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Low Carbon Green Concrete Made with Recyclable Locally Sourced Materials

[1]Akhademe Ferdinand Unumoste and [2]Ezeagu Akaolisa Celestine

[1, 2]Department of Civil Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria.

Abstract: *Concrete production has a significant environmental impact due to its heavy reliance on natural resources. To address this, incorporating recycled aggregates provides a sustainable solution by reducing the need for virgin materials and diverting construction waste from landfills. This research aims to investigate the effects of recycled aggregates on concrete properties like workability, strength, and durability. Through comprehensive laboratory studies, concrete mixes with varying proportions of recycled aggregates were examined using standardized testing procedures. The results showed that higher levels of recycled aggregates led to decreased workability and compressive strength. For instance, a mix without recycled aggregates and a water-to-cement ratio of 0.43 exhibited a slump measurement of 89 mm and a 28-day compressive strength of 52.0 MPa, while a mix with 100% recycled aggregates and the same water-to-cement ratio showed a slump value of 78 mm and a compressive strength of 41.1 MPa. Overall, this study offers valuable insights into the use of recycled aggregates in concrete production, benefiting stakeholders interested in promoting sustainability in the construction industry, such as engineers, designers, and policymakers.*

Keywords – *Green Concrete, recycled aggregates, construction, slump measurement, compressive strength*

I. INTRODUCTION

In recent years, there has been a growing recognition of the urgent need to address environmental sustainability within the construction industry. As a sector responsible for significant carbon emissions and resource consumption, the construction industry is increasingly seeking innovative solutions to reduce its environmental impact (Okah, J., & Amos, 2021). One such solution gaining prominence is the development of low carbon green concrete, which prioritizes the utilization of recyclable locally sourced materials. This approach represents a paradigm shift towards more sustainable construction practices by minimizing reliance on virgin resources and reducing the carbon footprint associated with concrete production (Ugboaja *et al.*, 2022).

Low carbon green concrete is characterized by its use of environmentally friendly materials sourced from local regions. By incorporating recycled aggregates, supplementary cementitious materials, and other eco-friendly additives obtained from nearby sources, this approach aims to promote circular economy principles and mitigate the environmental impact of concrete production (Amulu & Ezeagu, 2017). Unlike conventional concrete, which often relies on virgin materials transported over long distances, low carbon green concrete emphasizes the utilization of materials readily available within the vicinity of construction sites. This not only reduces transportation-related emissions but also fosters local economic development by supporting regional recycling and manufacturing industries (Ezeagu & Agbo-Anike, 2020).).

The aim of this study is to investigate and evaluate the feasibility and effectiveness of utilizing recyclable locally sourced materials in the production of low carbon green concrete. By diverting construction waste from landfills and reducing the extraction of natural resources, this approach contributes to the conservation of finite resources and the preservation of ecosystems. Additionally, the use of locally sourced materials minimizes energy consumption and greenhouse gas emissions associated with material extraction, processing, and transportation, thereby mitigating the carbon footprint of concrete production.

II. MATERIALS AND METHOD

A. Materials

Various materials have been selected for this study, including recycled aggregate sourced from a demolition site at Ngozika Estate, Awka, Anambra State, and natural aggregate obtained from a crushed granite dealer at Agu Awka, Anambra State. Cement will be procured from Eke Awka market in Anambra State, with each bag weighing 50kg. Prefabricated moulds will be utilized for shaping the concrete specimens, sourced from the same market. Among the items used for the slump test are a hollow frustum of a cone crafted from galvanized steel sheet, a metal rod, a base plate, a scoop, and a steel ruler, among other components.

B. Methodology

Preparation of mould for making sample particleboard:

The mould for making sample particleboard was prepared using a steel metal sheet. The formwork was constructed with inner dimensions of 200mm x 200mm and a depth of 200mm, allowing sufficient space for the particleboard sample. The thickness of the mould covers measured 15mm, providing stability and support during the particleboard casting process.

Particle Density Determination:

Particle density, a crucial factor in concrete mix design, was determined following the guidelines outlined in British Standard BS 812-2:1995 (Egbe, 2019). The objective was to calculate the volume and weight of aggregates needed for concrete mixes accurately. Testing involved various types of aggregates, including natural aggregates with grain sizes of 20mm, 10mm, and 7mm, recycled aggregates with grain sizes of 14mm and 5mm, and fine aggregates (sand). These tests were conducted meticulously in the engineering laboratory of Nnamdi Azikiwe University, Awka. Particle density, influenced by factors such as moisture content and geological properties, played a pivotal role in optimizing concrete formulations for desired properties and performance.

