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Assessment of Compressive Strength of Concrete Utilizing River Sand as Fine Aggregate

Prof. Dr. Hussam Ali Mohammed, Hussein Alaa
Al-Furat Al-Awsat Technical University/Al-Mussaib Technical Collage /Building & Construction Department

Abstract: The increasing demand for concrete in modern construction has raised concerns regarding the environmental impact and depletion of natural resources, particularly the excessive use of conventional fine aggregates such as manufactured or mined sand. As a response to these concerns, this study explores the potential of using river sand as a sustainable alternative for conventional fine aggregates in concrete. River sand, due to its natural origin, generally possesses well-rounded particles, better workability, and uniform gradation, which can influence the performance characteristics of concrete in a positive way.

To assess the effectiveness of river sand as a fine aggregate, an experimental approach was adopted. Three concrete mix designs were prepared: the first mix used 100% conventional sand and served as the control; the second contained a 50:50 combination of conventional and river sand; and the third used river sand exclusively. Each mix maintained a consistent water-cement ratio and similar aggregate grading to ensure accurate comparison. The concrete specimens were cast and cured for 28 days under controlled conditions before undergoing compressive strength testing according to standard procedures.

The results of the experimental investigation demonstrated a clear trend: as the proportion of river sand increased, so did the compressive strength of the concrete. The mix containing 100% river sand exhibited the highest compressive strength, outperforming both the control and the 50% blend. This enhancement in strength can be attributed to the better particle distribution and packing density offered by river sand, which helps minimize internal voids and results in a more compact and stronger concrete structure.

Moreover, the study highlights the environmental and economic benefits of adopting river sand in construction. Its widespread availability and natural properties reduce the need for processing and energy-intensive manufacturing, making it a cost-effective and eco-friendly option. The use of river sand can also ease the pressure on traditional sand sources, supporting resource conservation efforts.

In conclusion, the findings of this study indicate that river sand is a viable and effective substitute for conventional fine aggregates in concrete, particularly in terms of enhancing compressive strength. Its incorporation in concrete mixtures not only improves mechanical performance but also aligns with sustainable construction practices, offering a dual benefit of strength and environmental responsibility. This positions river sand as a promising material for future developments in green and efficient building technologies.

Keywords: River sand, fine aggregates, concrete, compressive strength, sustainable construction, environmental impact, manufactured sand, resource conservation, concrete mix design, mechanical performance.

1. Introduction

Concrete remains one of the most widely utilized construction materials globally, forming the backbone of buildings, bridges, roads, and numerous other infrastructure projects. Its widespread use is attributed to its durability, availability of raw materials, and its adaptability for different structural applications. A crucial component that significantly influences the performance of concrete is the aggregate, especially fine aggregates like sand. Fine aggregates not only contribute to the workability and finish of concrete but also affect its strength and durability. Typically, river sand has been the most commonly used fine aggregate due to its clean texture, well-graded particles, and minimal processing requirements (Guial & Jalbay, 2016).

However, the over-reliance on river sand has led to serious environmental implications, including riverbank erosion, loss of biodiversity, and disturbance of aquatic ecosystems. As noted by Akinboboye (2018), unregulated sand mining is becoming increasingly unsustainable and has driven the need to explore alternative aggregate sources. This concern has motivated a growing body of research focused on identifying substitutes that are both environmentally friendly and capable of maintaining, or even enhancing, the mechanical properties of concrete.

Among these alternatives, river sand continues to be of particular interest—not as an unregulated extraction product, but as a material whose use can be optimized or blended with other aggregates. Its rounded particles promote better flowability and compaction, contributing positively to the concrete's mechanical performance (Al-Thairy, 2018). Furthermore, the inclusion of river sand in the concrete mix has been shown to enhance bond strength between the aggregate and the cement paste, ultimately improving the compressive strength (Ekwueme et al., 2021).

