# Performance of Concrete with Recycled Concrete Aggregates and Cement Kiln Dust

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**Abstract**

*The rapid growth in infrastructure development has posed significant environmental challenges, particularly through the depletion of natural resources and the generation of construction and demolition waste (CDW). This study explores the use of recycled concrete aggregates (RCA) derived from CDW as a sustainable alternative to natural aggregates, aiming to reduce environmental impact by lowering landfill waste, carbon emissions, and the demand for non-renewable resources in construction. Concrete production also releases considerable $CO_2$ and generates a by-product known as Cement Kiln Dust (CKD) from unreacted and partially calcined raw materials. This research examines the potential of RCA and CKD in enhancing the sustainability of concrete by investigating their effects on physical, mechanical, and durability properties. Mixtures were prepared with RCA replacing natural coarse aggregate at levels of 0%, 25%, 50%, 75%, and 100%, and CKD replacing ordinary Portland cement at 10% and 20%, all at a water-to-cement ratio of 0.54. Compressive strength, splitting tensile strength, and durability (measured by water absorption and acid resistance) were tested on the RCA-CKD concrete. Fresh properties were assessed through slump flow and compaction factor tests. Concrete cube specimens (100 $mm^3$) were used for compressive and durability tests, while cylindrical specimens (200 mm diameter x 100 mm height) were used for tensile strength tests. Results showed that at 56 days, the control concrete achieved the highest compressive strength of 30.68 $N/mm^2$, while the 100% RCA with 20% CKD replacement mix reached 24.05 $N/mm^2$. Water absorption results indicated all RCA mixtures were within the recommended 10% limit (Neville, 2011). These findings suggest that RCA can entirely replace natural aggregates, and CKD can replace up to 20% of cement, without significantly compromising the target strength of 25 $N/mm^2$.*

**Keywords:** Recycled Concrete Aggregate, Cement Kiln Dust, Compressive Strength, Splitting Tensile Strength, Durability Tests, Water Absorption, Acid Resistance

## 1.0 INTRODUCTION

Global concrete production, estimated at 10 billion tons annually, is resource-intensive (Meyer, 2009), with demand expected to reach 18 billion tons by 2050 (Roskovic & Monteiro, 2006). Concrete remains an indispensable construction material worldwide, valued for its durability, versatility, and cost-effectiveness. Advances in concrete technology have introduced high-performance varieties, enhancing strength and longevity while addressing specific structural needs (Mindess, Young, & Darwin, 2003). The composition of concrete can be tailored through various additives to achieve desired properties, such as strength, workability, and durability (Kosmatka, Kerkhoff, & Panarese, 2002).

Rising construction material costs due to resource scarcity and energy prices are driving innovations in concrete production, such as incorporating supplementary materials like fly ash and slag to reduce cement use and emissions (Scrivener, John, & Gartner, 2018).

Recycled concrete aggregate (RCA) is produced from crushed concrete that contains remnants of mortar from construction and demolition (C&D) waste. The increasing volume of C&D waste, especially in urban areas, poses significant social and environmental challenges (Poon, Kou, & Lam, 2002). The possibility of recycling of waste from the construction industry is increasing which in addition to the environmental benefits is also reducing the demand on land for disposing the waste. The recycling of C&D wastes can also help to conserve natural materials and to reduce the cost of waste treatment prior to disposal (Johnson & Brown, 2019). Despite its benefits, RCA presents certain challenges, including variability in properties such as particle size and quality, which can affect concrete's performance. Studies highlight potential issues like increased shrinkage, reduced workability, and a higher susceptibility to alkali-silica reaction, which can compromise long-term durability (Tam, Tam, & Le, 2012; Zaharieva, Buyle-Bodin, & Wirquin, 2004).

Smith (2018) similarly states that the used of waste concrete for RCA reduced the continued exploration of virgin aggregates and minimized the environmental impact. It is estimated that more than 900 million tons of construction and demolition waste is being generated yearly in Europe, USA and Japan (Awoyera, Akinmusuru & Moncea 2017). Furthermore, developing countries are also beginning to utilize C&D waste in construction activities.The use of RCA in construction has gained prominence due to its potential to mitigate the depletion of natural resources (Jones, 2020). Studies in Nigeria show that, while some C&D waste is reused, much of it is discarded or sold at low prices to avoid storage costs (Mudashiru, Oyelakin, Oyeleke, Bakare, 2016). Johnson and Brown (2019) highlight the economic benefits of RCA, as it reduces disposal costs and fosters a circular economy by repurposing waste. Green (2021) emphasizes RCA's engineering properties, showing its suitability in applications like road bases and concrete production. Johnson (2024) conducted long-term studies on the performance of concrete with recycled content, reveals that with proper mix design and quality control, RCA concrete can have durability comparable to traditional concrete. However, challenges with RCA include contaminants from the original construction materials, which can affect new concrete's structural integrity (Khatib, 2015), and variations in RCA properties, like particle size and quality, which affect performance (Siddique, Khatib & Kaur, 2011).

Previous research by Richardson, Coventry, and Graham (2009) suggests that the use of RCA may reduce concrete compressive strength compared to virgin aggregate. Meyer (2009) found that using recycled coarse aggregate reduced strength by 5-24%, and incorporating both coarse and fine RCA resulted in a 15-40% strength reduction. Sagoe, Brown, and Taylor (2002) examine the durability and Performance characteristics of recycled aggregate concrete and reported that RCA concrete exhibits higher drying shrinkage and water absorption than natural sand concrete due to porous residual mortar. Jones (2020) and Rao, Jha, and Misra (2007) also document high absorption rates in mixed demolition waste, which can impact dimensional stability and increase shrinkage..

Zaharieva, Buyle-Bodin, and Wirquin (2004) highlight the high absorption rates of RCA as a challenge, as it reduces fresh concrete's workability even with superplasticizers; pre-soaking RCA can help mitigate this effect. concrete durability could be improve RCA through additives like fly ash and silica fume have proven effective (Rao, Jha & Misra, (2007). Etxerberria, Vázquez, Marí & Barra (2007) also found that replacing 25% coarse aggregate with C&D waste did not significantly reduce concrete shear strength.

Recycling advancements further support sustainability by conserving resources (Tam, Tam, & Le, 2020). Concrete's adaptability extends to diverse construction applications, including buildings, bridges, roads, and dams, while its strength and moldability enable architectural innovations (Mehta & Monteiro, 2014). However, Concrete production also contributes to environmental strain through cement manufacturing, which releases considerable $CO_2$ emissions and solid fine-grained highly alkaline waste removed as cement kiln dust.

