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Experimental Evaluation of Physical, Mechanical and Chemical Properties of Natural and Recycled Concrete Aggregates

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Abstract

The structural properties of concrete, such as workability, strength, serviceability, and durability, are heavily influenced by the quality and characteristics of the aggregates used. The growing urbanization and infrastructure development have led to the overexploitation of natural aggregates, especially from the ecologically sensitive Chure region of Nepal, causing deforestation, habitat loss, and geomorphological instability. Meanwhile, construction and demolition waste continues to rise without effective reuse or regulation. This study addresses these challenges by evaluating the potential of Recycled Concrete Aggregates (RCA) as a sustainable alternative to Natural Aggregates (NA) for building applications. The research investigates and compares the physical (bulk density, specific gravity, water absorption, porosity), mechanical (aggregate crushing value, impact value), and chemical properties (alkali, chloride, sulfate, and carbonation content) of RCA and NA, following IS and ASTM standards. Assessing the physical, mechanical, and chemical properties of aggregates before concrete production is a critical step to ensure the quality, workability, strength, serviceability, and durability of the final concrete product. The results revealed that RCA has lower bulk density and specific gravity, and significantly higher porosity compared to NA. While both aggregate types met acceptable limits for water absorption and most chemical contents, RCA exceeded the 5% limit for carbonation, posing risks in reinforced concrete. RCA also displayed higher mechanical properties – Aggregate Crushing Value (33.64% average) and Aggregate Impact Value (30.40% average), making it unsuitable for wearing surfaces but acceptable for general concrete use. The findings suggest that RCA, despite its limitations in density, porosity, and carbonation resistance, is a viable and eco-friendly option for non-structural applications, pavements, and general concrete works. Its adoption can reduce reliance on quarrying, conserve the Chure ecosystem, and promote sustainable construction in Nepal. However, standardized guidelines and public awareness are essential to enhance its effective use and address associated environmental and technical concerns.

Keywords

Natural aggregate, Recycle concrete aggregate, physical, mechanical, and chemical properties

1. Introduction

Concrete has been the most widely used building material in the world for many years, and it is essential to the development of long-lasting modern infrastructure. Its outstanding performance, combined with its cost and the availability of local raw materials, is what makes it so popular to construct a variety of infrastructures, including water systems, residential and commercial buildings, health systems, and transportation networks [1]. The need for additional physical infrastructure is rising because of population increase and fast urbanization. However, it has been shown that the extensive usage and manufacture of concrete has detrimental effects on the environment since it contributes to the use of natural resources and greenhouse gas (GHG) emissions. As a result, concrete is thought to be the second-largest source of CO_2 emissions worldwide and is mostly responsible for the over 26.8 billion tons of building aggregates that are needed annually [2]. Since the construction sector uses a lot of natural resources, it is anticipated that worldwide virgin aggregate output would reach over 60 billion tons by 2030 [3]. Natural aggregates like sand and stone are in high demand in the concrete industry, and the excessive usage and exploitation of natural sand and stone harms the environment. Because of the depletion of natural resources, pollution and solid waste production rise, threatening biodiversity and ultimately causing global warming. Global environmental damage has resulted from the unplanned consumption of natural resources without taking the circular economy into account [4].

Polyethylene terephthalate (PET) bottle and waste management is a global concern because 20–23% of PWP is generated during the production of PET pellets, which can be used as sustainable mortar material and help release harmful gases when burned [5]. Furthermore, the flexural and ductility qualities of structures could be improved by using the short, thin banana fiber as a sustainable substitute for synthetic fibers in the manufacturing of mortar [6]. Waste glass (WG), which is not biodegradable and often ends up in landfills, is a major environmental problem. However, it can be used to make concrete, which can be regarded as a sustainable material because it lowers CO_2 emissions and the demand for cement and aggregates, preventing environmental damage [7]. Eulaliopsis Binata (EB) fiber has recently been used in mortar and concrete applications to improve the manufacturing of inexpensive green concrete, which aids in the creation of sustainable infrastructure[8]. Similarly, the compressive strength of cement mortar indicates that Eupatorium Adenophorum Spreng (EAS) powder can be used to mortar in lieu of mineral admixtures. Improved burning conditions, finer particle grinding, and careful micro-characterization can all assist achieve the required compressive strength[9]. In addition to addressing important issues with plastic waste management, the use of plastic waste aggregate (PWA) in concrete makes it possible to produce sustainable structural and non-structural concrete [10]. It has been observed that only 20% of EPS can be utilized with the conventional (CON) mixing method, however up to 30% can be used with the High Ductile Mortar (HDM) method to generate the structural EPS mortar. By creating non-structural mortar with up to 60% EPS, both methods can replace non-load bearing infill and partition walls with autoclaved lightweight concrete (ALC) [11]. Innovation has emerged to create concrete and cement mortar utilizing a variety of sustainable ingredients, according to recent studies.

