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Mookambigai College of Engineering, Keeranur, Tamil Nadu, India

Evaluation of Concrete Strength using Eggshell Powder as Partial Replacement of Cement

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ABSTRACT: The growing environmental impact of cement production has driven the need for sustainable materials in the construction industry. This study investigates the potential of using eggshell powder (ESP) and palm oil fuel ash (POFA) as partial replacements for cement in concrete to enhance sustainability and mechanical performance. Eggshell powder, rich in calcium carbonate ($CaCO_3$), contributes to the lime content essential for hydration, while POFA, high in silica (SiO_2), exhibits pozzolanic properties that form additional calcium silicate hydrate (C–S–H) gel, improving long-term strength. In this experimental work, 20% of cement was replaced by a hybrid blend of 10% ESP and 10% POFA by weight. Concrete specimens and beam elements were cast and tested for workability, compressive strength, split tensile strength, and flexural strength at different curing ages. The results revealed that the hybrid mix achieved higher compressive strength than the conventional M35 grade concrete beam, indicating enhanced hydration efficiency and improved microstructural bonding due to the synergistic effect between ESP and POFA. The study further confirmed that the inclusion of these materials reduced the overall carbon footprint and promoted effective waste utilization without compromising structural performance. Hence, the combination of eggshell powder and palm oil fuel ash can serve as a sustainable, economical, and high-performance cement substitute for eco-friendly concrete production.

KEYWORDS: Eggshell powder, palm oil fuel ash, compressive strength, sustainable concrete, pozzolanic reaction, hybrid cement replacement, eco-friendly construction.

I. INTRODUCTION

Concrete is the most commonly used construction material worldwide, yet the production of ordinary Portland cement (OPC) contributes significantly to environmental degradation through high carbon dioxide emissions and energy consumption. To achieve sustainable development, researchers are exploring the use of industrial and agricultural waste materials as partial replacements for cement without compromising performance. Among these materials, eggshell powder (ESP) and palm oil fuel ash (POFA) have shown great potential due to their chemical and mineral compositions. ESP, rich in calcium carbonate ($CaCO_3$), enhances the lime content needed for hydration, while POFA, containing a high percentage of silica (SiO_2), exhibits pozzolanic reactivity that contributes to long-term strength development. In this study, 20% of cement was replaced with a hybrid mix of 10% ESP and 10% POFA by weight, and concrete specimens and beams were tested for workability and strength characteristics. The results demonstrated that the hybrid beam exhibited higher compressive strength than the conventional M35 grade beam, attributed to the synergistic reaction between calcium and silica compounds. This research supports the use of ESP and POFA as eco-friendly and sustainable alternatives that enhance structural performance while reducing the environmental footprint of concrete production.

II. SCOPE OF PROJECT

The research investigates the influence of this combination on the workability, compressive strength, split tensile strength, and flexural strength of concrete at different curing periods. Special emphasis is placed on the behavior of reinforced concrete beams made with the hybrid mix, particularly comparing their compressive strength to that of the conventional M35 grade concrete beam. The scope includes material characterization, mix design, specimen preparation, testing, and data analysis to understand the synergistic effect of the calcium-rich ESP and silica-rich

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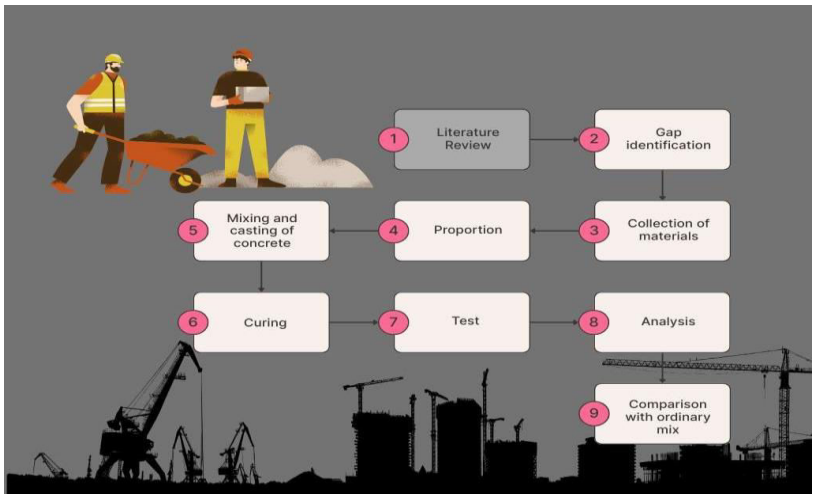
POFA on cement hydration and microstructural development. The study also aims to determine the suitability of this hybrid blend as a sustainable and cost-effective cement substitute that can enhance concrete strength while minimizing environmental impact. Ultimately, the research supports the integration of agricultural and industrial waste materials into construction practices, contributing to green and low-carbon concrete technologies.

III. PROCESS INVOLVED



IV. ANSYS ANALYSIS

A detailed finite element analysis was conducted using ANSYS Workbench to evaluate the structural performance of the concrete beam incorporating 20% cement replacement with a hybrid mix of 10% eggshell powder (ESP) and 10% palm oil fuel ash (POFA). The analysis compared the equivalent (von Mises) stress and total deformation of the hybrid beam with those of a conventional M35 grade concrete beam under identical loading and boundary conditions. The results revealed that the replaced beam exhibited lower equivalent stress and reduced deformation than the ordinary beam, indicating improved stiffness, enhanced stress distribution, and better resistance to loading. The decrease in equivalent stress values signifies a more uniform internal stress flow, attributed to the denser microstructure and enhanced bonding of the hybrid concrete. The lower deformation further confirms the beam's superior rigidity and load-bearing efficiency. Overall, the ANSYS simulation results validate that the incorporation of ESP and POFA improves the mechanical response and structural integrity of the concrete beam, demonstrating its suitability for sustainable and high- performance construction applications.

