



EXPERIMENTAL INVESTIGATION ON THE PERFORMANCE OF C30 CONCRETE INCORPORATING SAROOJ AND RECYCLED AGGREGATES

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ABSTRACT

The ties of natural resources and significantly contributes to environmental degradation. Cement manufacturing alone is responsible for nearly 8% of global CO₂ emissions, while large-scale quarrying for aggregates leads to depletion of natural resources, habitat loss, and land degradation. Therefore, the use of sustainable materials such as supplementary cementitious materials and recycled aggregates is essential to reduce the environmental impact of concrete production.



This study presents an experimental investigation on the performance of C30 grade concrete with partial replacement of cement by sarooj and coarse aggregates by recycled aggregates derived from construction and demolition waste. Sarooj, a locally available artificial pozzolana produced by calcining clay, exhibits cementitious properties when combined with lime and water, making it a potential eco-friendly alternative material. A total of four concrete mixes were prepared using British Standard (BS) mix design guidelines: a control mix, a mix with 10% cement replacement by sarooj, a mix with 25% coarse aggregate replacement by recycled aggregates, and a combined mix incorporating both replacements.

Concrete cubes of size 150 mm were cast and tested for compressive strength at 7 and 28 days. The results indicated that the control mix achieved the highest compressive strength, while partial replacement of cement with sarooj led to reduced early and 28-day strength due to its pozzolanic characteristics. The incorporation of recycled aggregates showed comparable early strength but a noticeable reduction in long-term strength. The combined use of sarooj and recycled aggregates produced moderate strength values, demonstrating that sustainable concrete with acceptable performance can be achieved depending on mix composition and curing duration.

The study highlights the potential of sarooj and recycled aggregates in minimizing carbon emissions, conserving natural resources, and promoting circular economy principles in construction. The outcomes contribute to the development of environmentally responsible concrete and support the transition towards sustainable infrastructure practices.

KEYWORDS: Sarooj, Recycled Aggregates, Sustainable Concrete, Compressive Strength, Carbon Emissions, Construction and Demolition Waste.

1. INTRODUCTION

Historically, Concrete is the most widely used construction material in the world due to its versatility, strength, and durability. However, its production is associated with significant environmental concerns, primarily due to the extensive consumption of natural resources and high carbon emissions. Cement, the key binding material in concrete, is responsible for approximately 8% of global carbon dioxide (CO₂) emissions, mainly due to the calcination of limestone and energy-intensive clinker production processes. In addition to cement production, the extraction of natural aggregates through quarrying contributes to environmental degradation, including depletion of rock resources, habitat destruction, land degradation, and increased pollution. These challenges have led to growing interest in sustainable construction materials that can reduce environmental impact while maintaining structural performance.

One promising approach to sustainable concrete is the use of supplementary cementitious materials (SCMs) and recycled aggregates. In the Sultanate of Oman, a locally available material known as *sarooj* has gained attention as a potential partial replacement for cement. Sarooj is an artificial pozzolanic material produced by calcining clay at temperatures typically ranging between 700°C and 800°C. It has been used historically in Oman for the construction of hydraulic structures such as *aflaj*, forts, and castles due to its good binding characteristics and durability. Chemically, sarooj contains reactive silica (SiO₂) and alumina (Al₂O₃), which contribute to its pozzolanic activity by reacting with calcium hydroxide in the presence of water to form calcium silicate hydrates (C-S-H) and calcium aluminate hydrates—the primary compounds responsible for strength in cementitious systems. The physical properties of sarooj, such as fineness, particle size distribution, and surface area, significantly influence its reactivity and strength development. Studies have shown that finer sarooj particles enhance compressive strength, particularly at later curing ages, due to improved pozzolanic reactions.

From a chemical composition perspective, sarooj typically consists of silica, alumina, iron oxide, and minor quantities of other oxides, with its performance depending on the calcination process and source clay materials. Physically, it behaves similarly to other pozzolanic materials, exhibiting delayed strength gain compared to ordinary Portland cement but improved long-term durability. The availability of sarooj in Oman is relatively abundant, particularly in regions such as Al-Hamra, Bahla, and Al-Mawal, where suitable clays are found and traditionally processed. This local availability makes sarooj an economically viable and environmentally sustainable alternative to reduce cement consumption in the region.