Despite concrete being a popular building material because of its strength, durability, and adaptability, it nonetheless produces significant waste. For the concrete industry, the idea and use of recycled aggregate concrete (RAC) provide a sustainable option. Concurrently, construction and demolition generate a significant amount of solid waste, and its use is growing quickly on a global scale. More sustainable concrete building methods are desperately needed, since resource scarcity and climate change continue to be significant obstacles. To address these issues, the construction sector is aggressively investigating and utilizing more environmental friendly methods and materials in concrete construction [12] by examining the properties of RCA and RAC. The viability of concrete waste recycling to produce recycled aggregate concrete has been the subject of much investigation over the last few decades. Recycled aggregate concrete is gaining popularity in the construction industry as a partial and full replacement for natural coarse aggregate. Furthermore, the use of RCA in concrete provides a viable remedy for the environmental problem caused by concrete waste and mitigates the negative environmental consequences of aggregate mining from natural resources [13], [14], [15]. It has been considered that normal concrete manufactured with natural aggregate (NA) has better qualities than RCA concrete, especially in terms of durability and modulus of elasticity, which are related to water absorption [16]. There has been much research on the use of recycled aggregates (RAs) to replace natural aggregate (NA) entirely or partially [17]. Despite successful traditional laboratory experiments demonstrating the potential of RA in concrete, its practical application is often restricted to non-structural concrete, and it is advised that the replacement ratio of RA by NA does not surpass 30% [18]. Nonetheless, the previous assessment of RCA as a possible sustainable substitute for natural aggregates in high-performance concrete, which was judged appropriate at 50% RCA [19], has shown its appropriateness as sustainable construction material. In recent years, several studies have examined the use of RCA or RAC in a variety of physical infrastructure projects, including building and road construction.

The performance of the RAC depends upon the lifespan of the demolished infrastructure and the origin of the RCA. While some studies claim that using RCA deteriorates the characteristics of concrete, others have successfully created RCA concrete that performs similarly to normal concrete (NC). Therefore, it is crucial to understand the characteristics of RCA, its state-of-the-art attributes, and how it affects concrete properties to guarantee the efficacy of its application. The use of RCA in the production of concrete has a major influence on its properties and design methodology. Impurities, cement content, and mortar all have a major influence on the characteristics of RCA, including shape, texture, density, specific gravity, porosity, and absorption[20]. The required properties of RCA must be obtained by carefully demolishing old concrete infrastructure before producing RAC from it. Some researchers indicate that coarse recycled concrete aggregates often have poor mechanical properties because of fractures that emerge during crushing, and they also have a lot of pores in the cement mortar that is bonded, making them less durable than natural aggregates [21], [22], [23]. Due to its significant qualities, cost-effectiveness, and environmental protection, RCA has been considered the valuable material for making concrete. To manufacture superior concrete based on the qualities of RCA, it is crucial to assess the various RCA properties prior to manufacturing RAC. Some of the mechanical and physical properties that affect the strength of concrete and durability include aggregate strength, gradation, absorption, specific gravity, form, and texture [21], [24].

For the reconstruction, a vast amount of the materials produced by every home wrecked in the Gorkha earthquake were reused. No specific waste management standards or processes were in place, yet half of the material was recycled and used for reconstructing the buildings in Nepal [25]. Reusing concrete and brick pieces made from recycled concrete leftover from a major earthquake 2015 in Nepal resulted in a 4.5% improvement in 28-day compressive strength and a 3–5 cm rise in slump at 100% recycled coarse aggregate [26]. However, the strength and durability of concrete has been influenced by the characteristics of RCA, including specific gravity, water absorption, and the quantity of contaminants present [27]. In comparison to natural coarse aggregate, it was found that recycled aggregates (RA) had a lower specific gravity and a higher water absorption which impacts the strength of the concrete.

Underutilization of Recycled Concrete Aggregates (RCA) and rising landfill strain are caused by inadequate regulations and a lack of public understanding about the usage of RCA and demolition waste management [28]. The use of construction and demolition (C&D) waste in concrete has not been widely accepted by the public and concerned authorities in Nepal. Due to their inconsistent and variable quality, construction and demolition waste require the use of standardized testing procedures and quality control systems to achieve performance criteria [29]. In low grade concrete (15 MPa), construction and demolition waste (CDW) was utilized to substitute 40% of the natural aggregate without considering how the properties of CDW might impact the concrete's strength[30]. In Nepal, appropriate management of trash and debris was hindered by the absence of legislation and processes pertaining to rubbish and debris, which became apparent after the Gorkha earthquake. However, people rebuilt homes using 57.96% of the debris that was produced [25]. The primary mechanical, geotechnical, and physical characteristics of recycled construction and demolition waste aggregates that make them suitable for use as subbase or pavement base materials but have not been frequently used for building construction. Although recovered construction and demolition waste aggregates have not been widely used in building construction, their main mechanical, geotechnical, and physical properties make them appropriate for usage as subbase or pavement base materials [31]. It has been discovered that only low-strength concrete materials can be created from building and demolition waste instead of sand; nevertheless, each material's unique qualities should be assessed independently. To reassure individuals about evidence-based research and development, thorough studies on the characteristics of RCA and their influence on the production of RAC are required. So, this research will be emphasized on the investigation of experimental evaluation of physical, mechanical and chemical properties of natural and recycled aggregates for concrete. Furthermore, the study will examine the performance of concrete built with RCA and NA, examining characteristics such as bulk density, specific gravity and water absorption, porosity, and resistance to impact, crushing, and abrasion. Laboratory testing, analysis, and comparison of RCA from various sources to natural aggregates will be part of the study to determine the ideal ratios that preserve or enhance concrete performance while abiding by sustainability standards.

2. Materials and Methods

2.1 Study Area and Data Collection

This research focuses on Nepal's southern Terai region, specifically Parsa, Morang, and Jhapa districts. Key natural aggregate (NA) extraction sites are the geologically young, erosion-prone Chure hills (sandstone, conglomerates) in Parsa, and the river systems Khutti Khola (Morang) and Mawa Khola (Jhapa). These rivers flow through flat, alluvial floodplains (sand, silt, gravel) prone to seasonal flooding and bank erosion. Sources of Recycled Concrete Aggregates (RCA) are distributed across these districts. The entire area faces environmental sensitivity due to unsustainable extraction, active tectonics, and seismic risks. Figure 1 highlights the location and distribution of data/material sources.