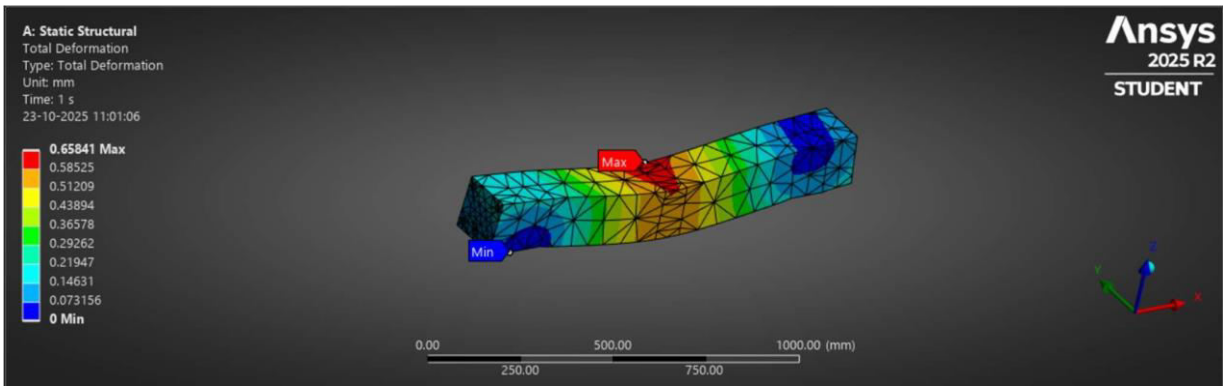


Image of deformation observed in ordinary M35 grade concrete beam

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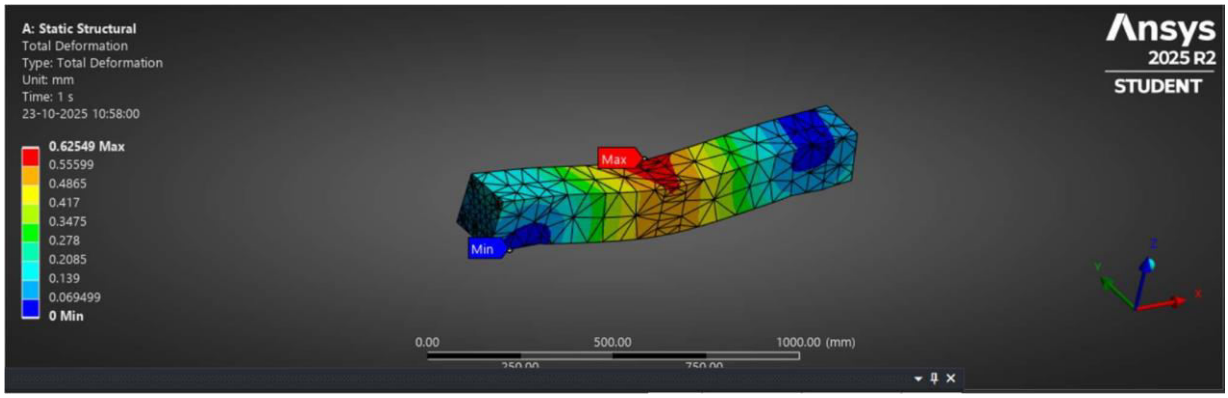

Image of deformation observed in 20% replaced M35 grade concrete beam

V. FINDINGS

The experimental investigation revealed that the concrete beam incorporating a 20% hybrid replacement of cement with 10% eggshell powder (ESP) and 10% palm oil fuel ash (POFA) demonstrated superior compressive strength compared to the conventional M35 grade concrete beam. The presence of calcium carbonate in ESP enhanced the lime content, promoting effective cement hydration, while the silica-rich POFA contributed to additional pozzolanic reactions, forming more calcium silicate hydrate (C–S–H) gel that improved the overall density and bonding of the concrete matrix. This synergistic effect between ESP and POFA led to a significant increase in compressive performance, indicating improved load-bearing capacity and structural integrity.

Furthermore, the beam exhibited good workability and consistent curing performance, with reduced porosity and enhanced durability characteristics. Although a slight reduction in early strength was observed, the long-term strength gain surpassed that of the control mix. These findings confirm that the combination of ESP and POFA can effectively enhance the mechanical properties of concrete, making it a viable and sustainable alternative for high-strength structural applications.

VI. ACKNOWLEDGEMENTS

We are thankful to our institution for providing the necessary facilities and resources to carry out this work. Our heartfelt thanks go to our teammates for their collaboration, dedication, and innovative contributions. We also appreciate the encouragement from our friends and family during this project. Special thanks to the open-source community behind n8n and AI tools for enabling our research. This project, **"Evaluation of concrete strength of concrete using eggshell powder as partial replacement of cement"** was made possible through collective effort and continuous learning. We are deeply grateful to everyone who contributed directly or indirectly to the successful completion of this work.

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