In parallel, the use of recycled aggregates derived from construction and demolition waste has emerged as an effective strategy to address both resource depletion and waste management challenges. The construction sector generates a substantial volume of waste materials, much of which can be processed and reused as aggregates in new concrete production. Recycled aggregates consist primarily of crushed concrete, masonry, and other debris, and are increasingly available in urban regions undergoing rapid development and demolition activities. Their use helps reduce the demand for natural aggregates, thereby decreasing quarrying activities and preserving natural resources. Furthermore, recycling construction waste contributes to reducing landfill requirements and supports the principles of a circular economy.

Generally, recycled aggregates exhibit higher water absorption and slightly lower density compared to natural aggregates due to the presence of residual cement paste. These characteristics can influence the workability and strength of concrete; however, studies indicate that partial replacement of natural aggregates (up to about 25–50%) can produce concrete with satisfactory mechanical properties. In regions like Oman and the broader Gulf area, the increasing volume of construction activities has led to significant generation of demolition waste, providing a steady supply of recycled aggregates with potential for reuse in concrete applications.

In this context, the combined use of sarooj and recycled aggregates presents a promising approach toward sustainable concrete production. By partially replacing cement with sarooj and

natural aggregates with recycled materials, it is possible to reduce carbon emissions, minimize environmental degradation, and promote efficient resource

2. Methodology:

This study adopts an experimental approach to evaluate the performance of sustainable concrete incorporating partial replacement of cement with sarooj and coarse aggregates with recycled aggregates. A C30 grade concrete mix was designed in accordance with British Standard (BS) specifications. Four different mix proportions were prepared: a control mix, a mix with 10% cement replaced by sarooj, a mix with 25% coarse aggregates replaced by recycled aggregates, and a combined mix incorporating both replacements. Concrete cubes of size 150 mm × 150 mm × 150 mm were cast for each mix and cured under standard conditions. Compressive strength tests were conducted at 7 and 28 days to assess the effect of material substitutions on strength development. The experimental results were analyzed and compared to determine the suitability and effectiveness of sarooj and recycled aggregates in producing sustainable concrete.

2.1 Material used

The materials used in this study include Ordinary Portland Cement (OPC), sarooj as a partial cement replacement material, natural coarse and fine aggregates, recycled coarse aggregates obtained from construction and demolition waste, and potable water for mixing and curing. All materials were selected to comply with relevant British Standard (BS) specifications. The properties of these materials were carefully considered to ensure consistent and reliable concrete performance.

2.1.1 Cement

Ordinary Portland Cement (OPC) was used as the primary binding material in all concrete mixes. Cement plays a critical role in concrete by reacting with water to form a hardened matrix that binds the aggregates together. The cement used in this study conforms to relevant British Standards (BS EN 197-1) and is suitable for general structural applications such as C30 grade concrete.

Portland cement is a hydraulic binder primarily composed of calcium silicates, aluminates, and ferrites. Upon hydration, it forms calcium silicate hydrate (C-S-H), which is responsible for the strength and durability of concrete. The physical properties of cement, such as fineness, setting time, and specific gravity, significantly influence the workability, strength development, and overall performance of concrete.

Table 2.1: Physical Properties of Ordinary Portland Cement

Property	Value (Typical)
Specific Gravity	3.10 – 3.15
Fineness (Blaine)	300 – 350 m ² /kg
Initial Setting Time	≥ 45 minutes
Final Setting Time	≤ 600 minutes
Standard Consistency	26% – 33%
Compressive Strength (28 days)	≥ 42.5 MPa (for 42.5 grade cement)

2.1.2 Fine aggregates

Fine aggregates used in this study consist of natural sand commonly available in the Sultanate of Oman. Sand plays a vital role in concrete by filling voids between coarse aggregates, improving workability, and contributing to the overall strength and durability of concrete. The fine aggregate used was clean, well-graded, and free from harmful substances such as clay, silt, organic impurities, and salts, conforming to the requirements of BS EN 12620 for aggregates used in concrete.

