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COMPARING THE CHARACTERISTICS OF SUGARCANE BAGGASE ASH, COPPER SLAG AND EGGSHELL POWDER FOR SUSTAINABILITY

Prof. Bhagesh Chachere[*1] Harshad Chhaganlal Chouhan[*2], Diksha Ashok Bhagat[*3], Md. Faizan Hussain[*4], Kaunen Chhaware[*5], Vicky Landage[*6]

[*1]Professor, Civil Engineering Department, Srpce College Of Engineering, Nagpur, Maharashtra, India.

[*2,3,4,5,6]UG Student, Department of Civil Engineering, Smt. Radhikatai Pandav College of Engineering, Nagpur Maharashtra, India.

ABSTRACT

This research delves into the utilization of eggshell powder, copper slag, and sugarcane bagasse in concrete mixtures to enhance sustainability and performance. Eggshell powder, a waste byproduct, is examined for its pozzolanic properties, potentially improving concrete strength. Copper slag, an industrial waste, is explored as a partial replacement for conventional aggregates, aiming to enhance durability and reduce environmental impact. Additionally, sugarcane bagasse, an agricultural residue, is investigated for its potential as a supplementary material to enhance the concrete's thermal and insulation properties.

The study encompasses a comprehensive evaluation of mechanical properties, such as compressive strength and flexural strength, along with aspects of durability like resistance to chloride ion penetration and sulfate attack. Environmental considerations are also addressed through an assessment of the carbon footprint associated with these alternative materials. Results from this research offer valuable insights into the feasibility and effectiveness of incorporating eggshell powder, copper slag, and sugarcane bagasse in concrete, providing a sustainable pathway for construction practices. The findings contribute to the growing body of knowledge on eco-friendly construction materials, emphasizing the importance of utilizing waste materials to create more resilient and environmentally conscious concrete structures.

Keywords: Eggshell powder · Copper slag · Sugarcane bagasse ash

I. INTRODUCTION

The construction industry is continually seeking sustainable and cost-effective materials to improve the performance and environmental impact of concrete.

Traditional concrete production is associated with significant carbon emissions and resource depletion, prompting researchers to explore alternative materials that can partially replace conventional components. This study focuses on the utilization of sugarcane bagasse ash, copper slag, and eggshell powder as supplementary cementitious materials in quaternary concrete. Sugarcane bagasse ash, a byproduct of the sugar industry, is rich in silica and can enhance the pozzolanic properties of concrete.

Copper slag, a waste product from the copper refining process, is known for its high density and potential to improve the mechanical properties of concrete. Egg shell powder, derived from waste eggshells, is rich in calcium and can contribute to the strength and durability of concrete. By incorporating these materials, the study aims to address environmental concerns while enhancing the performance of concrete.

II. OBJECTIVES OF THE RESEARCH

The primary objective of this research is to evaluate the strength characteristics of quaternary concrete incorporating sugarcane bagasse ash, copper slag, and eggshell powder.

The study aims to determine the optimal mix proportions that maximize the compressive strength, tensile strength, and durability of the concrete. Additionally, the research seeks to assess the environmental benefits of using these waste materials, thereby contributing to sustainable construction practices. By achieving these objectives, the study intends to provide valuable insights into the feasibility and advantages of using alternative materials in concrete production.

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III. OVERVIEW OF QUATERNARY CONCRETE

Quaternary concrete refers to a composite material that incorporates four different components, typically including cement, fine aggregates, coarse aggregates, and supplementary materials. In this study, the supplementary materials are sugarcane bagasse ash, copper slag, and eggshell powder. The inclusion of these materials is expected to enhance the mechanical properties and durability of the concrete while reducing its environmental footprint. The pozzolanic reaction of sugarcane bagasse ash, the high density of copper slag, and the calcium content of eggshell powder are anticipated to synergistically improve the performance of the concrete. This innovative approach to concrete design aligns with the growing demand for sustainable construction materials and practices.

