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Sustainable Reuse of Construction and Demolition Waste: Characterization of Recycled Coarse Aggregates from Abuja, Nigeria

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ABSTRACT

Rapid urbanization and infrastructure development in Nigeria have resulted in increased construction and demolition waste (CDW), with concrete waste being the major component. This study investigates both mechanical and physical properties of recycled coarse aggregates (RCA) acquired from CDW in Abuja, Nigeria, to evaluate its suitability as a sustainable substitute to natural coarse aggregate (NCA) in production of concrete. Laboratory tests, including workability, water absorption, and compressive strength, were carried out on RCA and NCA samples. Results showed that RCA-based concrete exhibited reduced workability with a slump value of 198 mm and higher water absorption (5.5%) compared to NCA (1.2%). The compressive strength of the control mix (28 days) (100% NCA) was 40.1 MPa, while 50% RCA replacement achieved 37.5 MPa and 100% RCA yielded 27.11 MPa. A perception survey revealed moderate industry awareness of RCA, with 65% of respondents familiar with its use, 43.5% citing cost savings, and 30.8% identifying environmental sustainability as a major benefit, though concerns included lack of standardization (40%) and quality control (31%). These findings demonstrate that RCA has potential for sustainable construction, particularly in non-structural and selected low-load applications, while highlighting the need for regulatory frameworks and improved processing methods to encourage wider adoption in Nigeria.

Keywords: Compressive strength, Concrete, Demolition waste, Natural aggregates, Recycled aggregates

I. INTRODUCTION

The construction industry sits as the foremost user of natural resource and energy. One of which is concrete. Standard concrete is made up of 12% cement and 80% aggregate by mass. Today, the global concrete production stands at around 30 billion tons per year, which is equivalent to 14 coffee mugs of concrete for every person daily, highlighting its immense scale and resource intensity [1]. However, the global utilization of sand, gravel, and other aggregates for concrete production is from 10 to 11 billion tons annually [2]. As urbanization increases and the demand for infrastructure rises, the quantity of CDW continues to escalate, aggravating environmental concerns and depletion of resources. Construction and demolition waste (CDW) is defined as the debris produced during demolition, renovation, and/or construction activities. Constituents such as concrete, blocks, wood, tiles, metals, asphalt, and plasterboard [3]. Demolition wastes volume can vary significantly depending on the project scope, site conditions, and resource management practices. Notably, demolition activities tend to produce 20 to 30 times more waste than construction per project [4], [5]. Coarse aggregates derived from crushed concrete waste present an opportunity to reduce reliance on natural aggregates (NA) while addressing the challenge of CDW disposal. In Nigeria, despite the large volume of CDW produced, waste management remains underdeveloped due to factors such as a lack of awareness and poor disposal practices [6].

Recycling has become an essential strategy as countries face increasing pressure to manage resource consumption and promote circular practices in remedy for the increasing need for raw materials [7] Lack of appropriate recycling equipment and understanding of CDW from several construction projects causes major problems in many countries. These challenges include disposal of CDW into rivers, leading to increased flood levels and unlawful dumping on hillsides [8]. The vast volume of CDW streams in various countries has highlighted the significance of taking local initiatives to manage, recycle, and reuse the wastes produced during the lifecycle of structures [3].

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Recycled concrete has proven to be a sufficient aggregate supply for new concrete, sub-bases and soil cement. Aggregate processing comprises breaking down, examination, and cleansing to ensure cleanliness and proper classification. Upgrades in quality may be achieved by using benefaction processes like jigging or heavy media separation. Therefore, it is expected that the cost of disposing of waste from either newly constructed or excluded units in pre-cast concrete plants will continue to rise [9].

Plate I: Demolished Sandcrete blocks and concrete rubbles

Plate II: Collected concrete waste and rubbles from site

Recycled concrete aggregate (RCA) is largely gotten from crushed concrete in demolished structures, sometimes containing remnants of masonry, bricks, or asphalt. RCA has shown potential for reuse in non-structural and structural applications, such as road bases, granular sub-bases, and even fresh concrete production, provided it undergoes appropriate processing such as crushing, screening, and washing [10]. Research supports the utilization of RCA as a fractional or complete substitute for natural aggregates in concrete, with noted environmental and economic benefits [11], [12].