Water Absorption Assessment:

Water absorption tests, following British Standard 8500-2:2002 guidelines (Padmini et al., 2002), evaluated moisture absorption by aggregates, crucial for concrete properties. Assessments were conducted under both saturated surface dry (SSD) and oven-dried conditions. SSD involved saturating aggregates with water and removing excess before weighing, while oven-drying yielded a constant weight. Discrepancies in weight determined water absorption capacity as a percentage. These evaluations informed concrete mix design decisions for sustainable construction practices.

Mix Design:

Before having any concrete mixing, the selection of mixed materials and their required materials proportion must go through a process called mix design. There are lots of methods for determining concrete mix design. According to Bairagi *et al.* (1999), the method called British Method was widely used in Australia. In this project, altogether eight batches of mixtures were determined in this project. The initial mix batch will be a 100% natural aggregate mix batch. The second mix batch was 80% natural aggregate and 20% recycled aggregate. There was an increase of every 20% of recycled aggregate added into every series of mix batch. To fully compare the different types of full recycled aggregate concrete, there were three mix batches that contained 100% recycled aggregate. Two batches of 100% recycled aggregate were used different water cement ratio and the remaining one batch was mixed with blended cement. Table 1 exhibits the Initial Data for Mix Design, while Table 2 showcases the Target Strength and Ratios.

Table 1 Initial data for mix design

	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6 to 8
Natural aggregate (%)	100	80	60	40	20	0
Recycled aggregate (%)	0	20	40	60	80	100

Table 2: Concrete Mix Design Parameters for Target Strength of 50 MP

Target strength (MPa)	50
Water/cement ratio	0.45
Aggregate / cement ratio	4.1
Weight of cement per bag (kg)	40

Mixing of concrete:

The performance and quality of recycled aggregate concrete hinge heavily on proper mixing practices, which ensure thorough homogeneity during and after the process (Hashmi *et al.,* 2022). This leads to enhanced strength and bonding between cement and aggregates. Following the determination of concrete mix design, mixing commenced using a 60-liter capacity electric pan mixer at the University of Southern Queensland's concrete laboratory. Before mixing, all materials were weighed and prepared as per the specified mix design. The procedure involved dampening the mixer surface, adding aggregates, followed by cement, and then slowly incorporating water while mixing for approximately 3 minutes. The mixer was then turned off, and the concrete was transferred to a wheelbarrow for further testing and casting (Achini *et al.,* 2021).

Placing, Compaction and Casting of Concrete Specimens:

Before concrete placement, it's crucial to oil the moulds for easy specimen stripping, using a mixture of diesel and kerosene (Somarathna *et al.,* 2021). Care is taken to prevent concrete stains on the moulds. Once the workability test is completed, fresh concrete is placed into moulds for subsequent testing (Somarathna et al., 2021). Each batch requires 15 small cylinders (100mm diameter, 200mm height) and 2 large cylinders (150mm diameter, 300mm height). Vibrations are applied with an immersion vibrator during concrete placement to ensure full compaction and air void release. Vibration starts after pouring one-third of the fresh concrete, becoming more challenging with increasing recycled aggregate percentages. After levelling, the concrete sets overnight in the moulds (Somarathna et al., 2021).

Stripping and Curing of Concrete Specimens:

After allowing the fresh concrete to set overnight in the moulds, the next step involved stripping the concrete specimens and cleaning and oiling the moulds for subsequent use (Pasupathy *et al.,* 2021). The stripped specimens were then transferred to a curing room maintained at 25ºC for 28 days to undergo the hardened properties test (Pasupathy *et al.,* 2021). Proper curing is crucial to prevent moisture loss, which could lead to unexpected cracks and compromise concrete strength. After the 28-day curing period, compression tests were conducted on the small cylinders, extracted on the specified day, to assess compressive strength. Workability tests, including the slump and compacting factor tests, were conducted on the fresh concrete, followed by compression tests on hardened specimens on days 1, 3, 7, 14, and 28 (Ortega-López *et al.,* 2021). Additionally, on day 28, indirect tensile and modulus of elasticity tests were performed.