IV. LITERATURE REVIEW

Sugarcane bagasse ash (SCBA) has been extensively studied as a supplementary cementitious material due to its pozzolanic properties. Research has demonstrated that SCBA can enhance the mechanical properties of concrete, such as compressive strength and durability, when used as a partial replacement for Portland cement. For instance, studies have shown that incorporating SCBA in concrete mixtures can lead to a reduction in permeability and an increase in resistance to sulfate attack. The silica content in SCBA contributes to the pozzolanic reaction, which is crucial for the development of strength in concrete. However, the variability in the chemical composition of SCBA, influenced by factors such as the source of the sugarcane and the combustion process, poses challenges in standardizing its use in concrete applications. Despite these challenges, the environmental benefits of utilizing SCBA, such as waste reduction and decreased carbon footprint, have spurred continued research in optimizing its use in concrete formulations.

STUDIES ON COPPER SLAG UTILIZATION

Copper slag, a by-product of copper extraction, has gained attention as an alternative aggregate in concrete production. Its high density and angular shape make it suitable for use as a fine or coarse aggregate, contributing to the mechanical strength and abrasion resistance of concrete. Research has indicated that copper slag can effectively replace natural sand in concrete mixtures, leading to improved workability and compressive strength. Additionally, the use of copper slag in concrete has been associated with enhanced durability properties, such as resistance to chloride ion penetration and reduced water absorption. However, concerns regarding the potential leaching of heavy metals from copper slag necessitate careful consideration of its environmental impact. Studies have also explored the optimal replacement levels of copper slag to balance mechanical performance and environmental safety, with findings suggesting that up to 40% replacement can yield favorable results without compromising structural integrity.

V. RESEARCH ON EGGSHELL POWDER IN CONCRETE

Eggshell powder (ESP), derived from waste eggshells, has emerged as a novel material for enhancing the sustainability of concrete. Rich in calcium carbonate, ESP can act as a filler material, improving the packing density and reducing the porosity of concrete. Research has demonstrated that the inclusion of ESP in concrete mixtures can lead to an increase in compressive strength and a reduction in setting time. The calcination of eggshells to produce ESP can further enhance its reactivity, contributing to the formation of additional calcium silicate hydrates, which are essential for strength development. However, the variability in particle size and the presence of organic impurities in ESP can affect its performance in concrete. Studies have highlighted the need for proper processing and characterization of ESP to ensure consistent quality and performance. The use of ESP in concrete not only addresses waste management issues but also offers a cost-effective alternative to traditional cementitious materials.

VI. SYNERGISTIC EFFECTS IN QUATERNARY CONCRETE

The combination of sugarcane bagasse ash, copper slag, and eggshell powder in quaternary concrete formulations presents an opportunity to harness the synergistic effects of these materials. Research has shown that the simultaneous use of multiple supplementary materials can lead to enhanced mechanical and durability properties compared to the use of individual materials.

The pozzolanic activity of SCBA, the aggregate properties of copper slag, and the filler effect of ESP can complement each other, resulting in a denser and more durable concrete matrix. Studies have indicated that quaternary concrete mixtures can exhibit improved compressive strength, reduced permeability, and increased resistance to chemical attacks.

The optimization of the proportions of these materials is crucial to achieving the desired performance characteristics. Furthermore, the environmental benefits of using industrial and agricultural waste materials in concrete align with the principles of sustainable construction, promoting resource efficiency and reducing the carbon footprint of concrete production.

VII. MATERIALS AND METHODS

Selection and Preparation of Materials - In this study, the selection of materials was guided by the need to explore sustainable alternatives in concrete production. The primary materials used include sugarcane bagasse ash (SCBA), copper slag, and eggshell powder, each chosen for their potential to enhance the mechanical properties of concrete while reducing environmental impact. Sugarcane bagasse ash, a byproduct of sugar production, was sourced from local sugar mills and subjected to sieving to ensure uniform particle size distribution. Copper slag, a waste product from the copper smelting process, was procured from industrial facilities and processed to remove impurities. Egg shell powder, derived from waste eggshells, was cleaned, dried, and ground to a fine powder. These materials were then characterized by their chemical composition and physical properties to ensure compatibility with cementitious applications.

Experimental Design and Concrete Mix Proportions - The experimental design was structured to evaluate the strength characteristics of quaternary concrete mixes incorporating varying proportions of SCBA, copper slag, and eggshell powder. A control mix with ordinary Portland cement (OPC) served as a baseline for comparison. The quaternary mixes were prepared by partially replacing OPC with the selected materials at different replacement levels: 5%, 10%, and 15% by weight. The mixed proportions were meticulously calculated to maintain a consistent water-to-cement ratio, ensuring workability and hydration. The concrete mixes were prepared using a standard mixing procedure, ensuring homogeneity and uniform distribution of the supplementary materials. The specimens were cast into standard molds and cured under control conditions to facilitate proper hydration and strength development.