Studies such as those by Salman et al. (2018) and Ambrose & Ekpo (2018) confirm that substituting a portion of conventional fine aggregates with river sand can yield promising results in terms of strength and durability. In contrast, full replacement scenarios have yielded mixed outcomes depending on the grading, purity, and regional characteristics of the sand. For instance, Mabui (2018) demonstrated that river sand can perform comparably or even superiorly to mountain or quarry sands in early-age compressive strength tests.

This study aims to further examine the role of river sand as a partial and full replacement for conventional fine aggregates in concrete production. Through systematic testing of concrete mixes with varying proportions of river sand, the research seeks to identify an optimal blend that balances mechanical performance with environmental sustainability. The findings may contribute to more eco-conscious construction practices and inform guidelines for aggregate selection in concrete mix design.

2. Materials and Methods

In this experimental study, materials were carefully selected to conform to established engineering standards while also reflecting practical choices commonly used in the construction industry. The quality, availability, and proven influence of each material on the mechanical behavior of concrete—particularly compressive strength—were key selection criteria. All materials underwent standard testing to ensure conformity with ASTM specifications, and insights from contemporary literature were used to support the selection and expected performance.

***Cement**

The binder used throughout all concrete mixes was Ordinary Portland Cement (OPC), specifically conforming to ASTM C150 Type I specifications. This type of cement is widely employed in general concrete construction where special properties like sulfate resistance or low heat of hydration are not required. OPC is known for its consistent chemical composition, reliable hydration kinetics, and favorable early-age strength gain. Its performance in different environmental conditions and with varying aggregate types has been widely documented. For instance, Mabui (2018) investigated concrete prepared with different sands and OPC, and found that the early-age compressive strength was significantly influenced by both the cement type and the microstructure it helped form when paired with specific fine aggregates. The cement used in this study was gray in color, with a Blaine fineness within the typical range (300–350 m^2/kg), and a specific gravity around 3.15, ensuring adequate reactivity during hydration. *(Mabui, 2018)*

Coarse Aggregate

Crushed granite, characterized by its angularity and mechanical strength, served as the coarse aggregate. The granite was sourced from a regional quarry and sieved to ensure a maximum nominal size of 20 mm. It was then washed to eliminate clay particles and fine contaminants that could negatively affect the bond with the cement paste. Crushed granite is favored in structural concrete because its angular particles promote mechanical interlock within the matrix, which in turn enhances load transfer and reduces internal slippage under stress. Moreover, the gradation complied with ASTM C33 requirements for coarse aggregates. Akinboboye (2018) compared concrete prepared with aggregates from various sources and concluded that crushed granite consistently delivered superior compressive strength, owing to its density and angular geometry which increase the interfacial bond with the paste. *(Akinboboye, 2018)*

Fine Aggregates

Fine aggregate, acting as a filler material that occupies voids between coarse particles and contributes to the paste-aggregate bond, was a critical component in this study. Two types of fine aggregates were used: commercially available construction sand and river sand. Both types underwent preliminary testing for particle size distribution, specific gravity, bulk density, and silt content, as per ASTM C136 and ASTM C128.

Commercial Sand

This type of sand was obtained from local suppliers and is typically composed of angular to sub-angular particles with a relatively rough surface texture. It is commonly used in general concrete applications due to its accessibility and acceptable physical properties. However, variability in grain shape and mineral composition can affect the workability and strength of the concrete mix. Ekwueme et al. (2021) highlighted in their study that sand from non-natural sources often required increased water demand due to its irregular shapes, leading to adjustments in mix design to preserve strength and slump characteristics. *(Ekwueme et al., 2021)*

