ratio (CBR), abrasion resistance, and strength are discussed. The review also evaluates the influence of RCA content on pavement performance and compares RCA with conventional natural aggregates. Overall, the reviewed studies indicate that properly processed RCA can provide satisfactory performance while reducing the consumption of natural resources and construction waste. Thus, RCA represents a promising sustainable material for pavement base and sub-base construction.

Keywords: Recycled Concrete Aggregate (RCA); Pavement Base; Sub-Base Layer; Construction and Demolition Waste; Sustainable Pavement Materials.

1. INTRODUCTION

The rapid growth of urbanization, infrastructure development, and road construction has resulted in a significant increase in the demand for natural aggregates. Conventional pavement construction relies heavily on natural aggregates for base and sub-base layers, leading to extensive quarrying, depletion of natural resources, environmental degradation, and increased transportation requirements. At the same time, the demolition and reconstruction of concrete structures generate large quantities of construction and demolition (C&D) waste. Effective utilization of this waste in pavement construction can provide an environmentally sustainable alternative to conventional materials [1].

Recycled Concrete Aggregate (RCA) is produced by processing and crushing waste concrete obtained from demolished buildings, bridges, pavements, and other concrete structures. RCA generally consists of natural aggregate particles covered with residual cement mortar. Because of this adhered mortar, RCA differs from natural aggregate in terms of water absorption, density, porosity, and mechanical behavior [2]. These characteristics can significantly influence the compaction, strength, stiffness, and moisture response of pavement layers [3].

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Fig.1. Recycled Concrete

Base and sub-base layers are essential structural components of flexible pavements because they distribute traffic loads to the underlying subgrade and provide adequate drainage and structural support. The performance of these layers depends on properties such as particle-size distribution, compaction characteristics, bearing capacity, abrasion resistance, shear strength, and moisture sensitivity [4]. Experimental investigations have therefore focused on evaluating the suitability of RCA for these applications through laboratory tests such as the California Bearing Ratio (CBR), Proctor compaction, Los Angeles abrasion, aggregate crushing value, water absorption, resilient modulus, and shear strength tests [5].



Fig.2. Recycling Process.

Several experimental studies have demonstrated that RCA can achieve satisfactory engineering performance when it is properly processed and appropriately incorporated into pavement base and sub-base materials. However, its relatively high water absorption, lower density, presence of adhered mortar, and variable quality depending on the source of demolished concrete can affect its performance. The percentage of RCA replacement, particle gradation, compaction energy, moisture content, and blending with natural or other recycled materials are important factors controlling the final properties of the pavement layer [6].

The use of RCA offers multiple environmental and economic benefits. It reduces the quantity of concrete waste disposed of in landfills, decreases the demand for virgin aggregates, conserves natural resources, and can reduce transportation and material costs when suitable recycling facilities are available near construction sites [1, 2]. Therefore, RCA contributes to

the principles of circular economy and sustainable infrastructure development. Its application in pavement construction can also provide an effective pathway for converting waste concrete into a useful engineering material.

Despite the growing body of experimental research, differences in source materials, processing methods, testing procedures, RCA replacement levels, and environmental conditions make direct comparison between studies difficult [3]. A systematic review of experimental investigations is therefore necessary to understand the engineering behavior of RCA and identify the conditions under which it can be effectively used in pavement base and sub-base layers [7].

The present review focuses on experimental investigations concerning the utilization of RCA in pavement base and sub-base layers. It examines the physical and mechanical characteristics of RCA, evaluates its performance through commonly used laboratory tests, compares RCA with conventional natural aggregates, and identifies the major factors influencing its performance. The review also highlights existing research gaps and future opportunities for improving the sustainable application of RCA in pavement construction.

