Incorporating Rice Husk Ash and Nano Particles to enhance the Sustainability of Self-Compacting Concrete

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Abstract— The pursuit of sustainable construction practices has driven researchers to explore innovative ways of improving the properties of concrete. This study delves into the realm of self- compacting concrete (SCC) to enhance its sustainability and performance by synergistically incorporating two distinct materials rice husk ash (RHA) and nano-alumina particles. The primary objective of this investigation is to assess the impact of varying proportions of RHA (ranging from 0% to 30%) and nano-alumina particles (at concentrations of 1%, 2%, and 3%) on the mechanical properties of SCC with a target grade of M30. A comprehensive evaluation is conducted, focusing on the concrete's compressive, split, and flexural strengths at different curing durations of 7, 14, and 28 days. Rice husk ash, a pozzolanic material, offers dual benefits. Firstly, it engages in the pozzolanic reaction, contributing to enhanced strength and durability. Secondly, its fine particles aid in optimizing the packing density of the concrete mixture. Nano-alumina particles, with their exceptional surface area and reactivity, have the potential to refine the interfacial transition zone and nucleation sites within the concrete matrix. This is expected to yield improved hydration kinetics and a denser microstructure, ultimately leading to heightened mechanical performance.

Index Terms— Self-compacting concrete (SCC), Rice husk ash (RHA), Nano-alumina particles, Sustainability, Mechanical properties, Compressive strength.

I. INTRODUCTION

In the realm of construction, self-compacting concrete (SCC) stands as a remarkable innovation, transforming the way we build. Its innate capacity to flow and fill formwork without the need for traditional compaction techniques has redefined construction efficiency, reduced labor costs, and mitigated noise pollution associated with conventional concrete placement methods. Yet, as the construction industry continues to grow and the world grapples with environmental challenges, the imperative to enhance the sustainability of SCC has become increasingly clear. Traditional SCC formulations, like their conventional concrete counterparts, rely heavily on non-renewable resources, particularly Portland cement, a primary contributor to carbon emissions during production. As global consciousness shifts towards ecological responsibility, the need to reconsider construction materials and practices to reduce their environmental impact has never been more pressing. This introductory narrative sets the stage for a comprehensive exploration of the potential to augment the sustainability of self-compacting concrete through the synergistic integration of two distinct elements: rice husk ash (RHA) and nanoparticles. The construction industry is a linchpin of societal development, shaping the infrastructure upon which modern life depends. It is responsible for constructing our homes, workplaces, roads, bridges, and countless other structures, fostering economic growth and societal advancement. Central to this industry is concrete, revered for its strength, versatility, and widespread availability, serving as the bedrock of construction materials across the globe. A monumental leap in concrete technology was the advent of self-compacting concrete (SCC), a material with a unique ability to flow and conform to formwork without necessitating traditional consolidation processes like vibration. This distinctive attribute has not only revolutionized construction efficiency but also reduced labor costs and mitigated the noise pollution traditionally linked with concrete placement. However, despite its indisputable merits, SCC, like conventional concrete, has been dogged by environmental drawbacks, most notably the substantial use of Portland cement, which is associated with high carbon emissions during its manufacturing process. The cement industry ranks as one of the world's largest carbon dioxide (CO_2) emitters, making it a significant contributor to climate change. Consequently, there is a growing emphasis on rendering SCC, and the construction industry as a whole, more sustainable.

II. LITERATURE REVIEW

Mehdizadeh B, Jahandari S, et al (2021) offered a comprehensive analysis of self-compacting (SC) mortars that incorporate varying proportions of alumina nanoparticles (NA) at 0%, 1%, 3%, and 5%, along with different levels of rice husk ash (RHA) at 0% and 30% to replace Portland cement. The research aims to assess the workability, mechanical properties, and durability of SC mortars enriched with NA and RHA. Various aspects, including fresh properties (such as slump flow diameter and V-funnel flow time), hardened properties (comprising compressive strength, flexural strength, and ultrasonic pulse velocity), and durability properties (including water absorption, rapid chloride permeability, and electrical resistivity), were investigated. The findings revealed that the incorporation of NA and RHA had minimal impact on the workability and water absorption characteristics of the SC mortars. However, notable improvements in compressive and flexural strength were observed in the SC mortars treated with NA or a combination of NA and RHA. Furthermore, the introduction of RHA and NA led to a reduction in rapid chloride permeability and a significant enhancement in the electrical resistivity of the SC mortars.
In conclusion, it was determined that the simultaneous utilization of 30% RHA and 3% NA as a replacement for cement in SC mortars yielded the most favorable mechanical and durability performance.

