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"A REVIEW ON BINARY BLENDING OF CEMENTITIOUS MATERIALS FOR IMPROVEMENT OF CONCRETE CHARACTERISTICS"

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ABSTRACT

Concrete, as the most widely used construction material globally, faces increasing scrutiny due to the environmental impact of cement production. To address sustainability and performance challenges, binary blending of cementitious materials has emerged as a promising solution. This review explores the influence of binary blends—such as fly ash, ground granulated blast furnace slag (GGBS), silica fume, metakaolin, and rice husk ash—on the fresh and hardened properties of concrete. The synergistic effect of these supplementary cementitious materials (SCMs) not only enhances mechanical strength and durability but also reduces carbon emissions and improves long-term performance. Key properties such as workability, setting time, compressive strength, permeability, and resistance to sulfate attack are critically examined. The review also highlights how optimal replacement levels and particle fineness significantly affect overall concrete performance. Challenges such as variability in SCM quality, compatibility with chemical admixtures, and curing requirements are discussed, providing a comprehensive outlook on practical implementation. This paper concludes that binary blending is an effective strategy to produce sustainable, high-performance concrete suitable for modern construction demands, and calls for further research into blend optimization and performance prediction models to support its broader application in the industry.

Key Words: *Concrete, SCMs, GGBS, Cementitious.*

I. INTRODUCTION

Concrete is the most widely used construction material in the world due to its excellent compressive strength, durability, and versatility. Its primary binding component, Ordinary Portland Cement (OPC), plays a crucial role in the hydration process, contributing to the strength and setting characteristics of concrete. However, the production of OPC is energy-intensive and accounts for nearly 7–8% of global carbon dioxide (CO_2) emissions. As the construction industry continues to grow, there is a pressing need to develop more sustainable materials and practices to mitigate environmental impact without compromising structural performance.
One of the most effective and widely researched strategies to achieve this goal is the partial replacement of OPC with supplementary cementitious materials (SCMs). These materials, often industrial by-products or naturally occurring minerals, possess pozzolanic or latent hydraulic properties that contribute to the concrete's strength and durability. Common SCMs include fly ash, silica fume, ground granulated blast furnace slag (GGBS), metakaolin, and rice husk ash. When blended with cement, these materials undergo secondary hydration reactions, forming additional calcium silicate hydrate (C–S–H) gel, which enhances the concrete microstructure.

Binary blending refers to the combination of OPC with one type of SCM in a concrete mix. This technique has gained significant attention due to its simplicity, cost-effectiveness, and performance-enhancing characteristics. Unlike ternary

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or more complex systems, binary blending is easier to control and implement in both large-scale infrastructure projects and small-scale constructions. Each SCM brings unique advantages to the blend. For example, fly ash improves workability and long-term strength, silica fume increases early strength and impermeability, and GGBS enhances resistance to chemical attacks and sulfate exposure.

From a performance perspective, binary blending has shown promising results in improving both the fresh and hardened properties of concrete. In fresh concrete, SCMs can modify workability, setting time, and water demand. In hardened concrete, they enhance compressive strength, reduce permeability, and increase resistance to aggressive environments, including chloride ingress and sulfate attack. Additionally, blended systems often demonstrate improved thermal properties, reduced alkali-silica reaction (ASR), and better long-term durability.

Beyond performance, binary blending also contributes to sustainability by reducing the carbon footprint of concrete, lowering energy consumption, and promoting the reuse of industrial by-products. This aligns with the principles of green construction and supports international goals for climate change mitigation and sustainable development.

Despite its advantages, binary blending also presents certain challenges. These include variability in the chemical composition of SCMs, slower early-age strength gain, and the need for precise quality control. Moreover, the selection of suitable SCMs and their optimum replacement ratios must be tailored to the specific requirements of a project, considering environmental exposure, structural load, and curing conditions.