Cement kiln dust (CKD) is solid fine-grained highly alkaline product formed during the manufacture of cement and is a waste material that is traditionally destined for landfills. CKD is considered industrial waste with high lime content makes it a potential supplementary material in concrete and other construction applications (Taylor, Fentiman & Thompson 2020). CKD is suitable for soil stabilization as a partial replacement for cement in concrete, although its high alkalinity and trace element content necessitate careful handling to mitigate environmental risks (Maslehuddin, Rahman, Ali, & Barry, 2009; Shoaib, Balaha, & Abdel-Rahman, 2000). Studies have explored its role in enhancing the mechanical properties of concrete, such as compressive strength and durability (Lee & Wang, 2021), and even in environmental applications like soil remediation (Kumar, 2023). However, environmental risks associated with CKD, such as leachability, necessitate proper handling and regulatory oversight (Wang and Chen, 2022).

Additionally, CKD has shown promise in mitigating soil acidity and serving as a source of supplementary nutrients for plant growth in agricultural applications (Smith and Jones, 2022).

This research aims to explore the combined use of RCA and CKD in concrete to develop a more sustainable construction material. It seeks to assess the impact on key properties like strength, durability, and resistance to aggressive environments, providing insights into the feasibility of using recycled and industrial by-products in mainstream construction.

## 2.0 Materials and Method

### 2.1 Cement and aggregate

Ordinary Portland cement (OPC), CEM I with strength of 42.5 MPa, conforming with ASTM C150 (2012) was purchased from commercial vendor. The fine aggregate (river sand) and natural coarse aggregates (NCA) used were locally sourced. A superplasticizer that complies with ASTM C494 (2013) was incorporated to enhance workability without increasing the water content in the mix.

### 2.2 Recycled concrete Aggregate

The Recycled concrete Aggregate (RCA) were extracted from demolished building in the premises area within the Federal Polytechnic Damaturu, Yobe State as shown in Figure 1. In preparing the recycled aggregates, the demolished concrete were first crushed manually using metal hammers. The aggregates were then manually separated from the mortar paste. Physical test data showed that it had: specific gravity = 2.6, relative density = 1.70 g/cm$^3$, and water absorption rate = 8.0%. The particle size distribution showed that the percentage passing of 20 mm sieve for RCA is 89% which indicates less than BS882 (1992) standard.

Figure 1: Demolished waste concrete

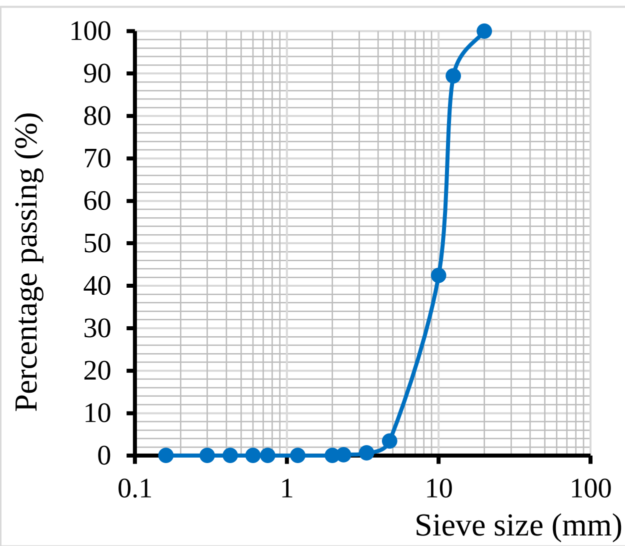


Fig. 2: Particle size distribution curve of NCA

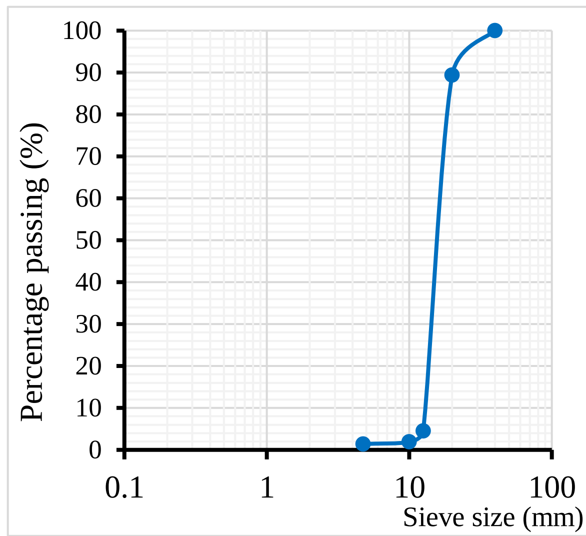


Fig. 3: Particle size distribution curve of RCA

### 2.2 Cement Kiln Dust (CKD)

Cement Kiln Dust (CKD) is a fine, powdery material generated as a by-product during cement production. It is typically captured using baghouse filters, electrostatic precipitators, or cyclone separators installed in the exhaust stacks of cement kilns. CKD primarily comprises unreacted raw materials, clinker dust, and trace amounts of heavy metals; the chemical composition of CKD is shown in Table 1. CKD is characterized by a milky color and a very fine texture, as depicted in Figure 4. For this study, CKD samples were sourced from the northeastern region of Nigeria.

Table 1: Chemical Composition of CKD

| Chemical composition (%) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $So_3$ | $Tio_2$ | $P_2O_5$ | $Mn_2O_3$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CKD** | 11 | 4.48 | 1.99 | 44.45 | 1.02 | 0.57 | 0.08 | 1.25 | 0.2 | 0.18 | 0.14 | 33.63 |

Fig. 4: Cement Kiln Dust (CKD

## 3.0 Mixture Proportion

Concrete mix proportions were designed following the British Department of Environment (D.O.E) method to achieve a grade C25 concrete at 28 days. Due to the high water absorption of RCA and CKD, a superplasticizer (SP) was used to improve workability without increasing the water content. The SP was added at 1% and 2% by weight of the cement until the desired slump was achieved. Natural coarse aggregate was partially or fully replaced with RCA at increments of 25% up to 100%, and cement was replaced with CKD at 10% and 20%, as shown in Table 2. These proportions were maintained across all mixtures to ensure consistent comparison of the behavior of RCA/CKD concrete against control specimens.

Workability was assessed using two main methods: the slump cone test and the compaction factor test.