CDW is typically heterogeneous and may be contaminated with materials such as gypsum, wood, plastics, metals, and soil. Efficient processing requires pre-sorting at demolition sites and further separation at recycling facilities. Crushing and sieving processes are employed to produce RCA with uniform grading, while magnetic sorting helps recover metals. Washing is recommended to improve RCA quality, though it is often cost-intensive and technically challenging, especially in regions with limited infrastructure. Massive amounts of hardened concrete waste can be generated and sifted at the source, or they can eventually be acquired from the destruction of concrete buildings or roadways, yielding tons of RCA [13].

Improper CDW disposal contributes to environmental degradation, including groundwater pollution and habitat loss [3], [14]. Globally, CDW accounts for a significant amount of landfill waste, over 25% in Australia [15], around 30% in the United States of America [16], and up to 38% in Hong Kong [17]. To address this challenge, developed nations have adopted circular economy principles, which lays emphasis to the "3Rs" (Reduce, Reuse, and Recycle) as a foundation for sustainable construction [18]. Initiatives such as the European Union's target to reuse 70% of C&D waste by 2020 have led to high recycling rates in countries like Austria and Belgium [12]. In contrast, Nigeria lacks comprehensive legislative backing and infrastructure for effective CDW recycling. Most waste is either landfilled or openly dumped [19], [20]. In emerging nations such as Nigeria, construction contributes substantially to fixed capital formation, yet suffers from weak regulatory enforcement and ineffective waste management.

Despite some use of strategies such as prefabrication, on-site sorting, and selective demolition, implementation remains inconsistent [21]. Research shows that most Nigerian construction firms struggle with financial, technical, and institutional barriers to effective waste management [22], [23]. Consequently, key challenges suchs as high cost of recycling technologies, lack in standard processing procedures, poor on-site segregation, and insufficient regulatory enforcement persist. These barriers are particularly prevalent in nations like Nigeria [24], other emerging economies [25], and contexts such as Kosovo [26]. Furthermore, stakeholder awareness and engagement remain low, especially among contractors and project owners. Unlike the United States of America, where the Environmental Protection Agency (EPA) imposed regulations governing waste handling, Nigeria lacks specific codes for construction waste disposal [27].

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Countries who have advanced systems for managing waste, demonstrate success through initiatives like Scotland's design-out-waste strategy and Portland's commercial deconstruction grant program, which emphasize stakeholder collaboration, material recovery, and optimized sorting. Tools such as Building Information Modeling (BIM) for CDW circularity and green certifications continue to facilitate better planning and material efficiency [28], [29], [30]. Despite these innovations, research has shown that significant gaps still exist, , particularly in developing countries, where implementation is often limited by local conditions. Therefore, there is an urgent need to develop technologies specifically tailored to these environments, considering the nature of waste materials, available infrastructure, and economic constraints.

In Abuja, research in solid waste management often overlooked the importance of CDW in creating sustainable urban areas. Thus, this study explores the characterization of RCA and assesses its viability. It offers context-specific recycling solutions to close the knowledge gap on the material qualities of leftover CDW. The research adds to the conversation on environmentally friendly building methods in Abuja by supporting integrated waste management and recycling principles that support the objectives of global sustainability. Through a comprehensive analysis of CDW, this study assessed the characteristics of RCA and its potential applications in concrete production.

II. MATERIALS AND METHODS

2.1 Materials

The key materials utilized in this study are shown in Plates III-V. RCA was obtained from a construction site at Lifecamp and two demolition sites, one at Apo Wumba district and the other in Garki 2, all located within the Abuja Municipal Area Council (AMAC), Abuja. NCA was sourced from a local quarry located at Giri, Gwagwalada. Both aggregate types were subjected to laboratory testing to determine their physical and mechanical properties. Dangote 3X – 42.5R cement was used as the binding ingredient to make the concrete samples of both NCA and RCA.

