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# Sustainable Green Concrete: Enhancing Strength and Eco-Efficiency through Ternary Blended Cement with Waste Supplementary Cementitious Materials

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## ABSTRACT

The modern construction industry is increasingly focused on developing energy-efficient and sustainable building materials to minimize environmental impact. Cement production is one of the major contributors to carbon dioxide ($CO_2$) emissions, necessitating alternative solutions to reduce its usage while maintaining structural integrity. One promising approach is the partial replacement of cement with waste-derived supplementary cementitious materials (SCMs), which enhances sustainability without compromising strength. This study investigates the development of sustainable green concrete by incorporating sugarcane bagasse ash (SCBA) and rice husk ash (RHA) as partial replacements for cement. These agro-industrial waste materials are rich in silica, making them suitable for pozzolanic reactions that contribute to improved concrete performance. The SCMs were obtained by collecting, drying, and finely grinding sugarcane bagasse and rice husks, followed by controlled burning to achieve reactive ash. Various mix proportions were prepared, where cement was partially replaced with SCBA and RHA at different percentages: 0%-0%, 5%-0%, 5%-2.5%, 5%-5%, 5%-7.5%, and 5%-10% (by mass of cement). Experimental investigations were conducted to analyze the compressive strength of concrete samples cured for 7, 14, and 28 days. The results demonstrated that ternary-blended green concrete exhibits improved strength characteristics at optimal replacement levels compared to conventional concrete. The presence of finely processed SCBA and RHA enhances the microstructure of concrete by reducing porosity and increasing durability. The results indicate that a balanced combination of these SCMs can yield a sustainable concrete mix with superior mechanical properties, making it a viable alternative to traditional cement-based concrete. The study highlights the potential of utilizing agro-industrial waste materials in the construction industry, promoting environmental sustainability, waste management, and carbon footprint reduction. By replacing a portion of cement with SCBA and RHA, this research contributes to the advancement of eco-friendly, high-performance concrete that meets modern construction standards. Future research could further optimize mix proportions and explore additional SCM combinations to enhance durability and long-term performance.

**Keywords:** Sustainable Green Concrete, Cement Replacement, Supplementary Cementitious Materials (SCMs), Eco-Friendly Construction, Agro-Industrial Waste Utilization.

## 1. INTRODUCTION

Sustainable green concrete, as defined in this thesis, represents an innovative approach where waste materials are utilized to create an eco-friendly alternative without sacrificing the concrete's strength or performance. Recognizing that cement is a cornerstone of construction worldwide, there is a pressing need to enhance its quality while simultaneously reducing the environmental footprint associated with its production. Cement manufacturing is notorious for its high energy consumption and significant use of natural resources, and it contributes considerably to $CO_2$ emissions—a primary driver of global warming. Though focusing mainly on $CO_2$ emission, it was equally important to focus on performance of concrete in order to increase its operational sustainability benefits. Reducing the cement consumption by partial replacement of cement with waste materials was an effective way to increase the performance of concrete and makes the concrete more sustainable with low $CO_2$ emissions. In addition, there were some barriers in using waste materials in concrete. Industrial revolution over last 200 years has drastically increased the level of $CO_2$ in air. Now day's cement-based materials were mostly used for construction material in the world. Ecologically, it was produced from natural materials and has many advantages. Worldwide the energy consumption was also reduced. The only ecological disadvantage of concrete was the discharge of carbon dioxide at the time of burning cement clinker. The sustainability of concrete can be enhanced by consuming waste materials as SCMs, which impacts mechanical properties of concrete, such as workability, compressive strength, durability etc. SCM material used concrete decreases its environmental destruction and improves the performance and life cycle sustainability.

## 2. LITERATURE REVIEW

Saand et.al., (2019) studied the effect of partial replacement of cement with rice husk ash at different percentage i.e., 0%,2.5%,5%,7.5%,10%,12.5% and 15%. It was found that up to 10% replacement of cement with rice husk ash the compressive strength and split tensile strength will get increased but further increase in the percentage of rice husk ash beyond 10% the strength starts decreasing. The maximum value of compressive strength and split tensile strength for 10% of cement replacement with RHA obtained is 4.4MPa and 0.53MPa respectively.

Kunchariyakun et.al., (2018) had done an experimental investigation on replacement of sand with two agricultural waste i.e., rice husk ash and bagasse ash in preparation of AAC blocks. These samples are autoclaved at different autoclaving temperature (140oc, 160oc and 180oc) and different time period (4h, 8h and 12h). It was found that the effect of the increase in autoclaving temperature and time is directly related to the increase in strength and microstructural properties. But at 180oc it was found that there is no significant increase in strength with increase in time. The reason for no significant increase in strength is because Si ions from the sand reach its maximum dissolution.