Table 2: Mix composition of concrete specimens incorporating RCA and CKD

| MATERIALS ($Kg/m^3$) | Percentage Replacement (%) | | | | |
|---|---|---|---|---|---|
| | **0** | **25** | **50** | **75** | **100** |
| **Cement** | 380 | 380 | 380 | 380 | 380 |
| **Fine Aggregate** | 694 | 694 | 694 | 694 | 694 |
| **Coarse Aggregate** | 1131 | 848.25 | 565.5 | 282.75 | 0 |
| **Recycled concrete aggregate** | 0 | 282.75 | 565.5 | 848.25 | 944.75 |
| **Water** | 205 | 205 | 205 | 205 | 205 |
| **CKD 10%** | 38 | 38 | 38 | 38 | 38 |
| **CKD 20%** | 76 | 76 | 76 | 76 | 76 |
| **Plasticizer SP** | 0% | 0% | 1% | 2% | 2% |
| **Water cement ratio** | 0.54 | 0.54 | 0.54 | 0.54 | 0.54 |

## 4.0 Experimental Work

### 4.1 Bulk density

The bulk density (ρ) of fine aggregate, natural coarse aggregate and RCA were determined using a cylindrical container and a weighing balance. The procedure involved measuring the mass of each material in the container and calculating the container's volume based on its dimensions. The bulk density was then computed using the relationship:

$$\rho = \frac{m}{V} \qquad \text{eqn. 1}$$

Where:

$\rho$ = Bulk density

$m$ = Mass of the material in the container

$V$ = Volume of the container

### 4.2 Specimen Casting and Curing

For each concrete mix, specimens were cast as 100 $mm^3$ cubes and 100 x 200 mm cylinders. The cubes were used to measure compressive strength, water absorption, and acid resistance, while the cylinders were tested for tensile strength. All specimens were demolded 24 hours after casting and cured in water until the testing age.

### 4.3 Compressive and Splitting Tensile Strengths

Compressive and splitting tensile strengths were determined using a compression machine with a loading capacity of 3000 kN. The loading rates applied in the compressive and splitting tensile strength were 2000 kN/min and 600 kN/min respectively. The results of the compressive strength are presented in Table 3 while tensile strength is plotted in Figure 5. The compressive strength test was carried out at the curing ages of 7, 14, 28 and 56 days while tensile strength was tested at ages of 7 and 28 days curing. All the tests were conducted in accordance to BS EN 12390-3 (2002).

### 4.4 Water Absorption Test

Following BS 1881: Part 122 (1983), the water absorption test was conducted at curing ages of 7, 28, 56, and 90 days. Three specimens were oven dried at 105° C for 72 hours and they were then allowed to cool in an air tight vessel for 24 hours. The specimens were weighed and immediately immersed in water tank for 30 ± 0.5 minutes. The specimens were then removed from the water and dried with a cloth, and weighed again.

Water absorption was calculated as an increase in weight expressed in percentage of the mass of the dry specimen as shown in eqn. 1.

$$W = \frac{Ww - Wd}{Wd} \times 100\% \qquad \text{eqn. 2}$$

Where:

$W$ = Percentage of water absorption

$W_W$ = Weight of specimen wet

$W_d$ = Weight of specimen dry

### 4.5 Acid Attack Test

The resistance of the different concrete compositions to sulphuric acid attack was investigated, concrete cubes specimens were cured for a period of 28 days and immersed in a 0.5% Solution of sulphuric acid. The concentration of acid was checked regularly and the depleted acid was replenished to maintain the concentration as close as possible to that required by doing measurements and the test specimens were performed after selected periods of immersion in the acid 7, 28, 56 and 90 days, specimens of each mix were lightly brushed, weighed, and their strength was measure and recorded.

## 5.0 Results and Discussion

### 5.1 Bulk Density

Table 3 presents the bulk density results for fine aggregate, natural coarse aggregate, and recycled concrete aggregate (RCA). The findings indicate that partially replacing natural coarse aggregate with RCA leads to a slight reduction in bulk density. This reduction is likely due to the residual cement mortar adhering to the RCA particles, which reduces the material's overall density.

The recorded densities of the aggregates are within the standard range specified for concrete applications, demonstrating their suitability for use. However, as revealed in the analysis, RCA consistently exhibits lower densities compared to natural aggregates. This is primarily attributed to the lightweight nature of the attached cement mortar. This trend aligns with observations by Meyer (2009), who reported similar density reductions when using RCA.

Table 3: Bulk Density Tests Results for Aggregates

| Description | Bulk density ($kg/m^3$) |
|---|---|
| Fine Aggregate | 1651 |
| Natural Coarse Aggregate | 1808 |
| RCA 25% Replacement | 1787 |
| RCA 50% Replacement | 1753 |
| RCA 75% Replacement | 1725 |
| RCA 100% Replacement | 1697 |

### 5.2 Slump Flow Test

The results of the slump flow test highlight the impact of incorporating recycled concrete aggregate (RCA) and cement kiln dust (CKD) on concrete workability as presented in Fig. 5. The findings show a significant reduction in slump values with increasing levels of RCA replacement (0%, 25%, 50%, 75%, and 100%), indicating a decline in workability. This reduction is attributed to the higher porosity and absorption capacity of RCA, as well as the presence of adhering mortar on the RCA particles.

The replacement of ordinary Portland cement (OPC) with CKD at levels of 10% and 20% further compounds the reduction in slump values. The lowest slump values were observed in mixes with 50% and 100% RCA combined with 20% CKD, highlighting the combined negative effects of these replacements on concrete workability. Concrete made with natural coarse aggregate consistently demonstrated higher slump values, reflecting superior workability compared to RCA-based mixes.

These observations are consistent with the findings of Alabi and Arum (2020), who also reported reduced slump values in RCA-based concrete due to its physical characteristics. The study underscores the importance of adjusting mix designs to mitigate the decline in workability when using RCA and CKD to enhance the sustainability of concrete.

