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Strength and Durability Evaluation of Self-Compacting Concret Incorporating Sea Sand And Ternary Binder

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Abstract: *Concrete, one of the most widely used construction materials, significantly contributes to carbon emissions due to its reliance on cement. Geopolymer concrete (GPC) offers a sustainable alternative by utilizing industrial by-products such as fly ash (FA), ground granulated blast furnace slag (GGBS), and rice husk ash (RHA). This study investigates the use of RHA and nanosilica (NS) as supplementary binders, along with RHA-based alkali activators, to enhance the performance of FA-GGBS-based GPC. Mix proportions were optimized by varying FA-GGBS ratios, sodium hydroxide molarity, and activator-to-binder ratio. The optimum mix (70% FA, 30% GGBS, 13M NaOH, A/B ratio 0.55) achieved a compressive strength of 38.3 MPa. Partial replacement with 15% RHA and 3% NS improved strength to 46.5 MPa, representing a 21.4% increase. RHA-based sodium silicate solutions were synthesized and demonstrated comparable properties to commercial activators. Mechanical performance of geopolymer concrete and reinforced beams showed superior results compared to conventional cement concrete, with higher load-carrying capacity and comparable deflection behavior. Finite element analysis using ANSYS closely matched experimental results, confirming model reliability. The study highlights the potential of RHA- and NS-modified GPC as a high-performance, eco-friendly alternative for sustainable construction..*

Keywords: GPC, RHA, GGBS, NS, Compressive Strength, Workability.

I. INTRODUCTION

Self-Compacting Concrete (SCC) represents a significant advancement in concrete technology, characterized by its ability to flow under its own weight, completely fill formwork, and achieve full compaction without the need for mechanical vibration. This unique property enhances construction efficiency, improves surface finish, and ensures better performance in structures with congested reinforcement. However, the growing demand for conventional materials such as river sand and cement has raised concerns regarding resource depletion, environmental impact, and sustainability in the construction industry.

In recent years, the utilization of alternative fine aggregates, particularly sea sand, has gained attention as a potential solution to the scarcity of natural river sand. Sea sand is abundantly available in coastal regions and offers economic advantages due to reduced transportation costs. However, its use in concrete is associated with challenges such as the presence of chlorides and salts, which can lead to corrosion of reinforcement and durability issues. Therefore, careful evaluation and appropriate treatment or mix design strategies are required to safely incorporate sea sand into concrete.

Simultaneously, the concept of ternary binder systems has emerged as an effective approach to enhance the performance and sustainability of concrete. A ternary binder typically consists of a combination of Ordinary Portland Cement (OPC) and two supplementary cementitious materials (SCMs) such as fly ash, ground granulated blast furnace slag (GGBS), silica fume, or other industrial by-products. These materials contribute to improved workability, reduced

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heat of hydration, enhanced durability, and lower carbon emissions. The synergistic interaction among these components helps in refining the microstructure and improving long-term strength characteristics.

The integration of sea sand with ternary binder systems in SCC presents a promising pathway toward sustainable construction. While SCC ensures excellent flowability and compaction, the ternary binder improves durability and mechanical properties, potentially offsetting the drawbacks associated with sea sand. However, the combined effects of these materials on strength and durability parameters need thorough investigation, particularly in terms of compressive strength, tensile strength, permeability, resistance to chloride ingress, and long-term performance.

This study focuses on the strength and durability evaluation of self-compacting concrete incorporating sea sand and a ternary binder system. The objective is to assess the feasibility of using sea sand as a fine aggregate replacement and to examine the role of ternary binders in enhancing concrete performance. The outcomes of this research are expected to contribute to sustainable material utilization, reduce dependence on natural resources, and support the development of durable and eco-friendly concrete for modern construction practices.

II. RESEARCH METHODOLOGY

The production of GPC involves preparing precursor materials with FA, GGBS, RHA, and NS followed by dry mixing with (NaOH) and RHA-based sodium silicate (Na2SiO3). The mixture was blended until a uniform mix was obtained, then cast into moulds, compacted, and cured under ambient or elevated temperatures based on the mix design. Figure 1. shows the workflow of GPC preparation with precursor and fillers activated with alkaline solution.