Il'ina and Rakov., (2016) studied the effect of grinding of Portland cement clinker with silica, carbonate components and mineral additive on mechanical properties of NAAC. Additives used are wollastonite and diopside to check the compressive strength, thermal conductivity and density of NAAC. Adding additives to NAAC will reduce energy consumption in concrete. It is found that the hardness and elastic modulus of additives diopside is higher. Adding 5% of diopside gives 3.3Mpa compressive strength, 0.131W/m.oc thermal conductivity and 580 kg/cm3 avg. density.

Kunchariyakun et.al., (2015) used rice husk ash as partial replacement of sand in autoclaved aerated concrete. Percentage of rice husk ash used for replacement of sand are 25%, 50%, 75%, and 100%. Researchers have checked the mechanical properties of the sample at autoclaving condition having temperature 180oc and pressure 12bar. Samples have been checked for two different time period i.e., 8 hours and 18 hours. The best replacement rate for replacement of sand with RHA is found at 75%. It is found that replacing sand with RHA increases water requirement which negatively impacts the compressive strength of AAC.

R.Srinivasan, Senior Lecturer, Department of Civil Engineering, Tamilnadu College of Engineering and K.Sathiya**,** Lecturer, Department of Civil Engineering, Avinashilingam University for Women in 2010 made experimental study on Bagasse ash in concrete. In this paper, Bagasse ash has been chemically and physically characterized and partially replaced in the ratio of 0%, 5%, 15% and 25% by weight of cement in concrete. Fresh concrete tests like compaction factor test and slump cone test were undertaken was well as hardened concrete tests like compressive strength, split tensile strength, flexural strength and modulus of elasticity at the age of 7 and 28 days was obtained. The result shows that the strength of concrete increased as percentage of bagasse ash replacement increased. From the observations, it is clear that the addition of SCBA in plain concrete increases its strength under compression, tension, young's modulus and flexure up to 10% of replacement after that strength results was decreases.

In the study conducted by A.D.V.S. Siva Kumar, K.V.G.D. Balaji, T. Santhosh Kumar, Assistant Professors of Civil Engineering in GITAM University, Andhra Pradesh in 2014, bagasse ash is used as partial replacement of cement because it is one of the by product which can be used as mineral admixture due to its high content in silica (SiO2), it is also a waste product produced from Sugar manufacturing industry. In this study, sugarcane Bagasse ash is partially replaced in the ratio of 0%, 5%,10%,15% and 25% by weight of cement in concrete and exposed to different elevated temperature (i.e., 2000, 4000, 6000, 8000) C for 1 hour and immediately cooled with water. The result shows that the strength of concrete specimens increased at 2000C than room temperature for all percentage of replacement of cement with SCBA**.**

Experimental study on compressive strength of concrete by partially replacement of cement with sugar cane bagasse ash was conducted by Jayminkumar A. Patel and Dr. D. B. Raijiwala in the year 2015. Present study is to investigate impact of sugar cane bagasse ash in concrete. In this experimental work sugar cane bagasse ash which is taken from Maroli sugar mill, Navsari, Gujarat, is partially replace with cement at 0%, 5%, 10%, 15% and 20% by weight in concrete. The grade of concrete is M25 and w/c ratio is 0.49 taken as a reference. 150x150x150 mm cubes are casted and tested for 7, 14, 28 and 56 days. Compressive strength result shows that up to 10% replacement of sugar cane bagasse ash in concrete gives comparable result with normal concrete without any admixture, but 5% replacement give maximum compressive strength. Also, the amount of sugar cane bagasse ash increase, workability of concrete increases.

## 3. PROPOSED SYSTEM

### 1. Overview

The proposed system aims to develop an eco-friendly, high-performance concrete by partially replacing cement with sugarcane bagasse ash (SCBA) and rice husk ash (RHA). This system focuses on optimizing the mix proportions, ensuring enhanced mechanical properties, and reducing the environmental impact of traditional concrete production. The system also integrates a structured approach to material processing, mix design, testing, and implementation in real-world construction.

