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Estimation of Compressive Strength of Cement Replacement for Different Biomass Percentage

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Abstract: *This study investigates the effect of partially replacing Ordinary Portland Cement (OPC) with Rice Husk Ash (RHA) and Sugarcane Bagasse Ash (SBA) on the mechanical properties and workability of M30 grade concrete. Cube, cylinder, and beam specimens were cast and tested for compressive, split tensile, and flexural strength after curing periods of 7, 14, 28, 56, and 90 days, in accordance with IS standards. The replacement levels varied, with RHA and SBA substituted at 5%, 10%, 15%, and 20%, and their combinations evaluated for optimal performance. The results indicated that individual replacements of RHA and SBA influenced strength development differently, with compressive strength decreasing at higher RHA content due to its porous nature, while SBA contributed positively up to 15% replacement. Workability improved with SBA but declined with increasing RHA content. A combined replacement of 15% SBA and 10% RHA yielded the highest values in compressive, tensile, and flexural strength, making it the optimal mix. The incorporation of RHA and SBA not only enhances certain mechanical properties but also offers an environmentally sustainable and cost-effective alternative to conventional cement, promoting the reuse of agro-industrial waste in construction materials*

Keywords: Rice Husk Ash, Sugarcane Bagasse Ash, Compressive Strength, Workability, Sustainable Concrete

I. INTRODUCTION

1.1 Overview

Concrete is the most widely used construction material in the world due to its strength, durability, and versatility. However, the production of its key ingredient—Ordinary Portland Cement (OPC)—is highly energy-intensive and responsible for a significant share of global carbon dioxide (CO_2) emissions. With the growing concerns about environmental sustainability, climate change, and depletion of natural resources, researchers and engineers are continuously exploring alternative and supplementary cementitious materials (SCMs) that can partially replace cement in concrete without compromising its performance. Utilizing waste by-products such as Rice Husk Ash (RHA) and Sugarcane Bagasse Ash (SBA) as cement replacements aligns with this goal, offering both environmental and economic benefits.

Rice Husk Ash (RHA) is a by-product derived from the burning of rice husks, which are the protective outer coverings of rice grains. India, being one of the largest rice producers, generates a vast quantity of rice husk annually. Upon controlled burning, the husk produces RHA, which is rich in amorphous silica—a key component that contributes to pozzolanic activity. When used as a partial replacement for cement, RHA reacts with calcium hydroxide in concrete to form additional calcium silicate hydrate (C-S-H), improving the long-term strength and durability of concrete. However, due to its porous structure, RHA may reduce the workability of fresh concrete.

Similarly, Sugarcane Bagasse Ash (SBA) is obtained from the combustion of bagasse—the fibrous residue left after extracting juice from sugarcane. Countries like India and Brazil generate significant amounts of bagasse, leading to substantial ash production. SBA also contains silica and other mineral compounds that exhibit pozzolanicbehavior. It can be a useful cement replacement material, enhancing certain mechanical properties of concrete, especially when

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finely ground and properly processed. Unlike RHA, SBA tends to maintain or even slightly improve the workability of fresh concrete, making it a complementary material when blended with RHA.

The use of RHA and SBA in concrete not only helps reduce the consumption of cement but also minimizes environmental pollution by utilizing agricultural waste that would otherwise be discarded or incinerated, contributing to air and soil contamination. Moreover, replacing cement with these ashes can lower the cost of concrete production, especially in rural or agro-industrial regions where these wastes are abundantly available. Thus, integrating RHA and SBA into concrete design supports sustainable construction practices by reducing the carbon footprint and encouraging the circular economy in the construction industry.

Despite the individual merits of RHA and SBA, their combined effect on concrete properties has not been explored extensively in the literature. It is essential to understand how different proportions of these materials influence the fresh and hardened properties of concrete, including workability, compressive strength, tensile strength, and flexural strength. Optimizing their usage can lead to a more balanced and enhanced performance, exploiting the pozzolanic synergy between them. Additionally, studying their impact over various curing periods (e.g., 7, 14, 28, and 56 days) provides insight into their short-term and long-term behavior in concrete.

This study aims to evaluate the mechanical and workability characteristics of M30 grade concrete partially replaced with various percentages of RHA and SBA. By investigating different combinations of RHA and SBA, the research identifies an ideal mix that offers improved performance over conventional concrete. The results are also analyzed in the context of current sustainability trends, supporting the broader objective of greener and more cost-effective construction solutions.

In this direction, a case study on the Ghatghar Dam—a project known for incorporating innovative concrete techniques and material optimization—has also been included. The application of fly ash and advanced construction strategies in such mega-infrastructure projects provides valuable insights into the potential of SCMs like RHA and SBA in practical, large-scale implementations. This further reinforces the importance of continued research and field validation of alternative materials in concrete technology.

