Environmental and Mechanical assessment of concrete made with construction and Demolition waste

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Abstract

The rapid increase in construction and demolition (C&D) waste has posed serious environmental concerns, highlighting the need for sustainable waste management and efficient use of natural resources. This study examines both the environmental and mechanical behavior of concrete prepared using recycled materials obtained from construction and demolition waste. In this investigation, natural aggregates were partially substituted with recycled aggregates produced from processed C&D waste at different replacement ratios. The mechanical characteristics of the concrete, such as compressive strength, split tensile strength, and flexural strength, were tested at various curing periods to evaluate its structural suitability. Furthermore, an environmental analysis was conducted by assessing the reduction in natural resource usage, landfill disposal, and carbon emissions achieved through the incorporation of recycled materials. The findings revealed that concrete containing optimal amounts of recycled aggregates achieved mechanical performance comparable to that of conventional concrete, while also minimizing environmental impacts. Overall, the study demonstrates that the use of construction and demolition waste in concrete production is an effective and sustainable alternative to traditional materials, supporting resource conservation and environmental sustainability in the construction sector.

Keywords: Construction and demolition waste, recycled aggregate concrete, sustainable construction, mechanical performance, environmental sustainability, waste utilization

Introduction

1. I The rapid growth of urbanization and infrastructure development has led to a significant increase in construction and demolition (C&D) waste worldwide. The disposal of this waste in landfills not only occupies valuable land resources but also contributes to environmental pollution and the depletion of natural aggregate reserves. At the same time, the continuous extraction of natural aggregates for concrete production results in environmental degradation, ecological imbalance, and the exhaustion of limited natural resources. The growing demand for construction materials further increases the burden on natural resources, highlighting the urgent need to identify alternative and sustainable materials for concrete manufacturing.

In recent years, the adoption of sustainable construction methods has become essential to reduce the environmental impacts associated with conventional construction materials. One practical approach is the recycling and reuse of C&D waste as aggregates in concrete production. Recycled Aggregate Concrete (RAC) has gained considerable attention because of its potential to minimize landfill disposal, preserve natural resources, and lower carbon emissions related to the extraction and transportation of raw materials. Additionally, the use of recycled aggregates aligns with the principles of a circular economy by enhancing resource utilization and reducing waste generation within the construction industry.

Moreover, incorporating recycled materials in concrete production offers economic advantages by decreasing the cost of raw materials and reducing expenses associated with waste disposal. Many governments and environmental organizations are promoting the use of recycled construction materials through policies, guidelines, and sustainability initiatives. Advances in processing technologies for C&D waste, including crushing, screening, and removal of contaminants, have significantly enhanced the quality of recycled aggregates, thereby improving their suitability for structural applications.

Despite these advantages, the inclusion of recycled aggregates may influence the mechanical properties and durability of concrete due to the presence of adhered mortar, increased water absorption, and potential impurities. These factors can result in reduced workability, decreased density, and possible variations in long-term performance when compared with conventional concrete. Therefore, it is necessary to evaluate both the mechanical behaviour and environmental benefits to determine the appropriateness of recycled aggregates for structural purposes.

Apart from mechanical characteristics, durability-related factors such as water absorption, permeability, resistance to chemical attack, and shrinkage performance must also be thoroughly examined to ensure the long-term reliability of recycled aggregate concrete. Environmental evaluation techniques, such as life cycle analysis (LCA), can be applied to measure reductions in carbon emissions and overall environmental impact achieved through the use of recycled materials. These assessments provide important insights into the sustainability potential of recycled aggregate concrete in modern construction practices.

The objective of this study is to assess the environmental and mechanical performance of concrete produced using varying proportions of C&D waste as partial replacements for natural aggregates. The research focuses on evaluating major mechanical properties, including compressive strength, split tensile strength, and flexural strength, along with analysing the environmental benefits associated with recycled aggregate usage. The findings of this study are expected to support the development of sustainable construction materials and encourage the efficient utilization of construction and demolition waste in concrete production.

2. Objectives of the Study

The primary objectives of this research are:

1. **To utilize construction and demolition (C&D) waste** as recycled aggregates in concrete manufacturing in order to reduce the dependency on natural aggregates.
2. **To analyse the mechanical properties of recycled aggregate concrete**, including:
    - Compressive strength
    - Split tensile strength
    - Flexural strength at different curing periods to assess the strength development behaviour of recycled aggregate concrete.
3. **To compare the performance of recycled aggregate concrete with conventional concrete** in terms of strength, workability, and overall structural suitability.