Praveenkumar T.R, Vijayalakshmi M et al (2020) investigated concrete formulations incorporating Titanium dioxide (TiO_2) nanoparticles and rice husk ash (RHA) as pozzolanic materials, which serve as partial replacements for Portland cement (PC). Specifically, a fixed 10% of RHA was used, while TiO_2 nanoparticles were introduced at various replacement levels ranging from 0% to 5% in lieu of PC. The morphological and mineralogical characteristics of TiO_2 nanoparticles were analyzed through Scanning Electron Microscope (SEM) and X-ray Diffraction (XRD) techniques, respectively. The blended cement concrete mixes underwent a comprehensive assessment focusing on both mechanical and durability performance aspects, which encompassed compressive, flexural, and splitting tensile strengths, as well as resistance to acid attack and chloride penetration. The results demonstrated that concrete mixes combining 10% RHA and 3% TiO_2 nanoparticles as partial replacements for PC exhibited the highest strengths and durability performance. Beyond the 3% replacement level of TiO_2 nanoparticles, there was a noticeable decline in both strength and durability properties. Hence, the replacement of 3% nano-TiO_2 can be considered the optimal level for achieving the desired concrete characteristics.

PengpZhang , ShiyaopWei ,etpal (2022) provides an overview of the physical and chemical properties of rice husk ash (RHA) and examines the properties of self-consolidating concrete (SCC) mixtures that incorporate RHA. The investigation covers various aspects, including fresh properties (focusing on workability evaluation methods and key factors), mechanical properties (such as compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity), and durability properties (including water absorption, sorptivity, acid resistance, chloride penetration resistance, electrical resistivity, and susceptibility to alkali silica reaction).

The findings indicate that the workability of SCC tends to decrease as the proportion of incorporated RHA increases. In the range of approximately 15–20% incorporation, RHA has a beneficial impact on the mechanical properties and durability of SCC. Incorporating RHA into SCC not only has the potential to reduce the environmental impact of rice husk disposal but also supports sustainable development in the cement industry while potentially lowering the cost of producing SCC.
Koti Chiranjeevi et al (2023) studied that Geopolymer concrete is typically made from alumina-silicate materials combined with an alkaline solution. It serves as an environmentally friendly alternative to traditional concrete by reducing or eliminating the need for cement. Agricultural and industrial byproducts, such as rice husk ash and fly ash, can be used as binding materials and activated with an alkaline solution. Concrete structures, including piers, dams, canals, and more, are integral across the nation. To ensure

the safety and longevity of these structures, it's crucial to address the durability of concrete.

This study investigates the strength and durability characteristics resulting from the combined effects of rice husk ash, fly ash, ground granulated blast furnace slag (GGBS), and nano TiO_2 in geopolymer concrete specimens. The inclusion of GGBS and rice husk ash significantly enhances the properties of the concrete. Furthermore, the addition of GGBS eliminates the need for controlled environmental curing of the concrete.

Mounika G, Baskar R et al (2022) explored the potential of utilizing rice husk ash (RHA) as a conventional binder in concrete. It encompasses an in-depth review of the physical, chemical, and mechanical properties of various types of concrete incorporating RHA. Summarily, the literature review indicates that concrete made with RHA tends to exhibit lower workability compared to conventional concrete. The density of RHA-containing concrete is generally less than that of its conventional counterpart, making it suitable for a wide range of applications. Furthermore, the mechanical properties, such as compressive strength, flexural strength, and splitting tensile strength, show improvement when RHA is used as a partial replacement (up to 30%). Concrete formulations with RHA exhibit enhanced bond strength compared to conventional mixes. Additionally, they demonstrate reduced chloride diffusion, minimized efflorescence, and increased resistance to sulfate and chemical attacks, making them a promising choice for various construction scenarios.

