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An Assessment of the Durability Properties of Binary and Ternary Blended Cement Concrete Produced with Shear Nutshell (Sna) and Guinea Corn Huslk (Gha) Ashes As Partial Replacement of Cement Subjected to Various Environmental Conditions.

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ABSTRACT
Concrete is the most widely used building material, and the high cost of construction materials has been a source of concern over the years in the building construction industry. In recent years innovative cementitious materials that can be used as an alternative for ordinary Portland cement are locally sourced to reduce the high cost of cement in concrete production. This study investigates the durability properties of concrete produced with shear nutshell ash and guinea corn husk ash as a partial replacement for cement in concrete production tested using aggressive chemicals such as Hydrogen Sulphate(H_2SO_4) and Magnesium Sulphate ($MgSO_4$). The effectiveness of the two materials were examined as binary and ternary blended cement in concrete. The sample of the concrete cubes were cured in both normal and aggressive environments.The percentage replacement was at 2%, 4%, and 6% respectively. The aging period was at 28, 56, and 90days. The overall comparison of the durability properties results of the specimenshowed that the ternary blended cement SNA│GHA│OPC were found to demonstrate consistent performance across all conditions to be highly durable and resistant in making excellent choices for the environment exposed to both aggressive and normal conditions, the research recommends that the SNA│GHA│OPC should be used in the production of concrete under the above conditions.

KEYWORDS: concrete, Ordinary Portland Cement, Shear Nutshell ash, Guinea Corn husk ash, Durability.

I. INTRODUCTION

The infrastructure industries in Nigeria are pivotal to the nation's growth and development, serving as a backbone for the expansion of various sectors such as construction, building, and real estate. The increasing demand for urban housing has significantly benefited the construction industry, resulting in a robust performance of the cement industry. Cement production has remained strong due to high demand from real estate, rural housing, and infrastructure projects, contributing to the overall economic development of the country (Abdulazeez, 2019).

Concrete, a composite material consisting of water, cement, and aggregates (both fine and coarse), is universally used in construction due to its excellent properties such as strength, durability, and versatility (Abdulazeez, 2019). However, the production of cement poses significant environmental challenges, particularly the emission of carbon dioxide (CO_2). The cement industry is a major contributor to global CO_2 emissions, necessitating the search for alternative materials like agricultural wastes to replace cement in concrete production to mitigate environmental impact (Ali, Babatunde, &Adejoh, 2019).

Agricultural wastes such as locust bean pod, groundnut shell, cassava peel, neem seed shell, corn husk, comb, soybean husk, and banana peel have shown potential as partial replacements for cement due to their pozzolanic properties when incinerated at certain temperatures. These waste materials, when processed correctly, can exhibit cementitious properties, making them viable alternatives to traditional cement (Agboola, Umar, Tukur, &Bappah, 2021).

According to Jergensen (2014), using pozzolana as a replacement for cement in concrete production lowers the heat developed during hardening and improves the durability of the final concrete structure. Pozzolanas are materials that, in the presence of moisture, react with calcium hydroxide released during the hydration of Portland cement to form compounds with cementitious properties (Ali, Babatunde, &Adejoh, 2019). This reaction not only improves the mechanical properties of the concrete but also enhances its durability and resistance to various forms of deterioration (Devi, Rao, &Srikanth, 2015).

Durability, defined as the ability of a product to maintain its physical and functional state without extensive maintenance during its operational life, is crucial for concrete structures. The durability of concrete is influenced by the environment to which it is exposed. Aggressive substances such as sulphates, chlorides, and acids can penetrate concrete through micro-cracks or pores, leading to deterioration and reduced structural usefulness. Supplementary cementitious materials (SCMs) in concrete mixes can reduce these pores and increase the density of the concrete, thereby enhancing its durability (Agboola, Idi, Tapgun, &Bappah, 2020).

Research has shown that concrete exposed to sulphuric acid experiences a significant loss in strength over time, emphasizing the need for enhanced durability properties in such environments (Abalaka, 2007). The introduction of waste materials such as ash, powder, and extract as partial replacements for cement has been explored as a means to improve the durability of concrete. This research focuses on the durability properties of concrete produced with binary and ternary blended cement in aggressive environments, specifically using shear nut shell ash (SNA) and guinea corn husk ash (GCHA) as partial replacements for cement (Agboolaet al., 2022).

II. STATEMENT OF THE PROBLEM

The construction industry's focus on sustainable development and compliance with new environmental regulations on waste disposal has necessitated the search for alternative, environmentally friendly materials to replace cement in concrete production. The extensive use of Portland cement significantly contributes to global warming due to carbon dioxide (CO_2) emissions. While compressive strength is often used as a primary measure of concrete quality, the importance of durability, especially in aggressive chemical environments, cannot be overstated.

Concrete structures exposed to aggressive chemical environments, such as those containing sulphates and acids, are prone to deterioration, which compromises their structural integrity and service life. Traditional concrete, even when exhibiting high compressive strength, may not be sufficiently durable under such conditions. This problem is exacerbated by the environmental impact of cement production, prompting the need for sustainable alternatives that can enhance both the durability and environmental footprint of concrete.

Key Problem:

- The need to reduce CO_2 emissions associated with Portland cement production.
- The requirement for concrete to maintain durability and structural integrity in aggressive chemical environments.
- The necessity to find sustainable, eco-friendly materials to replace a portion of cement in concrete production.

Therefore, this study intends toinvestigate the durability of concrete produced with binary and ternary blended cement in aggressive environments, utilizing shear nut shell ash (SNA) and guinea corn husk ash (GCHA) as partial replacements for cement.

2.1 Aim and Objectives

The primary aim of this study is to investigate the durability of concrete produced with binary and ternary blended cement in aggressive environments, utilizing shear nut shell ash (SNA) and guinea corn husk ash (GCHA) as partial replacements for cement. By exploring these alternative materials, the study seeks to enhance the sustainability and performance of concrete under challenging conditions.

a. To determine the rheological properties of binary and ternary blended concrete using setting time and workability tests.
b. To determine the compressive strength of binary and ternary blended SNA and GCHA concrete subjected to normal and aggressive environments.
c. To determine the durability properties of binary and ternary blended concrete.

Concrete as an innovation may be a very broad field that includes the study of concrete materials, plan, and development. It may be a multidisciplinary field that draws on information from materials science, structural engineering, and civil engineering. Concrete technology is essential for the plan and development of secure and solid concrete structures, such as buildings, bridges, and dams. Concrete could be a composite material made up of a blend of cement, water, and aggregates (such as sand and gravel). The cement acts as a binder, holding the aggregates together and shaping a difficult, solid material. The water permits the cement to hydrate, which could be a chemical reaction that causes the cement to solidify. The aggregates give quality and bulk to the concrete. The properties of concrete are impacted by a number of factors, counting the sort of cement, the water-cement proportion, the aggregate size and shape, and the curing conditions. Concrete innovation is concerned with understanding how these factors influence the properties of concrete, and how to plan and develop concrete structures that will meet the required execution prerequisites (Neville & Brooks, 2018).

Concrete is one of mankind's most flexible and valuable building materials. However concrete in some cases shows two undesirable features:destitute solidness in hostile environments and destitute aesthetic properties-ie. destitute visual appearance. There's developing prove that these impediments can be overcome by utilizing certain pozzolanic materials which are able to adjust the chemistry and micro-structure of concrete. Upkeep costs of concrete can be high, so the concept of life-time cost is increasingly being taken into consideration. By utilizing the rectify pozzolanic materials, the overall financial matters of a project can be improved, and an aesthetic issue can be changed over into a alluring highlight. Metakaolin could be a receptive pozzolan, delivered by the thermal activation of the mineral kaolin. It is accessible in a tall state of purity (more prominent than 90%) and can respond with more than its claim weight of calcium hydroxide to provide modern cementitious compounds. By supplanting portion (regularly 10 to 20%) of the Portland cement substance of concrete, metakaolin decreases calcium hydroxidelevels within the cured concrete. The pozzolanic response is quick, ie. inside 28 days at surrounding temperatures, and at the higher replacement level virtually all the calcium hydroxide is evacuated (Taylor & Francis 2017).