II. Literature Review

Siddique, R. et al (2010) An experimental program was conducted to study the properties of self-compacting concrete (SCC) made with Class F fly ash. Mixes were prepared with fly ash replacements ranging from 15% to 35%. The study evaluated fresh properties such as slump flow, L-box, and V-funnel, as well as hardened properties including compressive strength. The results indicate that SCC with Class F fly ash exhibits improved workability and adequate strength development, making it suitable for structural applications.[1]

Güneyisi, E. et al (2010) This experimental study evaluates the durability properties of self-compacting concretes (SCCs) with high-volume fly ash replacements. Eight SCC mixtures with varying fly ash contents (0%, 10%, 30%, 50%, 70%, and 85%) were designed and compared with normal vibrated concretes of equivalent strength grades. The results demonstrate that high-volume fly ash SCCs exhibit satisfactory durability performance, making them suitable for sustainable construction practices.[2]

Bilim, C. et al (2010) In this study, artificial neural networks (ANNs) were employed to predict the compressive strength of concrete containing ground granulated blast furnace slag (GGBFS). A total of 45 concrete mixtures with varying water–cement ratios and cement dosages were analyzed. The ANN models demonstrated high accuracy in predicting compressive strength, highlighting their potential as reliable tools for modeling the behavior of GGBFS concrete.[3]

Givi, A. N. et al (2010) This review paper presents an overview of the utilization of rice husk ash (RHA) as a partial replacement for cement in mortar and concrete. It discusses the physical and chemical properties of RHA, its pozzolanic reactivity, and its influence on the mechanical and durability properties of cementitious systems. The paper highlights the potential of RHA to enhance the performance of mortar and concrete, contributing to sustainable construction practices. [4]

Mazloom, M. et al (2010) This paper presents the results of experimental work on both mechanical properties and durability of concrete incorporating silica fume. The study indicates that as the proportion of silica fume increases, the workability of concrete decreases, but its short-term mechanical properties, such as compressive strength, significantly improve.[5]

ISSN : 2455-9679
SJIF Impact Factor : 6.008

Bentz, D. P. et al (2010) The influence of silica fume on the rheology of cementitious paste has been studied utilizing a parallel plate rheometer. The study examines how varying amounts of silica fume affect the plastic viscosity, yield stress, and thixotropy of cement pastes. Results show that silica fume increases the yield stress and plastic viscosity, indicating a reduction in workability.[6]

Khatib, J. M. et al (2010) The influence of including fly ash on the properties of self-compacting concrete (SCC) is investigated. Portland cement was partially replaced with fly ash at levels of 30%, 40%, and 50% by mass. The properties measured included slump flow, L-box, V-funnel, and compressive strength. The results indicate that SCC with fly ash exhibits improved workability and adequate strength development, making it suitable for structural applications.[7]

Kuder, K. G. et al (2011) This paper presents the results of a laboratory investigation of self-consolidating concrete (SCC) containing sustainable technologies. Twelve mixes were prepared with different combinations of fly ash, slag, and recycled asphalt pavement (RAP). Fresh and hardened concrete properties were evaluated to assess the feasibility of using these materials.[8]

Ghosh, S. et al (2011) et al This study compares the effects of fly ash and silica fume as partial replacements of cement in concrete. Various mixes were prepared with different proportions of these materials, and their impact on workability, compressive strength, and durability was evaluated. The results indicate that while both admixtures enhance certain properties of concrete, silica fume significantly improves compressive strength and reduces permeability compared to fly ash.[9]

Siddique, R. et al (2011) This paper reviews the physical and chemical properties of silica fume and its effect on the hardened properties of concrete. It discusses how silica fume influences workability, porosity, compressive strength, splitting tensile strength, flexural strength, creep, and shrinkage. The review indicates that silica fume significantly enhances the mechanical properties and durability of concrete.[10]

Li, G. et al (2012) This paper presents a laboratory study on the properties of high-volume fly ash high-strength concrete incorporating nano-SiO_2 (SHFAC). The results were compared with those of control Portland cement concrete (PCC) and high-volume fly ash high-strength concrete (HFAC). Assessments included compressive strength and pore size distribution. The incorporation of nano-SiO_2 enhanced the early-age strength and refined the pore structure of the concrete.[11]

Memon, F. A. et al. (2012) The results indicate that the addition of silica fume as a partial replacement of fly ash results in the loss of workability; nevertheless, the mechanical properties of hardened self-compacting geopolymer concrete are significantly improved by incorporating silica fume, especially up to 10 wt%. Applying this percentage of silica fume results in a 4.3% reduction in slump flow; however, it increases the compressive strength by 6.9%, tensile strength by 12.8%, and flexural strength by 11.5%. [12]