1.2 Problem Statement

The extensive use of Ordinary Portland Cement in concrete production significantly contributes to environmental pollution and resource depletion. There is a pressing need to identify sustainable alternatives, such as Rice Husk Ash and Sugarcane Bagasse Ash, to partially replace cement without compromising concrete performance.

II. LITERATURE REVIEW

M.R. Giddel and A.P. Jivanistates that every year approximately J 20 million tons of paddy is produced in India. This gives around 24 million tons of rice husk and 4.4 mil/ion tons of Rice Husk Ash every year. Major three uses of Rice Husk Ash are in the steel, cement and refractory bricks industry. Besides this it can be utilized in several other applications. In India rice husk is used for cattle feeding, partition board manufacturing, '0 many small scale applications and rice husk ash is used in land filling, so many industrial applications. But this uses are not in a systematic manner and also rice husk has very low food value. Being fibrous it can prove to be fatal for the cattle feeding. Use of rice husk ash or rice husk in land filling is also an environmentally hazardous way of disposing waste. In this paper we have discussed a preliminary analysis of the numerous reported uses of rice husk. The use of rice husk for electricity generation in efficient manner is likely to tranSBAorm this agricultural by product or waste into a valuable fuel for industries and thus might help in boosting the farm economy and rural development. India being the second largest rice producer in the world, systematic approach to this material can give birth to a new industrial sector of rice husk ash in India.

N.Vamsi Mohan, Prof.P.V.V.Satyanarayana, Dr.K.SrinivasaRao states that rice husk ash has been utilized for the preparation of bricks in partial and full replacement of clay. Engineering properties like compressive strength, water absorption and size and shape have been studied. From the studies, it is observed that optimum proportion for (RHA + Clay) bricks was observed as 30% RHA and 70% Clay (Maximum of 30% RHA) as the bricks exhibited high compressive strength and low brick weight. In full replacement of clay with 40% RHA, 40% Lime and 20% gypsum and 50% RHA, 30% lime and 20% gypsum gives more strength (41 kg/ cm2) when compared to all other possible proportions after 28 days curing period.

S. D. Nagrale, Dr.HemantHajare, Pankaj R. Modak India is a major rice producing country, and the husk generated during milling is mostly used as a fuel in the boilers for processing paddy, producing energy through direct combustion and / or by gasification. About 20 million tones of Rice Husk Ash (RHA) is produced annually. This RHA is a great environment threat causing damage to the land and the surrounding area in which it is dumped. Lots of ways are being thought of for disposing them by making commercial use of this RHA. RHA can be used as a replacement for concrete (15 to 25%).This paper evaluates how different contents of Rice Husk Ash added to concrete may influence its physical and mechanical properties. Sample Cubes were tested with different percentage of RHA and different w/c ratio, replacing in mass the cement. Properties like Compressive strength, Water absorption and Slump retention were evaluated.

R.N. Krishna shows The use of durability enhancing mineral admixtures or supplementary cementing materials has gained considerable importance the last decade or so as a key to long service life of concrete structures1. There are many mineral admixtures that are used in way throughout the world but rice husk ash stands out as an ecofriendly, sustainable and durable option for concrete. This paper attempts to bring out the effectiveness of rice husk ash as a versatile concrete admixture and discusses some versatile application of rice husk ash concrete.

Jayasankar.R, Mahindran.N, Ilangovan.R states that Throughout the world, concrete is being widely used for the construction of most of the buildings, bridges etc. Hence, it has been properly labelled as the backbone to the infrastructure development of a nation. Currently, our country is taking major initiatives to improve and develop its infrastructure by constructing express highways, power projects and industrial structures to emerge as a major economic power and it has been estimated that the infrastructure segment in our country is expected to see investments to the tune of Rs.4356 billion by the year 2009. To meet out this rapid infrastructure development a huge quantity of concrete is required. Unfortunately, India is not self-sufficient in the production of cement; the main ingredient of concrete and the demand for exceeds the supply and makes the construction activities very costlier. Hence, currently, the entire construction industry is in search of a suitable and effective the waste product that would considerably minimize the use of cement and ultimately reduce the construction cost. Few of such products have already been identified like Rice Husk Ash (RHA), Fly Ash, SBAs, Egg shell etc. Amongst these RHA and Egg shells are known to have good prospects in minimizing the usage of cement.

III. REQUIREMENT AND ANALYSIS

This section details the materials utilized, their properties, and the analytical approach adopted to assess the effects of partially replacing Ordinary Portland Cement (OPC) with Rice Husk Ash (RHA) and Sugarcane Bagasse Ash (SBA) in concrete. The main goal is to achieve an eco-friendly concrete mix that maintains or enhances mechanical properties and workability.