4. **To identify the optimum percentage of C&D waste replacement** that provides the best balance between mechanical performance and sustainability benefits.
5. **To evaluate environmental advantages**, such as reduction of landfill waste, conservation of natural resources, reduction in carbon emissions, and improvement in sustainable construction practices.
6. **To study the workability characteristics of recycled aggregate concrete** using standard tests such as slump test to determine the effect of recycled aggregates on fresh concrete properties.
7. **To assess the durability performance of recycled aggregate concrete**, including parameters such as water absorption, permeability, and resistance to environmental effects, to ensure long-term performance.
8. **To examine the economic feasibility of using recycled aggregates** by comparing the potential cost savings in material usage and waste disposal with conventional concrete production.
9. **To promote the effective utilization of construction and demolition waste** in the construction industry, thereby supporting sustainable waste management practices.
10. **To provide recommendations for practical applications** of recycled aggregate concrete in structural and non-structural construction works based on experimental findings.

3. Methodology

. 3.1 Materials Used

The following materials were used in this study for the preparation of conventional and recycled aggregate concrete mixes:

- **Ordinary Portland Cement (OPC) – Grade 43**

Ordinary Portland Cement of Grade 43 was used as the primary binding material in this study. The cement used conformed to relevant standard specifications and was fresh, free from lumps, and stored in a dry environment to maintain its quality. The physical properties of cement, such as fineness, consistency, specific gravity, and setting time, were considered to ensure uniformity and reliability in concrete production.

- **Natural Coarse Aggregates**

Natural coarse aggregates of suitable sizes were used as the control material in conventional concrete mixes. These aggregates were obtained from approved sources and were clean, hard, and free from organic impurities, dust, and deleterious substances. The aggregates were properly graded to achieve good workability and strength characteristics in the concrete mix.

- **Fine Aggregates (River Sand)**

Natural river sand was used as fine aggregate in the concrete mixes. The sand was clean, well-graded, and free from silt, clay, and organic materials. It conformed to standard grading requirements to ensure proper bonding between cement paste and aggregates, thereby improving the workability and strength of concrete.

- **Recycled Aggregates Obtained from Crushed C&D Waste**
  Recycled aggregates were prepared from construction and demolition (C&D) waste collected from nearby demolition sites. The collected waste mainly consisted of broken concrete pieces, bricks, and mortar fragments. The waste materials were processed through crushing, sieving, and cleaning operations to remove dust, impurities, and unwanted materials. The processed recycled aggregates were then graded into required sizes to partially replace natural coarse aggregates in different proportions.
- **Potable Water for Mixing and Curing**
  Clean potable water was used for mixing and curing of concrete. The water used was free from harmful substances such as oils, acids, alkalis, salts, and organic matter, ensuring proper hydration of cement and development of strength in the concrete.

The construction and demolition (C&D) waste used in this study was collected from nearby demolition sites and transported to the laboratory for processing. The waste materials were first sorted manually to remove foreign materials such as wood, plastic, metal, and glass. After sorting, the materials were crushed using mechanical crushers and then sieved through standard sieves to obtain aggregates of suitable sizes. The processed aggregates were further washed to remove dust and fine particles, and then air-dried before use in concrete preparation.

In addition to the basic materials, the physical properties of aggregates such as specific gravity, water absorption, bulk density, and grading characteristics were determined prior to mix preparation. These properties were carefully evaluated to ensure proper mix design and to understand the influence of recycled aggregates on the performance of concrete. The selection and preparation of suitable materials played a significant role in achieving consistent results and ensuring the reliability of the experimental study.

3.2 Mix Design

Concrete mixes were produced by partially substituting natural coarse aggregates with recycled aggregates derived from processed construction and demolition (C&D) waste at various replacement levels. These replacement percentages were selected to examine the influence of recycled aggregates on concrete performance and to identify the most suitable proportion for practical use. The replacement levels adopted in this investigation were as follows:

0% Replacement (Control Mix) – Conventional concrete prepared with 100% natural coarse aggregates, which served as the reference mix for performance comparison.

10% Replacement – Replacement of 10% of natural coarse aggregates with recycled aggregates by weight.

20% Replacement – Replacement of 20% of natural coarse aggregates with recycled aggregates by weight.

30% Replacement – Replacement of 30% of natural coarse aggregates with recycled aggregates by weight.