Tikalsky, P. J. et al (2012) This study investigates the effect of fly ash on the corrosion resistance of reinforcing steel in concrete. Various concrete mixes with different fly ash contents were evaluated for their permeability, chloride ion penetration, and corrosion potential. The results suggest that appropriate use of fly ash can enhance the durability of concrete by reducing its permeability and improving resistance to chloride-induced corrosion.[13]

Joshi, R. C. et al (2012) This comprehensive book examines the advantages of incorporating fly ash as an admixture in concrete. It delves into various aspects, including the types and properties of fly ash, its effect on the fresh and hardened properties of concrete, and its influence on durability and structural performance. The authors provide an in-depth analysis of production methods, quality control, and practical applications, offering valuable insights for both researchers and practitioners in the field of concrete technology.[14]

ISSN : 2455-9679
SJIF Impact Factor : 6.008

Thomas, M. D. A. et al (2012) This document discusses the benefits and challenges associated with using varying levels of fly ash in concrete. It provides guidance on optimizing fly ash content to enhance concrete properties, considering factors such as material composition, placement conditions, and exposure environments. The publication aims to assist practitioners in effectively utilizing fly ash to improve the performance and sustainability of concrete structures.[15]

Malhotra, V. M. et al (2012) This book provides an extensive examination of high-performance, high-volume fly ash (HVFA) concrete, focusing on its materials, mixture proportioning, properties, construction practices, and case studies. It discusses the role of HVFA concrete in sustainable development, detailing how incorporating large volumes of fly ash can improve concrete's mechanical properties and durability while reducing environmental impact.[16]

Aydın, S. et al (2013) This study investigates the development of mortars resistant to high temperatures by incorporating ground granulated blast furnace slag (GGBFS) and silica fume as partial replacements for cement. Mortar specimens were exposed to elevated temperatures up to 900 °C, and their residual compressive and flexural strengths were evaluated. The results indicate that the inclusion of GGBFS and silica fume enhances the high-temperature resistance of mortars, with significant improvements observed at 900 °C.[17]

Ganesan, K. et al (2013) In this study, rice husk ash (RHA) prepared from the boiler burnt husk residue of a particular rice mill has been evaluated for optimal level of replacement as blending component in cements. The physical, chemical and mineralogical characteristics of RHA were first analyzed. The properties of concrete investigated include compressive strength, splitting tensile strength, water absorption, sorptivity, total charge-passed derived from rapid chloride permeability test (RCPT) and rate of chloride ion penetration in terms of diffusion coefficient. This particular RHA consists of 87% of silica, mainly in amorphous form and has an average specific surface area of 36.47 m2/g. Test results obtained in this study indicate that up to 30% of RHA could be advantageously blended with cement without adversely affecting the strength and permeability properties of concrete. Another interesting observation emanating from this study is the linear relationship that exists among water sorptivity, chloride penetration and chloride diffusion.[18]

Nima, M. A., et al. (2016) This study examines the durability characteristics of concrete incorporating silica fume and fly ash as partial replacements for cement. Various concrete mixes were prepared with different proportions of these supplementary cementitious materials, and their resistance to chloride penetration, sulfate attack, and freeze-thaw cycles was evaluated. The findings indicate that the combined use of silica fume and fly ash enhances the durability performance of concrete, contributing to its longevity in aggressive environments.[19]

Hemalatha, T. et al (2017) This work exhaustively investigates the characteristics of different types of fly ashes and explores various methods to engineer concrete mixes with higher volumes of fly ash. The critical examination of properties of fly ash provides insight for wider utilization, facilitating higher replacement of cement with fly ash in concrete, thus promoting sustainability in construction.[20]

Bryan K. et al (2025) Ultra-high performance concrete (UHPC) is a specialized class of cementitious composites that is increasingly used in various applications, including bridge decks, connections between precast components, piers, columns, overlays, and the repair and strengthening of bridge elements. The mechanical and durability properties of UHPC are significantly influenced by factors such as low water-to-binder ratios, the inclusion of supplementary cementitious materials (SCMs), and fiber reinforcement. Machine learning (ML) has been employed to predict the performance of UHPC and optimize its mixture designs by using various raw materials. This study first provides a comprehensive review of ML applications in UHPC, focusing on predicting workability, mechanical, and thermal properties. The use of data crossing, generative AI, physics-guided ML models, and field-applicable software are explored as practical directions for future research. This study also develops ML models to predict the compressive strength of UHPC by using a database containing 1300 data-records. The influence of various input variables is evaluated using SHapley Additive ex Planations (SHAP), revealing that chemical compositions have relatively minor impacts, given the material types used. By excluding insignificant variables, the models enhance both efficiency and