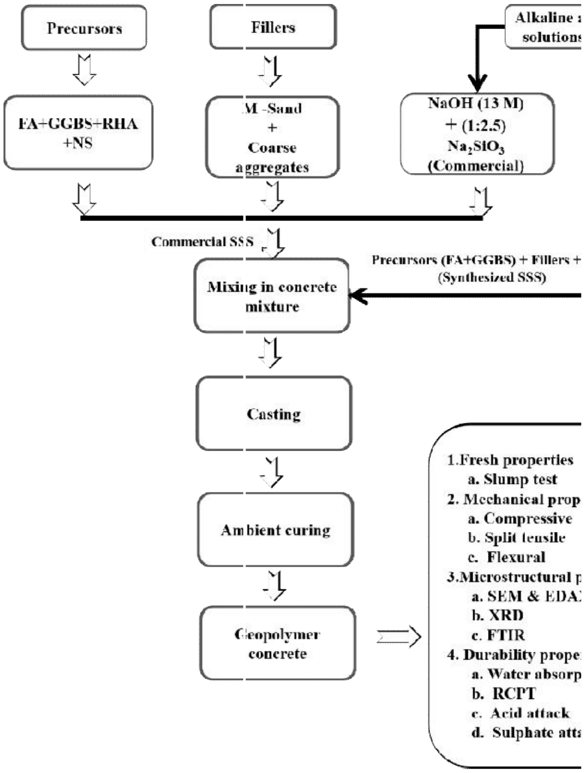


Fig 1 Workflow of GPC preparation

The quantitative elemental composition of FA was examined with SEM analysis (ZEISS EVO18 CARL, Germany) equipped with an EDAX system. The SEM micrograph Figure 3.7 (a) reveals that the FA particles are mostly spherical with relatively smooth surfaces. The corresponding EDAX spectrum It confirms significant levels of reactive silica (22.3 weight %) and alumina (15.3 weight %), with oxygen (49.2 weight %, 60.7 atomic %) contributed to compounds such as SiO2, Al2O3, and Fe2O3. Silicon exists in the form of quartz and amorphous aluminosilicate glass, while alumina appears in mullite and other aluminosilicate phases. The material's pozzolanic activity is confirmed by its low calcium levels and high silica and alumina contents, which categorize it as FA.

III. RESULT ANALYSIS

The SEM micrograph reveals that NS particles exhibit a predominantly spherical morphology, as indicated in the Figure. 2 (d). EDAX analysis confirms the elemental composition of NS as shown in the Figure. 3.8 (d), indicating the presence of carbon (59%), oxygen (38.5%), and active silica (2.4%). The high carbon content may result from organic coatings, exposure to ambient oxygen, or the use of carbon tape during sample preparation. Oxygen correlates with the silica structure, while the presence of silicon highlights the material's purity and suitability for geopolymer applications. SEM analysis also shows spherical or agglomerated particles with a high surface area, which contributed to enhanced reactivity. The EDAX spectrum further confirms NS's high purity, dominated by Si and O in the form of SiO2, with minimal traces of Ca, Al, C, and Na likely introduced during processing. This high surface area promotes rapid aluminosilicate gel formation and improves the geopolymerization, mechanical strength, and microstructural densification in cementitious systems. XRD analysis displays a broad peak between 16° and 30° of 2θ intensity as indicated in the Figure. 2 (d), indicating the amorphous nature of NS and its high silica content. The absence of sharp diffraction peaks beyond 30° of 2θ intensity confirms the lack of crystalline phases, further supporting its reactivity and surface area benefits. SEM images reinforce the observation of spherical morphology, a typical trait of amorphous nano-silica.