Workability Tests of Fresh Concrete:

Slump Test:

The slump test is a simple and cost-effective method for assessing the workability of fresh concrete, applicable both in laboratory and on-site conditions. Care must be taken during the test to avoid disturbances that could lead to inaccuracies, as significant slumps may occur with minor disruptions (Dey *et al.,* 2022**)**. While the test provides an indication of how easily a mix can be placed, it does not directly measure the work required to compact the concrete. Slumps of less than 25mm indicate very stiff concrete, while slumps exceeding 125mm indicate highly fluid concrete. However, the test may not accurately assess concrete with extremely high or low workability, as very workable concrete may lose its shape and collapse, while very low workability concrete may not exhibit any collapse **(**Okah & Amos, 2021**).**

Test Procedure of Compacting Factor Test: Compacting Factor Apparatus:

The test procedure followed the AS 1012.3.2 – 1998 standard (Aslani & Asif, 2019), and proceeded as outlined below: First, the internal surface of the mould was cleaned and moistened with a damp cloth to ensure proper preparation. Then, the compacting factor apparatus was positioned on a stable, level surface, free from vibrations or shocks, to ensure accurate testing conditions. Concrete was carefully added to the upper hopper until it reached full capacity, after which the trapdoor was opened, allowing the concrete to flow into the lower hopper and then into the cylinder. Any excess concrete protruding above the cylinder's level was trimmed off using towels. The mass (M1) of the partially compacted concrete in the cylinder was then determined and recorded. Subsequently, the cylinder was emptied, and concrete was added again in approximately 50mm deep layers, compacted using a metal rod. Finally, the mass (M2) of the fully compacted concrete in the cylinder was determined and recorded. The compacting factor was calculated using the equation provided by Aslani & Asif, 2019.

$$\text{Bulk density} = \frac{Mass\ of\ Partially\ Compacte}{Mass\ of\ fully\ compacted\ C}$$

Test Procedure of Compression Test:

Following the guidelines outlined in AS 1012.9 – 1999, the test procedure involved several steps to ensure accurate and reliable results (Jörgens *et al.,* 2021). Specimens were tested promptly after removal from the curing room, with measurements taken beforehand. The diameter, height, and weight of each specimen were recorded before cleaning the plates of the testing machine. Subsequently, the uncapped surface of the specimen was cleaned, and it was carefully placed in the testing machine, aligning its axis with the centre of thrust of the spherically seated platen. A rubber cap was then placed on the specimen, and force was applied gradually until failure, with the maximum force recorded for analysis.

