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COMPRESSIVE STRENGTH PROPERTIES OF CONCRETE CONTAINING CALCIUM CARBIDE RESIDUE

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ABSTRACT

This study investigates the potential of calcium carbide residue (CCR) as a sustainable alternative to traditional cement in concrete production, focusing on its impact on compressive strength. A total of 36 concrete cubes (150mm x 150mm x 150mm) were cast with varying CCR replacement levels (0%, 5%, 10%, and 15%) using a 1:2:4 mix ratio. Preliminary aggregate tests showed the river sand was well-graded with a specific gravity of 2.67, while granite had a specific gravity of 2.92. Slump tests indicated that all CCR replacement levels resulted in workable concrete, with a slight dip in workability at 5% CCR (24mm slump). Compressive strength tests were conducted at 7, 14, and 28 days, revealing a consistent increase in strength with higher CCR levels: 0% CCR: 11.12 N/mm² to 21.00 N/mm², 5% CCR: 11.48 N/mm² to 21.60 N/mm², 10% CCR: 12.44 N/mm² to 22.00 N/mm², 15% CCR: 12.95 N/mm² to 22.50 N/mm². The findings suggest that incorporating up to 15% CCR improves concrete's compressive strength, with an optimal replacement range of 5-10% CCR for a balance between performance and sustainability. This approach offers a practical and eco-friendly substitute for conventional concrete production, reducing waste and CO_2 emissions.

Keywords:: Calcium Carbide, Compressive strength, Concrete, Workability.

1.INTRODUCTION

The use of calcium carbide (CaC_2) in concrete has gained attention due to its potential to improve mechanical properties, including compressive strength [1]. The chemical composition of Calcium Carbide Residue (CCR) is primarily dominated by calcium hydroxide ($Ca(OH)_2$), which constitutes over 60% of its makeup. This high calcium content is crucial as it imparts the pozzolanic activity that makes CCR an effective supplementary cementitious material (SCM) [1]. The pozzolanic activity refers to the chemical process in which silica (SiO_2) and alumina (Al_2O_3), also present in CCR though in smaller quantities, react with calcium hydroxide in the presence of water to form calcium silicate hydrate (C-S-H) and other cementitious compounds. Additionally, minor quantities of iron oxide (Fe_2O_3) are present, further contributing to the overall reactivity of CCR. The presence of these compounds allows CCR to significantly enhance the properties of concrete when used as a partial replacement for traditional Portland cement.

In terms of physical characteristics, CCR is generally a fine, white powder with a particle size distribution that is quite similar to that of cement. This fine texture is crucial because it allows CCR to be effectively integrated into the concrete mix, filling the voids within the concrete matrix and leading to a denser and more cohesive structure. The fineness of CCR, often measured by its specific surface area, is a key factor influencing its reactivity [2]. A higher specific surface area provides more surface for the pozzolanic reactions to occur, thus enhancing the material's overall effectiveness in improving concrete properties. The fine particles of CCR act as fillers, contributing to the overall density and strength of the concrete by reducing porosity and creating a more compact matrix.

The pozzolanic activity of CCR is a significant property that determines its suitability as an SCM. This activity is characterized by the ability of CCR to react with calcium hydroxide in the presence of water, forming additional cementitious compounds that enhance the mechanical properties and durability of concrete. The pozzolanic reaction primarily results in the formation of calcium silicate hydrate (C-S-H), which is essential for the strength and durability of concrete. The extent of this activity is influenced by several factors, including the particle size of CCR, its chemical composition, and the curing conditions under which the concrete is prepared and set. Studies have consistently shown that CCR exhibits significant pozzolanic activity, making it a valuable addition to concrete mixes. This reactivity leads to improved compressive strength, reduced permeability, and enhanced durability of the concrete, making it more resistant to various forms of degradation over time [3].

This research is focused on maximizing CCR's reactivity and performance as an SCM, exploring its potential to support green construction practices and reduce the environmental impact of cement-based materials. The construction industry faces significant challenges related to the environmental impact of cement production and industrial waste disposal. The high carbon footprint of Portland cement production necessitates the exploration of alternative materials to reduce environmental impact. Managing industrial byproducts like CCR presents a waste management issue requiring innovative solutions [4].