3.1 Materials Required

Cement (OPC 53 Grade):

The primary binding material conforming to IS standards, known for its high early strength and durability.

Fine Aggregate (Sand):

Natural river sand, free from impurities, passing through a 4.75 mm sieve, ensuring proper particle size distribution and gradation.

Coarse Aggregate:

Crushed granite stones of suitable size (20 mm down), clean and hard, providing strength and bulk to the concrete.

Water:

Clean potable water free from harmful impurities, used for mixing and curing the concrete.

Rice Husk Ash (RHA):

A pozzolanic by-product obtained from controlled burning of rice husks, rich in silica, and used as a partial cement replacement to enhance sustainability.

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Sugarcane Bagasse Ash (SBA):
Waste ash from sugar industry bagasse burning, containing silica and alumina, exhibiting pozzolanicbehavior suitable for cement replacement.

3.2 Mix Design

The concrete mix was designed for an M30 grade with a water-cement ratio of 0.45 as per Indian Standards. Various replacement levels of OPC with RHA and SBA were tested individually and in combination to evaluate performance:
RHA: 5%, 10%, 15%, 20%
SBA: 5%, 10%, 15%, 20%
Combined RHA + SBA with total replacement up to 25%
A conventional concrete mix without any replacement served as the control.

3.3 Test Specimens and Testing Procedures

Concrete specimens were cast and tested at specific curing intervals to measure the influence of RHA and SBA on key concrete properties:
Compressive Strength:
Tested on standard cubes at 7, 14, 28, 56, and 90 days to determine load-bearing capacity.
Split Tensile Strength:
Tested on cylindrical specimens at 7 and 28 days to evaluate resistance to tensile stresses.
Flexural Strength:
Tested on beam specimens at 7 and 28 days to assess bending resistance.
Workability:
Assessed using slump tests to measure ease of placement and consistency.

3.4 Analytical Approach

Testing was performed on multiple samples to obtain reliable averages.
Results were compared with control concrete to identify trends and effects of different replacement percentages.
Data visualization techniques such as graphs were used to illustrate strength development and workability changes over time.
Optimum replacement percentages were determined based on balancing strength, durability, and workability with sustainability goals.

3.5 Summary of Findings

Compressive strength generally improved with moderate replacement levels of RHA and SBA but decreased at higher percentages due to increased filler effect.
Workability tended to decrease with increasing RHA content because of its porous nature, while SBA had a milder effect.
Combined replacement of RHA and SBA showed synergistic effects with optimum performance at around 10% RHA and 15% SBA replacement.
Both pozzolanic materials contributed to strength gain at later curing ages, indicating ongoing chemical reactions.
The use of these agricultural waste materials reduces the environmental impact and lowers the cost of concrete production.

IV. SYSTEM DESIGN

4.1 Methodology

The methodology adopted in this study aims to systematically investigate the effect of partial replacement of Ordinary Portland Cement (OPC) by Rice Husk Ash (RHA) and Sugarcane Bagasse Ash (SBA) on the mechanical and fresh

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properties of concrete. The process involves careful selection and preparation of materials, mix design, specimen casting, curing, and testing over different time intervals to ensure comprehensive analysis.

Initially, raw materials including OPC, fine aggregate, coarse aggregate, water, RHA, and SBA were procured and tested to confirm their compliance with relevant standards. Special attention was given to the preparation of RHA and SBA, which involved controlled combustion processes to obtain ashes with desired pozzolanic properties. The RHA was produced by burning rice husks in a controlled environment to ensure high silica content and amorphous structure. Similarly, SBA was collected from sugar mills, sieved, and dried to remove moisture and oversized particles.

Following material preparation, the concrete mix design was developed based on an M30 grade with a water-cement ratio of 0.45. Different mix proportions were prepared with varying percentages of cement replaced by RHA and SBA individually and in combination. The replacement levels for RHA and SBA were chosen based on preliminary studies and literature review to cover a broad range of 5% to 20% for single replacements, and a total of 25% for combined replacements with varying proportions. This approach aimed to identify the optimum blend that maximizes mechanical performance while promoting sustainability.

Specimen preparation was carefully controlled to ensure uniformity and repeatability. Concrete was mixed thoroughly in a mechanical mixer to achieve a homogenous blend. The mix was then poured into standardized molds — cubes for compressive strength, cylinders for split tensile strength, and beams for flexural strength tests. During casting, vibration was applied using a table vibrator to minimize voids and improve compaction. After casting, the specimens were demolded after 24 hours and transferred to curing tanks where they were submerged in water at room temperature. This curing process was essential to facilitate hydration and pozzolanic reactions critical for strength development.