Plates: (III) Processed recycled coarse aggregate, (IV) Selected natural coarse aggregate and (V) Dangote 3X 42.5R cement

2.2 Method

Mix design and sample preparation

The mix design was prepared for M30 grade concrete in accordance with IS: 10262-2009: recommendations for concrete mix design [31]. A 15 cm² cross-section mold was used. Fifteen samples were cast, five each with natural aggregates, a 50:50 mix of natural and recycled aggregates, and recycled coarse aggregates, as shown in Table 1. Mixing and curing followed ASTM C192/C192M (Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory) [32] and BS 1881-125:1986 (Methods for Preparation of Materials and Batching, Mixing and Sampling of Concrete in the Laboratory) to assess suitability.

Table 1: Mix Proportions for M30 Grade Concrete as per IS: 10262-2009

	Natural aggregate concrete (NAC)	50% recycled aggregate concrete (50RAC)	100% recycled aggregate concrete (100RAC)
Cement (kg/m^3)	360	427	448
Water (kg/m^3)	180	180	180

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Sand (kg/m^3)	703	780	930
Natural coarse aggregates (4-10 mm) (kg/m^3)	346	88	-
Natural coarse aggregates (10-20 mm) (kg/m^3)	692	131	-
Recycled coarse aggregates (4-10 mm) (kg/m^3)	-	145	218
Recycled coarse aggregates (10-20 mm) (kg/m^3)	-	218	326

Plate VII: Concrete cube samples of NCA and RCA samples

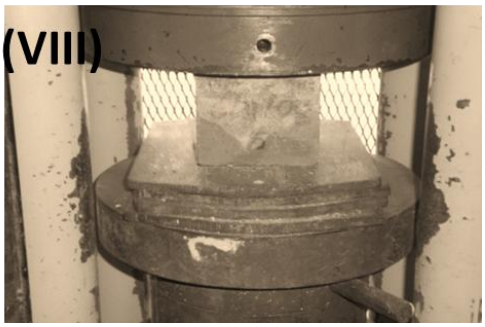

Plate VIII: Compressive strength test of concrete cube

Physical Test

Sieve Analysis

Sieve analysis of NCA and RCA were carried out to ascertain the particle size distribution of the aggregates, which influences workability, compaction, and strength development in concrete. The procedure followed ASTM C136/C136M [33] (Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates). Aggregates were oven-dried, weighed, and passed through a standard set of sieves set in descending order. The retained mass on each sieve was documented, and the cumulative percentages passing were calculated to develop the grading curve. Proper gradation ensures adequate packing and reduces voids, which directly affects the concrete's performance [34]. Similar approaches were adopted by Limbachiya et al. [35] and Rao et al. [36] in evaluating recycled aggregate properties

Slump test

The slump test was carried out to evaluate the workability and consistency of wet concrete in accordance with ASTM C143/C143M [37]. A standard slump cone (300 mm in height, 100 mm top diameter, and 200 mm base diameter) was packed with freshly mixed concrete in three equal layers, each compacted with approximately 25 strokes of a tamping rod. The cone was then vertically raised, and the drop in height of the resulting concrete (slump) was accessed to the nearest 5 mm (Plate VI). Achieving adequate slump is critical to ensuring proper compaction and interfacial bond strength. Similar procedures have been reported in studies on RAC, where increasing RCA replacement levels generally reduces slump because of higher water absorption and the angularity of RCA particles [38].

Plate VI: Slump testing of RAC100 sample

Water Absorption Test

Water absorption testing was performed on coarse aggregates to determine their porosity and capacity to retain moisture, which influence both strength and resilience of concrete. The method followed ASTM C127 [39] (Standard Test Method for Relative Density and Absorption of Coarse Aggregate). Aggregate samples were immersed in water for 24 hours, dried with a cloth, and weighed in the saturated

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surface-dry (SSD) condition. Then it was oven-dried at 105 ± 5 °C for 24 hours before being reweighed. The percentage water absorption was recoreded as the difference between SSD and oven-dry weights relative to the oven-dry weight. Higher absorption in RCA is typically associated with adhered mortar and microcracks, as stated by Poon et al. [12] and Tabsh et al [40].