III. RESULTS AND DISCUSSION

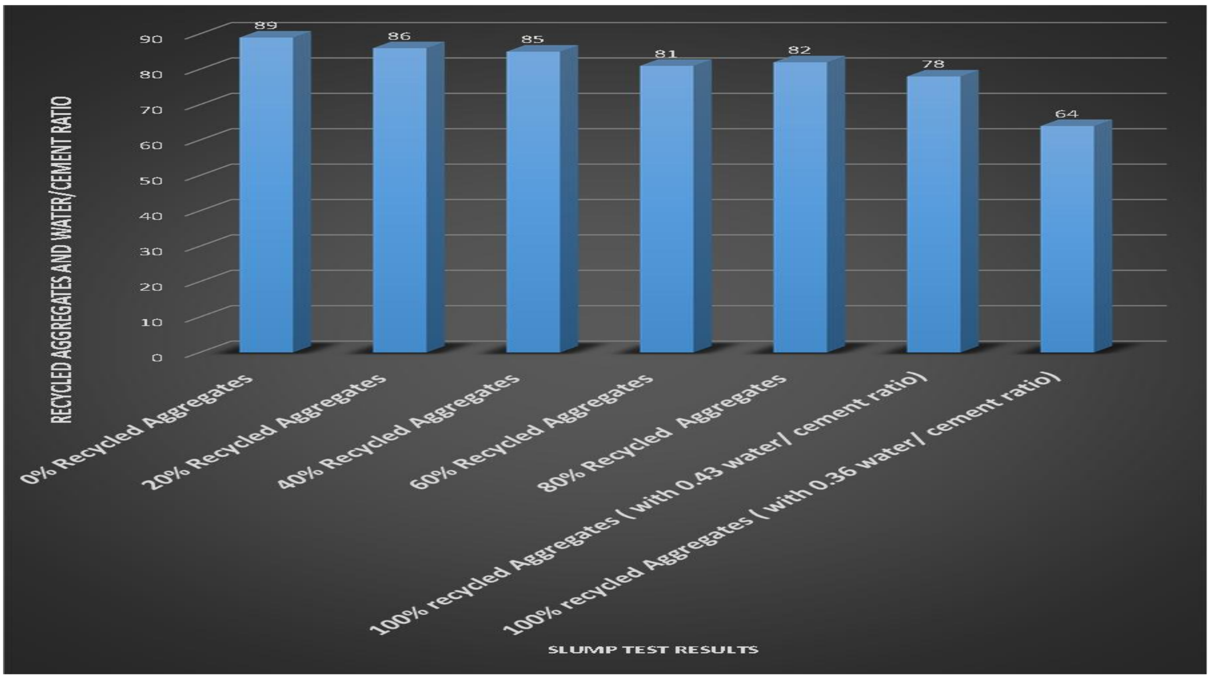

Fig.1: Histogram showing the Effect of Recycled Aggregates and Water/Cement Ratio on Slump Test Results

The results presented in Fig.1 illustrate the significant impact of recycled aggregates and water-to-cement ratio on the slump test results, providing valuable insights into the workability of concrete mixes. The comprehensive dataset unequivocally portrays a discernible pattern of declining slump values as the proportion of recycled aggregates escalates. This correlation aligns with theoretical expectations, as recycled aggregates often exhibit irregular shapes and rougher textures compared to their natural counterparts. Such irregularities invariably introduce heightened frictional forces within the concrete matrix, impeding the fluidity and ease of placement during construction activities (Lavado *et al.,* 2020).

Moreover, the tabulated results underscore the nuanced impact of fluctuating water-to-cement ratios on slump values, further elucidating the intricate interplay between mix constituents and workability characteristics. Notably, as the water-to-cement ratio decreases, the lubricating effect between particles diminishes correspondingly, exacerbating the challenges associated with particle cohesion and mobility within the concrete matrix. This phenomenon is integral to understanding the complex rheological behaviour of concrete mixes and highlights the critical role of water management in optimizing workability while preserving material integrity. The findings of this study carry profound implications for the practical landscape of the construction industry, where concrete stands as the cornerstone of infrastructure development and architectural advancement. These implications permeate through the intricate tapestry of material science, engineering design, and sustainable practices, fundamentally shaping modern construction methodologies.

One of the paramount implications is the necessity to strike a delicate balance between sustainability goals and functional performance criteria in concrete mix designs. While incorporating recycled aggregates represents a commendable stride towards environmental stewardship by mitigating resource depletion and waste generation, its seamless integration into concrete formulations demands meticulous attention to detail. The challenge lies in harmonizing the lofty aspirations of sustainability with the pragmatic demands of workability, ensuring that resulting concrete matrices not only uphold ecological integrity but also demonstrate operational efficacy. This imperative compels stakeholders across the construction spectrum – from visionary architects conceiving cutting-edge structures to adept contractors orchestrating intricate builds – to engage in a nuanced process of material selection and mix optimization, crafting tailored formulations that reconcile environmental responsibility with practical utility.

Moreover, the study's elucidation of the intricate relationship between water-to-cement ratio and slump values underscores the need for a recalibrated approach to water management in concrete production. Beyond mere volumetric proportioning, this interconnection highlights the holistic implications of water content on concrete behaviour, influencing every stage of its lifecycle – from batch mixing to final placement. Herein lies the crux of the matter: the judicious manipulation of water dosage to modulate concrete consistency, strength, and durability. However, this pursuit is fraught with challenges, as the allure of reduced water content – promising augmented strength and reduced shrinkage – must be balanced against the sobering reality of compromised workability and cohesion. Thus, achieving the elusive equilibrium between water, cement, and aggregate becomes not merely an engineering endeavour but a symphony of art and science, demanding adept orchestration and profound comprehension.