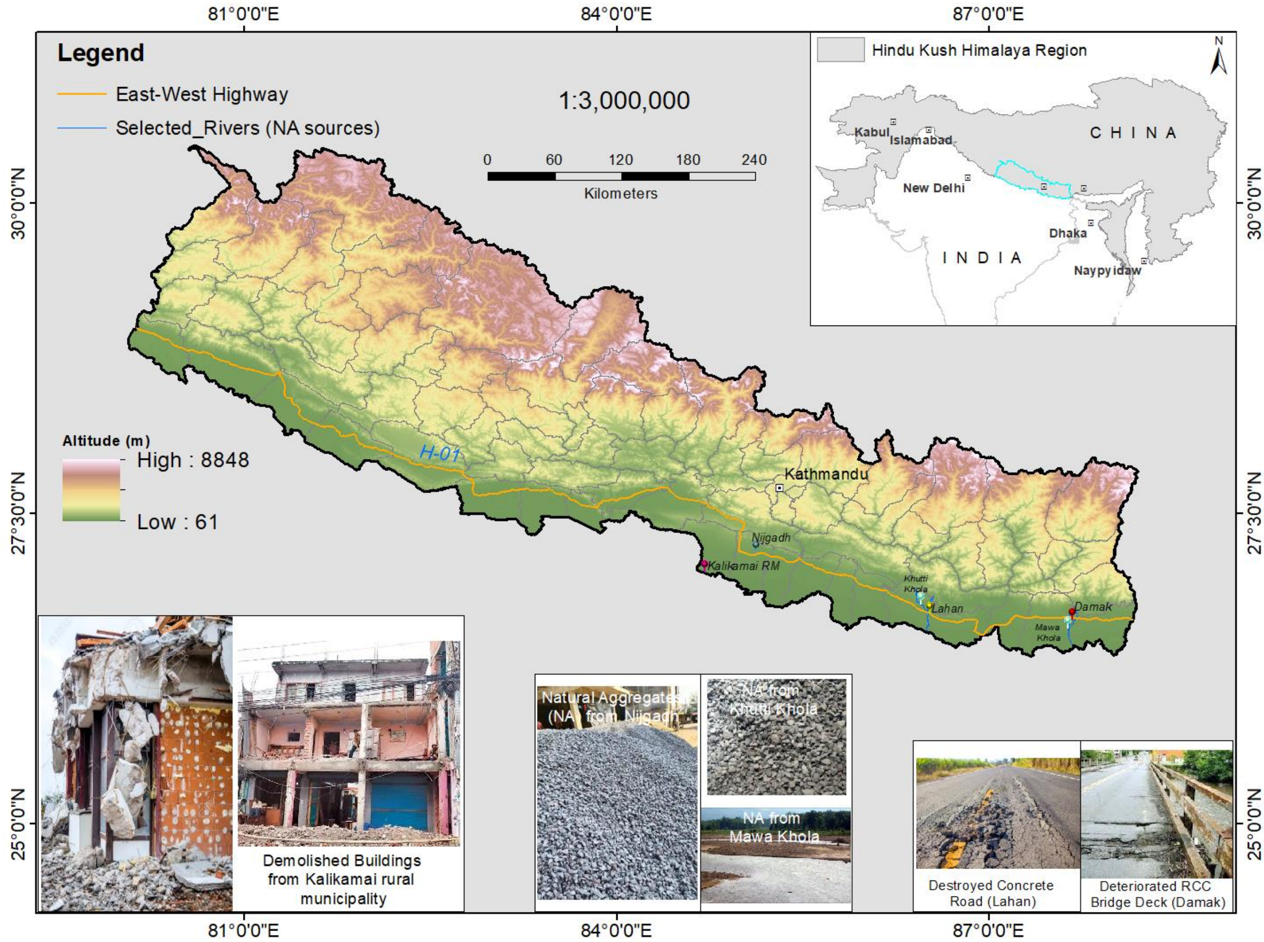

Figure 1: Map Showing the Location of Study Area and Sources for NA and RCA

2.2 Material used and Sample Preparation

The study material consists of Natural Aggregates (NA) and Recycled Concrete Aggregates (RCA) sourced from specific locations in Nepal, as detailed in Table 1. RCA was collected from demolished concrete structures: buildings in Kalikamai Rural Municipality-04, Parsa; a bridge deck in Damak Municipality, Jhapa; and road pavement along the East-West Highway, Morang. Natural Aggregates (NA) was collected from riverbeds/quarries: the Chure region in Nijgadh, Bara; Mawa Khola in Damak, Jhapa; and Khutti Khola in Lahan, Siraha.

Table 1: Number of Samples and Extraction Locations of materials used

Material	Sampling Location	Sample Source	No. of samples
RCA	Kalikamai Rural Municipal-04, Parsa	Demolished Buildings	3
	Damak Municipality-09, Jhapa	Deteriorated RCC Bridge	1
	East-West Highway, Siraha	Destroyed Concrete Pavement	1
NA	Nijgadh, Bara	Chure Region	3
	Damak, Jhapa	Mawa Khola	1
	Lahan, Siraha	Khutti Khola	1

Following systematic collection of the RCA from demolition sites and NA from natural deposits, samples underwent distinct preparation as per Codal provisions detailed in Table 2. For physical and mechanical testing, RCA was broken to remove debris, while both NA and RCA were sieved to a uniform 10 - 12.5 mm (Passing on 12.5 mm and retaining on 10 mm IS sieve) fraction; instruments were calibrated. For chemical analysis, concrete samples were cleaned, sequentially crushed using a jaw crusher and secondary crusher, sieved to achieve uniformity, then washed and oven-dried prior to testing.