2..LITERATURE REVIEW

2.1 Pozzolanicity of CCR in Concrete

The pozzolanic activity of CCR is a defining characteristic that determines its suitability as an SCM. This activity refers to the ability of material containing SiO_2, Al_2O_3 or Fe_2O_3 to react with calcium hydroxide in the presence of water, forming additional cementitious compounds, primarily calcium silicate hydrates (C-S-H) [5] – [7]. The formation of C-S-H is critical as it significantly enhances the mechanical properties and durability of concrete [7] - [9]. The formation of additional C-S-H phases enhances the bonding within the matrix, leading to improved compressive, tensile, and flexural strengths [8]-[9]. The pozzolanic activity of CCR is influenced by several factors, including particle size, chemical composition, and curing conditions. Studies have consistently shown that CCR exhibits significant pozzolanic activity, making it an effective and valuable SCM in concrete applications. The reactivity of CCR, driven by its chemical and physical properties, leads to improved compressive strength, reduced permeability, and enhanced durability of the concrete. Physically, CCR is generally a fine, white powder with a particle size distribution similar to that of cement. The fineness of CCR, which can be measured by its specific surface area, plays a significant role in its reactivity and interaction with cementitious materials. The fine particles of CCR can fill the voids in the concrete matrix, leading to a denser and more compact structure. This not only contributes to the overall density and strength of the concrete but also enhances its durability [1]. The high specific surface area of CCR increases the available surface for pozzolanic reactions, further boosting its reactivity.

2.2 Properties of CCR in Concrete

The early investigations revealed that inclusion of CCR in concrete improved its workability. The fine particles of CCR acted as a lubricant within the mix, reducing internal friction between aggregate particles and enhancing the overall flowability of the concrete. This improved workability made it easier to handle and place the concrete, especially in complex or detailed construction applications [10].

Another significant finding from early research was the influence of CCR on the setting time of concrete. Depending on the proportion of CCR used, it could either accelerate or retard the setting process. This flexibility in setting time provided advantages in different construction scenarios, allowing for adjustments based on specific project requirements. Additionally, early studies indicated that the use of CCR could enhance the early-age strength of concrete. The pozzolanic reaction between CCR and calcium hydroxide contributed to the early formation of calcium silicate hydrates (C-S-H), leading to a quicker gain in strength. This early strength development was beneficial for projects with tight schedules, as it allowed for faster progression to subsequent construction stages [11].

In terms of durability, the properties of CCR-modified concrete have been found to be comparable to or even superior to other SCMs. The reduced permeability and improved resistance to chemical attacks make CCR-modified concrete a viable option for various construction applications, particularly in environments where durability is a critical concern [12]. Overall, the comparative analysis of CCR with other SCMs has demonstrated its potential as a valuable addition to concrete mixes, offering unique benefits in terms of strength, durability, and sustainability. These findings provide a strong foundation for further research and practical applications of CCR in the construction industry.

Recent research has significantly expanded the understanding of CCR's impact on concrete properties, utilizing advanced analytical techniques such as X-ray diffraction (XRD) and scanning electron microscopy (SEM) to study the microstructural changes in CCR-modified concrete. These advanced techniques have provided detailed insights into how CCR interacts with the cement matrix at a microscopic level [13]. The findings from these studies have revealed that CCR contributes to the formation of additional C-S-H phases within the concrete matrix. The formation of C-S-H is crucial for the strength and durability of concrete, as it is the primary binding phase that holds the concrete together. This enhanced microstructure translates to improved mechanical properties and greater long-term performance.

In addition to microstructural analysis, recent research has explored the use of CCR in combination with other industrial byproducts, such as fly ash and slag, to develop high-performance concrete. These composite mixes have demonstrated superior mechanical properties and durability compared to conventional concrete. The synergistic effects of combining multiple SCMs have been found to enhance the overall performance of concrete, making it more resilient and long-lasting. Researchers have also focused on optimizing the proportions of CCR in concrete mixes to achieve the best possible performance, providing valuable insights into the optimal use of CCR in concrete [14].

2.3 Impact of CCR on Concrete Properties

The incorporation of Calcium Carbide Residue (CCR) into concrete has been the subject of extensive research, particularly focusing on its effects on both fresh and hardened concrete properties. These properties are critical in determining the performance, durability, and suitability of concrete for various construction applications.

i. Workability: This is a crucial property of fresh concrete, affecting its ease of mixing, placing, and compaction. The addition of CCR has been found to significantly enhance the workability of concrete. This improvement is primarily attributed to the fine particle size and high surface area of CCR [15]. The fine particles act as a filler, reducing internal friction and improving the flowability of the mix. Studies have shown that CCR-modified concrete exhibits better workability compared to conventional concrete, which can reduce the need for chemical admixtures and improve overall production efficiency. Enhanced workability also facilitates better compaction, reducing the likelihood of voids and leading to a denser, more uniform concrete matrix.

