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An Experimental Study on Partial Replacement of Cement with Bagasse Ash and Egg Shell Powder in Concrete: A Sustainable Approach

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Abstract: *The search for sustainable alternatives to Portland cement in concrete production has become a significant focus due to environmental concerns associated with cement production, such as CO2 emissions. This study explores the use of bagasse ash and egg shell powder as partial replacements for cement in concrete. Concrete mixes were prepared with different proportions of bagasse ash (5%, 10%, 15%, and 20%) and egg shell powder (5%, 10%, 15%, and 20%). The effects of these replacements on the workability, compressive strength, and durability of concrete were analysed. The results show that the incorporation of bagasse ash and egg shell powder can improve concrete sustainability without significantly compromising strength, offering a promising approach to reducing cement consumption in concrete production.*

Keywords: *Cement replacement, Bagasse ash, Egg shell powder, Sustainability, Concrete properties, Environmental impact& Green construction.*

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I. Introduction

Concrete is the most widely used construction material worldwide. However, the production of cement, a key ingredient in concrete, significantly contributes to CO2 emissions. The rapid growth in urbanization and infrastructure development has significantly increased the demand for concrete, the most widely used construction material in the world.

Cement, a primary component of concrete, is responsible for substantial carbon dioxide (CO_2) emissions— contributing nearly 7-8% of global greenhouse gas emissions. With increasing environmental concerns and the need for sustainable construction practices, there is a pressing demand to explore eco-friendly alternatives to traditional cement. Agricultural and industrial waste materials, when suitably processed, offer a promising solution for partial replacement of cement in concrete. This study focuses on two such waste materials—**bagasse ash** and **eggshell powder**—as partial replacements for cement. Bagasse ash is a byproduct of sugarcane processing in sugar mills, rich in silica and possessing pozzolanic properties. Eggshells, commonly discarded in huge quantities, are rich in calcium carbonate (Ca CO_3), which on processing can exhibit cementitious characteristics.

The incorporation of these materials not only helps in reducing the consumption of cement but also addresses the issue of waste management, promoting the concept of circular economy. Furthermore, replacing cement with such materials can reduce the environmental footprint of concrete production, enhance certain mechanical properties, and improve the overall sustainability of construction practices.

This project investigates the effects of partial replacement of cement with bagasse ash and eggshell powder on the **workability, compressive strength, and durability** of concrete. Various mix designs are tested to determine the optimal replacement levels, aiming to achieve performance comparable to or better than conventional concrete while minimizing environmental impact.

II. Literature Review

- **Study by K. Akhilesh Reddy and I. Siva Kishore (2020)**

In their study titled "Study on Behaviour of Sugarcane Bagasse Ash (SCBA) with Partial Replacement of Cement for High Strength Concrete Mix (HSC)", K. Akhilesh Reddy and I. Siva Kishore (2020) investigated the effect of incorporating SCBA as a partial cement replacement in high strength concrete.

- **Study by Yashwanth M.K, B.G. Naresh Kumar, and Sandeep Kumar D.S (2019)**

In their research titled "Potential of Bagasse Ash as an Alternative Cementitious Material in Recycled Aggregate Concrete", Yashwanth M.K, B.G. Naresh Kumar, and Sandeep Kumar D.S (2019) explored the dual use of sugarcane bagasse ash (SCBA) and recycled aggregates in concrete production, focusing on sustainability and material performance.

➢ **Study by N. Sathi Paran (2021)**

In the paper titled "Utilization Prospects of Eggshell Powder in Sustainable Construction Material", N. Sathi Paran (July 2021) explored the potential of eggshell powder (ESP) as an alternative material in the construction industry, with a focus on its applications in sustainable.

➢ **Study by Sagar Paruthi and Hassan M. Magbool (2023)**

In their comprehensive review titled "A Review on Mechanical Properties of Eggshell Concrete and Strength Prediction Using Artificial Neural Network", Sagar Paruthi and Hassan M. Magbool (May 2023) Analysis the behaviour of concrete incorporating eggshell powder (ESP) as a partial cement replacement, with a focus on mechanical properties and predictive modelling using Artificial Neural Networks (ANN).

III. Materials and Methods

Materials Used- The following materials were used in the experimental study.