Concrete is a composite construction material with changeable properties agreeing to the requirement. Concrete is a flexible development material with properties like strongest, solidness and financial, subsequently, versatile to a wide assortment of employments. Properties of concrete depend upon the properties of essential fixings, utilize of fitting admixture(s) and curing. Basic Ingredients of concrete are summarized as underneath:cement, aggregate, water and admixtures (pozzolans) (Mehta &Monteiro, 2016).

Constituents of concrete

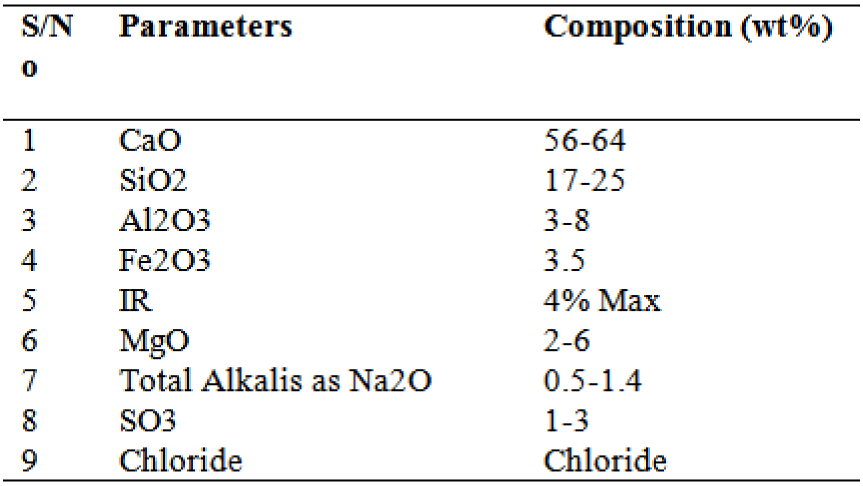
Cement

Cement is a fine-grained composite that sets and hardens within the nearness of dampness to tie other materials such as sand and, or coarse aggregates to create mortar or concrete. Cements utilized in development can be characterized as being either hydraulic or non-hydraulic, depending upon the capacity of the cement to be utilized within the nearness of water (Datok, Ishaka, Bulus and Amos, 2018).

Portland cement is without any contention among the foremost important and essential materials within the world. Without it, the development industry that utilizes huge tonnages of concrete yearly would battle to survive. Other than this, concrete is appraised as the second most highly consumed item after water. It is known that some developed countries depend on the development industry as one of the most columns for the development of their economies. In creating economies, the development industry gives many jobs for individuals in both the formal and the casual divisions. Any shortage that stagnates the development industry ordinarily leads to genuine financial droop (Check & Eric, 2016).

Ordinary Portland cement (OPC) is the world's driving cement. According to measurements from the U.S. government, approximately 4.1 billion tonnes of OPC were generated globally in 2015 alone. Since the creation of concrete, OPC has been coordinates as the primary binder material (Part, Ramli and Cheah, 2016). Ordinary portland cement (OPC) has been an vital material utilized in concrete development, nevertheless, other binding materials such as lime, fly ash, silica rage etc. are too utilized as binding specialist. Ordinary portland cement (OPC) is made by crushing a blend of limestone, clay and other remedial materials such as laterite, bauxite, press ore etc. burning appropriately in right manner and blend and at a tall temperature, cooling the resultant product called 'clinker' and crushing the same with retarder i.e. gypsum. Cement generation is mindful for approximately 5% of the worldwide man made CO2 emission. For each tone of cement being delivered, an normal of 0.87 tons of CO2 is being transmitted (Naitik, et al, 2016)

Table 1: Chemical Composition of Cement



S/No	Parameters	Composition (wt%)
1	CaO	56-64
2	SiO2	17-25
3	Al2O3	3-8
4	Fe2O3	3.5
5	IR	4% Max
6	MgO	2-6
7	Total Alkalis as Na2O	0.5-1.4
8	SO3	1-3
9	Chloride	Chloride

To address some of the afore specified issues of cost of cement, environmental debasement, harmful Ca (OH) 2, analysts have piloted studies on other binding specialists with cheaper cost of production to either partially or completely supplant the cement which is the customary binder in concrete. Discoveries has appeared that supplementary cementitious materials have demonstrated to be viable in assembly most of the prerequisites of solid concrete. Within the third world, the most common and readily accessible materials that can be utilized to partially replace cement without huge financial implications are agro – based wastes (Datok, et al, 2018).

Pozzolans

Pozzolana in its wonderfully partitioned state combines with calcium hydroxide (produced by the hydrating Portland cement) in the presence of moisture to make steady calcium silicates which shows cementitious properties (Datoket al. 2018). However, pozzolanas can be natural or artificial materials containing silica or/and alumina in a reactive form. The natural pozzolanic materials include: volcanic ash, pumice, opaline shale and chert, calcined diatomaceous soil, and burnt clay (Neville, 2011). Artificial pozzolans of natural root incorporate; most agricultural waste such as; rice husk, coconut shell, corn cob, palm nutshell fiber and Acha husk among numerous others. Another review(2)

Table 2: Classification of Pozzolanas

CHEMICAL REQUIREMENTS	MINERAL N	ADMIXTURE F	CLASS C
Silicon dioxide, aluminuim dioxide and iron oxide ($SiO_2 + Al_2O_3 + Fe_2O_3$) minimum%	70%	70%	50%
Sulfur trioxide (SO_3) maximum%	4	5	5
Moisture content, maximum%	3	3	3
Loss on ignition, maximum%	10	6	6
Available alkalis as Na_2O, maximum	1.5	1.5	1.5
PHYSICAL REQUIREMENTS	34	34	34
Fineness, maximum% retained on 325- Mesh (44um) sieve			

(ASTM C618-92a, 1994)

Table 3: Physical Requirements of a pozzolana

Material contents	**Mineral Admixture Class**		
	N	**F**	**C**
Fineness:			
Amount retained when wet-sieved on 45 µm (No. 325) sieve, max, %	34	34	34
Strength activity index:			
With Portland cement, at 7 days, min, percent of control	75^C	75^C	75^C
With Portland cement, at 28 days, min, percent of control	75^C	75^C	75^C
Water requirement, max, percent of control	115	105	105
Soundness:			
Autoclave expansion or contraction, max, %	0.8	0.8	0.8
Uniformity requirements:			
The density and fineness of individual samples shall not vary from the average established by the ten preceding tests, or by all preceding tests if the number is less than ten, by more than:			
Density, max variation from average, %	5	5	5
Percent retained on 45-µm (No. 325), max variation, percentage points from average	5	5	5

Source: ASTM C618-05

2.2 Aggregates

Aggregates are granular material such as sand, gravel, smashed stone, annihilation waste etc. that's utilized with cementing medium to create concrete. Good concrete results from good blend plan. Another critical component of concrete is aggregate. Aggregates are filler components and commonly 60 to 80 percent of the volume of concrete. Coarse aggregate alludes to the aggregate particles bigger than 4.75 mm and the term fine aggregate alludes to the aggregate particles littler than 4.75 mm but bigger than 75µm. All aggregates must be basically free of sediment and natural matter. Commonly, aggregates are non-reactive, but in case they are receptive in nature, subsequently they may cause the responses like alkali-silica response and alkali-aggregate response beneath favorable conditions, which may have inconvenient impacts on concrete.