ii. Setting Time: The presence of CCR has been observed to accelerate the setting time of concrete. This acceleration is primarily due to the high calcium hydroxide content in CCR, which promotes faster hydration reactions. Rapid setting can be particularly beneficial in applications requiring quick turnaround, such as repair works and precast concrete production. However, the accelerated setting time necessitates careful planning and execution to avoid premature setting during placement [16].

iii. Compressive Strength**:** Extensive research has demonstrated that incorporating CCR into concrete can significantly enhance its compressive strength. The pozzolanic reaction between CCR and calcium hydroxide results in the formation of additional calcium silicate hydrate (C-S-H) phases, which are crucial for strength development [1]. Optimal replacement levels of CCR for achieving maximum compressive strength typically range between 10% and 15%. This enhancement in compressive strength makes CCR-modified concrete suitable for structural applications where high strength is required.

iv. Flexural Strength: Research indicates that the incorporation of CCR can enhance the flexural strength of concrete. The fine particles of CCR contribute to a denser and more homogeneous concrete matrix, improving its resistance to flexural stresses. This enhanced flexural performance is beneficial in applications such as pavements and beams, where bending stresses are prevalent [1].

v. Resistance to Chemical Attack: Durability in aggressive environments is crucial for the long-term performance of concrete. CCR-modified concrete has been found to exhibit improved resistance to chemical attacks, including sulfate and chloride attacks. The pozzolanic reaction reduces the permeability of concrete, limiting the ingress of harmful chemicals and enhancing durability [17]. This reduced permeability also helps in preventing the formation of expansive compounds that can cause deterioration.

The impact of CCR on concrete properties is multifaceted, enhancing both fresh and hardened concrete characteristics. The incorporation of CCR improves workability and setting time, while also significantly enhancing compressive, tensile, and flexural strengths. Moreover, CCR-modified concrete exhibits superior durability, with improved resistance to chemical attacks, reduced water absorption and permeability, and enhanced freeze-thaw resistance [12]. These properties make CCR a valuable supplementary cementitious material, contributing to the development of high-performance and durable concrete for various construction applications.

The inclusion of CCR in concrete induces significant microstructural changes that enhance the material's properties. The fine particles of CCR effectively fill the voids within the concrete matrix, leading to a denser and more homogeneous structure. This filling effect reduces the number of pores and microcracks, which are typically sources of weakness in concrete [18] – [21].

3..MATERIALS AND METHODS

3.1 Materials

The following materials were used in the preparation and testing of the CCR-modified concrete:

(1) Cement: Ordinary Portland Cement (OPC) conforming to relevant standards was used as the primary binder in the concrete mix.

(2) Calcium Carbide Residue (CCR): CCR was sourced locally from Ado-Ekiti, where it is available as an industrial byproduct. The CCR was dried, ground, and sieved to achieve a fine powder suitable for use as a supplementary cementitious material.

(3) Fine Aggregate (River Sand): The river sand used as fine aggregate was also sourced from Ado-Ekiti. The sand was clean, well-graded, and free from impurities. Sieve analysis and specific gravity tests were performed to ensure its suitability.

(4) Coarse Aggregate (Granite): Crushed granite, obtained from a local supplier in Ado-Ekiti, was used as the coarse aggregate. The granite was well-graded, angular in shape, and free from deleterious substances. Specific gravity tests were conducted to confirm its density and quality.

(5) Water: Clean potable water was used for mixing and curing the concrete. The water was free from any harmful impurities that could affect the hydration process or the strength of the concrete.

3.2 Methods

3.2.1 Sieve Analysis

Sieve analysis was carried out on both the fine and coarse aggregates to determine their particle size distribution. This analysis is crucial for understanding the grading of the aggregates, which directly impacts the workability, density, and strength of the concrete.

3.2.2 Specific Gravity Tests

Specific gravity tests were performed on both the fine aggregate (river sand) and the coarse aggregate (granite) to determine their density relative to water.

3.2.3 Production and Curing of Concrete

Batching was done by weight. The process of mixing was performed manually. After weighing out the various quantities of materials, the cement and the fine aggregate were first mixed under dry condition until the mixture became thoroughly blended, then the coarse aggregate was introduced, mixed with the already mixed cement and sand until the mix becomes uniformly distributed throughout the batch. As the mixing process continued the quantity of water calculated for was carefully and gradually added. The mixing proceeded until a homogeneous concrete mix appears and the desired consistency emerged.