River Sand

River sand, collected from a naturally flowing water body, was used due to its smooth texture and rounded particle morphology, which contribute to improved workability and compaction of concrete. The particles generally exhibit a more uniform grading, lower angularity, and minimal impurities compared to commercially mined sands. This type of sand was particularly selected based on findings from Al-Thairy (2018), who demonstrated that concrete made with river sand exhibited higher workability and consistent compressive strength in both normal and high-strength mixes. Guial & Jalbay (2016) similarly observed that river sand contributed to better particle packing, which reduces voids and improves strength characteristics of concrete hollow blocks. Ambrose & Ekpo (2018) further reported that even partial replacement of conventional sand with natural river or lateritic sand yielded comparable strength results, suggesting river sand's effectiveness in practical construction settings.*(Al-Thairy, 2018; Guial & Jalbay, 2016; Ambrose & Ekpo, 2018)*

Water

The water used in both mixing and curing operations was clean, potable water from the municipal supply. It was ensured to be free of harmful dissolved salts, oils, organic matter, or suspended particles that could interfere with the cement hydration process. The use of potable water aligns with ASTM C1602 guidelines for mixing and curing water. Water plays a fundamental role in initiating the hydration reactions of cement and in determining the final microstructure and porosity of hardened concrete. Salman et al. (2018) emphasized the importance of water purity in their investigation of river sand mortar, noting that even small impurities in water could hinder the development of mechanical properties by disrupting the bond between the cement paste and aggregates.*(Salman et al., 2018)*

2.2 Mix Proportions

To investigate the effects of different fine aggregate types on the compressive strength of concrete, three distinct mix designs were prepared. Each mix was engineered to achieve a characteristic compressive strength of 25 MPa at 28 days, a commonly targeted strength grade for structural concrete applications. This target strength was selected based on its practical relevance in general construction, particularly for residential and light commercial structural elements.

The design methodology adopted for proportioning the mixes was the **Department of Environment (DOE) method,** which is widely accepted in engineering practice due to its empirical basis and adaptability to various material types. This method enabled the accurate calculation of material quantities needed to meet the desired performance criteria, while considering factors such as aggregate size, workability, and exposure conditions.

All mixes were designed with a **constant water-to-cement (w/c) ratio of 0.50**, a value supported in the literature as optimal for balancing strength and workability in normal-strength concrete. Maintaining a uniform w/c ratio across all mixes ensured that any observed variations in compressive strength would be primarily attributable to the changes in fine aggregate composition rather than differences in water content or cement hydration efficiency. The proportions for each batch are detailed below:

Mix 1 – Control Mix (100% Conventional Sand)

This mix served as the reference concrete against which the performance of other mixes was compared. It contained 100% conventional (commercial) sand as the fine aggregate. The control mix was designed to reflect standard industry practices and provide a performance baseline. As demonstrated in studies like those by Ekwueme et al. (2021), such control mixes are essential in comparative investigations to isolate the influence of material substitutions. *(Ekwueme et al., 2021)*

Mix 2 – Partial Replacement Mix (50% River Sand + 50% Conventional Sand)

In this mix, 50% of the conventional sand was replaced by river sand on a weight basis. The objective of this mix was to assess the combined effect of angular and rounded particles on both workability and strength. The blending of sands is known to influence packing density, water demand, and internal friction. Research by Ambrose & Ekpo (2018) supports the hypothesis that partial replacement may improve concrete compactness and enhance strength without compromising workability significantly.*(Ambrose & Ekpo, 2018)*

Mix 3 – Full Replacement Mix (100% River Sand)

This batch replaced all of the conventional fine aggregate with river sand. The purpose was to evaluate the feasibility of completely substituting conventional sand with river sand in structural-grade concrete. River sand, due to its rounded and smooth particles, is known to reduce internal friction, thus enhancing the flow of fresh concrete and improving compaction, as discussed by Al-Thairy (2018) and Guial & Jalbay (2016). However, concerns over potential reductions in inter-particle friction and aggregate-paste bonding necessitate thorough evaluation.*(Al-Thairy, 2018; Guial & Jalbay, 2016)*

2.3 Mixing Procedure and Sample Preparation

All concrete batches were prepared using a rotary drum concrete mixer with a capacity of 100 liters. The dry materials (cement, sand, and coarse aggregate) were mixed first for 60 seconds to ensure initial uniformity. Water was then gradually added while mixing continued for an additional 2 minutes, ensuring thorough hydration and an even distribution of water throughout the mix. The total mixing time did not exceed 3.5 minutes to avoid premature setting or loss of workability.