Mechanical Test

Compressive Strength Test

The compressive strength of concrete cubes were determined in accordance with ASTM C39/C39M and BS EN 12390-3 [41]. Concrete samples were prepared using NCA and different proportions of RCA (0%, 50%, and 100%). Fresh concrete was cast into standard cube moulds of 150 mm × 150 mm × 150 mm, compacted in three layers with 25 manual strokes per layer, and removed after 24 hours. The cubes were then water cured at a temperature of 20 ± 2 °C until the designated testing age. Testing for compressive strength was performed at 3, 7, 14, and 28 days using a 2000 kN capacity compression testing machine at a constant loading rate of 0.25 MPa/s until failure. This was carried out in triplicate and the average of three samplings was recorded and reported for each mix and age.

Qualitative data analysis

A structured questionnaire survey was administered to construction professionals, including engineers, architects, and project managers, to assess awareness, perceptions, perceived benefits, challenges, and willingness to adopt RCA in construction. A total of 85 questionnaires were distributed and all were returned, yielding a 100% response rate. The survey design adopted a combination of categorical (e.g., awareness) and Likert-scale questions (e.g., willingness to adopt RCA). Data was evaluated using descriptive statistics (frequency and percentage distribution), and findings are presented in Figures 3–8.

III. RESULTS AND DISCUSSION

Sieve analysis

Figure 1 presents the sieve analysis results for RCA and NCA used in this study. Both aggregates were predominantly single-sized, with particle size distributions ranging between 4.75 mm and 20 mm. The NCA sample consisted of crushed gravel stone with a relatively well-defined gradation, whereas the RCA comprised crushed construction and demolition waste with slightly higher variability.

For the fine aggregates, the gradation complied with Zone II limits specified in IS 383-2016 [42] confirming suitability for use in concrete mixes. The RCA exhibited a higher percentage of material retained on intermediate sieves (particularly the 16 mm sieve), signifying a more coarse particle distribution compared to that of NCA. This trend is consistent with previous studies, which reported that RCA often contains a less uniform gradation due to adhered mortar and crushing processes [43], [44]

The slightly poorer gradation of RCA suggests potential impacts on workability and packing density of concrete, aligning with earlier findings by Limbachiya et al. [35] and Rao et al. [36]. However, as seen in Figure 1, the overall distribution of RCA still falls within permissible ranges, making it applicable for concrete production with controlled mix design adjustments.

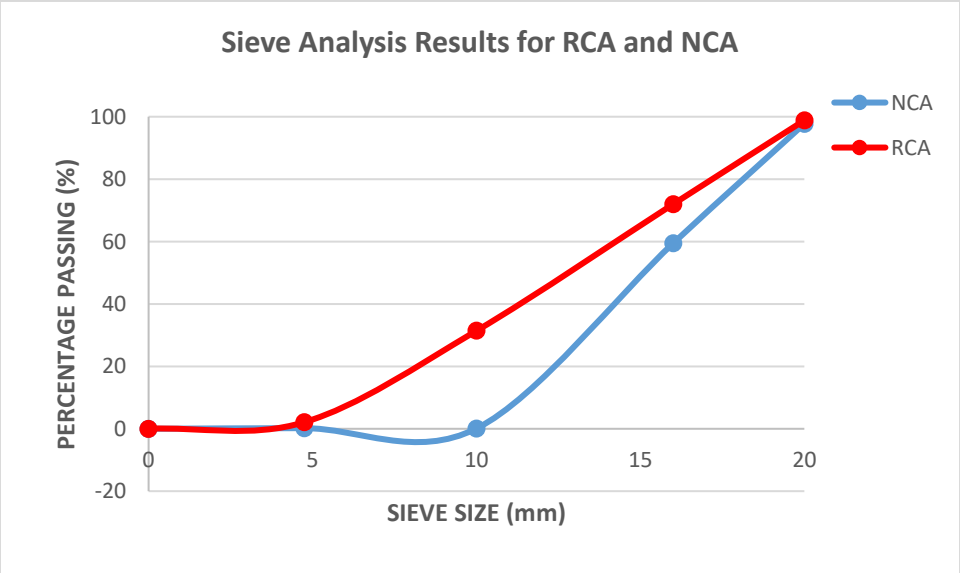

Figure 1: Sieve analysis results for recycled coarse aggregate (RCA) and natural coarse aggregate (NCA)

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Slump test

The result of the slump test (Plate VI) shows that the concrete's workability declines as the proportion of RCA increases (Table 4). The slumps were 85 mm, 60 mm, and 40 mm for NAC, RAC50, and RAC100, respectively. These represent reductions of approximately 29.4% and 52.9% for 50% and 100% RCA replacement relative to the control. Previous SEM studies have shown that RCA typically retains adhered mortar, exhibits a rougher surface texture, and contains higher porosity than natural aggregates, all of which increase water absorption and reduce workability [45], [46]. Before beginning mixing operations, it is advised to either increase the amount of water or maintain saturated surface dry conditions of aggregate so as to achieve the required workability using RCA [47].