Table 2: Details about physical, mechanical and chemical properties tests of NA and RCA

SN	Test Properties of NA and RCA	Name of Test	Test Methods
1	Physical Properties	Sieve analysis	IS:2386 (Part-III)
		Water absorption	IS:2386 (Part-III)
		Specific Gravity	IS:2386 (Part-III)
		Bulk Density	IS:2386 (Part-III)
2	Mechanical Properties	Aggregate Impact Test (AIV)	IS:2386 (Part-IV)
		Aggregate Crushing Value Test (ACV)	IS:2386 (Part-IV)
3	Chemical Properties	Alkali content	IS:2386 (Part-VII)
		Chloride content	IS:2386 (Part-II)
		Sulfate content	IS:2386 (Part-V)
		Carbonation content	IS:2386 (Part-II), IS:383

2.3 Research Approach and Methodology

An experimental research design was employed to systematically compare the physical, mechanical, and chemical properties of Recycled Concrete Aggregates (RCA) and Natural Aggregates (NA) against established standard limits. The methodology involved preparing samples (Section 2.2) and conducting standardized tests (Table 2) in accordance with relevant IS and ASTM procedures. Figure 2 presents a flowchart illustrating the overall research methodology.

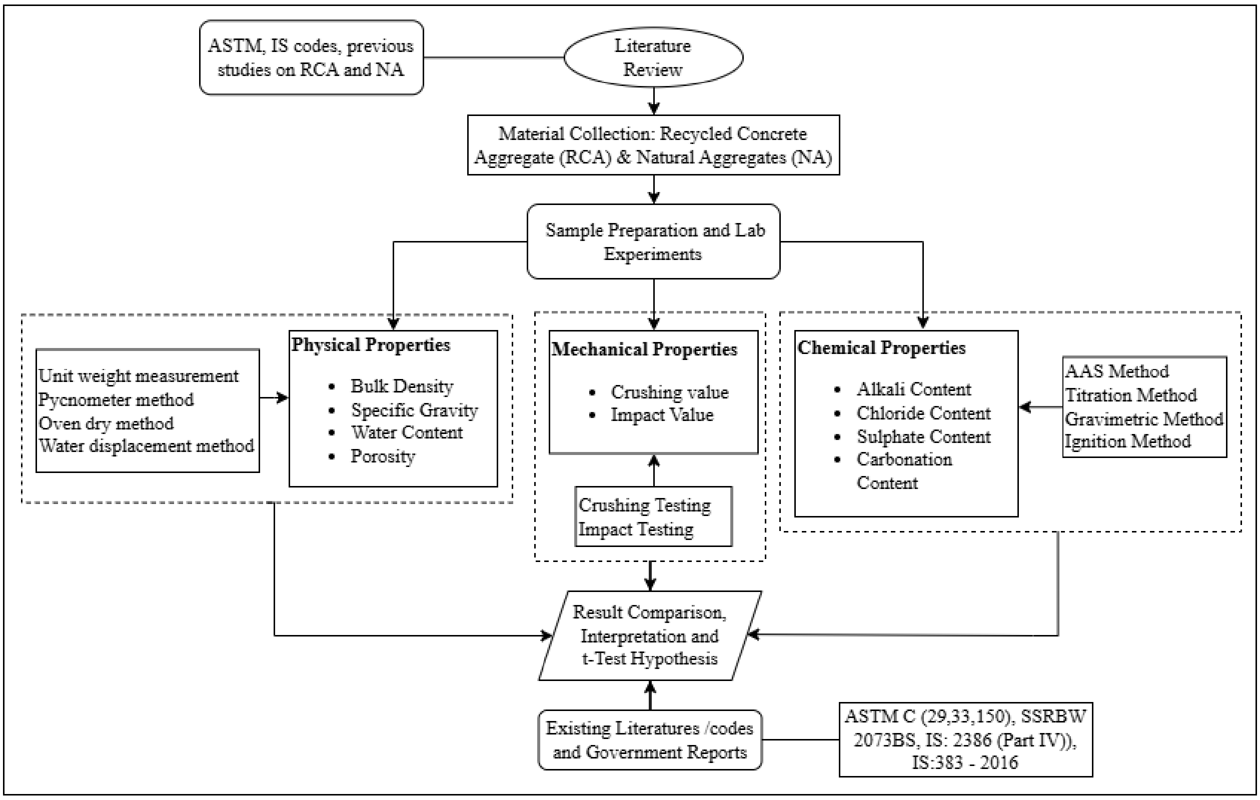

Figure 2: Flowchart Showing Methodological Framework of Study

3. Results and Discussion

The samples of natural and recycled concrete coarse aggregate were tested to find out their physical, mechanical, and chemical properties. The properties have been accessed based on ASTM C 29/ 29M – 97 (2003), ASTM C150 (2007), IS 383 (2016), IS 383 (2016), ASTM C33/ C33M (2008), SSRBW 2073BS (2016), DOR, Nepal; Manual of Standard Tests (2021). The experimental results have been presented in the following sections that utilized the test and test procedure mentioned in Table 2 following IS:2386 (Part-II), IS:2386 (Part-III), IS:2386 (Part-IV), IS:2386 (Part-V), and IS:2386 (Part-VII).

3.1 Physical properties of aggregate

The physical properties of Natural Aggregates (NA) and Recycled Concrete Aggregates (RCA) were evaluated in accordance with [32] and [33], to assess their suitability for use in concrete. Key parameters tested include bulk density, specific gravity, water absorption, and porosity (Figure 3).