Immediately after mixing, the **workability of the fresh concrete** was measured using the **slump test**, conducted in accordance with ASTM C143. The slump test is a simple yet effective method for assessing the consistency and ease of placement of fresh concrete. A moderate slump value (between 50 mm and 100 mm) was targeted to ensure adequate workability for structural applications without inducing segregation.

Following workability testing, the fresh concrete was poured into standard **cube molds measuring 150 mm × 150 mm × 150 mm**. Each mold was filled in three layers, with each layer compacted using a tamping rod to eliminate entrapped air. After casting, the specimens were covered with plastic sheeting to prevent moisture loss and left undisturbed for 24 hours under controlled ambient conditions.

Curing and Testing

After demolding at 24 hours, the concrete cubes were placed in a water-curing tank maintained at a constant temperature of **23 ± 2°C**, as recommended in ASTM C511. The curing period lasted for 28 days, during which hydration progressed, allowing the concrete to develop its full compressive strength.

At the end of the curing period, the **compressive strength tests** were performed using a calibrated hydraulic compression testing machine, in line with ASTM C39. The maximum load at failure was recorded and divided by the cross-sectional area of the specimen to determine the compressive strength.

This comprehensive procedure allowed for a controlled, systematic evaluation of how varying fine aggregate compositions influence the mechanical performance of concrete. By adhering to standardized practices, the study ensured repeatability and accuracy in comparing the different mix outcomes.

3. Results and Discussion

The compressive strength results obtained after 28 days of curing are presented in Table 1 and visualized in Figure 1. These results offer clear insights into the influence of fine aggregate composition on the mechanical performance of concrete.

Table 1: Compressive Strength Results after 28 Days

Mix ID	*Fine Aggregate Composition*	*Average Compressive Strength (MPa)*
Mix 1	*100% Conventional Sand*	*20.25*
Mix 2	*50% River Sand + 50% Conventional Sand*	*22.50*
Mix 3	*100% River Sand*	*24.00*

As observed, the compressive strength increased progressively with the incorporation of river sand in the fine aggregate composition. **Mix 1**, which contained only conventional sand, achieved an average strength of **20.25 MPa**, serving as the baseline performance. **Mix 2**, with a 50/50 blend of river and conventional sand, demonstrated a noticeable strength improvement, reaching **22.50 MPa**. This suggests that even a partial replacement can enhance the mechanical performance, likely due to improved particle packing and better compaction characteristics.

The most significant result was obtained from **Mix 3**, which utilized **100% river sand**, resulting in a compressive strength of **24.00 MPa**. This not only surpassed the control mix by **approximately 18.5%**, but also nearly reached the original design target of 25 MPa. The rounded particles of river sand likely contributed to better workability and more uniform distribution of the cement paste, thus enhancing the concrete's internal cohesion and strength. These findings are consistent with the results reported by Guial & Jalbay (2016), who highlighted the superior structural integrity and bond development in concrete mixes incorporating river sand.*(Guial & Jalbay, 2016)*

Additionally, the results support the claims of Ambrose & Ekpo (2018), who found that partial replacement of conventional sand with naturally sourced alternatives can produce favorable strength outcomes while reducing environmental strain caused by excessive mining of riverbeds and quarries. In this study, the **partial replacement mix (Mix 2)** serves as a **compromise solution**, balancing **mechanical performance** with **resource conservation** and **cost-efficiency**.*(Ambrose & Ekpo, 2018)*

This trend underlines the potential of **river sand** as a viable alternative to conventional construction sand, particularly in regions where natural resources are abundant or where environmental regulations limit the extraction of traditional aggregates. Future research could expand on these findings by exploring performance under different curing conditions, long-term durability metrics, and economic feasibility analyses.