2. RECYCLED CONCRETE AGGREGATE (RCA)

Recycled Concrete Aggregate (RCA) is a granular material obtained by processing and crushing waste concrete generated from demolished buildings, bridges, roads, pavements, and other civil engineering structures. The production of RCA generally involves the collection of waste concrete, removal of unwanted materials, crushing, screening, and separation into appropriate particle-size fractions. Unlike natural aggregate, RCA particles usually contain a certain amount of adhered cement mortar, which gives them different physical and mechanical characteristics. The quality of RCA depends strongly on the original concrete strength, type of aggregate used in the parent concrete, demolition method, processing technique, and degree of contamination [8].

One of the most important characteristics of RCA is its relatively high water absorption compared with natural aggregate. The adhered mortar contains pores and microcracks, allowing RCA to absorb more water. RCA may also have lower particle density and higher porosity than conventional aggregates [2,3]. These characteristics influence the optimum moisture content and compaction behavior of pavement materials. Therefore, appropriate moisture conditioning and compaction are important when RCA is incorporated into pavement base and sub-base layers.

The gradation of RCA is another important parameter controlling its pavement performance. Properly graded RCA can provide good particle interlocking and contribute to the development of stable pavement layers. During crushing and handling, however, RCA particles may undergo additional breakdown because of the relatively weaker adhered mortar. Excessive fines generation can modify the gradation and influence drainage and compaction characteristics. For this reason, screening and quality control are essential before RCA is used in pavement construction [9].

3. PAVEMENT BASE AND SUB-BASE LAYERS

Pavement base and sub-base layers are important structural components of a flexible pavement system. They are positioned between the surface or binder layers and the natural subgrade and are primarily responsible for distributing traffic loads over a wider area, reducing the stresses transferred to the subgrade, and providing structural stability to the pavement. The quality and performance of these layers significantly influence the service life, deformation characteristics, drainage, and overall durability of the pavement. The use of Recycled Concrete Aggregate (RCA) in these layers has gained considerable attention because it provides an opportunity to replace a portion of conventional natural aggregates with recycled materials.

3.1 Pavement Base Layer

The base layer is located directly below the bituminous surface or binder course. It is one of the major load-bearing layers of a flexible pavement and is subjected to repeated traffic stresses throughout the pavement's service life. A properly designed base layer should possess adequate strength, stiffness, shear resistance, durability, and resistance to permanent deformation. Traditionally, crushed natural aggregates are used for base construction; however, RCA can be used either as a partial or complete replacement depending on its quality and the applicable specifications [10].

The performance of an RCA-based base layer depends on several factors, including RCA gradation, water absorption, particle shape, crushing resistance, compaction level, moisture content, and the percentage of RCA used. The angular and rough texture of processed RCA particles can provide good interlocking between particles. However, the presence of adhered mortar can increase water absorption and influence the compaction and strength characteristics of the layer [5].

3.2 Pavement Sub-Base Layer

The sub-base layer is positioned below the base course and above the subgrade. Its primary function is to distribute traffic-induced stresses before they reach the subgrade [7]. It also contributes to pavement drainage, frost protection where applicable, and reduction of moisture-related problems. Since the stress level in the sub-base is generally lower than that in the base layer, properly processed RCA can be particularly suitable for this application.

RCA used in sub-base construction should have suitable particle-size distribution, adequate bearing capacity, acceptable durability, and satisfactory compaction characteristics [5,6]. The California Bearing Ratio (CBR) is commonly used to evaluate the load-bearing capacity of granular materials intended for pavement applications. Other properties such as modified Proctor compaction characteristics, abrasion resistance, particle crushing, and resilient behavior are also important when assessing RCA for sub-base applications.

4. PROBLEM IDENTIFICATION

The rapid expansion of road infrastructure has increased the demand for high-quality natural aggregates for pavement base and sub-base construction. Continuous extraction of natural aggregates from quarries causes depletion of non-renewable resources, land degradation, dust generation, and increased energy consumption. At the same time, large quantities of construction and demolition waste are generated from the demolition, rehabilitation, and

reconstruction of concrete structures. A significant portion of this waste is disposed of in landfills or uncontrolled dumping areas, creating environmental and waste-management problems. Therefore, there is a need to identify technically suitable and environmentally sustainable alternatives to conventional natural aggregates.