- **Cement**: Ordinary Portland Cement (OPC), conforming to IS 269:2015. Cement is a binding material widely used in construction for its strength and durability. It reacts with water through a process called hydration, forming a hard mass that binds aggregates together to form concrete. Ordinary Portland Cement (OPC) is the most commonly used type. However, its production is energy-intensive and contributes significantly to CO_2 emissions, making the exploration of partial replacements like industrial and agricultural waste crucial for sustainable construction.
- **Bagasse Ash**: Collected from a local sugarcane mill, sieved to remove large particles. Bagasse ash is a byproduct obtained from the combustion of bagasse—the fibrous residue left after sugarcane is crushed for juice extraction. Rich in silica, bagasse ash has pozzolanic properties, making it a suitable supplementary cementitious material. When finely ground, it enhances concrete strength and durability while improving resistance to chemical attacks. Using bagasse ash not only reduces the demand for cement but also solves the disposal problem of sugar industry waste.
- **Egg Shell Powder**: Egg shells were collected, cleaned, and ground into fine powder using a ball mill. Eggshells, mainly composed of calcium carbonate ($CaCO_3$), can be processed into a fine powder and used as a partial cement replacement. Upon calcination, they form calcium oxide (CaO), similar to the primary component of cement. Eggshell powder improves the early strength of concrete, enhances workability, and reduces the environmental footprint of concrete production. Utilizing eggshell waste in concrete also helps manage household and food industry waste effectively.

Figure 1. Egg shell and Egg shell powder.

Component	Cement	Bagasse Ash	Egg Shell Powder
SiO_2	20.5	55.2	0.5
CaO	62.5	12.3	94.0
Al_2O_3	5.1	4.8	0.7
Fe_2O_3	3.1	2.5	0.4
MgO	2.1	1.8	0.3
LOI (Loss on Ignition)	2.3	14.5	3.0

Chemical Composition of Materials (% by weight)

- **Aggregates**: Fine and coarse aggregates conforming to IS 383:2016. Aggregates are granular materials—such as sand (fine aggregate) and gravel or crushed stone (coarse aggregate)—that make up the bulk of concrete. They provide strength, volume, and stability to concrete structures. The quality, size, shape, and grading of aggregates significantly affect the concrete’s strength and workability. Sustainable alternatives like recycled or natural aggregates are being explored to reduce the environmental impact of extraction and transportation.

- **Water**: Clean potable water. Water is a key ingredient in the hydration process of cement and plays a vital role in workability and setting time of concrete. The water-cement ratio is crucial: too much water can weaken the concrete, while too little can affect workability and proper hydration. For concrete production, potable water free from impurities like salts, oils, or acids is generally recommended. Using treated wastewater or rainwater harvesting systems in concrete mixing is also a growing trend in sustainable construction.

Cement Bagasse Ash

Aggregate

METHODS:

This study involves the partial replacement of cement in concrete with bagasse ash and eggshell powder to evaluate its effect on the strength and workability of concrete. The methodology adopted is as follows:

1. **Collection of Materials**

- **Cement**: Ordinary Portland Cement (OPC) 43 grade was used as the base material.
- **Bagasse Ash**: Collected from a local sugar mill, sun-dried, and sieved through a 90-micron sieve.
- **Eggshell Powder**: Waste eggshells were collected, washed to remove impurities, dried, and ground into fine powder, then sieved through a 90-micron sieve.
- **Fine Aggregate**: Clean River sand conforming to Zone II of IS 383.
- **Coarse Aggregate**: Crushed granite of 20 mm size used.
- **Water**: Clean potable water used for mixing and curing.

2. **Mix Proportioning**

Concrete mix design was prepared for M20 grade using the nominal mix (1:1.5:3) as the control mix. Cement was partially replaced with bagasse ash and eggshell powder in varying percentages.

Mix	Cement (%)	Bagasse Ash (%)	Egg Shell powder (%)
M0	100	0	0
M1	90	5	5
M2	85	10	5
M3	80	10	10

3. **Batching and Mixing**

All materials were weighed and mixed in a pan mixer. The dry components (cement, bagasse ash, eggshell powder, fine and coarse aggregates) were first mixed thoroughly, followed by the gradual addition of water to achieve uniform consistency.

4. **Casting and Curing**

- Concrete cubes of size **150 mm × 150 mm × 150 mm** were cast for each mix.
- Molds were removed after 24 hours and the specimens were cured in water for **3,14 and 28days**.