4. Case Study: Comparative Analysis of River Sand Usage in Concrete Mixes

To contextualize the results of this study within real-world research applications, this section presents a comparative case study based on selected literature that has examined the performance of river sand as a fine aggregate in concrete production.

One relevant case is the experimental investigation by **Al-Thairy (2018)**, which explored the influence of river sand on both normal and high-strength concrete. The study employed Ordinary Portland Cement and local aggregates, comparing mixes with varying proportions of river sand. Al-Thairy's findings demonstrated that the inclusion of river sand improved workability and compressive strength, especially in high-strength concrete applications. Notably, mixes containing 100% river sand outperformed those using natural or crushed sand alone, achieving a compressive strength of up to **52 MPa**, compared to **47 MPa** for the control mix. These outcomes align with the current study's results, affirming that river sand contributes positively to strength development due to its consistent grading and rounded particle shape which enhances compaction and reduces voids (Al-Thairy, 2018).

Similarly, a study conducted by **Ekwueme et al. (2021)** investigated the structural performance of concrete using a combination of river sand and quarry dust. The research was carried out under tropical conditions and focused on sustainable construction practices. Results indicated that mixes with **50% river sand and 50% quarry dust** achieved compressive strengths comparable to, and in some cases exceeding, that of conventional mixes. The blend provided a cost-effective and environmentally responsible alternative without compromising structural integrity. This supports the findings from the current experiment, particularly regarding Mix 2, which utilized a 50/50 sand blend and still showed a marked strength improvement.

Furthermore, **Guial and Jalbay (2016)** conducted a comparative analysis between sea sand and river sand in the production of hollow concrete blocks. Their research concluded that blocks produced with river sand consistently showed higher compressive strength and better dimensional stability, attributed to the reduced salt content and finer grading of river sand. Although their study focused on block work rather than cast concrete, the underlying mechanism of strength enhancement via river sand is consistent across applications.

In another Nigerian-based investigation, **Ambrose and Ekpo (2018)** examined laterized quarry sand concrete and found that partial replacement of conventional materials with river-based alternatives improved both strength and workability, reinforcing the importance of resource diversity in material selection. Their work further emphasized the relevance of river sand in areas where conventional fine aggregates are either scarce or economically unsustainable.

In summary, the reviewed studies provide a coherent narrative that supports the findings of the present investigation. Across different regions, concrete applications, and mix proportions, river sand has repeatedly been shown to offer tangible mechanical and economic benefits. However, as emphasized in all reviewed cases, the sustainability and regulated extraction of river sand remain critical to ensuring that its benefits do not come at the cost of ecological degradation.

5. Conclusion

This experimental investigation has provided valuable insights into the effects of substituting conventional sand with river sand in concrete mixes, with particular focus on compressive strength performance. The results of the compressive strength tests conducted after 28 days of curing reveal a clear and consistent trend: the incorporation of river sand, whether partially or fully, leads to a notable improvement in the mechanical behavior of concrete compared to mixes made solely with conventional sand.

The control mix (Mix 1), which utilized 100% conventional sand, yielded the lowest average compressive strength at 20.25 MPa, reflecting the limitations of traditional fine aggregate in enhancing concrete strength under identical mix design conditions. In contrast, Mix 2, comprising a 50/50 blend of conventional and river sand, achieved a strength of 22.50 MPa, marking a significant increase of approximately 11.1%. This improvement can be attributed to the synergistic effect of combining angular conventional sand particles with the rounded, smooth texture of river sand, which likely enhances particle packing and workability, thereby contributing to more efficient hydration and strength development.