**2. Key Components of the Proposed System**

**A. Collection and Processing of Waste Materials**

1. **Raw Material Collection:**
   - Sugarcane bagasse and rice husks are sourced from sugar mills and rice mills, reducing agricultural waste.
2. **Drying and Grinding:**
   - The collected waste materials are dried and ground into fine powder to ensure proper reactivity in the cementitious mix.
3. **Controlled Burning Process:**
   - Both SCBA and RHA are subjected to controlled combustion at optimum temperatures to obtain high-reactivity pozzolanic ash.
4. **Quality Testing:**
   - The chemical composition ($SiO_2$ content), fineness, and reactivity of SCBA and RHA are tested to ensure suitability for use in concrete.

**B. Mix Design Optimization**

1. Ternary Blended Cement Formulation:
   - Various mix proportions are designed by replacing 5-10% cement with SCBA and RHA in different combinations.
2. Water-Cement Ratio Adjustment:
   - The mix design ensures an optimal water-cement ratio for achieving desired workability and strength.
3. Use of Superplasticizers (if required):
   - To enhance workability without increasing the water content, superplasticizers can be added where necessary.

**C. Testing and Performance Evaluation**

1. Fresh Concrete Tests:
   - Slump test is conducted to measure workability and ensure ease of placement.
2. Hardened Concrete Tests:
   - Compressive Strength Test (7, 14, 28 days) is performed to determine structural performance.
   - Durability Tests (water absorption, sulfate resistance) may be conducted for long-term evaluation.
3. Comparison with Conventional Concrete:
   - The results are benchmarked against control mix concrete to determine the efficiency of SCBA-RHA blended concrete.

**D. Implementation in Construction Applications**

1. Structural Feasibility Analysis:
   - The optimized SCBA-RHA concrete mix is tested for load-bearing applications like pavements, slabs, and columns.
2. Pilot Project Execution:
   - A small-scale construction prototype (e.g., pavement block, structural beams) is developed to study real-world applicability.

3. Cost-Benefit Analysis:
   - The economic advantages of using SCBA and RHA as cement replacements are assessed, including cost reduction and sustainability benefits.

## 4. RESULTS AND DISCUSSIONS

As per experimental programme results for different experiments were obtained. They are shown in table format and graph format, which is to be presented in this chapter.

### 4.1 Fresh properties of concrete (Workability Test)

#### 4.1.1 Slump Test

The Slump test was performed on the SCBA – RHA based concrete to check the workability of it at different replacements viz. 0-0%, 5-0%, 5-2.5%, 5-5%, 5-7.5%, 5-10% and the following results were obtained, according to which it can be concluded that with the increase in % of RHA from M3 to M6 workability increases. The results obtained for Slump test are shown below in Table 5.1.

**Table 4.1: Results of Slump test**

| Mix No | SCBA(%) – RHA(%) | Slump (mm) |
|---|---|---|
| M1 | 0-0 | 90 |
| M2 | 5-0 | 95 |
| M3 | 5-2.5 | 97 |
| M4 | 5-5 | 100 |
| M5 | 5-7.5 | 101 |
| M6 | 5-10 | 102 |

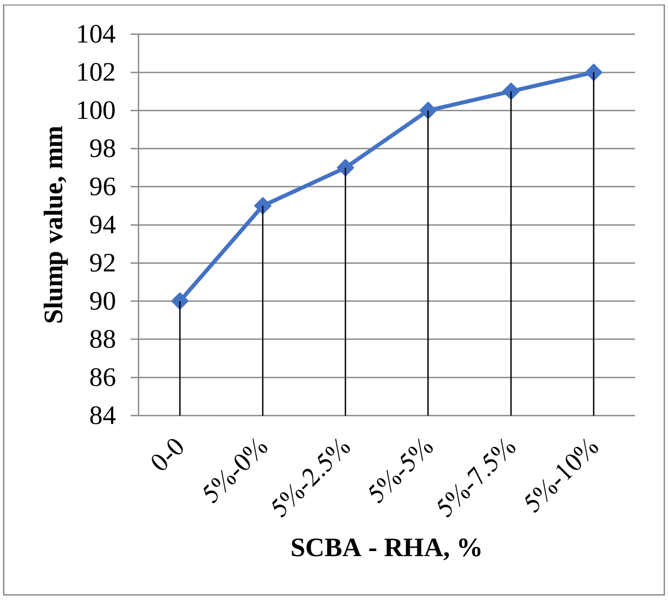


**Fig 4.1.1: Slump test results**

The above figure 5.1 shows the slump results. It was observed that, the slumps increased from M1 to M6 mix with increased RHA in the mix. It was obtained Medium Workability.