In Oman, sand is primarily sourced from wadis (riverbeds) and desert deposits. Wadi sand is widely used in construction due to its relatively well-graded particle distribution and rounded to sub-

angular particle shape, which enhances workability. However, desert sand is generally avoided due to its excessively fine and poorly graded particles, which negatively affect strength and bonding characteristics. The sand used in this study was wadi sand, selected for its suitability in structural concrete applications.

The physical properties of fine aggregates significantly influence concrete performance. Typical properties of sand available in Oman include a specific gravity ranging from 2.60 to 2.70, indicating good density and strength characteristics. The fineness modulus usually varies between 2.3 and 3.0, suggesting medium to coarse grading suitable for concrete production. Water absorption is generally low, typically below 2%, which helps maintain controlled water-cement ratios in the mix. Additionally, the particle size distribution complies with standard gradation limits, ensuring good packing density and reduced void content.

The grading and quality of fine aggregates are critical factors in achieving the desired workability and strength of concrete. Proper selection and control of sand properties contribute to improved cohesion, reduced segregation, and enhanced durability of the concrete mix.

2.1.3 Coarse aggregates

Coarse aggregates used in this study were sourced from locally available quarry materials in Oman, primarily consisting of crushed gabbro and limestone. Gabbro is commonly preferred due to its high strength, durability, and low water absorption. The aggregates are angular in shape, providing good interlocking and bonding with cement paste. Typically, aggregate sizes range from 10 mm to 20 mm and comply with BS EN 12620 specifications. Their physical properties, such as adequate strength and low water absorption, make them suitable for structural concrete applications.

2.1.4 Water

Water is an essential component in concrete, as it participates in the hydration process of cement and contributes to the workability of the mix. The quality of water significantly affects the strength and durability of concrete; therefore, it should be clean and free from harmful substances such as oils, acids, salts, and organic impurities. For the present investigation, potable tap water available in the laboratory was used for both mixing and curing concrete, ensuring consistency and suitability for concrete production.

2.1.5 Sarooj

Sarooj is a traditional Omani pozzolanic material that has been widely used in construction for centuries, particularly in hydraulic structures such as *aflaj*, forts, and historical buildings. It is an artificial pozzolana produced by calcining clay at controlled temperatures, which imparts hydraulic binding properties similar to cement when combined with water. Due to its pozzolanic nature, sarooj reacts with calcium hydroxide released during cement hydration to form additional cementitious compounds, contributing to strength and durability in concrete.

In the present investigation, sarooj was used as a partial replacement for cement to promote sustainable construction practices. Sourcing sarooj required considerable effort, as it is not readily available in standard construction material outlets. After contacting several local suppliers, the material was procured from a supplier within Oman who could ensure its quality and suitability for experimental use. The sarooj was collected in bulk quantities and transported to the laboratory.

Proper storage conditions were maintained to preserve the material properties. The sarooj was stored in sealed bags in a dry environment to prevent moisture absorption and contamination prior to use. Care was taken throughout handling and storage to ensure consistency in material quality during the experimental program.



Fig 2.1 Sarooj used as a replacement for cement

2.1.6 Recycled Aggregates

Recycled aggregates used in this study were obtained from previously tested and demolished concrete cubes available in the university laboratory. The concrete specimens were manually crushed into smaller pieces using a hand rammer and processed to achieve the required size range of 10–20 mm. The material was cleaned to remove dust and unwanted particles, and sieve analysis was carried out to ensure proper grading comparable to natural coarse aggregates. Recycled aggregates typically contain adhered mortar, resulting in slightly higher water absorption and lower density than conventional aggregates. Their use in concrete helps reduce the consumption of natural resources and promotes sustainable construction practices through the reuse of construction waste.



Fig 2.2 Recycled aggregates.



Fig 2.3 Hand Rammer

2.3 Concrete Mix Design

A CONCRETE MIX OF C30 WAS DESIGNED AND THE FOLLOWING IS THE MIX PROPORTION.