2.2.1 Fine-aggregate

Prerequisites of ASTM C 33 or AASHTO M 6/M 43 allow a moderately wide range in fine-aggregate degree, but details by other organizations are sometimes more restrictive. The most desirable fine-aggregate classification depends on the sort of work, the abundance of the blend, and the greatest estimate of coarse aggregate. In leaner blends, or when small-size coarse aggregates are utilized, a evaluating that approaches the greatest suggested rate passing each strainer is alluring for workability. In common, supposing the water-cement proportion is kept consistent and the proportion of fine-to-coarse aggregate is chosen accurately, a wide run in evaluating can be utilized without quantifiable impact on quality. However, the leading economy will sometimes be accomplished by altering the concrete blend to suit the degree of the local aggregates. Fine-aggregate evaluating inside the limits of ASTM C 33 (AASHTO M 6) is commonly palatable for most concretes. The ASTM C 33 (AASHTO M 6) limits with regard to sifter size are appeared inTable 5

Table 4: Fine-Aggregate Grading Limits (ASTM C 33/AASHTO M 6)

Sieve size	Percent passing by mass
9.5mm	100
4.75mm	95 to 100
2.36 mm (No. 8)	80 to 100
1.18 mm (No. 16)	50 to 85
600 µm (No. 30)	25 to 60
300 µm (No. 50)	5 to 30 (AASHTO 10 to 30)
150 µm (No. 100)	0 to 10 (AASHTO 2 to 10)

The AASHTO specifications allow the least rates (by mass) of material passing the 300 µm (No. 50) and 150 µm (No. 100) sifters to be decreased to 5% and 0% separately, given:

i. The aggregate is utilized in air-entrained concrete containing more than 237 kilograms of cement per cubic meter (400 lb of cement per cubic yard) and having an discuss substance of more than 3%.
ii. The aggregate is utilized in concrete containing more than 297 kilograms of cement per cubic meter (500 lb of cement per cubic yard) when the concrete isn't air entrained.
iii. An endorsed supplementary cementitious material is utilized to supply the insufficiency in material passing these two sifters.

Other necessities of ASTM C 33 (AASTHO M 6) are:

1. The fine aggregate must not have more than 45% held between any two sequential standard sifters.
2. The fineness modulus must be not less than 2.3 nor more than 3.1, nor change more than 0.2 from the normal esteem of the aggregate source. Supposing this value is surpassed, the fine aggregate ought to be rejected unless appropriate alterations are made in extents of fine and coarse aggregate. The sums of fine aggregate passing the 300 µm (No. 50) and 150, µm (No. 100) sifters influence workability, surface texture, air substance, and bleeding of concrete. Most details permit 5% to 30% to pass the 300 µm (No. 50) sifter. The lower limit may be adequate for simple putting conditions or where concrete is mechanically wrapped up, such as in asphalts. However, for hand-finished concrete floors, or where a smooth surface is desired, fine aggregate with at slightest 15% passing the 300 µm (No. 50) sifter and 3% or more passing the 150 µm (No. 100) sifter ought to be utilized.

2.2.2 Coarse-aggregate

The coarse aggregate evaluating prerequisites of ASTM C 33 (AASHTO M 80) allow a wide run in evaluating and a assortment of evaluating sizes. dealing with aggregates much bigger than 50 mm (2 in.) may counterbalanced the reserve funds in utilizing less cement. Moreover, aggregates of distinctive greatest sizes may allow marginally diverse concrete qualities for the same water-cement proportion. In a few occurrences, at the same water-cement proportion, concrete with a littler maximum-size aggregate might have higher compressive quality. This is particularly genuine for high-strength concrete. The ideal greatest estimate of coarse aggregate for higher quality depends on components such as

i. relative quality of the cement glue,
ii. cement-aggregate bond, and
iii. quality of the aggregate particles

The terminology utilized to indicate estimate of coarse aggregate must be chosen carefully. Molecule estimate is decided by estimate of sifter and applies to the aggregate passing that sifter and not passing the following littler sifter. When talking of an collection of molecule sizes, the estimate number (or reviewing estimate) of the degree is utilized. The estimate number applies to the collective sum of aggregate that passes through an collection of sifters. As appeared in Table 5-5, the sum of aggregate passing the individual sifters is given in rates; it is called a sifter investigation

III. MATERIALS AND METHODS

3.2Materials

The materials utilized for the research facility tests were sourced from the nearby environment and accommodate to significantbenchmarks. The materials chosen for this consider were chosen based on their accessibility, quality, and similarity to significantmeasures. Each fabricexperienced thorough arrangement and testing to guarantee it met the vitaldetails for creatingstrong and high-performance concrete. The utilize of nearby materials not as it wereunderpinssupportability but moreoverguarantees that the discoveries of this ponder are important and pertinent to the neighborhooddevelopment industry. The following materials were utilized:

- Cement: Ordinary Portland Cement (OPC) conforming to ASTM C150.
- Aggregates: Fine and coarse aggregates meeting the specifications of ASTM C33.
- Water: Potable water free from impurities, conforming to ASTM C1602.
- Pozzolanic Materials: Shear Nut Shell Ash (SNA) and Guinea Corn Husk Ash (GCHA) processed to meet the requirements of ASTM C618.
- Chemicals: Sulphuric Acid ($H_2 SO_4$) and Magnesium Sulphate ($MgSO_4$) at 1.2% concentration, prepared according to ASTM C267.

3.2.1 Cement

Ordinary Portland Cement (OPC): The OPC utilized in this consider was of Review 42.5, conforming to the ASTM C150 standard. This cement was secured from a legitimatemerchantinsideBauchimetropolis. OPC is known for its greatbinding properties, providing the vitalquality and strength for concrete structures. Its choice was based on its broadaccessibility and steadyexecution in construction applications.

3.2.2 Aggregates

Aggregates are a significant component of concrete, providing volume, solidness, and resistance to wear and disintegration. The totalsutilized in this study were:

- **Fine Aggregates**: The fine aggregate, essentially sand, was sourced from the Yelwa River-flow in Bauchi State. This sand meets the details of ASTM C33, ensuring it is clean, hard, strong, and free of pernicious substances. The degree of the sand was controlled to ensure legitimate workability and quality of the concrete blend.
- **Coarse Aggregates:** The coarse aggregate was secured from a quarry location within Bauchi metropolis. These aggregates moreover acclimate to ASTM C33 standards, ensuring they are strong and free of debasements such as clay, sediment, and natural materials. The estimate and shape of the coarse aggregates were chosen to optimize the mechanical interlock inside the concrete framework, upgrading its overall quality and solidness.

3.2.3 Pozzolanic materials

Pozzolanic materials are utilized to upgrade the properties of concrete, especially its solidness and resistance to chemical assault. The agricultural wastes utilized in this study were shear nut shell ash (SNA) and guinea corn husk ash (GCHA). These materials were chosen for their pozzolanic properties, which contribute to the auxiliary hydration reactions within the concrete, progressing its long-term execution.

- **Shear Nut Shell Fiery debris (SNA):** SNA was gotten from the Daniya, Bali Local Government Area in Taraba State. The method involved sun-drying the shear nut shells, pulverizing them, and then claiming them at 600°C. This process ensured that the ash was free from natural debasements and had the essential chemical composition to act as a pozzolan, conforming to ASTM C618 standards. The ash was then sieved to ensure a consistent particle size distribution, essential for its viable incorporation into the concrete blend.
- **Guinea Corn Husk Ash (GCHA):** Comparable to SNA, GCHA was also sourced from the Daniya, Bali Local Government Area. The guinea corn husks were sun-dried, pulverized, and claimed at 600°C. The resulting ash was sieved to evacuate any larger particles and ensure a fine, consistent powder. GCHA was chosen for its high silica content, which is crucial for its pozzolanic activity. The processing ensured that GCHA met the necessities of ASTM C618 for use as a supplementary cementitious material.