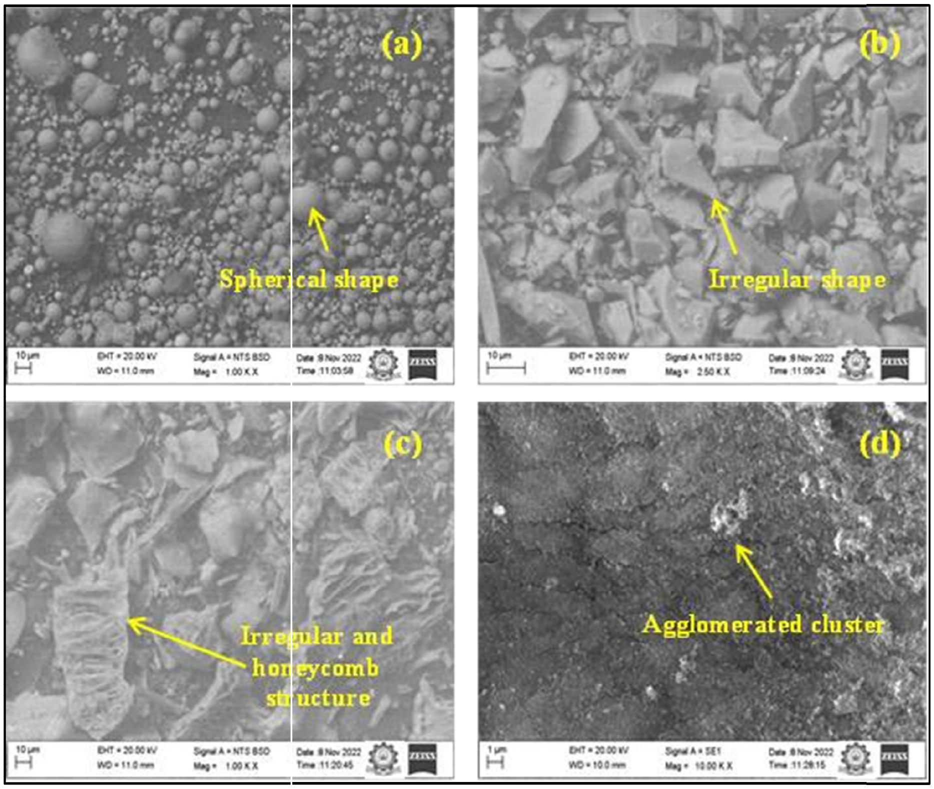
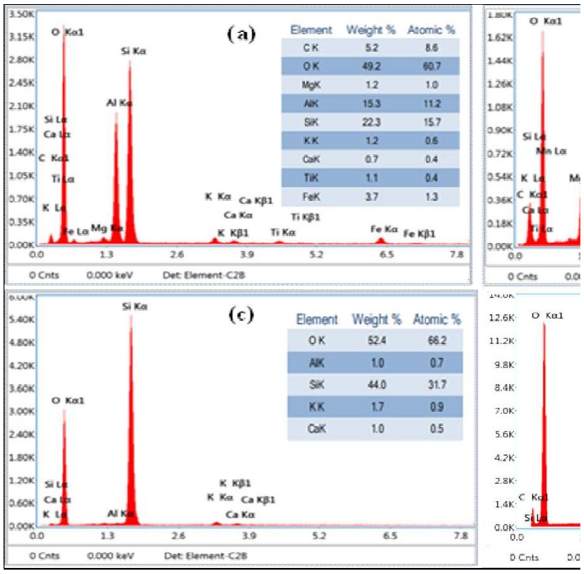


Figure 2. SEM images of a) F.A b) G.G.B.S C) RHA d) NS



Element	Weight %	Atomic %
C K	5.2	8.6
O K	49.2	60.7
MgK	1.2	1.0
AlK	15.3	11.2
SiK	22.3	15.7
K K	1.2	0.6
CaK	0.7	0.4
TiK	1.1	0.4
FeK	3.7	1.3

Element	Weight %	Atomic %
O K	52.4	66.2
AlK	1.0	0.7
SiK	44.0	31.7
K K	1.7	0.9
CaK	1.0	0.5