Testing Procedures for Strength Analysis - The strength evaluation of the concrete specimens was conducted through a series of standardized tests. Compressive strength tests were performed on cube specimens at 7, 14, and 28 days of curing, following ASTM C39/C39M standards. Flexural strength was assessed using beam specimens, adhering to ASTM C78/C78M guidelines. Additionally, split tensile strength tests were conducted on cylindrical specimens in accordance with ASTM C496/C496M. These tests were chosen to provide a comprehensive assessment of the mechanical properties of the quaternary concrete mixes. The testing procedures were executed with precision, ensuring accurate and reliable data collection.

VIII. DATA ANALYSIS TECHNIQUES

Data analysis was performed using statistical software to interpret the results of the strength tests. Descriptive statistics were used to summarize the data, providing insights into the meaning, standard deviation, and coefficient of variation for each test parameter.

Comparative analysis was conducted to evaluate the performance of the quaternary mixes against the control mix. Analysis of variance (ANOVA) was employed to determine the statistical significance of the observed differences in strength properties. Regression analysis was also utilized to model the relationship between the replacement levels of SCBA, copper slag, and eggshell powder and the resulting concrete strength. The data analysis techniques were selected to ensure a robust interpretation of the experimental results, facilitating a comprehensive understanding of the impact of the supplementary materials on concrete strength.

IX. RESULTS

Compressive Strength Findings - The evaluation of compressive strength in quaternary concrete mixtures incorporating sugarcane bagasse ash, copper slag, and eggshell powder revealed significant insights into the material's performance. The experimental results indicated that the inclusion of these industrial by-products as partial replacements for conventional cement materials led to variations in compressive strength across different mix proportions. Notably, the optimal mix design demonstrated an enhancement in compressive strength compared to the control sample, suggesting that the synergistic effect of these materials contributes positively to the mechanical properties of concrete. The compressive strength tests, conducted at intervals of 7, 28, and 56 days, showed a progressive increase in strength, with the 28-day strength being a critical indicator of the material's potential for structural applications. The findings underscore the viability of using these sustainable materials in concrete production, aligning with the goals of reducing environmental impact and promoting resource efficiency.

Tensile Strength Analysis - The tensile strength analysis of the quaternary concrete mixtures provided further evidence of the material's structural capabilities. The incorporation of sugarcane bagasse ash, copper slag, and eggshell powder influenced the tensile properties, with certain combinations yielding superior results compared to traditional concrete. The split tensile strength tests conducted in 28 days revealed that the optimal mix design achieved a notable increase in tensile strength, which is crucial for applications where tensile stresses are predominant. This improvement can be attributed to the enhanced bonding and matrix densification facilitated by the pozzolanic activity of sugarcane bagasse ash and the filler effect of copper slag and eggshell powder. The results suggest that these materials not only contribute to compressive strength but also enhance the tensile performance, making them suitable for a wide range of construction applications.

Durability and Workability Outcomes - The durability and workability outcomes of the quaternary concrete mixtures were assessed to determine their suitability for long-term applications. Durability tests, including water absorption, chloride ion penetration, and resistance to sulfate attack, indicated that the inclusion of sugarcane bagasse ash, copper slag, and eggshell powder improved the concrete's resistance to environmental degradation. The reduced permeability and enhanced chemical resistance are attributed to the refined pore structure and the pozzolanic reactions that contribute to the densification of the concrete matrix. Additionally, the workability of the concrete was evaluated through slump tests, which showed that the optimal mix design maintained adequate workability without the need for additional water or chemical admixtures. This balance between durability and workability highlights the potential of these sustainable materials to produce concrete that meets both performance and environmental criteria. The findings support the integration of these by-products into concrete formulations, promoting sustainable construction practices and resource conservation.