The moulds used for the casting was 150mmx 50mmx150mm. Before the casting operation was carried out, the moulds were properly cleaned and inside oiled with used engine oil (as releasing agent) to ensure easy de-molding operation. The concrete in the mould were filled in three layers approximately 50mm thick with the Concrete (that is, about 50mm depth). Adequate compaction by hand was done using a standard steel tamping rod; each layer was compacted with at least 25 strokes per layer using the tamping rod before the cube mold is fully filled up with concrete and then compact completed. The trowel was used to give smooth finish on the surface after casting.

Table 1: Mix Design of Concrete

Percentage (%)	No of required cubes	Mass of coarse aggregate	Mass of fine aggregate	Mass of CCR
0	3	41.67	20.79	0
5	3	41.67	20.79	0.058
10	3	41.67	20.79	0.116
15	3	41.67	20.79	0.174

Plate 1: Casting of Cubes

After the casting, proper identification marks were given showing time interval and the type of coarse aggregate used. Then the concrete moulds were left in the laboratory for 24 hours. It was left uncovered because the relative humidity of the period was fairly high since it was done during the rainy season. The cubes were demoulded after 24 hours and then transferred into the curing tank as shown in figure 2.


Figure 2.: Curing of Concrete

3.2.4. Slump Test

Slump test is used for the measurement of a property of fresh concrete. The test is an empirical test that measures the Workability or flow of fresh concrete. ASTM C143 More specifically, it measures Consistency between batches. The slump test*(Figure 3)* is used to ensure uniformity for different batches of similar concrete under field conditions.


Figure 3: Slump Test

3.2.5 Compressive Strength

Test The compressive strength test was carried out using the compressive strength test machine*(Figure 4)* as find in the test method BS 1881 part 116, 1983. An increasing compressive strength was introduced to the cube specimen until failure occurred to obtain the maximum compressive load. The specimen dimension was taken before testing. The testing was carried out for 7, 14 and 28 days after curing.

$$\text{Compressive strength} = \frac{\text{Compressive strength}}{\text{Surface Area}}\ \text{kN/m}^2$$


Figure 4: Compressive Strength Machine

4. RESULTS AND DISCUSSION

4.1 Sieve Analysis

The particle distribution graph of aggregates is shown in Figure 5.

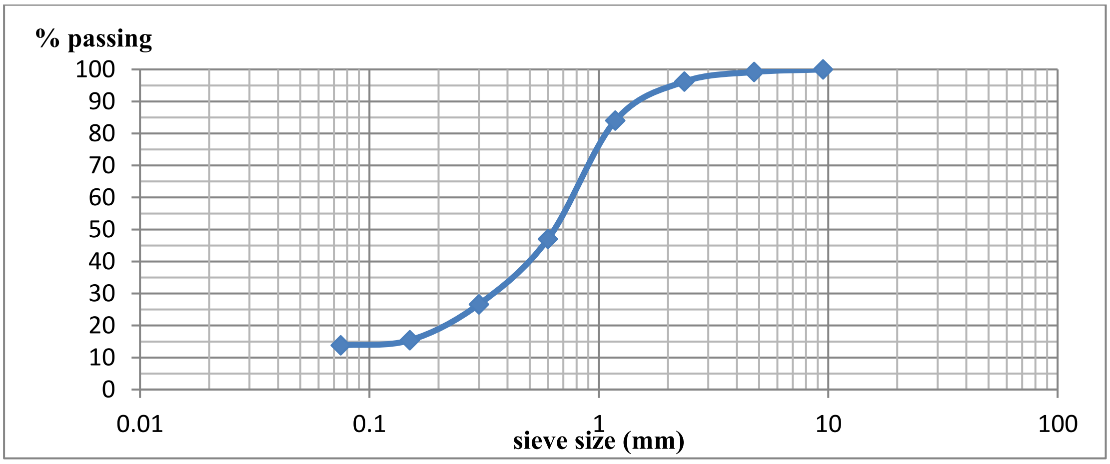

Figure 5: Particle Size Distribution Curve for Aggregates

4.2 Specific Gravity

Specific gravity is an essential property of aggregates, as it impacts the density and strength of the concrete. The specific gravity test was performed on both the fine and coarse aggregates used in this study. The average specific gravity of river sand across the two trials was calculated as 2.67. The specific gravity results show that the granite used in this study has an average specific gravity of 2.92, while the river sand has an average specific gravity of 2.67. These values are within the typical range for aggregates used in concrete production, indicating their suitability for creating a dense, strong concrete mix which is in accordance with ASTM C127 &12 and are shown in Tables 2 and 3