Table 4: Workability analysis

Mix	Slump (mm)
NAC (Natural Aggregate Concrete)	85
RAC50 (Recycled Aggregate Concrete with 50% replacement)	60
RAC100 (Recycled Aggregate Concrete with 100% replacement)	40

Water Absorption Test

The results in Table 5 show that the water absorption of NCA was 1.2%, which falls within the usual range for NCA (0.5–3%), as also reported by Silva et al. [44] In contrast, the RCA recorded a significant greater water absorption of 5.5%, consistent with the existence of porous adhered mortar and microcracks on the recycled particles. Silva et al. have documented similar findings [44]. Kisku et al. [43], and Poon et al. [12] stated that RCA generally exhibits higher water absorption compared to natural aggregates.

One of the primary causes of RCA's restricted use in concrete is its increased water absorption.

Due to the presence of porous adhered mortar and cement paste, there is a higher demand of water in concrete built using RCA and also a higher capacity of water absorption. Natural coarse aggregates typically absorb between 0.5% and 3% of water (e.g., granite aggregates around 0.5%, with most natural aggregates staying under 3%) while natural fine aggregates typically absorb up to about 2%, as higher absorption may adversely affect concrete mix consistency [46]. Conversely, crushed RCA can absorb up to 15% of water by mass, while fanned RCA can absorb up to 20% [44].

Table 5: Water absorption analysis

Aggregate Type	Water Absorption (%)
Natural Coarse Aggregate	1.2
Recycled Coarse Aggregate	5.5

Compressive Strength Test

Table 6: Compressive strength analysis

Mix Type	Day 3	Day 7	Day 14	Day 28
NAC	25.20	27.80	30.10	40.70
RAC50	20.59	24.90	28.75	35.50
RAC100	16.82	19.10	23.20	27.11

At 28 days of curing, the compressive strength test of the 100% NCA mix was 40.7 MPa, while the 50% RCA mix recorded 35.5 MPa. The 100% RCA mix showed the lowest value, 27.11 MPa (Table 6, Figure 2), indicating a regular decrease in strength occurs with increasing RCA content.

This reduction can be attributed to adhered mortar and increased porosity of RCA, which weakens the interfacial transition zone (ITZ). Similar observations have been stated by Kisku et al. [43], Okafor [48], and Arum et al. [49], who found that RCA's weaker matrix and micro-cracks reduce compressive strength

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compared to natural aggregates. While partial replacement (50%) can still achieve moderate strength suitable for some structural or non-structural applications, full replacement (100%) is better suited for non-structural elements where strength requirements are lower.