5. **Testing**

Compressive Strength Test: Conducted on a compression testing machine at 3,14 and 28days.

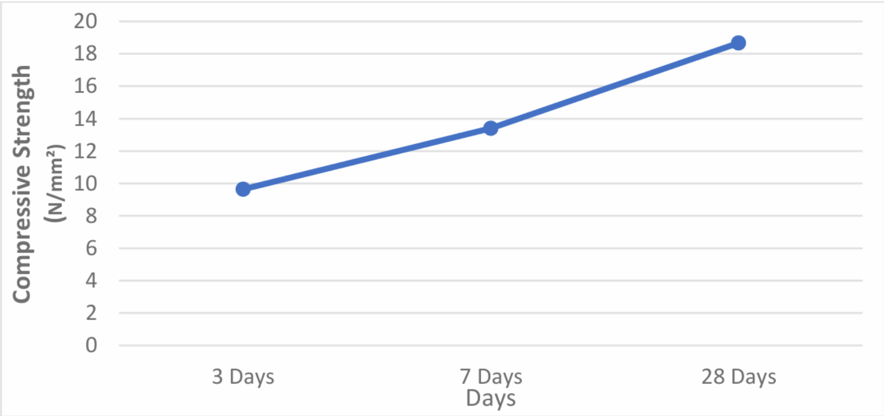
IV. Results and Discussion

Compressive strength tests were conducted on M20 grade concrete with 30% replacement of cement (20% Sugarcane Bagasse Ash and 10% Eggshell Powder) after 3, 7, and 28 days of curing. The following results were obtained:

Compressive Strength Results of M20 Concrete (30% Replacement):

Age of Concrete	Compressive Strength (MPa)
3 Days	9.64
7 Days	13.4
28 Days	18.67

Compressive Strength Development of M20 Concrete with 30% Cement Replacement



V. Discussion:

- 3 days, the concrete achieved 9.64 MPa, indicating good early-age strength (around 48% of 28-day strength).
- At 7 days, it reached 13.4 MPa, which is approximately 72% of its 28-day strength—suggesting strong hydration and pozzolanic reaction from the additives.
- At 28 days, the concrete achieved 18.67 MPa, which is slightly below the target of 20 MPa for M20 concrete but still acceptable for non-critical applications.

The combination of SCBA and ESP contributed effectively to strength development while promoting sustainability by reducing cement usage.

VI. Conclusion

The experimental study demonstrated that partial replacement of cement with Sugarcane Bagasse Ash (SCBA) and Eggshell Powder (ESP) in M20 grade concrete can yield satisfactory results in terms of compressive strength. A mix containing 20% SCBA and 10% ESP achieved an average 28-day compressive strength of 18.67 MPa, which is close to the standard requirement of 20 MPa. The results indicate that such replacements can reduce cement consumption, lower carbon emissions, and promote sustainable construction without significantly compromising strength. Hence, SCBA and ESP are promising supplementary cementitious materials for eco-friendly concrete applications.

VII. Future Scope

The outcomes of this research open promising avenues for further exploration in the domain of sustainable construction materials. While the current study demonstrates the feasibility of using Sugarcane Bagasse Ash (SCBA) and Eggshell Powder (ESP) as partial cement replacements in concrete, several aspects warrant deeper investigation to support their widespread application in real-world projects.

One of the most significant areas for future study is the **long-term durability performance** of SCBA- and ESP-blended concrete under various environmental conditions. Assessing resistance to sulphate and acid attacks, chloride ion penetration, carbonation, and freeze-thaw cycles will provide critical insights into its behaviour over extended periods, especially in aggressive environments such as coastal or industrial zones. Furthermore, **microstructural and mineralogical analyses** using advanced techniques such as Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Spectroscopy (EDX), X-ray Diffraction (XRD), and Thermogravimetric Analysis (TGA) can yield a detailed understanding of the material interactions, hydration behaviour, and formation of secondary reaction products like calcium-silicate-hydrate (C-S-H) gels. These insights can help optimize replacement ratios and improve the performance of blended concrete.

Future research may also investigate **higher replacement levels** of cement with SCBA and ESP, both individually and in combination, across various concrete grades (e.g., M30, M40, and beyond). Studying their impact on mechanical properties such as **flexural strength, tensile strength, modulus of elasticity**, and fracture toughness will contribute to a comprehensive understanding of their structural reliability.