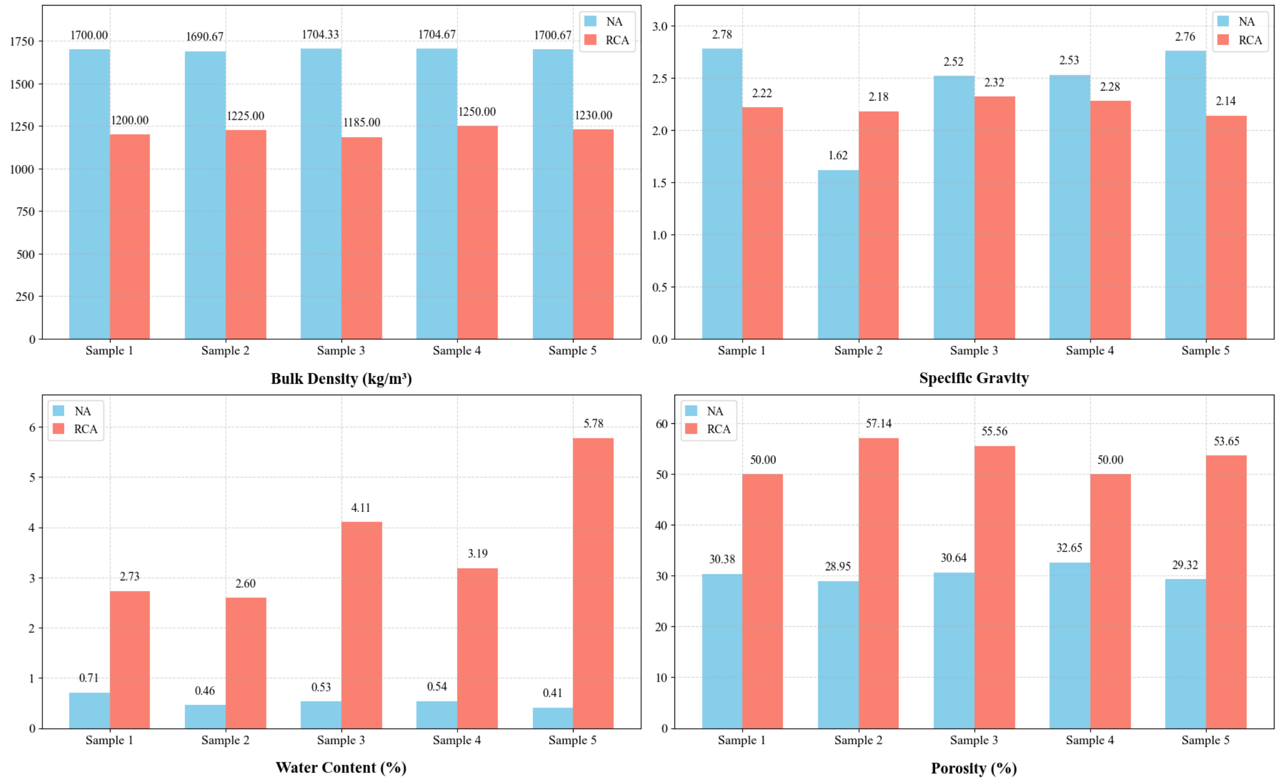

Figure 3: Physical Properties (Bulk Density, Specific Gravity, Water Content, and Porosity) of NA and RCA

The physical properties of Natural Aggregates (NA) and Recycled Concrete Aggregates (RCA) were assessed in accordance with standard procedures to determine their suitability for concrete production. Key parameters evaluated include bulk density, specific gravity, water absorption, and porosity. The mean bulk density of NA was 1700.07 kg/m³ with a 95% confidence interval (CI) of 1695.63–1704.50 kg/m³, falling within the typical range for coarse aggregates (1280–1920 kg/m³). In contrast, RCA showed a significantly lower mean bulk density of 1218 kg/m³ (95% CI: 1197.90–1238.10 kg/m³), reflecting the presence of adhered mortar and voids. The specific gravity of NA and RCA averaged 2.442 and 2.228, respectively. While NA nearly meets the required minimum of 2.50 for natural stones, RCA remained within acceptable aggregate limits (2.1–3.2), although slightly lower due to its recycled nature.

Water absorption and porosity were notably higher in RCA compared to NA, consistent with expectations. NA showed a mean water absorption of 0.53%, well below the 5% limit, while RCA averaged 3.68%, approaching the upper permissible threshold. The mean porosity values were 30.39% for NA and 53.27% for RCA. Although NA's porosity aligns with standard fine aggregate values (30–45%), RCA exceeded the typical range due to its retained mortar content and internal voids. These results confirm that RCA possesses lower density, higher absorption, and greater porosity than NA, which may influence its behaviour in concrete applications and necessitates appropriate mix design adjustments. The high absorption and porosity in RCA are attributed to residual adhered mortar.

Table 3: Summary of Physical properties Test

S.N.	Test Name	Natural Aggregates (NA)	Recycled Aggregates (RCA)	Standard Limits	Reference	NA Remarks	RCA Remarks
1	Bulk Density (kg/m³)	1700.07	1218	(1280–1920) kg/m³	[34]	Acceptable but not compliance	Compliance
2	Specific Gravity	2.442	2.228	>2.5	[35]	Acceptable but not compliance	Acceptable but not compliance
3	Water Content (%)	0.53	3.68	<5%	[35]	Compliance	Compliance
4	Porosity (%)	30.39	53.27	(25–40)%	[34]	Compliance	Not Compliance

Both natural aggregates (NA) and recycled concrete aggregates (RCA) meet the bulk density standards set by ASTM C 29/29M, indicating good compaction characteristics. However, the specific gravity of RCA consistently falls below the acceptable limit of 2.5, largely due to the presence of lighter materials like residual mortar, while NA mostly meets the requirement with only some exceptions (Table 3). In terms of water content, both NA and RCA perform within the acceptable range of less than 5%, although RCA exhibits higher water absorption due to its increased porosity. Porosity tests reveal that NA generally conforms to the ASTM standard range, while RCA shows significantly higher porosity, leading to its rejection as it implies a weaker structure with more voids. Overall, RCA fails to meet key criteria related to specific gravity and porosity, which raises concerns about its structural reliability compared to NA.