The most pronounced enhancement was observed in Mix 3, which consisted entirely of river sand. This mix recorded an average compressive strength of 24.00 MPa—an increase of nearly 18.5% over the control mix. These results validate previous studies such as Guial and Jalbay (2016), who found that river sand contributes positively to the internal cohesion and structural integrity of concrete due to its natural grading and smooth morphology. The increased strength in the fully substituted mix suggests that river sand can serve as a highly effective fine aggregate in structural concrete, particularly in applications where higher compressive strength is desired without altering the water-to-cement ratio or other key parameters.

Despite the favorable mechanical performance, the practical implementation of river sand substitution must be approached with caution. The widespread use of river sand in construction raises several concerns, including environmental degradation due to excessive mining, seasonal availability, and regional disparities in cost and accessibility. Therefore, while river sand offers technical advantages in terms of compressive strength, its sustainability and economic feasibility must be carefully evaluated in the context of local resource management and regulatory frameworks.

Moreover, this study primarily focused on early-age compressive strength. It is strongly recommended that future research efforts extend the scope of investigation to include other performance metrics such as durability under aggressive environmental conditions, resistance to shrinkage and cracking, and long-term performance over the concrete’s service life. Incorporating environmental impact assessments and life cycle cost analyses would also provide a more comprehensive understanding of the viability of river sand as a large-scale alternative to traditional fine aggregates.

In conclusion, the findings underscore the potential of river sand to not only serve as a viable substitute for conventional sand but also to enhance the quality and strength of concrete. With appropriate sourcing, regulation, and engineering judgment, river sand can be integrated effectively into concrete mix designs, paving the way for stronger and potentially more sustainable construction practices.

6. Future Recommendations

Building upon the findings of this study and corroborating evidence from related literature, several avenues for future research and practical application are recommended to advance the understanding and responsible use of river sand as a fine aggregate in concrete production:

1- **Long-Term Durability Studies**

While this research focused on 28-day compressive strength, long-term performance indicators such as resistance to sulfate attack, chloride penetration, carbonation, and freeze-thaw cycles remain unexplored. Future studies should investigate the durability of concrete made with river sand under various environmental stressors to evaluate its suitability for infrastructure exposed to harsh conditions.

2- **Microstructural and Mineralogical Analysis**

Advanced techniques such as scanning electron microscopy (SEM) and X-ray diffraction (XRD) can be employed to study the microstructure and hydration products of river sand concrete. This would provide deeper insights into how the physical and chemical characteristics of river sand influence cement bonding and strength development.

3- **Optimization of Mix Designs**

A broader range of mix proportions, including varying water-cement ratios and the incorporation of supplementary cementitious materials (SCMs) like fly ash, silica fume, and slag, should be tested alongside river sand. This will help identify optimal combinations that balance performance, cost, and sustainability.

4- **Life Cycle Assessment (LCA) and Environmental Impact**

Given increasing environmental concerns, it is crucial to conduct comprehensive life cycle assessments comparing the ecological footprint of river sand and conventional aggregates. Future research should evaluate not only emissions and energy usage, but also the impact of riverbed mining on ecosystems, groundwater, and sediment flow.

5- **Alternative and Artificial Sands**

Future work should compare river sand with artificial alternatives such as manufactured sand (M-sand), desert sand, or recycled sand. Such comparisons would help establish performance benchmarks and support decisions in regions where river sand is scarce or extraction is environmentally damaging.

6- **Field Applications and Structural Performance**

Pilot projects and real-scale construction using river sand concrete should be undertaken to assess its behavior in actual structural systems, including slabs, beams, and foundations. Monitoring structural integrity over time would validate laboratory findings and ensure safe implementation.

7- Economic Feasibility and Regional Resource Mapping

Further studies are needed to assess the economic implications of replacing conventional sand with river sand in different regions. This includes cost-benefit analyses, transportation logistics, and the development of guidelines for sustainable extraction and use of river sand in construction.

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