Recycled Concrete Aggregate (RCA) provides a potential solution by converting waste concrete into useful pavement construction material. However, the engineering properties of RCA are different from those of natural aggregates because RCA particles generally contain adhered cement mortar. This adhered mortar can result in higher water absorption, higher porosity, lower density, and variable mechanical properties. These characteristics may influence the compaction, bearing capacity, stiffness, durability, and moisture behavior of pavement base and sub-base layers [9].

A major problem is the variation in RCA quality obtained from different sources. RCA produced from high-strength structural concrete may exhibit different characteristics from RCA obtained from old or deteriorated concrete pavements. Differences in the original concrete, aggregate type, demolition process, crushing method, particle size, and contamination level can significantly affect the final performance of RCA. Consequently, a standardized assessment of RCA is necessary before its application in pavement construction.

Another important issue is the uncertainty regarding the optimum percentage of RCA replacement. Increasing RCA content may provide greater environmental benefits by reducing natural aggregate consumption, but excessive RCA may adversely affect certain engineering properties. Therefore, experimental investigation is required to determine suitable RCA proportions that provide an acceptable balance between strength, durability, compaction, bearing capacity, and sustainability [4, 6, 8].

The moisture sensitivity of RCA is also an important concern. Its relatively high water absorption can alter the optimum moisture content and maximum dry density during compaction. Changes in moisture conditions can further influence CBR, resilient behavior, and deformation characteristics. This creates challenges in achieving consistent field performance, particularly under varying environmental and drainage conditions.

There is also a lack of uniformity in experimental findings reported in previous research. Different studies have used different RCA sources, replacement levels, gradations, testing procedures, and compaction conditions. As a result, the reported values of CBR, density, abrasion resistance, strength, and other performance indicators can vary considerably. A systematic review is therefore required to compare these experimental investigations and identify the major factors responsible for differences in performance [2, 3].

5. LITERATURE REVIEW

1. Pouranian et al. (2025) investigated the long-term field performance of Recycled Concrete Aggregate (RCA) as a base material in flexible pavements. The study compared RCA with conventional lime rock through field monitoring of an actual pavement test section. Parameters including pavement deflection, cracking, rutting, smoothness, and ride quality were evaluated. The results indicated that the RCA section demonstrated satisfactory long-term structural performance and showed favorable behavior compared with the conventional

base material. The study provides important evidence that RCA can be successfully used beyond laboratory conditions in flexible pavement base layers.

2. Ali et al. (2025) experimentally investigated the durability of RCA used as a pavement base material, with particular emphasis on drainage conditions. Laboratory testing and pavement simulation were used to assess the behavior and durability of RCA under different conditions. The research demonstrated the importance of drainage and moisture management in maintaining the performance of RCA-based pavement layers. The study concluded that properly designed RCA base layers can provide a sustainable alternative to conventional aggregates while maintaining satisfactory durability.

3. A 2025 study on natural-rubber-latex-modified geopolymer-stabilized RCA evaluated RCA as a sustainable pavement base material after stabilization with bottom-ash-based geopolymer and natural rubber latex. Unconfined compressive strength tests were performed at 7 and 28 days, together with SEM, EDX, and XRD analyses. The optimum mixture containing 0.1% natural rubber latex and a geopolymer ratio of 1:1 achieved UCS values of approximately 4.0 MPa at 7 days and 5.17 MPa at 28 days. The results demonstrated that stabilization can significantly improve RCA strength and make it suitable for pavement sub-base applications.