3.2 Mechanical properties of aggregate

The mechanical properties of Natural Aggregates (NA) and Recycled Concrete Aggregates (RCA) were evaluated using Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) tests (Figure 4) in accordance with established standards. The mean ACV for NA was 25.03%, well within the permissible limit of 30% for aggregates used in wearing surfaces. In contrast, RCA recorded a higher mean ACV of 33.64%, which exceeds the limit for wearing surfaces but remains acceptable for general concrete applications (up to 45%).

This reflects the relatively lower crushing resistance of RCA due to the presence of residual mortar and micro-cracks from the parent concrete. Similarly, NA exhibited a lower mean AIV of 24.36%, compared to 30.40% for RCA. While both fall within the acceptable limit of 45% for general concrete use [32], [37] only NA satisfies the stricter requirement of 30% for wearing surfaces such as pavements and runways [38]. The higher AIV of RCA is attributed to its reduced toughness, a consequence of the recycling process. Overall, RCA demonstrated comparatively lower mechanical strength than NA, suggesting the need for careful consideration in structural or high-strength concrete applications. For the Aggregate Crushing Value (ACV)**,** natural aggregates had lower values (24.90% to 25.20%), which made them strong enough for both road surfaces and other concrete uses. Recycled aggregates had higher values (32.70% to 35.40%), so they were only good for general concrete work, not road surfaces. For the Aggregate Impact Value (AIV)**,** natural aggregates (23.70% to 25.00%) were strong and suitable for all uses. Recycled aggregates (28.60% to 31.80%) were accepted for general concrete but may not always be strong enough for road surfaces because natural aggregates are stronger, while recycled ones are weaker, so they are more limited in use (Table 4).