In addition to laboratory-based testing, **field trials and real-time performance evaluations** are crucial to assess behaviour under actual service conditions. These trials could examine shrinkage, creep, thermal conductivity, and performance under dynamic loading or sustained stress. Research can also explore **compatibility with admixtures** like plasticizers, retarders, and superplasticizers, which are commonly used in modern concrete production.

An important area of expansion involves **environmental and economic impact assessments**. Life Cycle Assessment (LCA) studies can quantify the ecological benefits in terms of carbon footprint reduction, energy consumption, and resource efficiency. Moreover, cost-benefit analyses will help determine the financial viability of incorporating SCBA and ESP on a commercial scale, especially in regions where these wastes are abundantly available.

Another potential scope lies in the **standardization and codification** of SCBA and ESP use in cementitious materials. Establishing guidelines, specifications, and testing protocols through collaboration with regulatory bodies and industry stakeholders will promote wider acceptance and ensure safety, consistency, and performance across different applications.

Lastly, interdisciplinary research involving **material science, environmental engineering, and structural design** could further accelerate the development of eco-efficient, high-performance concrete. The integration of artificial intelligence (AI) and machine learning (ML) models for predicting performance based on mix parameters and curing conditions could also become a future research frontier.

In summary, the use of SCBA and ESP as supplementary cementitious materials presents a sustainable alternative for conventional cement. Continued research focusing on durability, microstructure, performance, economics, and standardization can pave the way for their effective integration into mainstream construction practices, supporting the global agenda for sustainable development.

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References

[1]. K. Akhilesh Reddy and I. Siva Kishore (2020). Study on Behaviour of SCBA with Partial Replacement of Cement for High Strength Concrete Mix (HSC). IRJET, Volume 7, Issue 6. https://www.irjet.net/archives/V7/i6/IRJET-V7I6223.pdf

[2]. Yashwanth M.K, B.G. Naresh Kumar, Sandeep Kumar D.S. (2019). Potential of Bagasse Ash as Alternative Cementitious Material in Recycled Aggregate Concrete. IJITEE, Volume 8, Issue 8. https://www.ijitee.org/wp-content/uploads/papers/v8i8/H6677068819.pdf

[3]. Lavanya M.R., Sugumaran B., Pradeep T. (2012). An Experimental Study on the Compressive Strength of Concrete by Partial Replacement of Cement with Sugarcane Bagasse Ash. IJERA, Vol. 2, Issue 4. https://www.ijera.com/papers/Vol2_issue4/EW2421352139.pdf

[4]. Sagar Paruthi, Hassan M. Mag Bool (2023). A Review on Mechanical Properties of Eggshell Concrete and Strength Prediction Using Artificial Neural Network. Materials Today: Proceedings, Elsevier. https://doi.org/10.1016/j.matpr.2023.05.419

[5]. N. Sathi Paran (2021). Utilization Prospects of Eggshell Powder in Sustainable Construction Material. Case Studies in Construction

Materials, Elsevier. https://doi.org/10.1016/j.cscm.2021.e00525

[6]. Deepa A., Abhijeet R. (2018). Experimental Study on Partial Replacement of Cement with Egg Shell Powder and Fly Ash. IJERT, Vol. 7, Issue 4. https://www.ijert.org/research/experimental-study-on-partial-replacement-of-cement-with-egg-shell-powder-and-fly-ash-IJERTV7IS040226.pdf

[7]. R. Ramesh, K. Vijay (2016). Experimental Investigation on Partial Replacement of Cement with Bagasse Ash. IJESRT. https://www.ijesrt.com/issues%20pdf%20file/Archive-2016/June-2016/66.pdf

[8]. Arivazhagan K., Thenmozhi R. (2019). Influence of Egg Shell Powder on the Mechanical Properties of Concrete. IJCIET, Volume 10, Issue 3. http://www.iaeme.com/MasterAdmin/UploadFolder/IJCIET_10_03_036/IJCIET_10_03_036.pdf

[9]. Vishwakarma, V., & Ram, L. (2018). A Review on Use of Eggshell Powder in Concrete. IJOER, Vol. 4, Issue 4. https://ijoer.com/a-review-on-use-of-eggshell-powder-in-concrete/

[10]. IS 2386 (Parts I–VIII):1963. Methods of Test for Aggregates for Concrete. BIS. https://law.resource.org/pub/in/bis/S03/is.2386.1.1963.pdf