In summary, the implications drawn from this study transcend the confines of laboratory experimentation, permeating the very ethos of contemporary construction practices. They beckon industry stakeholders to embark on a transformative journey – one that reconciles the imperatives of sustainability with the demands of functionality, the aspirations of innovation with the constraints of pragmatism. Through this journey, the construction fraternity charts a course towards a future where concrete not only bears the weight of structures but also shoulders the burden of responsibility – responsibility towards the planet, towards posterity, and towards a built environment that is both enduring and enlightened.

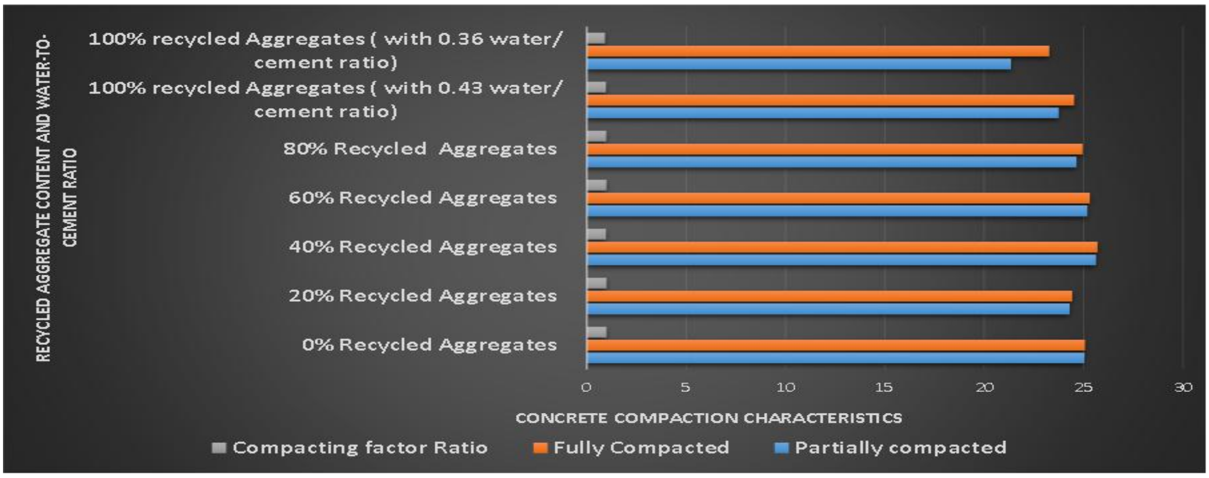

Fig. 2: Bar Chart Representing the Effect of Recycled Aggregate Content and Water-To-Cement Ratio on Concrete Compaction Characteristics

The results presented in Fig.2 offer detailed insights into the interplay of recycled aggregate content and water-to-cement ratio on concrete compaction characteristics. Firstly, the data indicate a clear correlation between the percentage of recycled aggregates and the compaction behaviour of the concrete mix. As the proportion of recycled aggregates increases, there is discernible variability in the measurements of partially and fully compacted concrete. This variability underscores the significant influence of recycled aggregates on the physical properties and workability of the concrete mixture. Factors such as particle shape, size distribution, and surface texture of recycled aggregates can substantially affect compaction efficiency, leading to challenges in achieving optimal compaction levels (Kang *et al.,* 2015).

Moreover, the impact of water-to-cement ratio on compaction characteristics is evident from the data. Lower water-to-cement ratios result in reduced values for both partially and fully compacted concrete, indicating decreased workability attributed to limited fluidity of the concrete mix. Conversely, higher water-to-cement ratios yield higher values for partially and fully compacted concrete, suggesting improved workability but potential compromises in strength and durability due to increased porosity. The intricate balance between water content and cementitious materials is critical in determining the overall performance of the concrete mix, emphasizing the importance of judicious mix design and optimization (Yurdakul *et al.,* 2014).

Furthermore, the calculated compacting factor ratio provides valuable insights into the efficiency of compaction. Ratios close to 1.000 signify efficient compaction with minimal discrepancies between partially and fully compacted volumes, indicative of well-optimized mix designs (Sankeerth *et al.,* 2021). Conversely, ratios below 1.000 suggest incomplete compaction, raising concerns about potential voids, segregation, and reduced density in the hardened concrete. These findings underscore the complex interaction between mix constituents and compaction behaviour, highlighting the need for meticulous attention to detail in concrete mix design and construction practices (Sankeerth *et al.,* 2021).