Meddah M.S, Praveenkumar T.R et al (2020) investigated the effects of combining Al_2O_3 nanoparticles with Rice Husk Ash (RHA) on various aspects of concrete, including mechanical properties (such as flexural, splitting tensile, and compressive strengths) and durability properties (specifically, resistance to hydrochloric acid attack and chloride permeation). The study involves replacing a fixed amount of 10% of Portland cement (PC) with RHA, and Al_2O_3 nanoparticles are introduced as partial substitutions for PC at levels of 1%, 2%, 3%, and 4%. The surface morphology and microstructure of the modified cement concretes were examined using Scanning Electron Microscope (SEM). The findings indicate that Al_2O_3 nanoparticles serve a dual role as both a filling material and a reactive one. Their increased contribution to the volume of calcium silicate hydrates (C-S-H) leads to improved strengths and durability properties in the concrete material. Furthermore, the study identifies that a 3% content of Al_2O_3 nanoparticles represents the optimal proportion for replacing part of the cement, resulting in the greatest enhancements in both mechanical and durability properties. The combination of up to 3% Al_2O_3 nanoparticles with 10% RHA in the design of modified cement concretes proves to be an effective and environmentally friendly approach, yielding concrete with enhanced strength and durability.

III. METHODOLOGY

The experimental design and approach for incorporating rice husk ash (RHA) and nanoparticles to enhance the sustainability of self-compacting concrete (SCC) encompass a systematic and comprehensive process to achieve the research objectives. The overall experimental design involves several key components:

1. Literature Review: The experimental design begins with an extensive literature review to gather existing knowledge about the use of RHA and nanoparticles in SCC. This step is critical for understanding prior research, identifying knowledge gaps, and determining the current state of the art in sustainable concrete technology.
2. Material Selection: The research involves the careful selection of materials, including RHA and nanoparticles. The choice of RHA sources and types, as well as the selection of specific nanoparticles (e.g., silica, titanium dioxide), is a crucial initial step. Material characterization is conducted to assess their properties, including particle size, chemical composition, and reactivity.
3. Mix Design Development: The research focuses on developing SCC mix designs that incorporate RHA and nanoparticles effectively. Mix proportions are formulated, considering the desired concrete performance criteria, including workability, strength, and durability. Various combinations of RHA and nanoparticles are explored to optimize the mixture.
4. Experimental Setup: Laboratory experiments are conducted to evaluate the performance of SCC mixtures. These experiments encompass a wide range of tests to assess fresh properties, mechanical properties, workability, durability, and environmental impact. Specific tests may include:

• Compressive strength tests to evaluate the mechanical properties.
• Flexural strength tests to assess the material's capacity to withstand bending stresses.
• Flowability tests, such as the slump flow test and V-funnel test, to determine workability.
• Rheological measurements to understand the SCC's flow behavior.
• Environmental impact assessments, including life cycle analysis to quantify carbon emissions and sustainability benefits.

5. Pozzolanic Reaction Analysis: The research delves into the pozzolanic reaction between RHA and the hydration products of SCC. Techniques such as X-ray diffraction (XRD) and scanning electron microscopy (SEM) may be employed to analyze the formation of calcium silicate hydrate (C-S-H) gel and other reaction products.

6. Optimization: The research seeks to optimize the use of RHA and nanoparticles in SCC. This involves adjusting mix proportions, considering various factors such as the water-to-cement ratio, superplasticizers, viscosity-modifying agents, and the percentage of supplementary materials to achieve the desired balance between flowability, stability, and performance.

7. Durability Assessment: The durability of SCC mixtures is evaluated through exposure to environmental stressors, including freeze-thaw cycles, chemical exposure, and alkali-silica reaction (ASR) testing. These assessments aim to determine how RHA and nanoparticles enhance the resistance of SCC to these factors.

8. Long-Term Performance Evaluation: Accelerated aging tests simulate long-term conditions, providing insights into the performance and sustainability of SCC mixtures over extended periods. These tests contribute to the understanding of how the materials will perform in real-world applications.