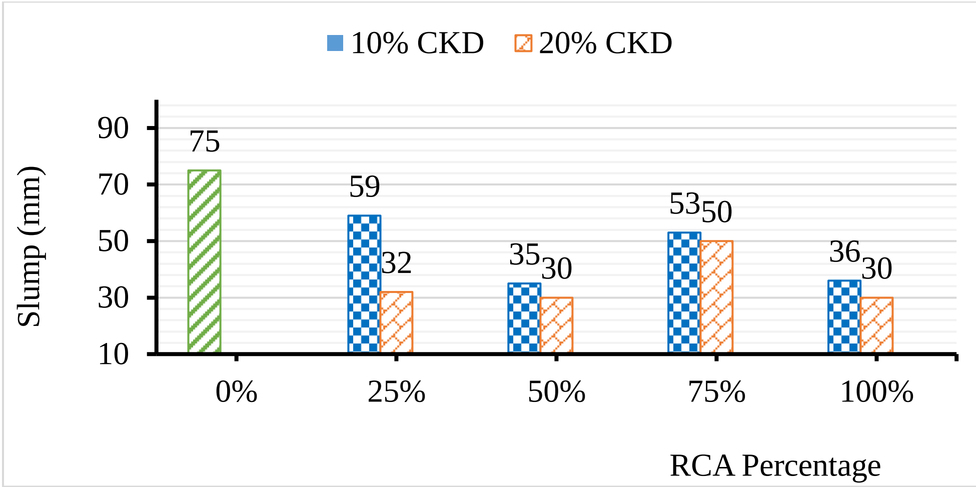


Fig. 5: Result of Slump flow test

### 5.3 Compaction Factor

Figure 6 presents the compaction factor test results, which measure the workability of freshly mixed concrete. Workability was observed to decrease at 100% RCA replacement and this decreased in workability can be attributed to the high water absorption rate of RCA. However, with 10% CKD and 25% RCA replacements, the compaction factor value was higher compared to the other mixes. The observed compaction factor values for all the mixes are within the typical range for compaction factors, indicating that the material is within standard parameters for workability. Typically, compaction factors range from 0.82 to 95, (BS 1881-103, 1993) and a values of 0.91 to 0.95 in this research suggests that the material is appropriately workable for its intended use.

The reduction in compacting factor with higher RCA concentrations highlights the influence of RCA properties on workability. While the decreased notable, in the values remain within acceptable limits for construction applications, provided proper adjustments are made to the mix design. Optimizing the water-cement ratio and incorporating admixtures can effectively enhance the workability of RAC mixes with high RCA content.

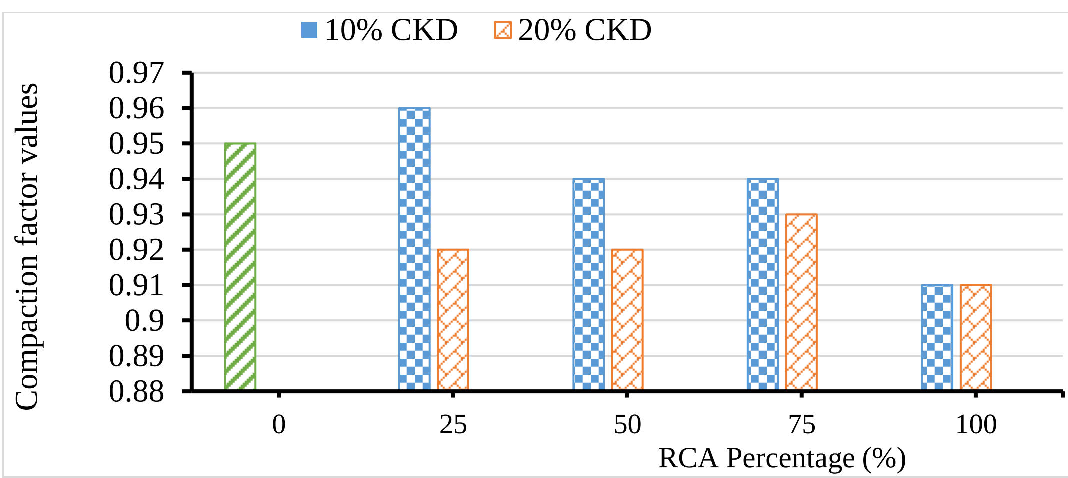


Fig. 6: Compaction Factor for Various Proportions

### 5.4 Compressive Strength

The compressive strengths measured at 7, 14, 28 and 56 days of the concrete mixtures are presented in Table 4. The 56 days compressive strength of concrete mixtures met the target strength of 25MPa with 0%, 25%, 50% and 75% RCA at 10% CKD replacement to cement. However, only 25% and 50% RCA with 20% CKD replacement met the target strength of 25 MPA. It was also found that the compressive strength of concrete decreased when coarse aggregate and cement were replaced by RCA and CKD, respectively. The reduction in 56 days compressive strength of concrete specimens ranges from 14% at 25% RCA content to 31% at high RCA content (i.e., 100%) with 10% CKD.

Table 4: Compressive strength of concrete specimens

| RCA AND CKD Replacement (%) | 7 days | 14 days | 28 days | 56 days |
|---|---|---|---|---|
| Control (0%) | 23.6 | 26.6 | 30.7 | 34.0 |
| 25% RCA and 10% CKD | 21.1 | 22.6 | 21.3 | 29.2 |
| 50% RCA and 10% CKD | 19.2 | 20.1 | 22.5 | 26.9 |
| 75% RCA and 10% CKD | 18.6 | 21.0 | 25.1 | 28.2 |
| 100% RCA and 10% CKD | 19.2 | 21.9 | 20.9 | 23.4 |
| 25% RCA and 20% CKD | 19.8 | 20.9 | 23.5 | 27.8 |
| 50% RCA and 20% CKD | 17.3 | 18.8 | 20.3 | 25.1 |
| 75% RCA and 20% CKD | 14.6 | 18.5 | 21.8 | 24.1 |
| 100% RCA and 20% CKD | 14.4 | 15.4 | 20.7 | 22.2 |