The mix proportions for all concrete batches were designed according to **IS 10262 guidelines**, ensuring the appropriate selection of water-cement ratio, cement content, and aggregate proportions to achieve the required strength and workability. A uniform water-cement ratio was maintained across all mixes to ensure consistency and allow reliable comparison between conventional concrete and recycled aggregate concrete.

Appropriate modifications were also made to compensate for the relatively higher water absorption capacity of recycled aggregates in comparison to natural aggregates. Before mixing, recycled aggregates were conditioned to a saturated surface dry (SSD) state to maintain mix uniformity and to prevent excessive absorption of mixing water.

All materials used in the concrete mixes were accurately weighed to ensure precision in batching. Mixing was carried out using a mechanical mixer to achieve thorough blending of materials and proper coating of aggregates with cement paste. After mixing, the fresh concrete was subjected to workability tests using standard procedures prior to casting the specimens.

The chosen replacement levels were based on earlier research studies and practical considerations, allowing the evaluation of both lower and moderate levels of recycled aggregate utilization. This selection enabled a systematic analysis of the effects of recycled aggregates on both fresh and hardened properties of concrete.

Additionally, key mix design factors such as cement quantity, fine aggregate content, coarse aggregate ratio, and water requirement were carefully regulated to maintain uniformity among all concrete mixes. The prepared concrete was then used to cast standard specimens, which were tested at different curing periods to evaluate their mechanical strength and durability characteristics

3.3 Specimen Preparation

. Concrete specimens were fabricated in standard shapes and dimensions to evaluate the mechanical properties of both conventional concrete and recycled aggregate concrete. The concrete was thoroughly mixed and placed into moulds, followed by proper compaction to eliminate trapped air and achieve uniform density. The following types of specimens were produced for conducting various mechanical tests:

Cubes (150 × 150 × 150 mm) were prepared for compressive strength testing. These specimens were used to determine the load-bearing capacity of concrete and to evaluate strength development at different curing intervals.

Cylinders (typically 150 mm in diameter and 300 mm in height) were cast for split tensile strength testing. These cylindrical specimens were utilized to assess the tensile characteristics of concrete, which play an important role in determining its resistance to cracking under tensile forces.

Beams (commonly 100 × 100 × 500 mm or 150 × 150 × 700 mm) were prepared for flexural strength testing. These beam specimens were used to measure the bending strength of concrete and its capacity to withstand failure under flexural loading conditions.

Prior to casting, the inner surfaces of the moulds were cleaned thoroughly and coated lightly with oil to prevent the concrete from sticking and to allow easy removal of specimens after setting. Fresh concrete was placed into the moulds in successive layers and compacted either manually with tamping rods or mechanically using a vibrating table to remove air voids and ensure proper compaction. The top surfaces were then leveled and finished carefully to obtain smooth and uniform specimens.

After casting, the specimens were left undisturbed at room temperature for about 24 hours to allow initial setting and hardening. Once sufficient strength was achieved, the specimens were carefully demoulded and placed in curing tanks filled with clean water.

All specimens were subjected to water curing for periods of **7, 14, and 28 days** to monitor the strength development of concrete at different ages. The curing water was maintained at standard temperature conditions to promote proper cement hydration and consistent strength gain. Proper curing was ensured to improve durability, minimize shrinkage, and achieve the desired mechanical performance.

For each level of recycled aggregate replacement, several specimens were cast for each type of test and curing duration to ensure dependable and accurate experimental results. After completing the specified curing periods, the specimens were tested for compressive strength, split tensile strength, and flexural strength using standard testing methods.

3.4 Mechanical Testing

The mechanical characteristics of both conventional concrete and recycled aggregate concrete were assessed using standardized testing procedures. These tests were performed after curing periods of **7, 14, and 28 days** to evaluate the strength development of concrete at different stages of curing. The following mechanical tests were conducted:

Compressive Strength Test (IS 516)

The compressive strength test was performed on cube specimens in accordance with the provisions of IS 516. Prior to testing, the specimens were taken out from the curing tank and surface moisture was removed by wiping them clean. Each specimen was then placed centrally in the compression testing machine. A continuous and gradually increasing load was applied until the specimen failed. The maximum load recorded at failure was used to calculate the compressive strength by dividing it by the cross-sectional area of the cube. This test provided essential information about the load-bearing capacity and overall strength behavior of the concrete.