Table 2.2 Concrete Mix Proportion

Mix	Cement	Fine aggregates	Coarse aggregates	Water
C30	1	1.685	2.528	0.5

Four sets of concrete cubes were prepared for the experimental investigation, with each set consisting of six cubes. The first set served as the control mix with conventional concrete. The second set comprised concrete with 10% replacement of cement by sarooj. The third set included concrete with 25% replacement of natural coarse aggregates by recycled aggregates. The fourth set incorporated both 10% cement replacement with sarooj and 25% replacement of coarse aggregates with recycled

aggregates. The quantities of materials required for each mix proportion are presented in the following table.

Table 2.3: Material Quantities for Control and Modified Concrete Mixes

Material	Set 1 (kg)	Set 2 (kg)	Set 3 (kg)	Set 4 (kg)
Cement	10.14	9.13	10.14	9.13
Sarooj	—	1.01	—	1.01
Fine Aggregate	17.14	17.14	17.14	17.14
Natural Coarse Agg.	25.78	25.78	19.34	19.34
RCA	—	—	6.44	6.44
Water	5.04	5.04	5.04	5.04
Superplasticizer	—	—	Added *	Added *

* Super plasticizers are used for set 3 and set 4 based on the consistency required

3. Test set-up and Testing procedure

3.1 Preparation and casting of cubes.

Concrete cubes were cast in batches, with each batch consisting of six specimens, using the calculated quantities of materials for each mix proportion. The dry materials, including cement, fine aggregates, coarse aggregates, and where applicable sarooj and recycled aggregates, were first thoroughly mixed to achieve a uniform distribution. Water was then added gradually while mixing continued until a homogeneous concrete mix with the desired workability was obtained. Prior to casting, a slump test was carried out on the freshly prepared concrete to determine its workability and to allow comparison between different mix proportions.

The prepared concrete was placed into clean and oiled cube moulds of size 150 mm × 150 mm × 150 mm in three equal layers. Each layer was compacted properly using a tamping rod to eliminate air voids and ensure adequate compaction. The top surface was levelled and finished smoothly using a trowel.

Several precautions were taken during the casting process to ensure consistency and quality of specimens. The moulds were properly cleaned and greased before use to prevent adhesion and facilitate easy demoulding. Care was taken to maintain accurate batching of materials and uniform mixing for all batches. Adequate compaction was ensured to avoid honeycombing, and excess water was avoided to maintain the designed water-cement ratio. After casting, the specimens were kept undisturbed in the laboratory for 24 hours before demoulding and subsequent curing.



Fig. 2.4 Slump Test



Fig 2.5 Casting of cubes

3.2 Curing of Concrete specimens

Curing is a critical process in concrete construction, as it ensures proper hydration of cement, leading to the development of strength and durability. In this study, the concrete cubes were carefully removed from the moulds after 24 hours of casting and immediately transferred to a curing tank available in the laboratory. The specimens were fully immersed in clean water to maintain a constant moisture condition throughout the curing period.

Proper curing helps in preventing moisture loss, reducing shrinkage cracks, and improving the overall mechanical properties of concrete. The cubes were maintained under water until the respective testing ages of 7 and 28 days, ensuring consistent curing conditions for all specimens. Care was taken to keep the water clean and at ambient laboratory temperature to achieve uniform strength development.

3.3 Testing of concrete specimens

The compressive strength test is one of the most important methods used to evaluate the mechanical performance of concrete. In this study, the concrete cubes from all four sets were tested to determine their compressive strength after specified curing periods. The tests were conducted at two different ages, namely 7 days and 28 days, to assess both early strength development and long-term performance of the concrete mixes. The results obtained from these tests were used to compare the effects of partial replacement of cement with sarooj and coarse aggregates with recycled aggregates on the strength characteristics of concrete.

3.4 Test setup and Testing

After completion of the required curing periods, the concrete cubes were removed from the curing tank and allowed to surface dry. The specimens were then tested using a calibrated compression testing machine (CTM). Each cube was placed centrally on the testing platform, and load was applied gradually and uniformly until failure occurred. The maximum load at failure was recorded in kilonewtons (kN), and the corresponding compressive strength was calculated in megapascals (MPa) based on the cross-sectional area of the cube. The procedure was carried out for all specimens at both 7-day and 28-day curing intervals, and the test results were carefully noted for analysis and comparison.