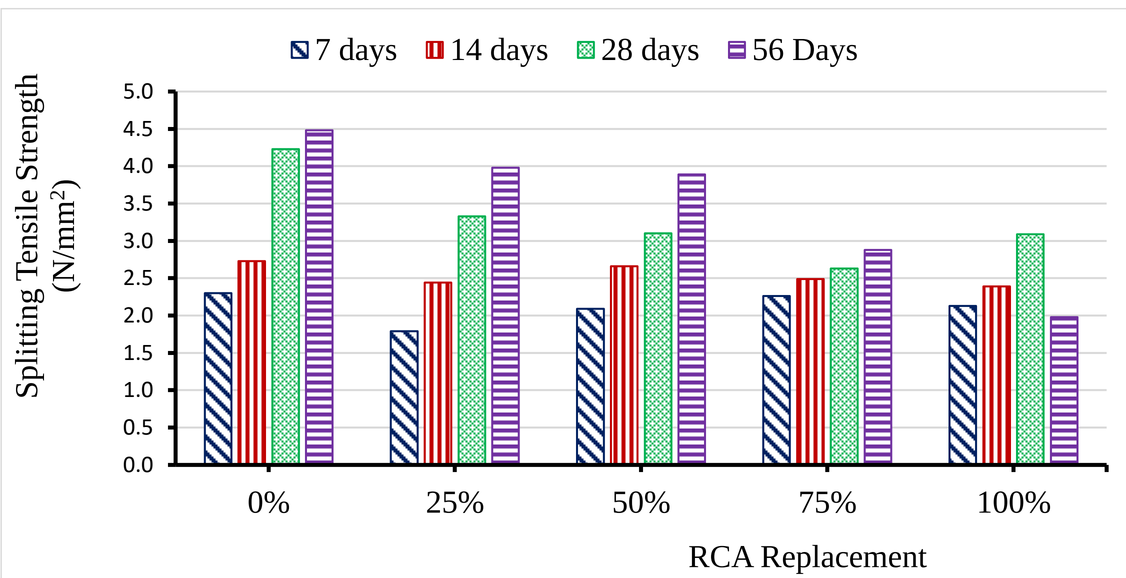


Fig. 7: Splitting tensile Strength concrete specimens for 10% Cement Kiln Dust

## 5.5 Splitting Tensile Strength

Figures 7 and 8 present the experimental results of splitting tensile strength for concrete with 10% and 20% cement kiln dust (CKD) replacement, measured at 7, 14, 28, and 56 days for various recycled concrete aggregate (RCA) replacement levels. The control mix achieved the highest splitting tensile strength of 4.58 N/mm² at 56 days, followed closely by the mix with 10% CKD, which recorded 4.48 N/mm² at the same curing age.

It was also observed that splitting tensile strength generally increases with extended curing periods (7, 14, 28, and 56 days) across most RCA and CKD replacement levels. However, the lowest splitting tensile strength was observed at 20% CKD and 25% RCA replacement, with a value of 1.71 N/mm² at 7 days, followed by 75% RCA and 20% CKD replacement, which recorded 1.76 N/mm² at 7 days.

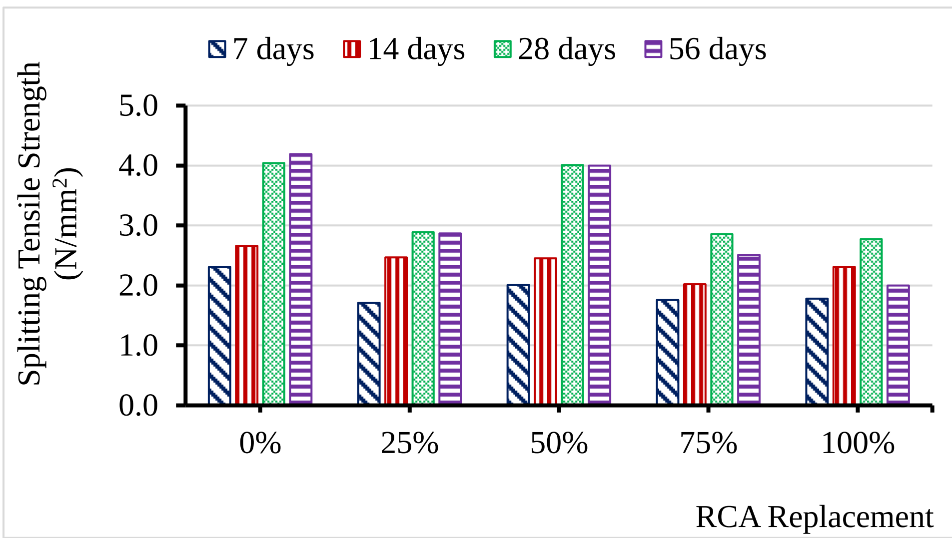


Fig. 8: Splitting tensile Strength concrete specimens for 20% Cement Kiln Dust

## 5.6 Water Absorption of concrete specimens

Figures 9 and 10 present the results of the water absorption test conducted on concrete mixes containing cement kiln dust (CKD) and recycled concrete aggregate (RCA) at 7, 28, 56, and 90 days, with 10% and 20% CKD replacements, respectively. The findings show a slight increase in concrete permeability as the curing age progresses. Additionally, the control specimen demonstrated lower water absorption compared to the CKD/RCA concrete mixes.

The relatively higher absorption capacities of the CKD/RCA concrete are likely due to the high water absorption characteristic of RCA and the residual cement paste attached to it. This trend aligns with findings from similar research by Cadersa, Rana, and Ramjeawon (2014), who observed increased water absorption with higher proportions of Coal Bottom Ash used as aggregate. According to their study, water absorption by immersion rises with the proportion of such aggregates in the concrete mix.

Notably, all water absorption test results remained below 10% by mass, consistent with guidelines by Neville (2011). However, as Chan and Sun (2013) point out, higher water absorption can negatively impact concrete workability and durability, which should be considered in assessing the practical application of CKD and RCA.