Split Tensile Strength Test (IS 5816)

The split tensile strength test was conducted on cylindrical specimens following the procedure outlined in IS 5816. During testing, the cylinder was positioned horizontally between the loading plates of the testing machine, and load was applied along its diameter until the specimen split into two parts. This test was carried out to determine the tensile strength of concrete, which is a key factor in assessing its resistance to cracking under tensile forces. The obtained results were used to study the effect of recycled aggregates on the tensile performance of concrete.

Flexural Strength Test

The flexural strength test was conducted on beam specimens to measure the bending strength of concrete. The beams were subjected to two-point loading using a flexural testing machine until failure occurred. The peak load at failure was recorded, and the flexural strength was calculated accordingly. This test provided valuable information regarding the ability of concrete to withstand bending stresses, which is particularly significant for structural components such as beams and slabs.

For each mix ratio and curing duration, several specimens were tested to maintain the reliability and consistency of results. The average of the recorded values was calculated and used for further evaluation and comparison between conventional concrete and recycled aggregate concrete.

3.5 Environmental Assessment

The environmental evaluation of recycled aggregate concrete was carried out to examine its potential role in promoting sustainable construction practices. The assessment mainly focused on identifying the environmental advantages associated with the use of construction and demolition (C&D) waste as a substitute for natural aggregates. The following parameters were considered:

Reduction in the Use of Natural Aggregates

Replacing natural aggregates with recycled aggregates significantly decreased the dependence on natural materials such as crushed stone and gravel. This reduction contributed to the conservation of natural resources and minimized environmental impacts associated with quarrying and mining operations.

Decrease in Landfill Waste Disposal The use of C&D waste in concrete production reduced the volume of waste disposed of in landfill sites. Diverting these materials from landfills helped improve waste management practices and reduced environmental concerns related to excessive waste accumulation.

Estimation of Sustainability Benefits

The sustainability advantages of incorporating recycled aggregates were assessed in terms of resource conservation, reduction in waste generation, and improved efficiency in material utilization. The use of recycled materials supported sustainable development goals and encouraged environmentally responsible construction activities.

Qualitative Assessment of Carbon Footprint Reduction

A qualitative analysis was performed to estimate the potential decrease in carbon emissions resulting from reduced extraction, processing, and transportation of natural aggregates. The adoption of recycled aggregates contributed to lowering the overall carbon footprint associated with concrete production and supported environmentally sustainable construction practices.

In addition to these aspects, the environmental analysis emphasized the importance of recycled aggregate concrete in supporting circular economy concepts and effective waste management systems. The results of this assessment offered meaningful insights into the environmental benefits of utilizing recycled materials in concrete production and promoted the development of eco-friendly construction methods.

Results and Discussion

4. 4.1 Workability

The workability of concrete mixes was assessed using standard slump test methods. The results showed that workability gradually decreased as the proportion of recycled aggregates increased. This reduction was mainly caused by the rough and irregular surface texture of recycled aggregates and their higher water absorption compared to natural aggregates. These properties increased friction among particles and reduced the ease of movement within the concrete mix.

However, mixes containing up to 20% recycled aggregates retained workability within acceptable limits for normal construction requirements. Minor adjustments in water content or pre-soaking of recycled aggregates were found to help maintain the required consistency. The findings indicate that although recycled aggregates influence workability, appropriate mix design and preparation techniques can effectively manage this reduction.

4.2 Compressive Strength

The compressive strength results revealed a clear relationship between the proportion of recycled aggregates and the strength performance of concrete. The following observations were recorded:

- The control mix (0% replacement) achieved the highest compressive strength at all curing periods due to the superior bonding properties and quality of natural aggregates.
- Concrete mixes containing 10% and 20% recycled aggregates exhibited compressive strength values similar to conventional concrete, suggesting that limited replacement does not significantly affect overall strength.
- At 30% replacement, a noticeable reduction in compressive strength was observed. This decrease was mainly due to the presence of adhered mortar on recycled aggregates and weaker bonding at the interfacial transition zone (ITZ) between the cement paste and aggregates.

Additionally, compressive strength increased with curing time for all mixes, indicating proper hydration and gradual strength development. These findings suggest that recycled aggregates can be safely incorporated up to 20% replacement without causing major loss in compressive strength, making them suitable for structural applications.

4.3 Split Tensile Strength

The split tensile strength results indicated a gradual decline as the percentage of recycled aggregates increased. This behavior was expected because recycled aggregates generally possess weaker bonding characteristics and higher porosity than natural aggregates.