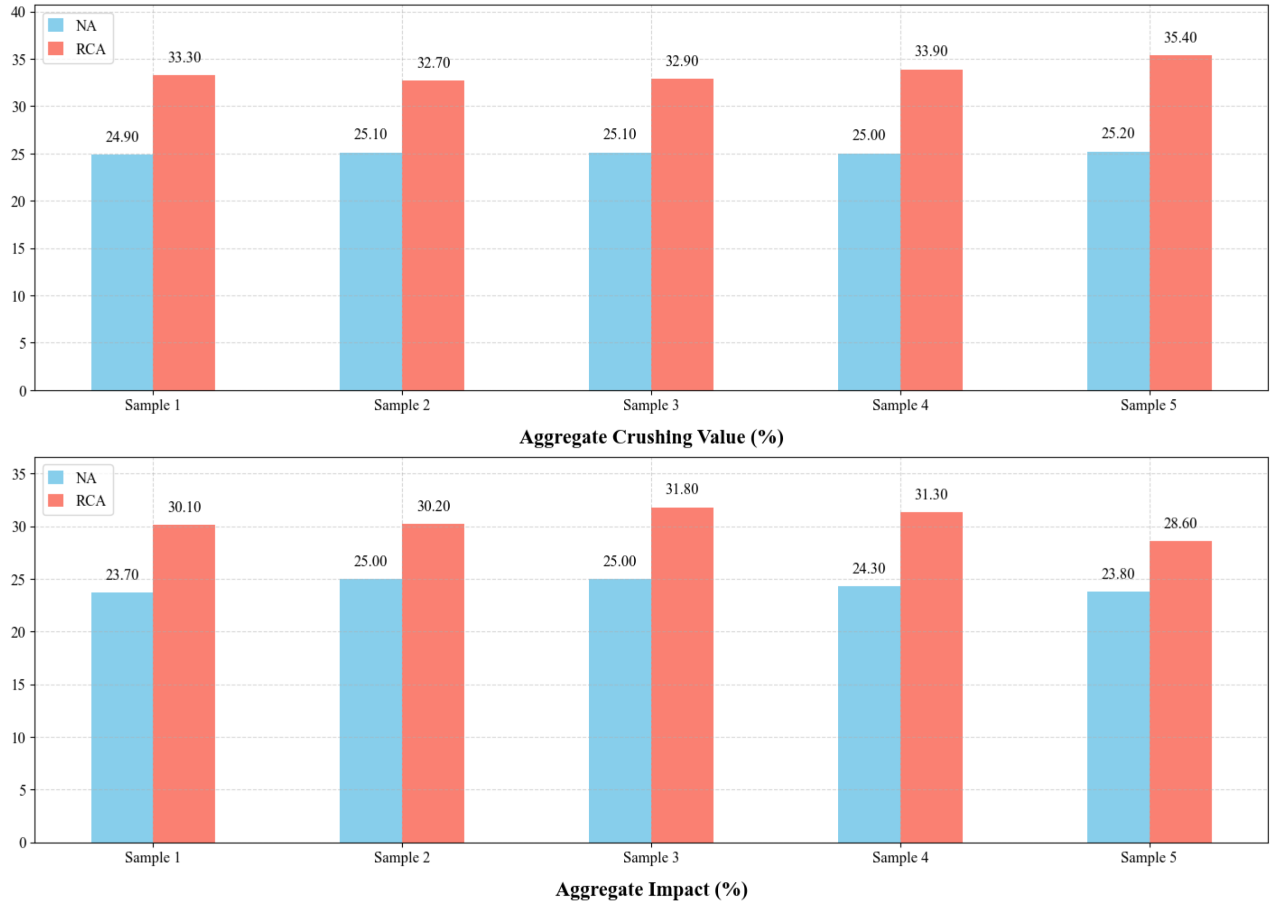

Figure 4: Mechanical Properties (Crushing and Impact Value) of NA and RCA

Table 4: Summary of Mechanical properties Test

S. N.	Test Name	Natural Aggregates	Recycled Aggregates	Standard Limit	Remarks	
					NA	RCA
1	ACV	25.06	33.64	< 30% for Wearing Surfaces & < 45% for other Concrete [32]	Accepted for wearing surfaces as well as other concrete works	Accepted for other concrete works only
2	AIV	24.36	30.40	< 30% for Wearing Surfaces & < 45% for other Concrete [32]	Accepted for wearing surfaces as well as other concrete works	Accepted for other concrete works only Accepted for both

3.3 Chemical properties of aggregate

The chemical properties of Natural Aggregates (NA) and Recycled Concrete Aggregates (RCA) were analyzed to assess their suitability for use in concrete, focusing on alkali, chloride, sulphate, and carbonation contents (Figure 5). The mean alkali content (Na_2O) for NA was 0.0502%, while for RCA it was higher at 0.111%, yet both were well below the commonly accepted threshold of 0.60% [39]. However, IS: 383–2016 recommends a maximum limit of 0.3% [36], indicating RCA may exceed acceptable levels in some cases. The potassium oxide (K_2O) content was also slightly higher in RCA (0.556%) compared to NA (0.498%) [40].

Chloride content in NA averaged 0.1614%, exceeding the general limit of 0.03–0.04% for reinforced concrete set by BS and ACI standards[40], [41]. RCA, in contrast, had a much lower mean chloride content of 0.021%, within permissible limits. Both NA and RCA showed sulphate contents (as SO_3) below the maximum allowed 0.5% in aggregates [36], complying with IS: 456–2000 which sets a total limit of 4.0% by cement weight or 0.4% by aggregate weight, whichever is lower [35]. Carbonation content in both aggregate types remained below the 5% maximum permitted by IS: 383–2016 [36], ensuring durability and minimizing corrosion risk.

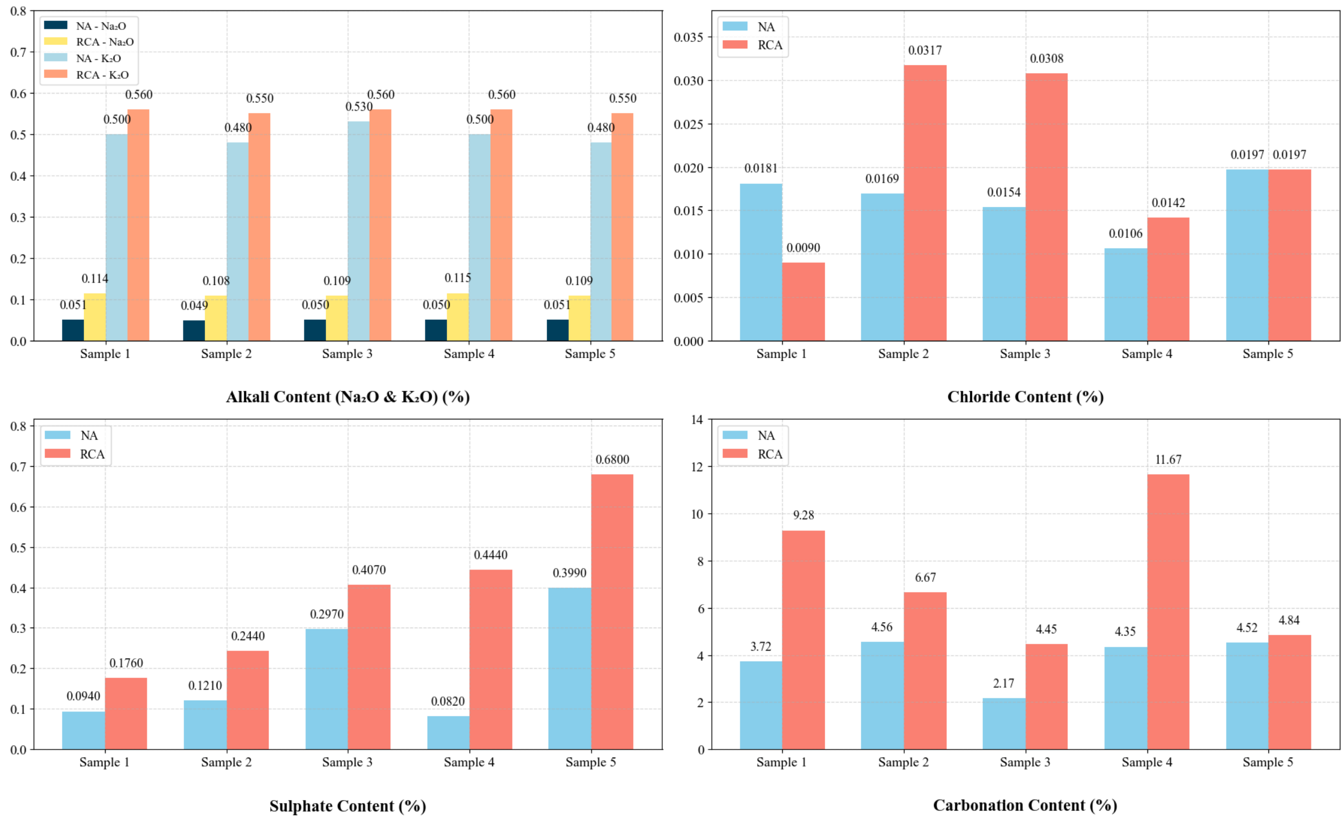

Figure 5: Chemical Properties (Alkali, Chloride, Sulphate, and Carbonation Contents) of NA and RCA