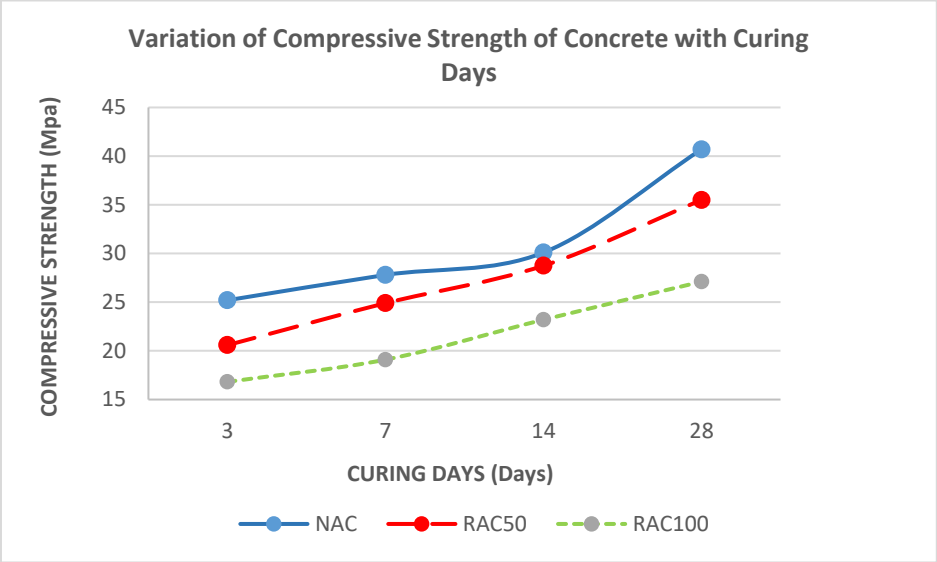

Figure 2: Compressive Strength development of NAC, RAC50 and RAC100 at 3, 7, 14, and 28 days

Qualitative data analysis

The respondents represented a diverse professional background (Table 7–10, Figures 3–5). The majority were between 31–45 years (41.2%), with 65.9% male and 34.1% female participation. About 60% had more than 10 years of industry experience, indicating that responses were drawn from knowledgeable professionals.

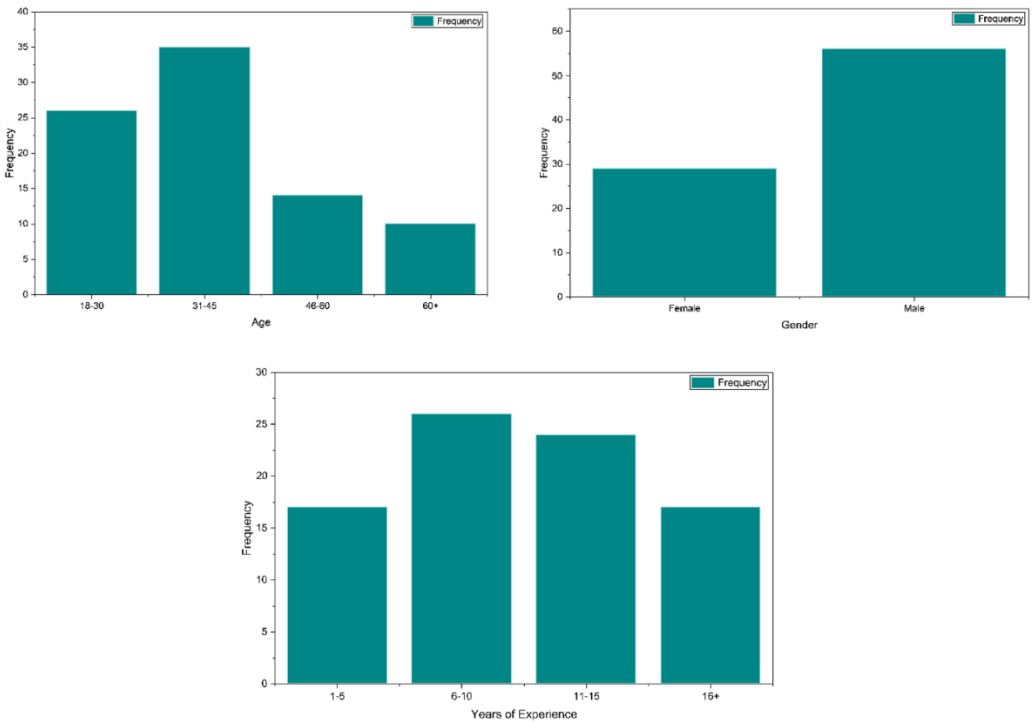

Figure 3: Demographic Information of Respondents (Age, Gender, and Years of Experience)

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The demographic results presented in Figure 3 show that most of the respondents (41.2%) fall inside the 31–45 years age group. This indicates that most participants are in their mid-career stage, which is expected since professionals within this age bracket are usually active in construction project management and site supervision. A similar trend was reported by Adeyemi et al. [50], who found that respondents aged 30–45 dominated their sample due to their involvement in technical decision-making.

In terms of gender, 78% of the respondents were male, reflecting the male-dominated nature of the Nigerian construction industry. This agrees with findings of Jimoh et al. [51], who noted limited female participation in construction-related professions.