4. A 2024 study on the resilient behavior of RCA investigated the combined influence of fines content and moisture content on RCA used as an unbound granular pavement material. Laboratory testing showed that fines content strongly influences the soil-water characteristics and resilient modulus of RCA. The study found that an optimum fines content exists at which resilient modulus reaches a maximum, while increasing moisture initially increased and subsequently reduced resilient modulus. These findings emphasize that moisture and gradation control are critical for achieving reliable RCA performance in pavement base and sub-base layers.

5. Jing et al. (2024) examined the effect of self-cementing properties on the resilient behavior of RCA used in pavement base and sub-base layers. Two types of RCA with different self-cementing characteristics were evaluated at curing periods of 1, 180, 360, and 720 days. Calorimetry, mercury intrusion porosimetry, and repeated-load triaxial tests were used to investigate material development and resilient deformation. The research highlighted that the self-cementing behavior of RCA can contribute to increased strength and stiffness with curing time, demonstrating an important mechanism for long-term performance of unbound RCA layers.

6. A 2024 experimental study evaluated cement-treated RCA for sustainable pavement base and sub-base construction. The research investigated both untreated and cement-treated RCA using particle-size distribution, Los Angeles abrasion, aggregate impact, modified Proctor compaction, UCS, wet-dry durability, SEM, and EDS analyses. Cement treatment significantly improved the strength and durability of RCA. The study reported that cement contents of 3% or higher could satisfy specified UCS requirements for several pavement applications, while higher cement contents were required for more demanding base-layer conditions.

7. A 2024 laboratory study investigated the utilization of RCA in pavement base courses using cement-stabilized recycled concrete aggregate mixtures. RCA replacement levels from 0% to 100% and cement contents from 3% to 7% were examined. Strength, elastic modulus, indirect tensile strength, fatigue, drying shrinkage, and durability were evaluated. The results showed that cement content had a greater influence on performance than RCA percentage. Mixtures containing up to 50% RCA with 5% cement satisfied the investigated strength and durability requirements, indicating that partial RCA replacement can provide a suitable alternative for conventional cement-treated base materials.

8. A 2024 study investigated the environmental and engineering performance of recycled aggregates in pavement base layers. The experimental program included routine characterization, matric suction, static triaxial testing, and repeated-load triaxial testing to evaluate the response of recycled materials under static and cyclic loading. The study demonstrated that recycled aggregates can provide a technically feasible alternative to virgin aggregates while also offering potential environmental benefits. The findings support the use of recycled materials in pavement base construction where appropriate engineering and environmental conditions are satisfied.

9. A 2025 field-oriented investigation by the Florida Department of Transportation evaluated RCA against conventional lime rock in flexible pavement base construction. Unlike studies based only on laboratory testing, the investigation used an actual pavement test site and monitored structural and functional performance over time. RCA exhibited favorable performance in terms of structural integrity, deflection, rutting, smoothness, and ride quality. This study is particularly important because it provides evidence of the practical long-term applicability of RCA as a pavement base material.

10. A 2026 study investigated the performance grading and mechanistic design of pavement base courses containing RCA and recycled concrete powder (RCP) stabilized with asphalt. The research proposed a performance-grading approach and mechanistic design methodology for recycled base courses. The study emphasized the synergistic utilization of RCA and RCP and addressed the need for systematic performance evaluation and structural design of recycled pavement bases. The research represents a recent development toward moving RCA applications from simple material replacement toward performance-based pavement design.

6. RESEARCH GAP

Although numerous experimental studies have established the potential of Recycled Concrete Aggregate (RCA) for pavement base and sub-base construction, several important research gaps remain. Most existing investigations are based on laboratory-scale testing, while comparatively fewer studies have evaluated the long-term field performance of RCA under actual traffic and environmental conditions. Therefore, the relationship between laboratory performance indicators and real pavement service behavior requires further investigation.

A major gap exists in the variability of RCA properties. RCA characteristics depend on the source concrete, original aggregate type, adhered mortar content, demolition technique, crushing process, and contamination level. Because of this variability, experimental results reported by different researchers are often difficult to compare directly. A standardized

characterization and quality-control framework for RCA intended specifically for pavement base and sub-base applications is still required.