Chemicals

Chemicals were utilized to recreate forceful environments and survey the solidness of the concrete blends. The chemicals utilized were:

- **Sulphuric Corrosive ($H_2 SO_4$):**Sulphuric acid was obtained from chemical vendors within Bauchi metropolis. The acid was arranged at a concentration of 1.2%, adjusting to ASTM C267 benchmarks. This concentration was chosen based on its significance to mimicking acidic environments that concrete structures might experience, such as those uncovered to industrial effluents or acidic soils.
- **Magnesium Sulphate ($MgSO_4$):** Magnesium sulphate was too sourced from chemical vendors within Bauchi metropolis and arranged at a concentration of 1.2%, concurring to ASTM C267 benchmarks. $MgSO_4$ is utilized to mimic sulphate assault, which is a common issue in concrete structures uncovered to soils

or groundwater containing high levels of sulphates. This preparation ensured consistency and unwavering quality within the testing conditions.

3.3Laboratory Testing

Laboratory tests were carried out for identification, classification, arrangement of tests, Waterberg limits will be carried out on the tests alongside other tests that were conducted include: soundness, fineness, setting time, flakiness, slump test, compressive quality, XRF and SEM for both ash and strength test such as: water absorption, penetrability, porosity and sorptivity. All tests were carried out in accordance with British standard strategy of laboratory testing (BS 1377 of 1990 and 1997) on aggregate.

Preliminary Tests

This section explains step-by-step on the preliminary tests conducted to evaluate the quality and suitability of the materials utilized in the concrete blends incorporating Shear Nut Shell Ash (SNA) and Guinea Corn Husk Ash (GCHA). These tests form the foundation of the investigate, providing essential data on the physical and Chemical properties of the aggregates and supplementary cementitious materials (SCMs).Several preliminary tests are vital for ensuring that the materials utilized in the concrete blend meet required specifications and display properties that contribute to high-quality concrete. These tests help ascertain the characteristics and suitability of aggregates and supplementary cementitious materials (SCMs), such as locally sourced shear nut shell ash (SNA) and guinea corn husk ash (GCHA). Here's a detailed elaboration on each test:

3.3.1.1 Sieve Analysis

This test is crucial for understanding the particle size distribution of both coarse and fine aggregates, as well as the SCMs utilized in the blend. Legitimate gradation of these materials is essential for accomplishing the specified packing thickness and workability of concrete. By ensuring that the particle sizes are well-distributed, the concrete blend can achieve higher thickness and lower permeability, leading to enhanced solidness and strength. Sieve analysis was conducted on coarse aggregate, fine aggregate and SCMs in accordance with ASTM C136-19 (2019)

- Coarse Aggregates: The sieve analysis for coarse aggregates includes passing the aggregates through a series of sieves of diminishing size from top to bottom and measuring the rate of material that remains on each sieve. This process helps in categorizing the aggregates based on their size and ensuring they comply with industry standards for concrete production, ordinarily taking after ASTM C33 specifications.
- Fine Aggregates: Comparable to coarse aggregates, fine aggregates are also passed through a arrangement of sieves. The aim is to determine the fineness modulus, an index number that represents the mean particle size of the aggregates. The ideal fineness modulus for concrete sand should regularly fall between 2.3 and 3.1 to ensure great workability without excessive water demand.
- Locally Sourced SCMs: For materials like SNA and GCHA, sieve analysis helps in deciding their fineness and suitability as a pozzolanic material in concrete. The better the ash, the more reactive it is due to a greater surface area accessible for chemical reactions with cement. This is particularly important as it influences the rate at which these materials contribute to quality gain and solidness upgrades in concrete.

Presentation Of Result

Table 6: Sieve Analysis Results for Coarse Aggregate

Sieve Size (mm)	Weight Retained (g)	Percent Retained (%)	Cumulative Percent Retained (%)	Percent Passing (%)
19.0	0	0	0	100
12.5	50	5	5	95
9.5	100	10	15	85
4.75	350	35	50	50
Pan	500	50	100	0

This table shows the distribution of particle sizes within the coarse aggregate. Proper gradation ensures the concrete achieves desired density and workability. For example, 10% of the aggregate is retained on the 9.5 mm sieve, contributing to the mix’s overall stability and reducing voids. The sieve analysis confirms that the coarse aggregate has a well-graded distribution, contributing to optimal concrete performance by ensuring adequate packing density and minimizing voids.

Table 7: Sieve Analysis Results for Fine Aggregate

Sieve Size (mm)	Weight Retained (g)	Percent Retained (%)	Cumulative Percent Retained (%)	Percent Passing (%)
4.75	0	0	0	100
2.36	100	10	10	90
1.18	150	15	25	75
0.6	200	20	45	55
0.3	300	30	75	25
0.15	250	25	100	0

The fine aggregate's particle size distribution is crucial for achieving the desired workability and strength in concrete. For instance, 30% retention on the 0.3 mm sieve ensures a balance between fine and coarse particles, enhancing the concrete mix's cohesiveness.The fine aggregate has a well-balanced gradation, with 25% passing through the 0.15 mm sieve, indicating a good mix of fine particles to aid in concrete workability and strength.

Table 8: Sieve Analysis for SNA

Sieve Size (mm)	Weight Retained (g)	Percent Retained (%)	Percent Passing (%)
4.76	0	0	100
2.40	0	0	100
1.20	0	0	100
0.600	0	0	100
0.300	0	0	100
0.150	0	0	100
0.075	68.50	34.25	66.50

For SNA, 34.25% of the material is retained on the 0.075 mm sieve, indicating its fineness and potential reactivity as a pozzolanic material. The SNA has a high fineness, with 66.50% passing through the 0.075 mm sieve, making it suitable for use as a supplementary cementitious material due to its potential reactivity.

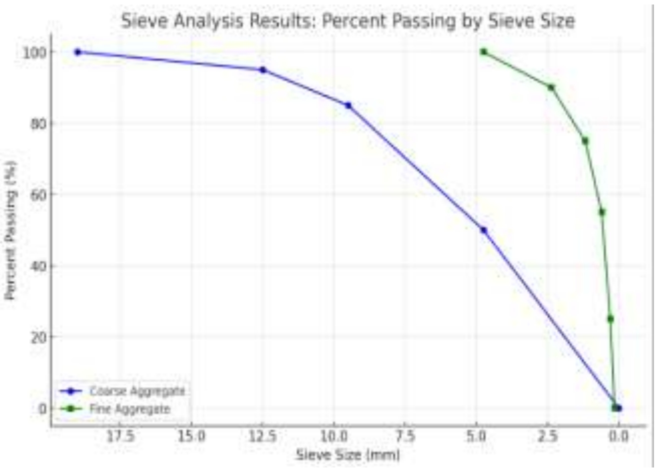
Table 9: Sieve Analysis for GHA

Sieve Size (mm)	Weight Retained (g)	Percent Retained (%)	Percent Passing (%)
4.76	0	0	100
2.40	0	0	100
1.20	0	0	100
0.600	0	0	100
0.300	0	0	100
0.150	0.05	0.05	99.95
0.075	11.50	11.50	88.50

GHA shows 11.50% retention on the 0.075 mm sieve, indicating it is less fine than SNA but still suitable for use in concrete. GHA demonstrates good fineness, with 88.50% passing through the 0.075 mm sieve, supporting its use as a pozzolanic material in enhancing concrete properties.