Regarding years of experience, most respondents (32%) had 6–10 years of experience, followed closely by 28% with 11–15 years. This suggests that the sample consists of experienced professionals capable of providing reliable insights into recycled aggregate use and construction waste management. The dominance of respondents with over five years of experience strengthens the validity of the study's responses, consistent with the pattern observed by Adeyemi et al [50].

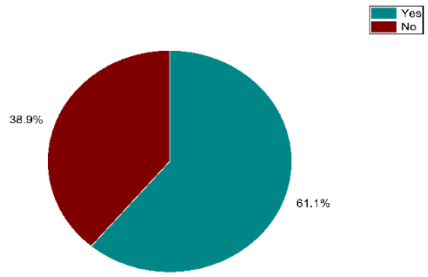

Figure 4: Awareness of RCA among respondents

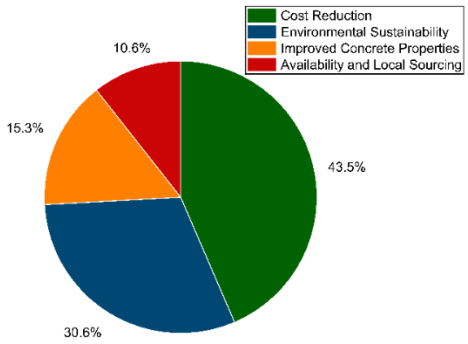

Figure 5: Perceived Benefits of Using RCA

The survey revealed that most respondents (61.1%) were aware of RCA and its possible applications in construction, while 38.9% had limited or no knowledge of it. This level of awareness indicates a growing recognition of sustainable material alternatives within the industry. Ameh (2016) reported a similar trend in Nigeria, where construction professionals demonstrated moderate awareness of RCA but limited practical application due to concerns about quality and availability [52]

When asked about the perceived benefits of RCA, the majority (43.5%) identified cost reduction as the most significant advantage. This was followed by environmental sustainability (30.8%), reflecting increasing interest in green construction practices. A smaller proportion of respondents highlighted improved concrete properties (15.1%) and availability through local sourcing (10.6%) as notable benefits. These results align with the findings of the IOSR study, which also identified cost efficiency and environmental benefits as the key motivations for adopting RCA in Nigerian construction projects [53]. Overall, these findings suggest that while awareness of RCA is relatively high, perceptions are largely driven by its economic and environmental advantages rather than its technical performance.

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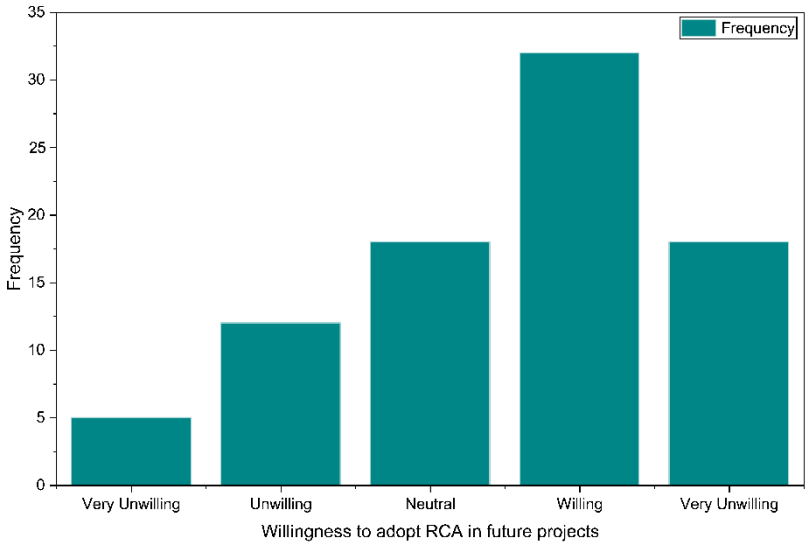