Another important gap concerns the optimum RCA replacement level. Previous studies have investigated different replacement percentages, but there is no universally accepted optimum percentage applicable to all pavement conditions. Increasing RCA content may improve waste utilization and reduce natural aggregate consumption, but excessive RCA can increase water absorption, particle degradation, and moisture sensitivity. Further experimental studies are therefore required to establish optimum RCA proportions based on pavement traffic category and layer requirements.

The influence of moisture and drainage conditions also requires greater attention. RCA generally possesses higher water absorption than natural aggregate because of adhered cement mortar. However, many laboratory studies evaluate RCA under controlled moisture conditions that may not adequately represent seasonal changes, rainfall, groundwater, and drainage conditions in actual pavements. More research is needed to evaluate the coupled effects of moisture, drainage, repeated traffic loading, and environmental exposure.

There is also limited research on the long-term resilient behavior and permanent deformation of RCA under realistic cyclic loading. Although repeated-load triaxial and resilient modulus tests have been conducted, differences in stress states, moisture conditions, gradation, and testing protocols make comparison difficult. Mechanistic studies connecting RCA material properties with pavement-level rutting, fatigue, and structural response remain comparatively limited.

The use of RCA combined with supplementary materials represents another research opportunity. Stabilization using cement, geopolymer, asphalt, fly ash, slag, or other sustainable binders has demonstrated potential for improving strength and durability. However, the optimum combination of RCA and stabilizing materials, together with its long-term environmental and mechanical performance, requires further investigation.

Finally, although the environmental benefits of RCA are widely recognized, relatively fewer studies have integrated engineering performance, environmental impact, and economic feasibility into a single evaluation framework. Life-cycle assessment and life-cycle cost analysis should be combined with laboratory and field performance data to determine whether RCA provides a genuinely sustainable alternative to natural aggregate under different pavement conditions.

7. CONCLUSION

The review of experimental investigations confirms that Recycled Concrete Aggregate (RCA) has significant potential for use in pavement base and sub-base layers as a sustainable alternative to conventional natural aggregates. The utilization of RCA can reduce the consumption of virgin aggregates, minimize construction and demolition waste, and support more environmentally responsible pavement construction.

The reviewed studies indicate that RCA generally exhibits higher water absorption, lower density, and greater porosity than natural aggregate because of the presence of adhered cement mortar. These characteristics influence its compaction behavior, moisture

requirements, bearing capacity, and durability. However, when RCA is properly processed, graded, compacted, and proportioned, it can achieve satisfactory engineering performance for pavement applications.

Experimental results reported in recent studies demonstrate that RCA can provide adequate California Bearing Ratio (CBR), resilient modulus, strength, abrasion resistance, and deformation characteristics for base and sub-base layers. Its performance is strongly dependent on RCA quality, replacement percentage, gradation, moisture condition, compaction, and curing period. Stabilization using cement, geopolymer, asphalt, and other binders can further improve the strength and durability of RCA-based pavement materials.

The review also indicates that optimum RCA content cannot be considered universal because it depends on the source and quality of RCA, pavement layer requirements, traffic loading, and environmental conditions. Therefore, laboratory characterization should be conducted before field implementation to determine appropriate RCA proportions and construction conditions.

Despite promising experimental results, limitations remain regarding long-term field performance, moisture and drainage effects, repeated traffic loading, material variability, and standardized specifications. Future research should focus on large-scale field trials, mechanistic pavement analysis, long-term monitoring, sustainable stabilization methods, and integrated life-cycle environmental and economic assessments.

Overall, RCA represents a technically feasible, economically attractive, and environmentally sustainable material for pavement base and sub-base construction. Its wider adoption can contribute to natural resource conservation, reduction of construction waste, and development of sustainable road infrastructure, provided that appropriate material characterization, quality control, mix design, and pavement performance evaluation are carried out.

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