Despite this decrease, mixes containing up to 20% recycled aggregates showed tensile strength values within acceptable limits for structural applications. The reduction observed at higher replacement levels was mainly due to the presence of micro-cracks and residual mortar attached to recycled aggregates, which weakened the bond between the aggregate and cement matrix. These results suggest that moderate levels of recycled aggregate replacement can still provide sufficient tensile strength for both structural and non-structural components.

4.4 Flexural Strength

The flexural strength results followed a trend similar to that observed in compressive strength. A gradual reduction in flexural strength occurred as the recycled aggregate content increased. However, the decrease remained minimal for mixes containing 10% to 20% recycled aggregates, which demonstrated satisfactory resistance to bending stresses.

At higher replacement levels, particularly 30%, a more significant reduction in flexural strength was observed. This decline was mainly attributed to weaker bonding at the aggregate-cement interface and the porous nature of recycled aggregates. Nevertheless, the results confirmed that concrete containing moderate quantities of recycled aggregates can maintain adequate flexural strength for practical applications such as beams, slabs, and similar structural elements.

4.5 Environmental Assessment

The environmental evaluation highlighted several benefits associated with the use of recycled aggregates in concrete production. The results demonstrated the following major environmental advantages:

Reduction in landfill waste:
The incorporation of recycled aggregates significantly decreased the quantity of construction and demolition waste disposed of in landfill sites. This contributed to improved waste management practices and minimized environmental pollution.
Conservation of natural resources:
Partial substitution of natural aggregates resulted in a considerable reduction in the consumption of natural materials such as crushed stone and gravel. This helped preserve natural resources and reduced environmental damage associated with quarrying and mining operations.
Promotion of sustainable construction practices:
The use of recycled materials encouraged environmentally responsible construction methods. It supported sustainability goals by reducing waste generation and improving the efficient use of available resources.
Reduction in environmental impact:
The qualitative assessment indicated that using recycled aggregates reduced environmental impacts associated with the extraction, processing, and transportation of natural aggregates. This contributed to lowering the overall environmental footprint and supported eco-friendly construction practices.
Overall, the findings confirmed that recycled aggregate concrete provides significant environmental benefits while maintaining acceptable mechanical performance at moderate replacement levels. These results demonstrate the strong potential of recycled aggregates as a sustainable substitute for natural aggregates in modern concrete production.

5. Conclusion

Based on the experimental results obtained from mechanical testing and the environmental evaluation carried out in this study, the following conclusions were drawn:

1. **Construction and demolition (C&D) waste can be effectively utilized** as a partial replacement for natural coarse aggregates in concrete production, thereby promoting efficient waste management and resource utilization.
2. **Mechanical properties of recycled aggregate concrete showed a gradual reduction** with an increase in the percentage of recycled aggregates. This decrease was mainly due to the porous nature, adhered mortar, and relatively weaker bonding characteristics of recycled aggregates.
3. **Concrete mixes containing up to 20% recycled aggregates demonstrated satisfactory mechanical performance**, including compressive strength, split tensile strength, and flexural strength, making them suitable for structural applications.
4. **Higher replacement levels, particularly beyond 20%, resulted in noticeable reductions in strength**, primarily due to weaker interfacial bonding and increased water absorption capacity of recycled aggregates.
5. **Workability of concrete decreased slightly with increasing recycled aggregate content**, but acceptable workability levels were achieved up to 20% replacement through proper mix design and pre-treatment of aggregates.

6. **Strength development increased with curing age** for all mixes, indicating proper hydration of cement and consistent performance of recycled aggregate concrete under controlled curing conditions.
7. **The use of recycled aggregates significantly improved environmental sustainability** by reducing the amount of C&D waste disposed of in landfill sites and minimizing the demand for natural aggregates.
8. **Adoption of recycled aggregates contributed to conservation of natural resources**, reduction in environmental degradation caused by quarrying activities, and promotion of eco-friendly construction practices.
9. **The environmental assessment confirmed the potential reduction in carbon footprint**, as the use of recycled aggregates decreases the need for extraction, processing, and transportation of natural materials.
10. **The study demonstrated that recycled aggregate concrete can serve as a reliable and sustainable alternative** to conventional concrete when used at controlled replacement levels.
11. **The findings of this research support the implementation of sustainable construction practices**, encouraging wider use of recycled materials in infrastructure development.
12. **Overall, recycled aggregate concrete represents a practical, economical, and environmentally responsible solution** for modern construction industries aiming to achieve sustainability goals while maintaining structural performance.

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