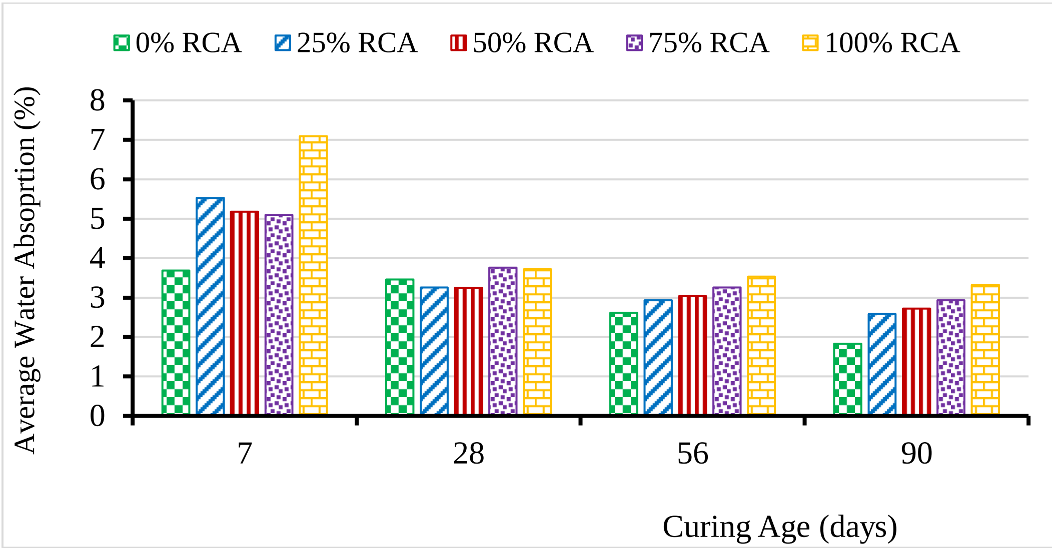


Fig. 9: Results of water absorption of concrete specimens at 10% CKD replacement

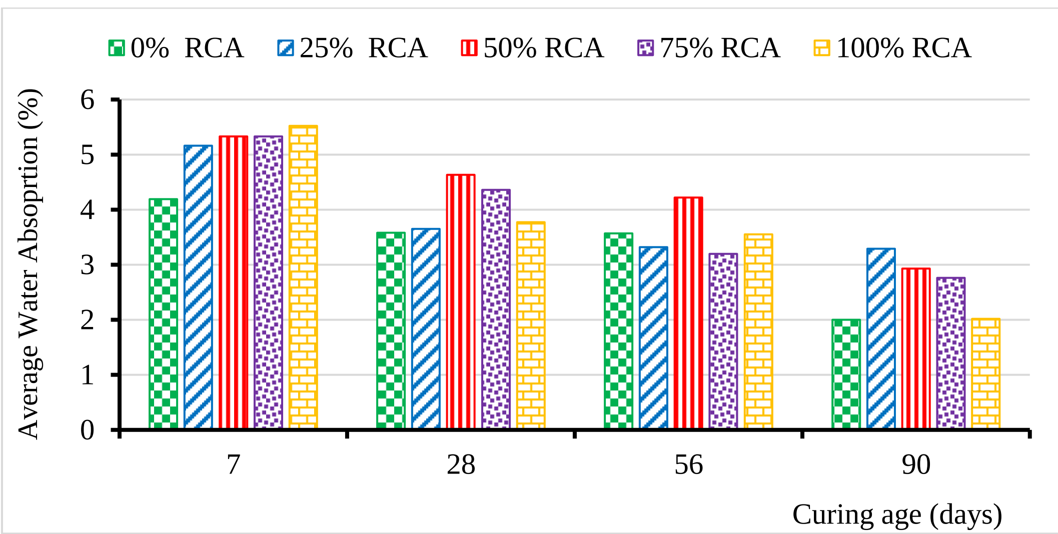


Fig. 10: Results of water absorption of concrete specimens at 20% CKD replacement

## 5.7 Results of Acid attack on concrete specimens

The experimental results assessing acid resistance are presented as follows:

### 5.7.1 Weight loss of various concrete specimens due to acid attack

Figures 11 and 12 show the weight loss of various concrete mixes exposed to sulfuric acid attack for 10% and 20% cement kiln dust (CKD) replacements, respectively. The results indicate that the rate of weight loss is notably higher for the mix with 20% CKD and 50% recycled concrete aggregate (RCA), which contains a higher cement content replacement with CKD than the other mixes. This suggests that increased CKD and RCA content may lead to greater susceptibility to acid attack, as reflected by the weight loss measurements.

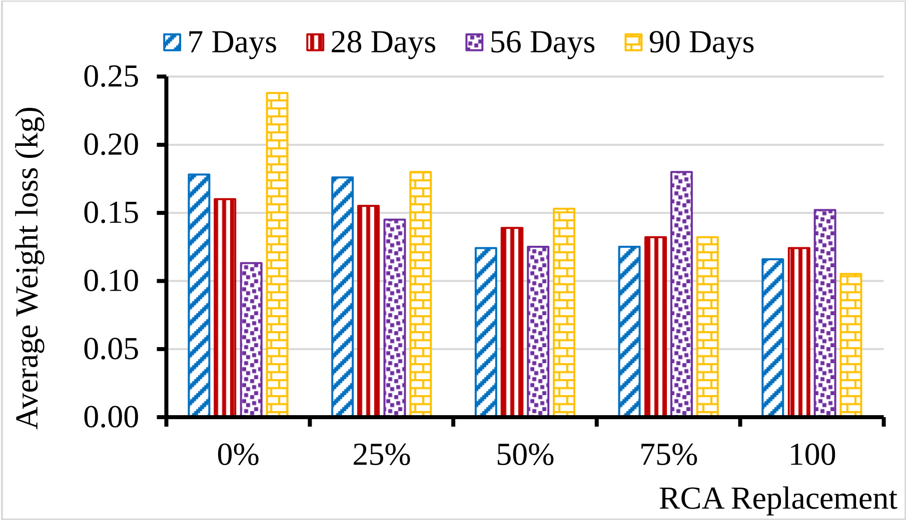


Fig. 11: Results of Weight loss of concrete specimens due to acid attack at 10% CKD

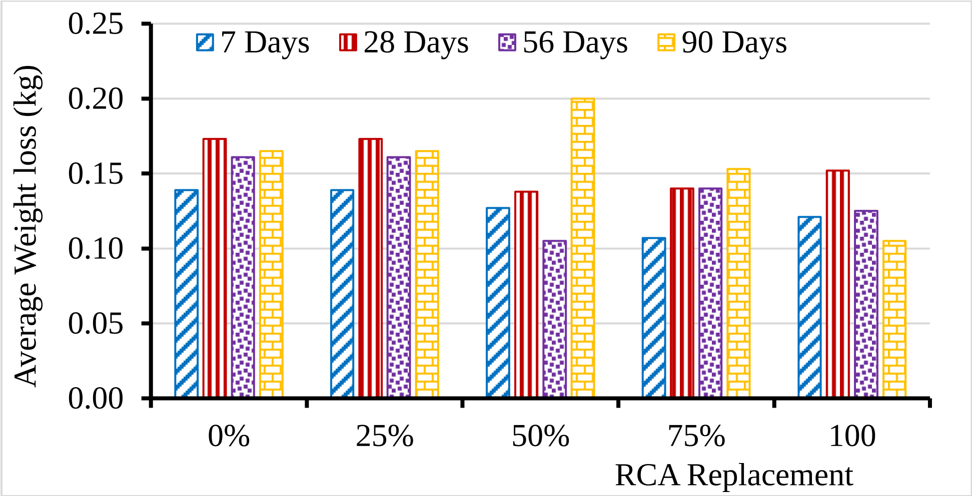


Fig. 12: Results of weight loss of concrete specimens due to acid attack at 20% CKD

**5.7.2 Compressive strength loss due to acid attack**

Figures 13 and 14 illustrate the compressive strength loss of concrete specimens exposed to acid attack for 10% and 20% cement kiln dust (CKD) replacements, respectively. It was observed that the concrete specimen with 20% CKD and 25% recycled concrete aggregate (RCA) replacement exhibited the highest compressive strength, with a value of 31.12 N/mm² after 7 days of immersion in acid. This was followed by the specimen with 10% CKD replacement, which achieved a compressive strength of 29.76 N/mm², comparable to the control specimen's target design strength of 25 N/mm².