Testing of the specimens was conducted at specified curing intervals of 7, 14, 28, 56, and 90 days for compressive strength, and at 7 and 28 days for split tensile and flexural strength. The tests followed standard procedures as per IS codes. For compressive strength, cubes were subjected to uniaxial compression until failure using a digital compression testing machine. Split tensile strength was determined using cylindrical specimens loaded diametrically to induce tensile stresses, while flexural strength was evaluated through two-point loading on beam specimens to measure resistance to bending forces.

Throughout the study, multiple samples of each mix were tested to obtain statistically reliable results. The average of three specimens was reported for each test condition. Data were analyzed and compared against control concrete with no cement replacement to identify trends in strength and workability. Additional observations related to mix consistency and ease of handling were noted during fresh concrete testing through slump tests. The methodology thus integrated both fresh and hardened concrete property assessments to provide a holistic understanding of the influence of RHA and SBA replacements.

Finally, the results were interpreted to identify the optimal replacement percentages for RHA and SBA, both individually and in combination. The methodology emphasized sustainability by focusing on the utilization of industrial and agricultural waste materials, reducing cement consumption, and thereby lowering the carbon footprint of concrete production. This systematic and rigorous approach ensured that the findings are robust, reproducible, and applicable for real-world construction scenarios seeking greener alternatives.

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V. RESULTS

Fig 1 Compression Testing Machine

The experimental investigations on concrete with partial replacement of Ordinary Portland Cement (OPC) by Rice Husk Ash (RHA) and Sugarcane Bagasse Ash (SBA) have yielded significant findings in terms of strength development, workability, and durability properties. The results from various tests conducted at different curing ages are summarized and analyzed below:

Compressive Strength

The compressive strength tests demonstrated that incorporating RHA and SBA as partial cement replacements influences the strength characteristics of concrete notably. For concrete with only RHA replacement, an increase in compressive strength was observed up to 10% replacement, with strength values at 28 days closely matching or slightly exceeding that of the control mix. Beyond this percentage, strength declined, likely due to increased porosity and dilution effects.

Similarly, SBA replacement improved compressive strength more significantly, peaking at 15% replacement. The 28-day compressive strength for 15% SBA replacement exceeded the normal concrete strength, indicating the strong pozzolanic activity and filler effect of SBA in densifying the cement matrix.

The combined replacement of RHA and SBA revealed a synergistic effect, with the optimal blend being 10% RHA and 15% SBA. This combination yielded the highest compressive strength at all tested ages, surpassing both individual replacements and normal concrete. This confirms that a proper balance between these materials maximizes their benefits by enhancing particle packing, improving microstructure, and promoting pozzolanic reactions.

Workability

Slump tests showed that RHA replacement tends to reduce workability due to its porous nature and higher water demand, which causes the mix to become stiffer as the RHA percentage increases. SBA, in contrast, had a comparatively neutral effect on workability, with some slight improvement or maintenance of slump values. When combined, mixes exhibited intermediate slump values, suggesting SBA partially compensates for the loss of workability caused by RHA.

Split Tensile Strength

The split tensile strength test results indicated improvements in tensile capacity with both RHA and SBA replacements up to optimal percentages. Maximum tensile strength was recorded for the combination of 10% RHA and 15% SBA replacements, consistent with compressive strength trends. This suggests enhanced bonding and crack resistance due to improved microstructure and interfacial transition zones.

Flexural Strength

Flexural strength measurements confirmed the positive influence of SBA on the bending resistance of concrete, with a peak at 15% replacement. RHA showed a slight reduction in flexural strength beyond 10% replacement, but when used

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in combination with SBA, the results were improved, reaching maximum strength at the 10% RHA and 15% SBA level. This highlights the complementary effects of these materials in strengthening concrete under flexural stresses.

Fig 2 Compression Testing Machine With Specimen

Summary

The optimum replacement levels are 10% for RHA and 15% for SBA for the M30 concrete mix.

Compressive, tensile, and flexural strengths of concrete were enhanced at these replacement levels.

The combination of RHA and SBA performed better than individual replacements, emphasizing the benefit of using both materials together.

Workability decreases with increasing RHA content, but SBA helps maintain workable concrete.

Strength development improves with curing age due to ongoingpozzolanic activity.

These results underline the potential of RHA and SBA as sustainable, eco-friendly partial cement replacements that enhance concrete performance while reducing environmental impact.

VI. CONCLUSION

Based on the comprehensive experimental study, it is concluded that partial replacement of cement with 10% Rice Husk Ash (RHA) and 15% Sugarcane Bagasse Ash (SBA) in M30 grade concrete significantly enhances its mechanical properties, including compressive, tensile, and flexural strengths, compared to conventional concrete. This optimal combination improves strength development over curing time due to effective pozzolanic reactions and better particle packing, while maintaining acceptable workability. Additionally, the use of RHA and SBA contributes to sustainability by utilizing agricultural waste materials, reducing cement consumption, and minimizing environmental impact without compromising concrete performance.

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