### 4.2 Harden properties of concrete

#### 4.2.1 Compressive Strength Test

The compressive strength test was performed on the cubes of size 15 cm x 15 cm x 15 cm to check the compressive strength of SCBA-RHA based concrete and the results obtained are given in Table 5.2.

**Table 4.2: Results of compressive strength test**

| Mix No | SCBA(%) – RHA(%) | Compressive strength of cubes (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 7 days | 14 days | 28 days |
| M1 | 0-0 | 16.12 | 22.32 | 24.8 |
| M2 | 5-0 | 16.77 | 22.76 | 25.8 |
| M3 | 5-2.5 | 17.1 | 23 | 26.1 |
| **M4** | **5-5** | **17.53** | **23.4** | **26.5** |
| M5 | 5-7.5 | 16.87 | 22.54 | 25.6 |
| M6 | 5-10 | 16.3 | 22.45 | 25 |

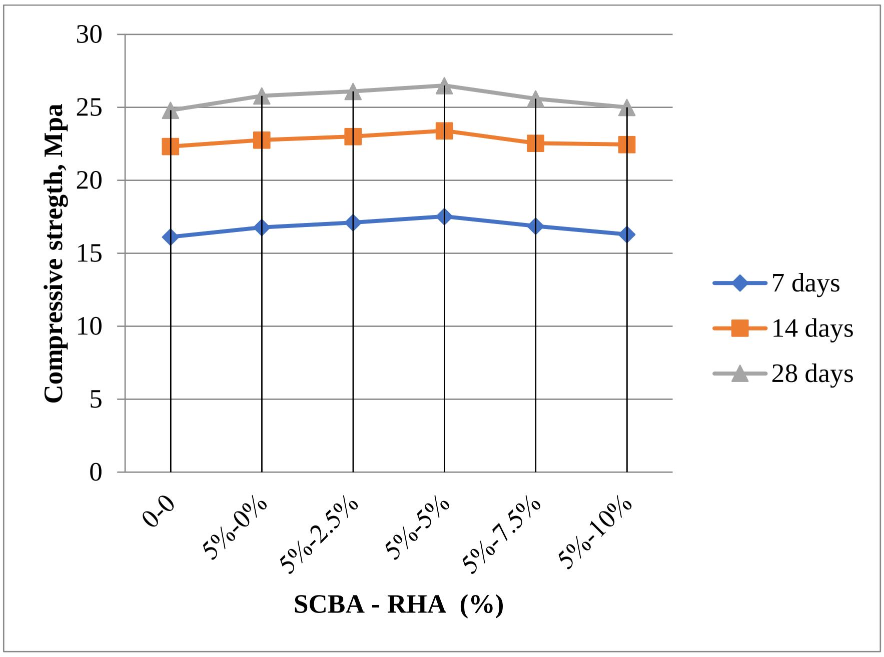


**Fig 4.2.1: 7days Compressive strength test result graph**

From the above results it was observed that with the increase in percentage of 5%SCBA with RHA from M2 to M6 in concrete the compressive strength more than control mix M1. The highest compressive strength gained for 5%SCBA – 5%RHA replacing with cement in the preparation of concrete. The optimum dosage suggested from this study was 5%SCBA – 5%RHA.

## 5. CONCLUSIONS

This experimental investigation evaluates the impact of SCBA-RHA blended concrete on the compressive strength and workability of concrete cubes, comparing the results with conventional control mix concrete. The study reveals that incorporating sugarcane bagasse ash (SCBA) and rice husk ash (RHA) as partial cement replacements significantly influences the concrete's performance. One of the key findings is that workability improves as the percentage of SCBA-RHA replacement increases, making the concrete more manageable and easier to place, which can be beneficial for various construction applications. Furthermore, compressive strength analysis demonstrates that the optimal replacement level is achieved at 5% SCBA and 5% RHA, where the concrete exhibits the highest strength gain. This enhancement in strength is attributed to the pozzolanic reaction of SCBA and RHA, which contributes to improved microstructural density and reduced porosity. Beyond strength and workability, the incorporation of these supplementary cementitious materials (SCMs) offers significant economic and environmental benefits. By reducing cement consumption, the cost of construction decreases, making this an economically viable solution. Additionally, the utilization of agricultural waste materials helps in effective waste management, addressing disposal issues while simultaneously minimizing the environmental footprint of cement production. This research highlights the potential of SCBA and RHA as sustainable alternatives in concrete. Their use not only enhances the mechanical properties of concrete but also contributes to the global effort of reducing $CO_2$ emissions, conserving natural resources, and promoting greener construction practices.

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