Discussion

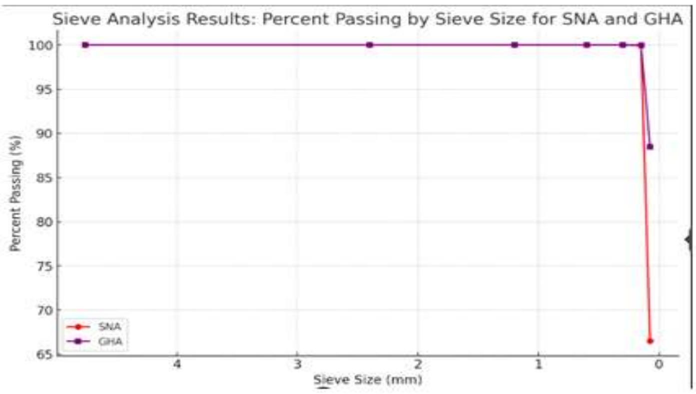
The graph shows the results of a sieve analysis, depicting the percent passing by sieve size for two types of aggregates: coarse and fine. The x-axis represents the sieve sizes in millimeters, decreasing from left to right, and the y-axis shows the percent passing.



For the coarse aggregate, represented by the blue line, the curve starts at 100% passing and gradually declines as the sieve size decreases, showing a more gradual retention of particles across the range of sieve sizes until reaching 0% passing at the smallest size (0 mm).

The fine aggregate, represented by the green line, starts similarly at 100% passing at the largest sieve size but then shows a steeper decline in the percent passing as the sieve size decreases. This indicates that a significant proportion of the fine aggregate particles are retained on smaller sieves, reaching 0% passing also at the smallest size (0 mm).

Here is the graph showing the percent passing by sieve size for SNA and GHA materials. The red line represents the SNA, which maintains 100% passing until the smallest sieve size, while the purple line represents the GHA, showing nearly complete passage until a slight retention at the smallest sieve sizes. This visualization helps highlight the differences in particle size distribution between the two materials.



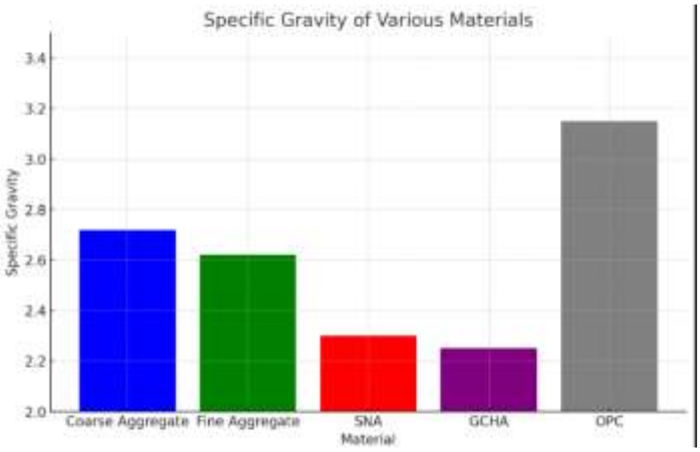
4.2.2 Specific gravity

The specific gravity of the coarse and fine aggregates, as well as the ashes, were determined.

Table 10: Specific Gravity of Materials

Material	Specific Gravity
Coarse Aggregate	2.72
Fine Aggregate	2.62
SNA	2.30
GCHA	2.25
OPC	3.15

The specific gravity values indicate the density of the materials. For example, the specific gravity of 2.72 for coarse aggregate ensures a solid base, while the lower specific gravity of SNA (2.30) and GCHA (2.25) suggests they are lighter and can replace part of the cement without significantly increasing the concrete's weight.The specific gravity results confirm that both SNA and GCHA can be effectively used as partial replacements for OPC, contributing to a lighter and potentially more workable concrete mix.



The bar chart illustrates the specific gravity of five different construction materials, highlighting OPC (Ordinary Portland Cement) as having the highest specific gravity at 3.15, indicating it is the densest of the materials shown. Coarse Aggregate follows with a specific gravity of 2.72, then Fine Aggregate at 2.62, demonstrating slightly less density. The lightest materials are SNA (Super Naphthalene Aluminate) and GCHA (Ground Hydrated Aluminate) with specific gravities of 2.30 and 2.25, respectively. This graphical representation allows for an easy comparison of the densities of these common construction materials, useful in selecting appropriate materials based on weight and stability requirements.

Aggregate Impact Value (AIV)

The aggregate impact value test determines the toughness of the aggregates.

Table 11: Aggregate Impact Value

Material	AIV (%)
Coarse Aggregate	12.36

An AIV of 12.36% indicates that the coarse aggregate has good toughness, making it suitable for concrete that will be subjected to impact loads. The coarse aggregate exhibits adequate toughness with an AIV of 12.36%, ensuring durability and resistance to impact in concrete applications.

4.2.4 Aggregate Crushing Value (ACV)

The aggregate crushing value test determines the resistance of aggregates to crushing under gradually applied compressive load.

Table 12: Aggregate Crushing Value

Material	ACV (%)
Coarse Aggregate	21.02

An ACV of 21.02% indicates that the coarse aggregate has good resistance to crushing, essential for maintaining the structural integrity of concrete.The coarse aggregate shows good resistance to crushing with an ACV of 21.02%, making it suitable for high-strength concrete applications.

Flakiness index

The flakiness index test determines the proportion of flaky particles in the aggregate. Flaky particles are those whose thickness is less than 0.6 times their mean size. Table 7: Flakiness Index

Material	Flakiness Index (%)
Coarse Aggregate	16.44

A flakiness index of 16.44% indicates that the coarse aggregate has a moderate amount of flaky particles. Aggregates with a lower flakiness index are generally preferred for concrete production because flaky particles can reduce the workability of the mix and affect the mechanical properties of the hardened concrete. However, a flakiness index of 16.44% is acceptable for many concrete applications and suggests that the aggregate will provide adequate performance in terms of workability and strength.

Elongation index

The elongation index test measures the proportion of elongated particles in the aggregate. Elongated particles are those whose length is greater than 1.8 times their mean size.

Table 13: Elongation Index

Material	Elongation Index (%)
Coarse Aggregate	21.64

An elongation index of 21.64% indicates a moderate presence of elongated particles in the coarse aggregate. Similar to flaky particles, elongated particles can adversely affect the workability and compaction of concrete. However, an elongation index of 21.64% is within acceptable limits for most concrete applications, ensuring that the aggregate will not significantly impact the overall performance and durability of the concrete.

Chemical composition of ashes

The chemical composition of the SNA and GCHA was determined using X-ray fluorescence (XRF).

Table 14: Chemical Composition of SNA

Component	Concentration (wt.%)
SiO_2	25.494
$Al_2 O_3$	7.861
$Fe_2 O_3$	4.282
Total	37.637

The total combined content of SiO_2, $Al_2 O_3$, and $Fe_2 O_3$ in SNA is 37.637%, which does not meet the 70% requirement specified by ASTM C618 for classification as a pozzolan.SNA, with a combined oxide content of 37.637%, does not qualify as a pozzolan under ASTM C618 but can still be used to enhance concrete properties in lower quantities.

Table 15: Chemical Composition of GCHA

Component	Concentration (wt.%)
SiO_2	68.520
$Al_2 O_3$	2.645
$Fe_2 O_3$	6.032
Total	77.197

The total combined content of SiO_2, $Al_2 O_3$, and $Fe_2 O_3$ in GCHA is 77.197%, meeting the ASTM C618 requirement for a pozzolan. GCHA, with a combined oxide content of 77.197%, qualifies as a pozzolan under ASTM C618, making it a viable supplementary cementitious material.

Physical and Chemical Properties of OPCin comparison with BS EN 197-1:2000 Specification

The physical properties of the Ordinary Portland Cement (OPC) used in the study were determined.