In real-life applications, the implications of these results are significant for concrete producers, contractors, and engineers. By understanding how recycled aggregate content and water-to-cement ratio influence compaction characteristics, stakeholders can tailor mix designs to meet specific project requirements while promoting sustainability and environmental stewardship. Optimal mix designs not only enhance construction efficiency but also contribute to long-term performance and durability of concrete structures. However, achieving the desired balance between workability, strength, and sustainability requires careful experimentation, testing, and collaboration among industry stakeholders.

In a nutshell, the comprehensive analysis of results presented in Fig. 3 provides valuable insights into the complexities of concrete mix design and compaction behaviour. By leveraging these insights and considering their real-world implications, stakeholders can make informed decisions to optimize mix designs, enhance construction practices, and advance sustainability goals in the built environment.

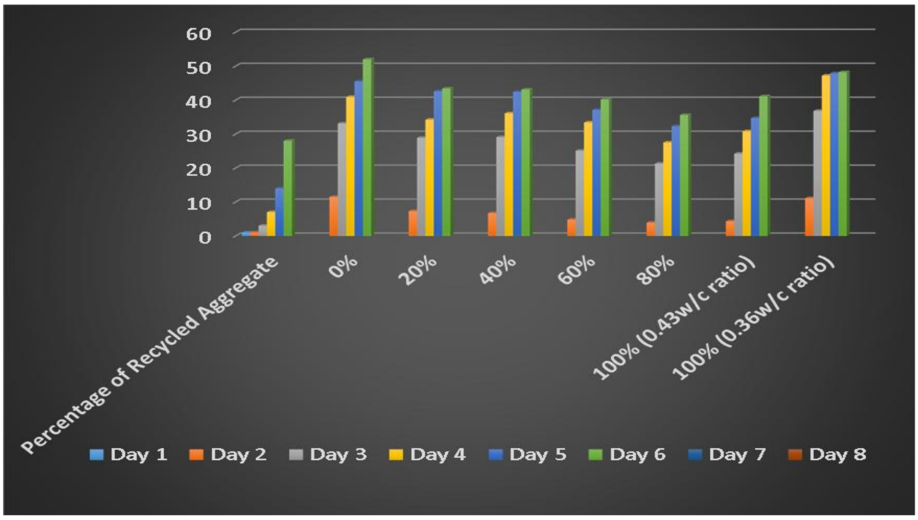

Fig. 3: Bar chat displaying the Effect of Recycled Aggregate Percentage on Compressive Strength at Various Curing Days and Water-to-Cement Ratios

Fig.3 provide a comprehensive analysis of the impact of recycled aggregate percentage on compressive strength at various curing days and water-to-cement ratios. The data reveal notable trends in compressive strength development over time, shedding light on the influence of recycled aggregates on concrete performance. At an early age of 1 day, the compressive strength values exhibit a wide range across different percentages of recycled aggregates. Concrete mixes with lower recycled aggregate content (0% and 20%) demonstrate relatively higher compressive strength compared to mixes with higher percentages of recycled aggregates. This trend persists at subsequent curing days, highlighting the potential detrimental effects of increased recycled aggregate content on early-age compressive strength. As the curing period progresses, the compressive strength of all concrete mixes gradually increases, indicating ongoing hydration and development of concrete strength. However, the rate of strength gain varies among mixes with different percentages of recycled aggregates. Concrete mixes with lower percentages of recycled aggregates consistently exhibit higher compressive strength values compared to mixes with higher recycled aggregate content, even at later curing stages.

Furthermore, the influence of water-to-cement ratio on compressive strength is evident from the data. Concrete mixes with lower water-to-cement ratios generally demonstrate higher compressive strength values across all percentages of recycled aggregates and curing days. This underscores the importance of optimizing the water-to-cement ratio to achieve desired strength levels while ensuring adequate workability and durability of the concrete mix.

In real-life applications, these findings have significant implications for concrete mix design and construction practices. Engineers and concrete producers must carefully balance the use of recycled aggregates with the desired strength requirements of the project. By understanding the effects of recycled aggregate content and water-to-cement ratio on compressive strength development, stakeholders can make informed decisions to optimize mix designs, enhance construction efficiency, and promote sustainability in the built environment.