Fig 3.1 Compression Testing Machine.

4. Presentation of Test Results

The results obtained from the slump test, indicating the workability of the concrete mixes, along with the compressive strength values of all four sets of concrete cubes at 7 days and 28 days curing periods, are presented in the following tabular columns.

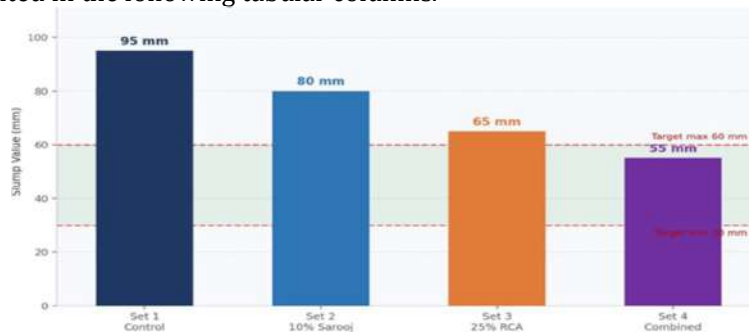


Fig 4.1 Workability: Slump test results

Table 4.1 Summary of Compressive Strength and Slump test results

Set	7-Day (MPa)	28-Day (MPa)	Slump (mm)	C30 (28d)?
Set 1 — Control	21.07	31.23	95	✓ Yes
Set 2 — 10% Sarooj	15.16	25.26	80	✗ No
Set 3 — 25% RCA	20.40	21.07	65	✗ No
Set 4 — Combined	23.26	24.7	55	✗ No

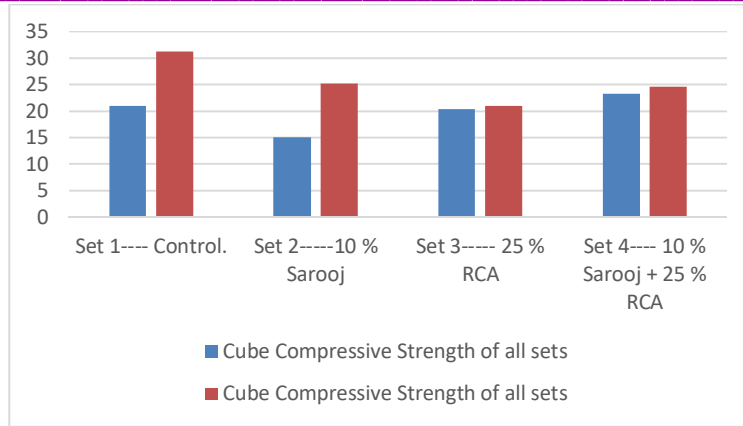


Fig 4.2 Comparison of Compressive Strength

5. Conclusions and inferences

5.1 Conclusions

- The control concrete achieved compressive strengths of approximately **21.07 MPa (7 days)** and **31.23 MPa (28 days)**, confirming the suitability of the designed C30 mix.
- Partial replacement of cement with **10% sarooj resulted in reduced early and 28-day strength** (15.16 MPa and 25.26 MPa), indicating slower strength development due to its pozzolanic nature.
- Replacement of **25% coarse aggregates with recycled aggregates** showed comparable early strength (20.40 MPa at 7 days) but a noticeable reduction at 28 days (21.07 MPa), highlighting the influence of recycled aggregate properties.
- The combined use of **10% sarooj and 25% recycled aggregates** achieved moderate strength values (23.26 MPa at 7 days and 24.70 MPa at 28 days), demonstrating the feasibility of sustainable concrete with acceptable performance.

5.2 Inferences

- Sarooj contributes to **delayed strength gain**, as evidenced by lower early strength but relatively improved performance at later ages.
- Recycled aggregates primarily affect **long-term strength** due to higher porosity and weaker interfacial bonding compared to natural aggregates.
- The combination of sarooj and recycled aggregates produces **balanced performance**, indicating potential for sustainable applications where high strength is not critical.
- The experimental results demonstrate that partial replacement materials can be effectively used to **reduce environmental impact while maintaining acceptable structural performance**.

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