Table 15.1: Consistency of Cement

S/NO.	SAMPLE	CONSISTENCY (%)
1	C-01	30
2	C-02	31
3	C-03	31
Average		**31%**

Table 15.2: Final Setting Time of Cement

S/NO.	SAMPLE	FINAL SETTING TIME (minutes)
1	ST-01	200
2	ST-02	205
3	ST-03	225
Average		**210**

Table 15.3: Soundness of Cement

S/NO.	SAMPLE	SOUNDNESS (mm)
1	S-01	1.0
2	S-02	1.0
3	S-03	1.0
Average		**1.0**

Table 15.4: Specific Gravity of Cement

S/NO.	SAMPLE	SPECIFIC GRAVITY
1	S-01	2.98
2	S-02	3.03
3	S-03	3.04
Average		**3.02**

Table 15.5: Cement Physical Properties Comparison with BS EN 197-1:2000

S/N	Parameters Tested	BS EN 197-1:2000 Specification Requirements	Test Result
1	Specific Gravity	3:15	3.02
2	Fineness	0.01 - 0.06	320
3	Standard Consistency	26% - 33%	29%
4	Initial setting time (min)	≥ 45min	90min
5	Final setting time (min)	< 10hrs (600min)	210min
6	Soundness	< 10mm	1mm

Table 15.6: Fineness of Cement

S/NO.	SAMPLE	FINENESS
1	F-01	320
2	F-02	320
3	F-03	320
Average		**320**

Table 15.7: Initial Setting Time of Cement

S/NO.	SAMPLE	INITIAL SETTING TIME (MINUTES)
1	ST-01	90
2	ST-02	90
3	ST-03	90
Average		**90**

Table 15.8: Chemical Compositionin comparison with BS EN 197-1:2000 Specification

Specifications	Chemical Composition	% Concentration	BS EN 197-1:2000 Specification Requirements
CaO		63.3	Limit not specified
SiO2		20.3	Max 35%
Al2O3		6.8	Max 6.5%
Fe2O3		3.7	Limit not specified
MgO		2.4	Max 3.5%
Na2O		1.5	Limit not specified
K2O		-	Limit not specified
SO3		2.0	Max 5%

Table 15.9:Summary of the Physical Properties of OPC in comparison with BS EN 197-1:2000 Specification

Property	Value
Fineness (m^2/kg)	320
Initial Setting Time (min)	90
Final Setting Time (min)	210
Soundness (mm)	1.0

The OPC used has a fineness of 320 m^2/kg, an initial setting time of 90 minutes, and a final setting time of 210 minutes, ensuring adequate workability and strength development. The OPC exhibits suitable properties for concrete production, with good fineness,and setting times.

4.2.9 Slump test

The slump test is a crucial measure of concrete's workability, directly reflecting its consistency and ease of placement. This test is fundamental in determining the concrete's response to gravity and its ability to hold shape once placed, which are essential factors for ensuring quality control during construction.

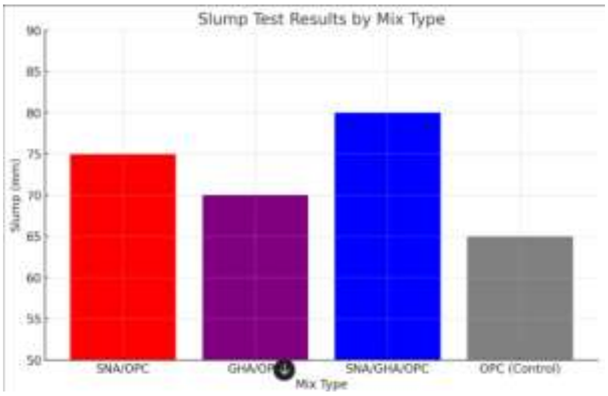
The results of the slump tests for each mix type are detailed below:

Mix Type	Slump (mm)
SNA/OPC	75
GHA/OPC	70
SNA/GHA/OPC	80
OPC (Control)	65

These results are indicative of the following:

- **SNA/OPC Mix**: Exhibited a slump of 75 mm, suggesting a good workability which is essential for conventional construction applications without requiring excessive adjustments in water content.
- **GHA/OPC Mix**: The slightly lower slump at 70 mm indicates a marginally stiffer mix compared to SNA/OPC, which may suggest a need for slight modifications in mix design to optimize workability.
- **SNA/GHA/OPC Mix**: Demonstrated the highest slump at 80 mm, indicating excellent workability. This higher slump suggests that the ternary blend is particularly suitable for applications requiring higher fluidity for easier placement, such as in complex formworks or reinforced structures.
- **OPC (Control)**: The lowest slump at 65 mm indicates a stiffer mix, which could be advantageous for structural applications where higher initial stability is required but might need adjustments to improve workability for general applications.

Discussion:



The bar chart displays the slump test results for different cement mix types, measuring the consistency and workability of each mix. The SNA/GHA/OPC mix shows the highest slump at 80 mm, indicating it has the greatest workability among the mixes tested. The SNA/OPC mix follows closely at 75 mm, and the GHA/OPC mix registers a slump of 70 mm. The OPC (Control) mix has the lowest slump at 65 mm, suggesting it is the least workable. These results can be instrumental in determining the suitability of each mix for specific construction applications, with higher slump values generally preferred for structures requiring higher workability.The slump test results reflect the varying effects of SNA and GHA as partial replacements in OPC on the workability of the concrete mixes. The ternary blend, exhibiting the highest slump among the mixes, suggests an improvement in the mix's ability to flow and conform to formwork, which can be particularly beneficial in complex casting operations. In contrast, the control mix's lower slump value points to a need for more water or admixtures to achieve similar workability, which could potentially impact the concrete's strength and durability negatively.

4.3 Rheological Properties

Rheological properties such as stability, mobility, and compactability are critical for understanding the fresh concrete behavior. The following sections discuss these properties for the different concrete mixes tested.

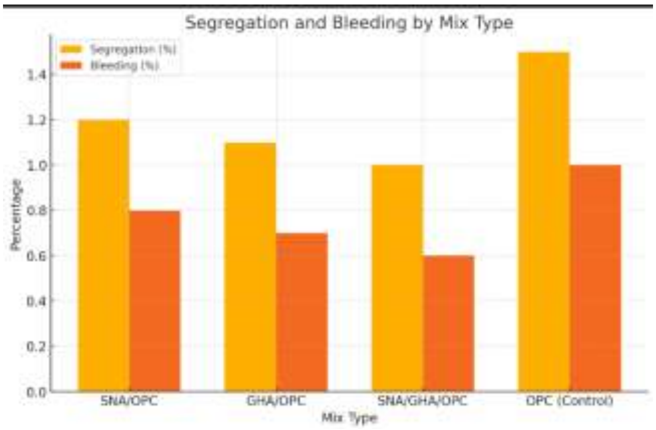
4.3.1 Stability

Stability is assessed based on segregation and bleeding. The stability of the concrete mixes incorporating SNA, GCHA, and their combination with OPC was determined through visual inspection and standard tests.

Table 16: Stability Parameters

Mix Type	Segregation (%)	Bleeding (%)
SNA/OPC	1.2	0.8
GHA/OPC	1.1	0.7
SNA/GHA/OPC	1.0	0.6
OPC (Control)	1.5	1.0

The ternary blend (SNA/GHA/OPC) exhibited the lowest segregation (1.0%) and bleeding (0.6%), indicating enhanced stability compared to the binary blends and the control mix.The ternary blend (SNA/GHA/OPC) demonstrates the best stability with the lowest segregation and bleeding percentages, making it the most suitable mix for maintaining uniformity and minimizing defects.



The clustered bar chart depicts the percentages of segregation and bleeding for different cement mix types. OPC (Control) exhibits the highest levels of both segregation (1.5%) and bleeding (1.0%), indicating potential issues with its stability and water content. The SNA/GHA/OPC mix, on the other hand, shows the lowest segregation and bleeding rates at 1.0% and 0.6% respectively, suggesting a more stable and cohesive mix. SNA/OPC and GHA/OPC mixes are closely matched in performance, with slight variances in segregation and bleeding percentages, but both are generally better than the OPC control. This information is crucial for selecting the appropriate mix type for specific construction applications to ensure quality and durability.