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accuracy in predicting strength. This advancement facilitates optimized material design and performance prediction while reducing the experimental workload required to inform ML models. Adding more diverse data to the database could further enhance the prediction performance and generalizability of the proposed ML models. [21]

Kandou, C et al (2025) Developing High-Performance Concrete (HPC) with advanced materials is crucial for achieving superior concrete that aligns with sustainable building practices. The use of innovative materials enhances both fresh and hardened properties, offering improved workability and strength. This study explores the impact of incorporating advanced materials into concrete mixtures by evaluating the performance of different compositions. Three mix variations were prepared by adjusting the types and dosages of admixtures. The first mix used a conventional Type F superplasticizer, while the other two applied advanced materials at varying dosages. Slump tests were conducted on fresh concrete and cylindrical specimens (10x20 cm) were tested to measure unit weight and compressive strength after 7, 14, and 28 days. Results indicate that the use of advanced materials significantly improves concrete performance, even at lower dosages compared to traditional superplasticizers. This research confirms that incorporating advanced materials improves both workability and compressive strength of concrete. The findings suggest that these materials offer a sustainable solution for developing high-performance concrete with enhanced durability and reduced material consumption. Consequently, their integration in construction can contribute to more sustainable, efficient, and resilient building structures. Further research is recommended to explore the long-term effects of advanced materials on concrete performance under various environmental conditions. The study highlights the potential of advanced material technologies as a transformative approach in concrete quality management within the construction industry.[22]

Chengzhi Jiang et al (2024) Under ultra-low water-to-binder ratio conditions, the liquid-bridge effect between powders seriously restricts the development of reactive powder concrete (RPC). Ice crystal homogenization technology fundamentally solves the liquid-bridge problem between powders. However, high carbon emissions still constrain the application of RPC. This paper introduces an innovative RPC material incorporating silica fume (SF) as a supplementary cementitious material to solve environmental concerns and alleviate powder aggregation challenges based on the ice crystal homogenization technology. Experimental results show that there was a significant improvement in compressive and flexural strengths observed, particularly in RPC material containing 15 % SF, which exhibited the most notable enhancements: a 19.7 % increase in compressive strength to 296.3 MPa and a 23.6 % increase in flexural strength to 43.8 MPa. Moreover, the optimized microstructure was reflected in a substantial reduction in water absorption rate and cumulative pore volume by 44.7 % and 54.4 %, respectively. Besides, RPC incorporating 15 % SF achieved the lowest carbon emissions efficiency, with carbon emissions efficiency could be reduced by 79~93 % compared with conventional UHPC. In conclusion, the use of SF and ice crystal homogenization technology in RPC provides the great potential for developing sustainable construction materials and promoting carbon reduction strategies.[23]

III. METHODOLOGY

Studies were selected based on the following criteria:

- Focus on binary cementitious systems (OPC + one SCM).
- Evaluation of mechanical properties such as compressive strength, flexural strength, and split tensile strength.
- Examination of durability indicators like permeability, sulfate resistance, chloride ion penetration, and carbonation resistance.
- Analysis of fresh properties including workability, setting time, and slump retention.
- Environmental assessments such as carbon footprint and energy efficiency were considered when available.

Exclusions were made for papers focusing solely on ternary or quaternary blends, or those that did not report specific data on binary blending performance.

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IV. CONCLUSION

Binary blending of cementitious materials represents a practical and sustainable approach to improving concrete properties. By partially replacing OPC with SCMs such as fly ash, GGBS, silica fume, and others, the construction industry can produce durable, high-performance, and eco-friendly concrete. While there are some technical and practical challenges, the benefits in terms of performance, cost, and environmental impact make binary blending a valuable strategy in the quest for sustainable construction.

V. FUTURE SCOPE

Further research is essential to optimize blend ratios for different construction needs and environmental conditions. Advanced characterization techniques and modeling tools can help predict performance and durability. Incorporating nano-materials or hybrid SCMs may further enhance concrete behavior.

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