Figure 3. EDAX of a) FA b) GGBS C) RHA d) NS

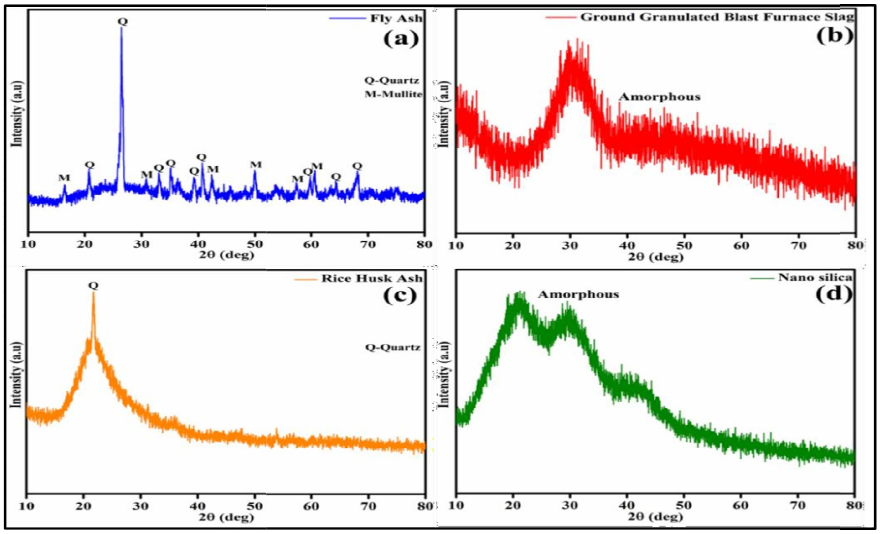


Figure 4. XRD of a) F.A b) G.G.B.S C) R.H.A d) NS

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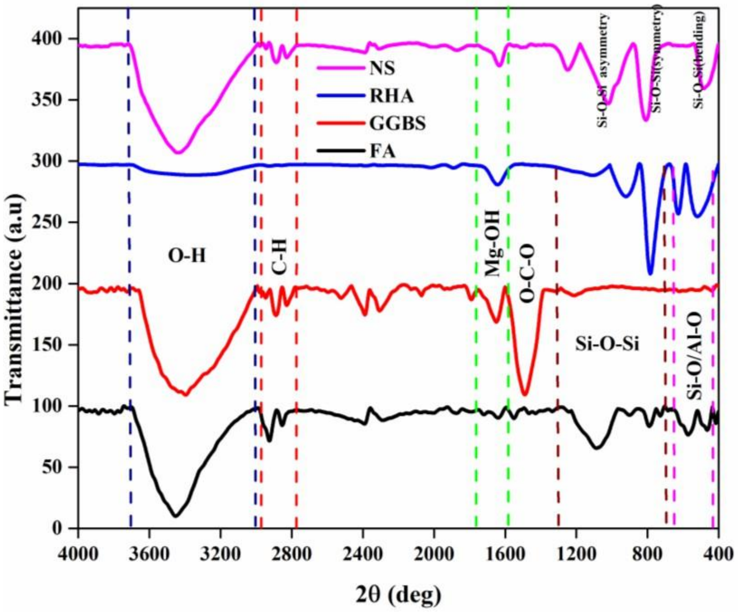

Figure 5. FTIR of F.A, G.G.B.S, RHA, NS

The FTIR spectrum of NS indicating the presence of hydrogen bonding and uniform dispersion as filler in polymer or cement matrices. Symmetrical Si-O-Si stretching vibrations were observed at 800 cm-1 and 950 cm-1, while bending vibrations of Si-O-Si were present between 470 and 490 cm-1, typical features of silica.

IV. CONCLUSION

The study demonstrates that the successful production of geopolymer concrete (GPC) relies on the effective preparation and activation of precursor materials such as fly ash (FA), ground granulated blast furnace slag (GGBS), rice husk ash (RHA), and nanosilica (NS). The experimental workflow confirms that proper mixing, casting, and curing conditions are essential to achieve a uniform and high-performance geopolymer matrix. Microstructural characterization using SEM, EDAX, XRD, and FTIR provides strong evidence of the suitability of these materials for geopolymer applications.SEM analysis reveals that FA and NS possess predominantly spherical morphology, contributing to improved workability and packing density. EDAX results confirm the presence of high silica and alumina content in FA and high purity silica in NS, which are crucial for effective geopolymerization. The amorphous nature of NS, as indicated by XRD analysis, enhances its reactivity and promotes the formation of a dense aluminosilicate gel network. FTIR analysis further validates the presence of characteristic silica bonds, confirming strong chemical interactions within the matrix.

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