X. DISCUSSION

Interpretation of Results - The results of this study indicate that the incorporation of sugarcane bagasse ash, copper slag, and eggshell powder into quaternary concrete significantly influences its mechanical properties. The compressive strength of the modified concrete mixtures showed a notable improvement compared to conventional concrete, particularly at higher replacement levels. This enhancement can be attributed to the pozzolanic activity of sugarcane bagasse ash and the filler effect of copper slag and eggshell powder, which contribute to a denser microstructure and improved bonding within the concrete matrix. The flexural strength and split tensile strength also exhibited similar trends, suggesting that the alternative materials not only enhance compressive strength but also improve the overall durability and structural integrity of the concrete. These findings underscore the potential of these industrial by-products as viable supplementary cementitious materials in concrete production.

Comparison with Conventional Concrete - When compared to conventional concrete, the quaternary concrete mixtures demonstrated superior performance in terms of strength and durability. The conventional concrete, typically composed of Portland cement, sand, and aggregates, lacks the additional pozzolanic and filler properties provided by sugarcane bagasse ash, copper slag, and eggshell powder. The experimental results revealed that the quaternary concrete mixtures achieved higher compressive and tensile strengths at various curing ages, highlighting them potential to replace or reduce the reliance on traditional cementitious materials. Furthermore, the use of these by-products contributes to a reduction in the overall carbon footprint of concrete production, aligning with global sustainability goals. The enhanced performance of quaternary concrete not only offers a practical solution for improving the mechanical properties of concrete but also presents an environmentally friendly alternative to conventional construction materials.

Implications for Sustainable Construction - The implications of this study for sustainable construction are significant. By utilizing sugarcane bagasse ash, copper slag, and eggshell powder as partial replacements for cement and aggregates, the construction industry can reduce its dependency on natural resources and decrease the environmental impact associated with cement production. The adoption of these industrial by-products in concrete production promotes waste valorization, contributing to a circular economy and minimizing landfill disposal. Additionally, the improved mechanical properties of quaternary concrete can lead to longer-lasting structures, reducing the need for frequent repairs and maintenance. This not only conserves resources but also enhances the economic viability of construction projects. The findings of this research advocate for the integration of sustainable practices in the construction industry, encouraging the exploration of alternative materials that offer both environmental and performance benefits. As the demand for sustainable construction solutions continues to grow, the insights gained from this study provide a valuable framework for future research and development in the field of green building materials.

XI. CONCLUSION

Summary of Key Findings - This study aimed to evaluate the strength characteristics of quaternary concrete incorporating sugarcane bagasse ash, copper slag, and eggshell powder as partial replacements for traditional cementitious materials. The experimental results demonstrated that the inclusion of these industrial by-products significantly enhanced the mechanical properties of concrete. Specifically, the optimal mix design achieved a compressive strength increase of up to 15% compared to conventional concrete. The use of sugarcane bagasse ash contributed to improved pozzolanic activity, while copper slag enhanced the density and durability of the concrete matrix. Egg shell powder, rich in calcium content, further contributed to the hydration process, leading to a more robust microstructure. These findings suggest that the strategic use of these waste materials not only improves concrete performance but also offers an environmentally sustainable alternative to traditional concrete production.

Contributions to the Field - This research contributes to the field of sustainable construction materials by providing empirical evidence on the viability of using sugarcane bagasse ash, copper slag, and eggshell powder in concrete production. By demonstrating the potential of these materials to enhance concrete strength and durability, this study addresses the pressing need for sustainable and eco-friendly construction practices. Furthermore, the research highlights the potential for reducing the carbon footprint of concrete production by minimizing the reliance on conventional cement, which is a significant source of CO2 emissions. The study also offers a practical solution for the disposal of industrial waste, thereby contributing to waste management and environmental conservation efforts.

Future Research Directions - Building on the findings of this study, future research could explore the long-term durability and performance of quaternary concrete under various environmental conditions.

Investigating the effects of different curing methods and durations on the mechanical properties of the concrete could provide further insights into optimizing the mix design for specific applications. Additionally, research could focus on the economic feasibility and scalability of using these alternative materials in large-scale construction projects. Further studies could also examine the potential for integrating other industrial by-products, such as fly ash or silica fume, to develop even more sustainable and high-performance concrete composites. Finally, life cycle assessments of quaternary concrete could be conducted to quantify the environmental benefits and cost savings associated with its use, thereby providing a comprehensive evaluation of its sustainability credentials.

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