The Figures also reveal a trend where compressive strength decreases progressively as the percentage of RCA and CKD replacement increases. The lowest compressive strength under acid attack was recorded for the specimen with 10% CKD and 75% RCA replacement, with a value of 9.94 N/mm² at 28 days. This reduction in strength could be attributed to the increased water absorption and the residual cement paste on the RCA, which may contribute to the reduced acid resistance of the concrete specimens.

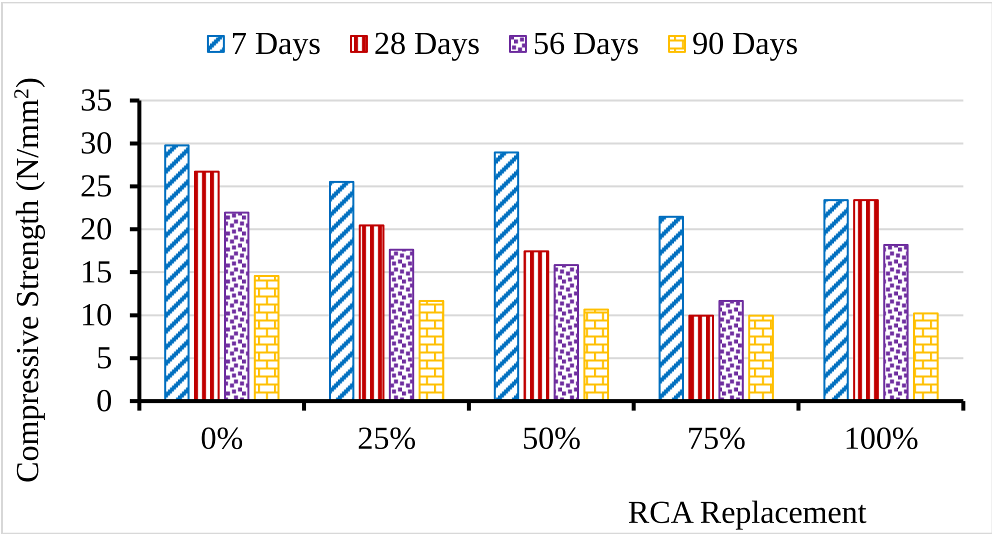


Fig. 13: Results of compressive strength loss due to acid attack at 10% CKD

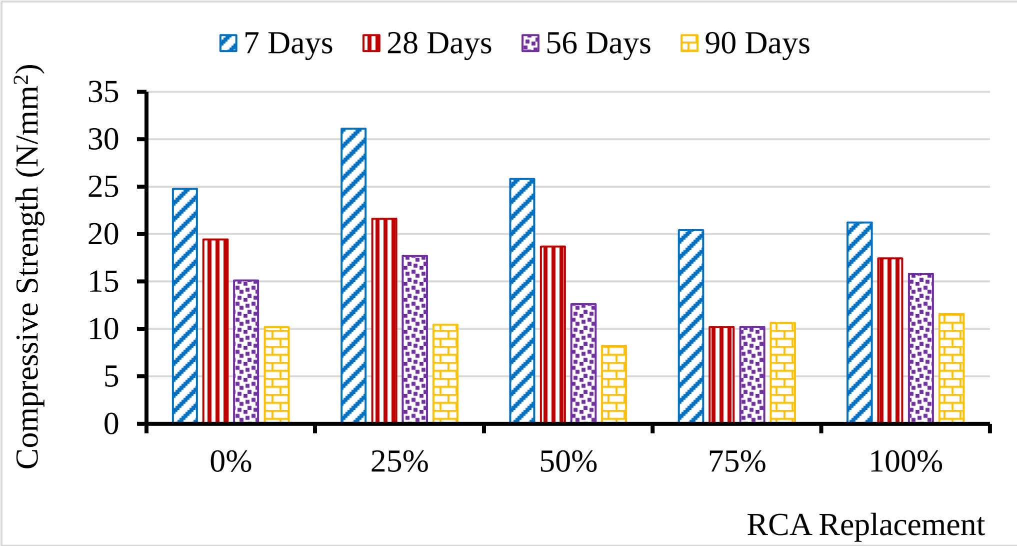


Fig. 14: Results of compressive strength loss due to acid attack at 20% CKD

**7.0 Conclusion:**

Based on the findings of this investigation, the following conclusions are drawn:

1. The addition of cement kiln dust (CKD) and recycled concrete aggregate (RCA) led to a reduction in the workability of concrete.
2. The control mix achieved the highest compressive strength of 34.02 N/mm² at 28

days. In contrast, the mix with 100% RCA and 20% CKD replacement exhibited the lowest compressive strength, at 14.40 N/mm².

3. The compressive strength generally decreased as the proportions of CKD and RCA increased, highlighting the negative impact of these materials on the concrete's strength.

4. The highest water absorption (4.63% at 14 days) occurred in the mix with 20% CKD and 50% RCA replacement, while the lowest absorption (1.83%) was observed in the mix with 10% CKD and no RCA.

5. Concrete specimens with higher CKD and RCA replacements showed greater deterioration when exposed to sulfuric acid, indicating that increased replacement levels reduce the material's durability.

## 6.0 Recommendations:

Based on the findings of this investigation, the following recommendations are proposed:

1. Additional research should be conducted to enhance the understanding and practical application of concrete incorporating cement kiln dust (CKD) and recycled concrete aggregate (RCA) as sustainable structural materials.
2. Future studies should explore the impact of different water/cement ratios on the behavior and performance of concrete containing CKD and RCA in other to determine the optimal mix for various applications.
3. Further research should focus on the long-term durability of concrete with CKD and RCA, particularly in terms of resistance to carbonation, alkali-aggregate reactions, and chloride penetration, to assess its suitability for diverse environmental conditions.

## References

Alabi, S. A & Arum C. (2020), Mechanical Performance of Recycled Aggregate Concrete Containing Lathe Waste Steel Fibre. Nigerian Journal of Technological Development, Vol. 17, No.4, pp 306-311.