Overall, Fig. 3 provides valuable insights into the complex relationship between recycled aggregate percentage, curing duration, water-to-cement ratio, and compressive strength of concrete. By leveraging these insights, stakeholders can develop strategies to address challenges related to sustainable concrete production while ensuring the long-term performance and durability of concrete structures.

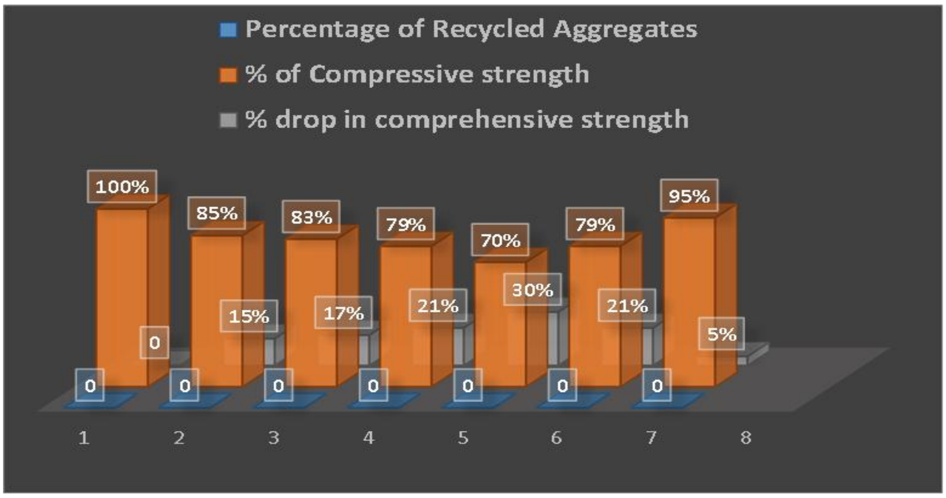

Fig. 4: Bar chart showing the Impact of Recycled Aggregate Percentage on Compressive Strength and Percent Drop in Comprehensive Strength

Fig. 4 revealed the Impact of Recycled Aggregate Percentage on Compressive Strength and Percent Drop in Comprehensive Strength The data demonstrate a clear inverse relationship between the proportion of recycled aggregates in the concrete mix and its compressive strength. As the percentage of recycled aggregates increases from 0% to 100%, there is a notable decline in compressive strength, as evidenced by the decreasing percentages relative to the control sample with 0% recycled aggregates. For instance, with 20% recycled aggregates, the compressive strength reduces to 85% of the control sample, indicating a 15% drop in comprehensive strength. This trend continues as the percentage of recycled aggregates further increases, with 40%, 60%, and 80% recycled aggregates resulting in compressive strengths of 83%, 79%, and 70% respectively, compared to the control sample. These reductions in compressive strength correspond to percentage drops in comprehensive strength of 17%, 21%, and 30% respectively.

Interestingly, the data also reveal variations in compressive strength based on the water-to-cement ratio. For concrete mixes containing 100% recycled aggregates, the compressive strength differs depending on the water-to-cement ratio utilized. When the water-to-cement ratio is 0.43, the compressive strength is 79%, resulting in a 21% drop in comprehensive strength. However, when the water-to-cement ratio is reduced to 0.36, the compressive strength increases to 95%, resulting in a significantly lower 5% drop in comprehensive strength. The findings from Table 9 are further elucidated in Fig. 29, which visually represents the impact of recycled aggregate percentage on compressive strength and the subsequent percentage drop in comprehensive strength. The bar chart clearly illustrates the decreasing trend in compressive strength as the percentage of recycled aggregates increases, with each bar corresponding to the respective percentage drop in comprehensive strength.

Practically, these results have profound implications for the construction industry, particularly in sustainable concrete production. While the incorporation of recycled aggregates offers environmental benefits by reducing the demand for natural resources and mitigating waste, it also poses challenges in maintaining the desired compressive strength of concrete. Engineers and contractors must carefully balance sustainability objectives with structural requirements when designing concrete mixes. Strategies such as optimizing mix proportions, adjusting water-to-cement ratios, and incorporating supplementary cementitious materials may help mitigate the negative impact of recycled aggregates on compressive strength while ensuring the overall performance and durability of concrete structures.

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