Table 2: Specific Gravity of Granite

TRIAL	A	B
EMPTY BOTTLE (W1)	392	396
BOTTLE + SOIL (W2)	569	578
BOTTLE + SOIL +WATER (W3)	753	766
BOTTLE + WATER (4)	638	645
(W2-W1)	177	182
(W4-W1)	246	249
(W3-W2)	184	188
SPECIFIC GRAVITY	2.85	2.98
AVERAGE	2.92	

Table 3: Specific Gravity of River Sand

TRIAL	A	B
EMPTY BOTTLE (W1)	28	29
BOTTLE + SOIL (W2)	74	71
BOTTLE + SOIL +WATER (W3)	107	104
BOTTLE + WATER (4)	78	78
(W2-W1)	46	42
(W4-W1)	50	49
(W3-W2)	33	33
SPECIFIC GRAVITY	2.71	2.63
AVERAGE	2.67	

4.3 Compressive Strength Test

Compressive strength was assessed at the ages of 7, 14 and 28 days of curing on 150 mm by 150mm by 150mm cube mortar specimens, as per means of compression testing machine at standard loading rate. The machine automatically stops when failure occurs and then displays the failure load. The compressive strength development in OPC, 5% CCR, 10% CCR and 15% CCR concrete specimens with curing period is shown in Table 4
.

Table 4: Compressive Strength for different CCR Replacement levels at 7, 14, and 28 Days

CCR Replacement Level (%)	Compressive strength at 7 days (N/mm^2)	Compressive strength at 14 days (N/mm^2)	Compressive Strength at 28 days (N/mm^2)
0%	11.12	15.69	21.00
5%	11.48	16.58	21.60
10%	12.44	17.03	22.00
15%	12.95	17.47	22.50

4.4.Effect of Curing Time on Compressive Strength. The compressive strength increases at all percentage replacement with curing time as seen in the figure 5. At 0% replacement of calcium carbide residue, compressive strength increased gradually from 11.12N/mm2 to 21.00N/mm2 at 28 days. For 5% replacement of calcium carbide residue, the compressive strength increased from 11.45 N/mm2 at 7 days curing time to 21.60 N/mm2 at 28days.

At 10% replacement of calcium carbide residue, the compressive strength increased from 12.44N/mm2 to 22.00N/mm2 at 28 days. For 15% replacement of CCR Compressive strength increased from 12.95N/mm2 at 7 days to 22.50N/mm2 at 28 days. It can therefore be said conclusively that giving more time for curing concrete cubes the compressive strength increases.

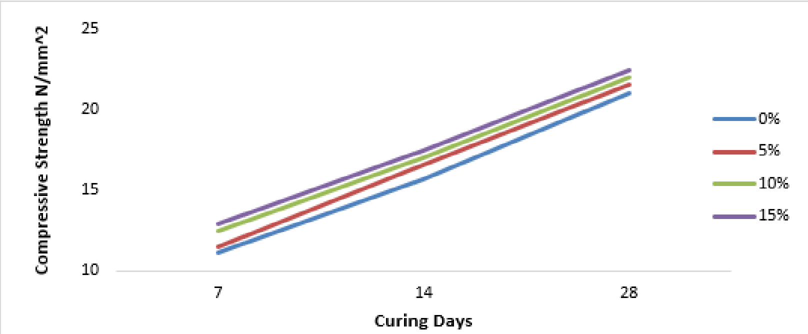

Figure 5: Compressive Strengths Against Curing Days

5. Conclusion and Recommendations This study investigated the feasibility and effectiveness of using Calcium Carbide Residue (CCR) as a supplementary cementitious material (SCM) in concrete production. Key findings include:

(i)CCR can be successfully integrated into concrete, reducing the carbon footprint associated with cement production and promoting sustainability.

(ii)Workability decreases with increasing CCR content, requiring adjustments with water-reducing admixtures.

(iii)Compressive strength improves with CCR replacement, with 15% providing the highest strength.Optimal replacement levels are between 5-10%.

(iv)Using CCR reduces cement use and environmental impact, supporting sustainable building practices.

Based on this study's findings, the following recommendations are made

(i) Mix Design Adjustments: Adjust water-cement ratio or use water-reducing admixtures for CCR content above 10% to maintain workability.

(ii) Further Research on Long-Term Durability: Investigate CCR-modified concrete's resistance to environmental factors like freeze-thaw cycles, sulfate attack, and chloride penetration.

(iii) Optimization of CCR Content: Adopt 5-10%CCR range for most structural applications; explore performance in specialized applications and conditions.

(iv)Industry Standards and Adoption: Develop standards and guidelines for CCR use in concrete, including mix design, testing, and best practices.

(iv)Utilization of Local CCR Resources: Prioritize local CCR use in concrete production to reduce environmental impact and support local industries.

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