ASTM C150. (2012). American Standard Testing of Materials -Standard Specification for Portland Cement. *American society of testing and materials Publication*. doi: 10.1520/c0150_c0150m-12

ASTM C494. (2013). American Standard Testing of Materials - Standard Specification for Chemical Admixtures for Concrete. *American society of testing and materials Publication*, 10. doi: 10.1520/c0494_c0494m-13

Awoyera, P.O.; Akinmusuru, J.O.; Moncea, A. (2017). Hydration mechanism and strength properties of recycled aggregate concrete made using ceramic blended cement. *Cogent Eng.* Vol. 4, 1282667.

BS882. (1992). British standard Specification for Aggregate from natural sources for concrete. *BSI Standards Publication*.

BS 812-112. (1990). Methods for determination of aggregate impact value (AIV). *BSI Standards Publication.*

BS 1881, part 122 (2011) Specification for Method for determination of water absorption. BSI Standards Publication, London

BS EN 12390-3. (2002). Testing hardened concrete - Compressive strength of test specimens. *BSI Standards Publication, London*.

Cadersa, A. S., Rana, J. and Ramjeawon, T (2014), Assessing the Durability of Coal Bottom Ash as Aggregate Replacement in Low Strength Concrete. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 5 (5), ISSN: 2141-7016: 344-349

Chan, D. and Sun, P. C (2013), Effects of Fine Recycled Aggregate as Sand Replacement in Concrete. Taylor & Francis, 13 (4), 2-7.

Etxeberria, M., Vázquez, E., Marí, A., Barra, M. (2007), "Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete", Elsevier, Cement and Concrete Research 37, pp. 735–742

Green, S. (2021). "Engineering Properties and Applications of Recycled Concrete Aggregate." Construction and Building Materials, 278, 122345.

Jones, A. (2020). "Economic Benefits of Recycled Concrete Aggregate in Construction." Environmental Economics Review, 25(3), 45-58.

Johnson, M., & Brown, P. (2019). "Circular Economy: Incorporating Recycled Concrete Aggregate in Construction Practices." Journal of Construction Engineering and Management, 145(6), 04019050.

Johnson, M. (2024). "Long-Term Performance of Concrete with Recycled Content." Cement and Concrete Research, 60, 40-48.

Khatib, J. M. (2015). Properties of concrete incorporating fine recycled aggregate. Construction and Building Materials, 83, 8-15.

Kosmatka, S. H., Kerkhoff, B., & Panarese, W. C., (2002). Design and Control of Concrete Mixtures. Journal of Portland Cement Association.

Kumar, S., (2023). "Cement Kiln Dust (CKD) as a Stabilizing Agent for Hazardous Waste." Journal of Hazardous Materials, 250, 112-120.

Lee, H., & Wang, Q. (2021). "Effect of Cement Kiln Dust on Mechanical Properties of Concrete." Journal of Construction and Building Materials, 198, 723-731.

Maslehuddin, A., Rahman, M. O. M. Ali, M. and Barry, M. [2009] "Properties of cement kiln dust concrete," *Construction and Building Materials*, vol. 23, no. 6, pp. 2357-2361,

Mehta, P. K., & Monteiro, P. J. M. (2014). Concrete: Microstructure, Properties, and Materials. McGraw Hill Professional.

Meyer, C. (2009). The greening of the concrete industry. *Cement and Concrete Composites*, *31*(8), 601-605. doi: 10.1016/j.cemconcomp.2008.12.010

Mindess, S., Young, J. F., & Darwin, D., (2003). Concrete 2nd Edition. Prentice Hall

Neville, A. M. (2011). Properties of Concrete (5th ed.). Pearson Education Publication, Essex, England, UK

Poon, C. S., Kou, S. C., & Lam, L. (2002). Use of recycled aggregates in molded concrete bricks and blocks. *Construction and Building Materials, 16*, 281–289.

Roskovic R. and Monteiro P.J.M. (2006). Concrete: microstructure, properties, and materials. 3rd ed. New York: McGraw-Hill

Rao, A., Jha, K. N., & Misra, S. (2007). Use of aggregates from recycled construction and demolition waste in concrete. *Resources, Conservation and Recycling, 50*(1), 71-81. doi: 10.1016/j.resconrec.2006.05.010

Richardson, A. E., Coventry, K., & Graham, S. (2009). Concrete manufacture with un-graded recycled aggregates. *Structural Survey, 27*(1), 62 - 70. doi: 10.1108/02630800910941692

Sagoe, C. K. K., Brown, T., & Taylor, A. H. (2002). *Durability and Performance Characteristics of Recycled Aggregate Concrete*. Paper presented at the CSIRO Building Construction and Engineering, Victoria Australia.

Scrivener, K., John, V. M., & Gartner, E. (2018). Eco-Efficient Cements: Potential Economically Viable Solutions for a Low-CO2 Cement-Based Materials Industry. Cement and Concrete Research, 114, 2-26.

Shoaib, M. Balaha, M. and Abdel-Rahman, A. [2000]"Influence of cement kiln dust substitution on the mechanical properties of concrete," *cement & concrete research*, vol. 30, no. 3, pp. 371-377.

Siddique, R., Khatib, J., & Kaur, I. (2011). Use of recycled concrete aggregates in structural concrete. Construction and Building Materials, 25(7), 519-527.

Smith, J. (2018). "Recycled Concrete Aggregate: A Sustainable Alternative." Journal of Sustainable Construction, 15(2), 123-136.

Smith, P & Jones, A. (2022). "Cement Kiln Dust (CKD) as a Soil Amendment for Improved Agricultural Productivity." Environmental Science and Technology, 227, 45-52. 224-232.

Tam, V. W. Y., Tam, C. M., & Le, K. N. (2012). A review on the viable technology for construction waste recycling. Resources, Conservation and Recycling, 64, 9-17.

Tam, V. W. Y., Tam, C. M., & Le, K. N., (2020). Recent Advances in Recycling of Concrete: An Overview. Journal of Cleaner Production, 243, 118631.

Taylor, H. F. W., Fentiman, C. H., & Thompson, S. L., (2016). Cement chemistry. Thomas Telford publisher.

Wang, L., & Chen, Y. (2022). "Environmental Impacts and Regulatory Considerations of Cement Kiln Dust Utilization." Journal of Environmental Engineering, 225, 88-96

Zaharieva, R., Buyle-Bodin, F., & Wirquin, E. (2004). Frost resistance of recycled aggregate concrete. *Cement and Concrete Research, 34*(10), 1927-1932. doi: http://dx.doi.org/10.1016/j.cemconres.2004.02.025