9. Comparative Analysis: Comparative analyses are conducted to assess the sustainability and performance benefits of SCC with RHA and nanoparticles against traditional SCC and conventional concrete mixtures. The research quantifies reductions in carbon emissions, resource conservation, and economic advantages associated with supplementary materials.

10. Economic Viability Assessment: The research includes an assessment of the economic viability of using RHA and nanoparticles in SCC. A cost-benefit analysis examines the initial costs of materials and construction and compares them with long-term savings, considering factors such as reduced maintenance, improved durability, and reduced environmental compliance costs.

11. Guidelines and Recommendations: Based on the research findings, practical guidelines and recommendations are developed for construction professionals. These guidelines address mix design, material selection, and best practices for sustainable SCC construction, making it easier for industry stakeholders to implement the research findings.

12. Knowledge Dissemination: The research design includes a plan for the dissemination of findings through academic publications, industry conferences, and outreach to construction professionals, policymakers, and the public. This ensures that the research has a broader impact on sustainable construction practices.

13. Future Prospects: The research design is forward-looking, considering the potential for further innovation and development in the field of sustainable SCC. It identifies emerging trends in construction materials, supplementary materials, and construction practices, fostering a future-oriented perspective.

The rationale behind selecting the specific approach of incorporating rice husk ash (RHA) and nanoparticles into self-compacting concrete (SCC) to enhance sustainability is grounded in addressing critical challenges facing the construction industry while leveraging the potential of innovative materials and technology. This approach is driven by a set of compelling reasons that highlight its significance and potential for advancing the field of construction and sustainable development.

IV. RESULTS AND DISCUSSIONS

The compressive strength test is a crucial evaluation method used to determine the ability of concrete to withstand compressive loads before failure. This test is fundamental in assessing the quality, performance, and durability of concrete in various construction applications.

1. Sample Preparation

Concrete specimens are cast into standardized molds, ensuring proper mixing to eliminate air voids. The concrete is left to cure for a specific period, typically 7 or 28 days.

2. Mould Removal

After the curing period, carefully remove the specimens from the molds, avoiding any damage to the surfaces.

3. Surface Preparation

Surface irregularities on the specimens are smoothed out using a grinder or by careful trimming to ensure flat and even surfaces.

4. Measurement

Precise measurements of the specimen dimensions are taken using calipers, ensuring accurate records of the length, width, and height.

5. Testing Machine Setup

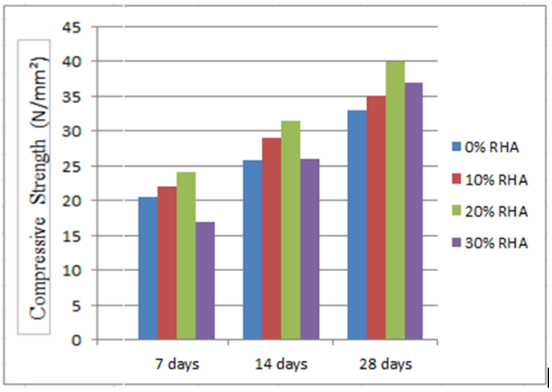
Each specimen is placed in the compression testing machine, properly aligned along the loading axis to ensure accurate testing.

6. Load Application

The compression testing machine applies a compressive load to the specimen at a controlled and consistent rate. This force is increased gradually until the specimen fractures.

7. Data Recording

Throughout the test, the applied load is monitored continuously, and any signs of failure, such as cracking or crushing, are observed and noted.



V. CONCLUSIONS

1. Optimal RHA Percentage: The compressive strength results indicate that a 20% replacement of cement with Rice Husk Ash (RHA) in M30 concrete yields a favorable compressive strength of 40.00 N/mm² at 28 days. This aligns with existing literature recommending RHA replacement values between 10% to 20%, confirming the suitability of the chosen percentage.

2. Nano Aluminum Enhancement: The compressive strength tests further reveal that the addition of Nano Aluminum (NA) positively influences the strength of concrete. Notably, the mixture with 2% NA in combination with 20% RHA consistently demonstrates superior compressive strength, reaching 42.00 N/mm² at 28 days.

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