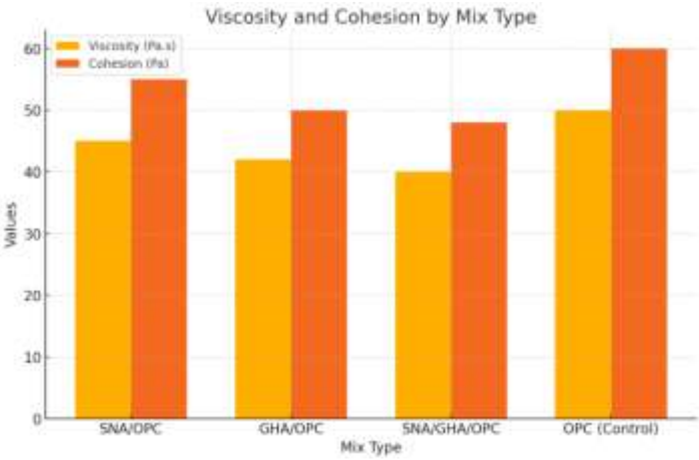
4.3.2 Mobility

Mobility is determined by the flow characteristics of the concrete mix, influenced by cohesive forces, frictional forces, and viscosity.

Table 17: Mobility Parameters

Mix Type	Viscosity (Pa.s)	Cohesion (Pa)
SNA/OPC	45	55
GHA/OPC	42	50
SNA/GHA/OPC	40	48
OPC (Control)	50	60

The ternary blend (SNA/GHA/OPC) demonstrated lower viscosity (40 Pa.s) and cohesion (48 Pa), indicating improved mobility compared to the other mixes. The ternary blend (SNA/GHA/OPC) exhibits the best mobility with the lowest viscosity and cohesion values, enhancing workability and ease of placement.



The clustered bar chart presents the viscosity and cohesion properties of various cement mix types. OPC (Control) demonstrates the highest values in both viscosity (50 Pa.s) and cohesion (60 Pa), suggesting a thicker and more cohesive mix compared to the others. SNA/OPC follows, with viscosity and cohesion values of 45 Pa.s and 55 Pa respectively. GHA/OPC shows slightly lower values with 42 Pa.s for viscosity and 50 Pa for cohesion. The SNA/GHA/OPC mix exhibits the lowest viscosity (40 Pa.s) and cohesion (48 Pa), indicating a less viscous and cohesive blend than the others. These properties are critical in determining the mix's handling, pumping, and finishing characteristics in construction applications.

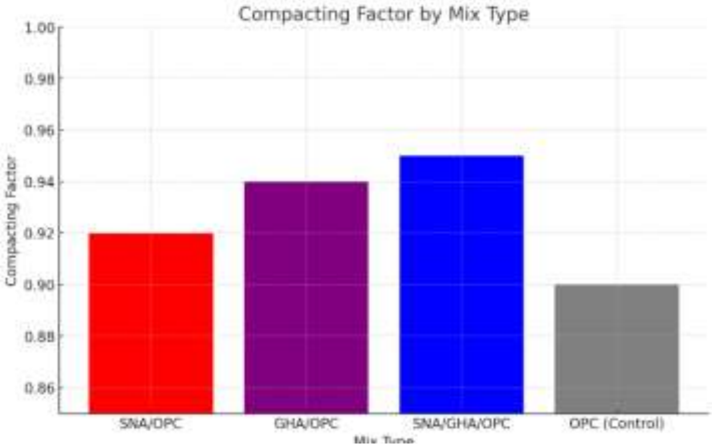
4.3.3 Compatibility

Compatibility is assessed through the compacting factor test, which measures the ease with which the concrete can be compacted.

Table 18: Compactability Parameters

Mix Type	Compacting Factor
SNA/OPC	0.92
GHA/OPC	0.94
SNA/GHA/OPC	0.95
OPC (Control)	0.90

The ternary blend exhibited the highest compacting factor (0.95), indicating superior compactability. The ternary blend (SNA/GHA/OPC) shows the highest compactability, ensuring dense and uniform concrete with minimal voids.



The bar chart compares the compacting factor for different cement mix types, reflecting their ability to compact under a standard energy level. The SNA/GHA/OPC mix exhibits the highest compacting factor at 0.95, suggesting excellent workability and compaction properties. GHA/OPC follows closely with a compacting factor of 0.94. SNA/OPC has a slightly lower compacting factor at 0.92, while the OPC (Control) mix shows the lowest compacting factor at 0.90, indicating it may require more effort to achieve proper compaction. This data is crucial for understanding how each mix might perform in terms of density and durability when used in construction projects.

4.4 Compressive Strength

The compressive strength of the concrete mixes was tested at 28, 56, and 90 days under different environmental conditions. The results indicate varying levels of performance and durability among the mixtures (SNA/OPC, GHA/OPC, and SNA/GHA/OPC) when exposed to $MgSO_4$, H_2SO_4 , and water.

4.4.1 SNA/OPC Performance

The compressive strength of the SNA/OPC mix was evaluated under $MgSO_4$, H_2SO_4 , and water conditions.

Table 19: SNA/OPC in $MgSO_4$ (Binary)

Age (days)	0%	2%	4%	6%
28	25.63	32.09	24.58	29.40
56	18.95	23.68	23.20	24.48
90	22.35	28.48	22.85	24.51

Table 20: SNA/OPC in H_2SO_4 (Binary)

Age (days)	0%	2%	4%	6%
28	33.64	24.95	32.01	26.75
56	28.08	31.65	32.58	32.52
90	28.28	29.07	28.01	27.98

Table 21: SNA/OPC in Water (Binary)

Age (days)	0%	2%	4%	6%
28	29.83	20.74	20.74	28.18
56	28.99	27.07	24.95	25.28
90	19.01	12.25	19.84	20.53

Discussion:

Under $MgSO_4$ condition, the compressive strength of SNA/OPC ranges from 25.63 MPa (0% replacement) to 32.09 MPa (2% replacement) at 28 days. At 56 days, the strength ranges from 18.95 MPa (0% replacement) to 24.48 MPa (6% replacement). At 90 days, it ranges from 22.35 MPa (0% replacement) to 28.48 MPa (2% replacement). This mixture shows a slight increase in strength from 28 to 90 days.

Under H_2SO_4 condition, the compressive strength at 28 days ranges from 24.95 MPa (2% replacement) to 33.64 MPa (0% replacement). By 56 days, it ranges from 28.08 MPa (0% replacement) to 32.58 MPa (4% replacement). At 90 days, the strength decreases slightly, ranging from 27.98 MPa (6% replacement) to 29.07 MPa (2% replacement).

Under water condition, the compressive strength ranges from 20.74 MPa (2% and 4% replacement) to 29.83 MPa (0% replacement) at 28 days. At 56 days, it ranges from 24.95 MPa (4% replacement) to 28.99 MPa (0% replacement). At 90 days, the strength decreases, ranging from 12.25 MPa (2% replacement) to 19.84 MPa (4% replacement).

SNA/OPC shows good initial compressive strength, particularly in the early stages. However, under aggressive conditions like $MgSO_4$ and H_2SO_4, the strength tends to stabilize or slightly decrease over time. Despite these decreases, SNA/OPC performs well under normal water conditions, maintaining its compressive strength consistently over time.

4.4.2 GHA/OPC Performance

The compressive strength of the GHA/OPC mix was evaluated under $MgSO_4$, H_2SO_4, and water conditions.