Figure 7: Willingness to adopt RCA in future projects

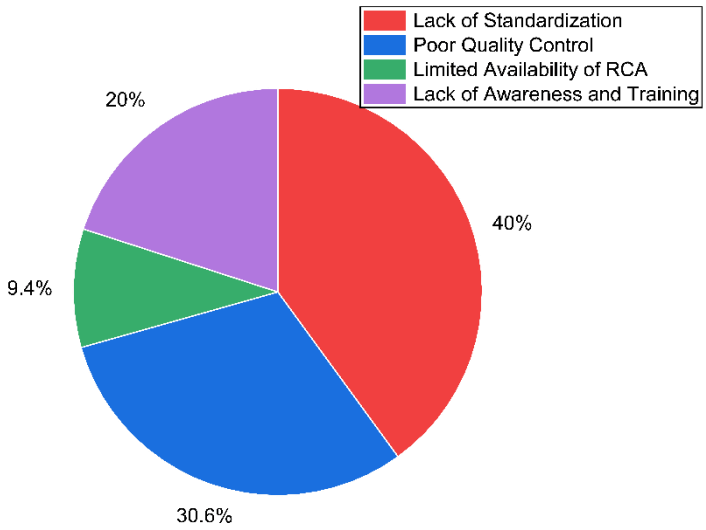

Figure 8: Challenges in using RCA

As illustrated in Figure 7, the majority of respondents were willing (38%) or very willing (21%) to use RCA in future construction projects, while only a small proportion indicated unwillingness (20% combined). This positive outlook reflects a growing acceptance of sustainable materials in the construction sector. The results are consistent with Ameh et al., who observed that a significant proportion of construction professionals in Abuja expressed readiness to adopt RCA, provided that clear standards and quality assurance measures are implemented [52]. Similarly, the IOSR (International Organization of Scientific Research) Journal reported that most practitioners showed interest in adopting RCA once its performance reliability and cost benefits were demonstrated through research and pilot projects [53]. Respondents also identified several key challenges affecting the practical use of RCA, as shown in Figure 8. The most prevalent challenge was the lack of standardization (40%), followed by poor quality control (31%), lack of awareness and training (20%), and limited availability (9%). These findings align with Ameh et al., who highlighted the absence of clear technical standards and inadequate testing procedures as major obstacles to RCA adoption in Nigeria [52]. The IOSR

Journal similarly noted that uncertainty regarding the structural reliability of RCA discourages its use in critical projects [53]. In addition, Akinkurolere et al. emphasized that poor awareness, weak policy enforcement, and inadequate training of construction stakeholders remain recurring barriers to the use of recycled aggregates and other sustainable materials in Nigeria [54].

IV. CONCLUSION

This study evaluated concrete made with recycled coarse aggregate (RCA) from construction and demolition waste in Abuja against mixes with natural coarse aggregate (NCA), combining laboratory testing with an industry perception survey. RCA exhibited higher water absorption (5.5% vs. 1.2% for NCA) and reduced workability (slump 40–60 mm vs. 85 mm for NCA), indicating the need for mix adjustments such as added water, admixtures, or pre-saturation. Compressive strength decreased with RCA content: 40.1 MPa at 28 days for 100% NCA, 37.5 MPa for 50% RCA, and 27.1 MPa for 100% RCA. Thus, 100% RCA is most appropriate for non-structural or lightly loaded elements, while partial replacement (≤50%) is viable where moderate strengths are acceptable.

The industry survey revealed moderate readiness for adoption: 65% awareness, with cost savings (43.5%) and environmental benefits (30.8%) identified as drivers, while lack of standardization (40%) and quality control (31%) remain barriers. Broader uptake will require improved aggregate processing, clear technical standards, and practical mix design guidance. To advance RCA use in Nigeria, future work should include large-scale demonstration projects, durability and life-cycle cost assessments, and investigations into additives and pre-treatment methods. With supportive policies, training, and industry engagement, RCA can make a significant contribution to sustainable construction and circular-economy practices in Abuja, Nigeria.

AUTHORS CONTRIBUTIONS

I.D. Chukwuka: Conceptualization, Methodology, Investigation, Data Curation, Writing- Original draft. **E.N.Anosike-Francis:** Supervision, Validation, Writing- Review and Editing**. I.I. Obianyo:** Supervision, Resources, Writing- Review and Editing. **A. Sanusi**: Methodology, Data Curation, Resources. **P.A. Ubi:** Resources, Writing- Review and Editing. **A.A.Adeleke:** Supervision, Writing-Review and Editing.

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