Table 5: Summary of Chemical Properties Test

S.N.	Test Name	Natural Aggregates	Recycled Aggregates	Standard Limits	Remarks NA	Remarks RCA
1	Alkali Content (Na_2O & K_2O)	0.0502, 0.498	0.111, 0.556	[39] <0.60 % [36] 0.30%	Compliance	Compliance
2	Chloride Content	0.01614	0.021	[41] <0.03 % [40] Around 0.04%	Compliance	Compliance
3	Sulfate Content	0.1986	0.3902	[35] <0.4 % [36] <0.5 %	Compliance	Compliance
4	Carbonation Content	3.863	7.381	[36] <5 %	Compliance	Not Compliance

Table 5 summarizes the chemical properties of both natural aggregates (NA) and recycled concrete aggregates (RCA) in comparison to standard limits. The alkali content values for both NA and RCA fallen within the acceptable range specified by [39] remaining below 0.60%. Hence, all values were accepted. Similarly, the chloride content in both aggregates adheres to the permissible limits of below 0.04% [40], resulting in acceptance. The sulphate content was also within the limits established by [36], which specified maximums of 0.5%, leading to acceptance for both NA and RCA. However, while the NA values complied with the specified carbonation limit of 5% per [36], the RCA values exceeded this standard; therefore, the carbonation content for RCA is marked as not accepted. Comparing recycled concrete to natural concrete, RCA significantly reduced the freezing resistance and resistance to chloride ion permeability[42]. These problems were brought on by the new cement mortar's inferior interfacial transition zones with the aggregate in RCA, which hindered the old mortar's ability to adhere. In contrast to natural coarse aggregate, RCA exhibits greater porosity, a higher crushing value, a lower apparent density, and a higher water absorption rate. When using recycled concrete in engineering, it is imperative that recovered aggregate be modified.

4. Conclusions

The study systematically evaluated and compared the physical (bulk density, specific gravity, water absorption, porosity), mechanical (aggregate crushing value, impact value), and chemical (alkali, chloride, sulphate, carbonation contents) properties of Natural Aggregates (NA) and Recycled Concrete Aggregates (RCA) sourced from various locations in Nepal. The study was carried out to evaluate the strengths and weakness associated with the properties of RCA with respect NA. After proper reviewing the results and comprehensive comparison of properties of both NA and RCA following conclusions were drawn out:

- Natural aggregates exhibited a higher bulk density and met the standard limit compared to recycled aggregates, indicating a denser and more compact structure. Recycled aggregates had lower bulk density and didn't meet the standard limit, which affect their performance in high-density applications.
- Natural aggregates met the standard limits for specific gravity, while recycled aggregates fell short due to higher porosity and a lower density, impacting their overall quality.
- The water content in natural aggregates and recycled aggregates met the required limits
- Recycled aggregates had significantly higher porosity compared to natural aggregates. Natural aggregates met the standard limit while recycled aggregate fell to meet met the standard limit. This increased porosity led to higher water absorption and potentially weaker performance in concrete.
- Natural aggregates were within acceptable limits for both wearing surfaces and general concrete uses, while recycled aggregates exceeded limits for wearing surfaces but were acceptable for other concrete applications.
- Natural aggregates were suitable for high-impact applications, including wearing surfaces, while recycled aggregates exceeded the limit for wearing surfaces but were appropriate for less demanding concrete applications.
- Both types of aggregates showed significant deviations from standard limits. Natural aggregates were well within the acceptable range for Na_2O, while recycled aggregates, though within limits, approached the upper boundary. For K_2O, recycled aggregates were closer to the upper limit, indicating potential concerns for alkali-silica reactions (ASR).
- Both natural and recycled aggregates met the standard limit for chloride content, which is safe from risks for corrosion in reinforced concrete.
- Both types of aggregates fell within the acceptable sulphate limit, posing very low risks of sulfate attack.
- Natural aggregates fell within the acceptable limit while recycled concrete aggregates exceeded the standard limit for carbonation, indicating risk of carbonation-induced damage.

Recycled concrete aggregates (RCA) showed some differences from natural aggregates (NA), particularly in terms of higher porosity, lower density, and limitations in high-impact or chemically aggressive environments. However, RCA remained a practical and sustainable alternative for many construction applications, especially for non-structural elements, pavements, and general concrete works. While RCA is not ideal for high-strength or load-bearing structures, it can be used effectively where sustainability and cost are prioritized. In building works and other concrete applications, RCA can be used as a substitute for natural aggregates, provided project-specific requirements are carefully assessed, and potential risks such as alkali-silica reactions or chloride-induced corrosion are managed.

Conflicts of Interest

The authors have declared that no competing interests exist. The data used for this research are commonly and predominantly used in our area of research and country. There is no conflict of interest between the authors and other stakeholders because we do not intend to use these products as an avenue for litigation but for the advancement of knowledge. Also, the research was not funded by any authorities; rather, it was funded by the personal efforts of the authors.

Data Availability Statement

The data that support the findings of this study are available to the main author, upon reasonable request.

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