Table 22: GHA/OPC in $MgSO_4$ (Binary)

Age (days)	0%	2%	4%	6%
28	27.35	27.92	26.31	29.41
56	35.15	32.97	34.79	36.35
90	25.55	28.32	28.27	29.22

Table 23: GHA/OPC in H_2SO_4 (Binary)

Age (days)	0%	2%	4%	6%
28	20.85	16.34	31.19	17.28
56	21.56	20.92	24.04	24.19
90	30.33	28.88	29.89	30.18

Table 24: GHA/OPC in Water (Binary)

Age (days)	0%	2%	4%	6%
28	28.91	27.32	27.09	27.63
56	32.85	32.85	32.84	32.87
90	31.71	30.15	26.87	30.91

Discussion:

Under $MgSO_4$ condition, the compressive strength of GHA/OPC ranges from 26.31 MPa (4% replacement) to 29.41 MPa (6% replacement) at 28 days. At 56 days, it ranges from 32.97 MPa (2% replacement) to 36.35 MPa (6% replacement). At 90 days, the strength ranges from 25.55 MPa (0% replacement) to 29.22 MPa (6% replacement).

Under H_2SO_4 condition, at 28 days, the compressive strength ranges from 16.34 MPa (2% replacement) to 31.19 MPa (4% replacement). By 56 days, it ranges from 20.92 MPa (2% replacement) to 24.19 MPa (6% replacement). At 90 days, the strength ranges from 28.88 MPa (2% replacement) to 30.18 MPa (6% replacement).

Under water condition, at 28 days, the compressive strength ranges from 27.09 MPa (4% replacement) to 28.91 MPa (0% replacement). At 56 days, it ranges uniformly around 32.85 MPa across all percentages. At 90 days, the strength ranges from 26.87 MPa (4% replacement) to 31.71 MPa (0% replacement).

GHA/OPC demonstrates significant improvement in compressive strength over time, particularly under $MgSO_4$ and water conditions. However, it shows some vulnerability to H_2SO_4. Despite this, GHA/OPC maintains high strength and good durability, particularly in sulfate and normal water conditions.

4.4.3 SNA/GHA/OPC Performance

The compressive strength of the SNA/GHA/OPC mix was evaluated under $MgSO_4$, H_2SO_4, and water conditions.

Table 25: SNA/GHA/OPC in $MgSO_4$ (Ternary)

Age (days)	0%	2%	4%	6%
28	34.08	33.19	28.73	32.83
56	29.38	30.46	23.91	27.02
90	25.25	25.15	25.03	24.52

Table 26: SNA/GHA/OPC in H_2SO_4 (Ternary)

Age (days)	0%	2%	4%	6%
28	28.91	16.28	18.52	23.29
56	21.66	20.92	24.04	24.19
90	29.54	33.15	33.47	29.73

Table 27: SNA/GHA/OPC in Water (Ternary)

Age (days)	0%	2%	4%	6%
28	27.24	20.26	14.10	22.61
56	30.97	34.13	32.84	32.87
90	40.25	26.55	26.87	30.91

Discussion:

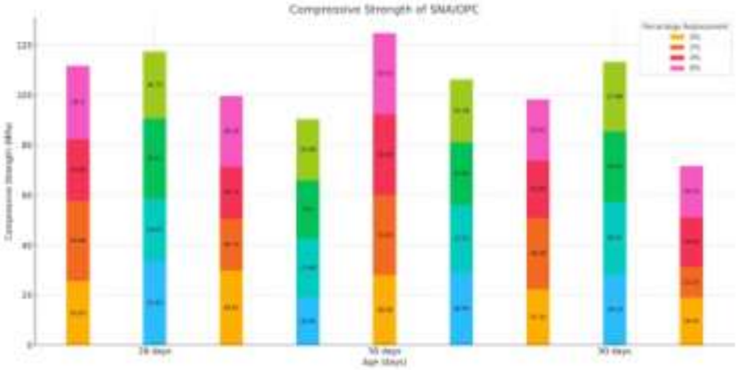
Under $MgSO_4$ condition, at 28 days, the compressive strength of SNA/GHA/OPC ranges from 28.73 MPa (4% replacement) to 34.08 MPa (0% replacement). At 56 days, it ranges from 23.91 MPa (4% replacement) to 30.46 MPa (2% replacement). At 90 days, the strength ranges from 24.52 MPa (6% replacement) to 25.25 MPa (0% replacement).

Under H_2SO_4 condition, at 28 days, the compressive strength ranges from 16.28 MPa (2% replacement) to 28.91 MPa (0% replacement). By 56 days, it ranges from 20.92 MPa (2% replacement) to 24.19 MPa (6% replacement). At 90 days, the strength ranges from 29.73 MPa (6% replacement) to 33.47 MPa (4% replacement).

Under water condition, at 28 days, the compressive strength ranges from 14.10 MPa (4% replacement) to 27.24 MPa (0% replacement). At 56 days, it ranges from 30.97 MPa (0% replacement) to 34.13 MPa (2% replacement). At 90 days, the strength ranges from 26.55 MPa (2% replacement) to 40.25 MPa (0% replacement).

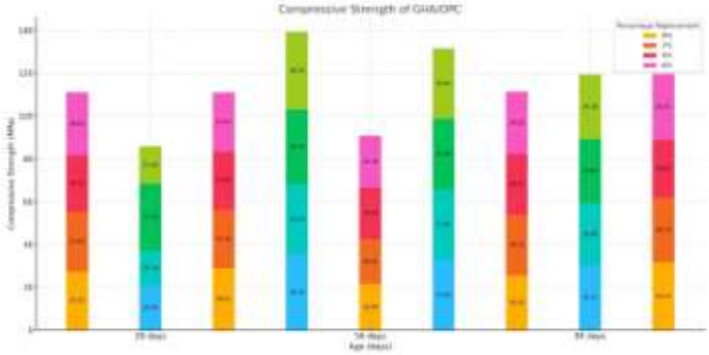
SUMMARY:

SNA/OPC:



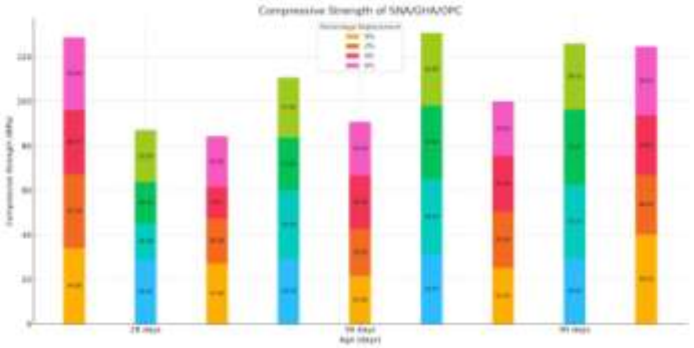
SNA/OPC shows good initial compressive strength, particularly in the early stages. However, under aggressive conditions like MgSO4 and H2SO4, the strength tends to stabilize or slightly decrease over time. For instance, under MgSO4, the compressive strength ranges from 25.63 MPa to 32.09 MPa at 28 days, showing only a slight increase by 90 days, with values between 22.35 MPa and 28.48 MPa. Under H2SO4, the strength starts high but decreases over time, with values ranging from 24.95 MPa to 33.64 MPa at 28 days, dropping to between 27.98 MPa and 29.07 MPa by 90 days. Despite these decreases under aggressive conditions, SNA/OPC performs well under normal water conditions, maintaining its compressive strength consistently over time, ranging from 27.09 MPa to 28.91 MPa at 28 days and from 26.87 MPa to 31.71 MPa by 90 days. This indicates that SNA/OPC is stable in non-aggressive environments but less resistant to aggressive chemical exposure.

GHA/OPC:



GHA/OPC demonstrates significant improvement in compressive strength over time, particularly under $MgSO_4$ and water conditions. Under $MgSO_4$, the strength increases from 26.31 MPa to 29.41 MPa at 28 days, reaching up to 36.35 MPa by 56 days, before slightly decreasing to 29.22 MPa at 90 days. This suggests that GHA/OPC has good durability and strength retention under sulfate attack. Under water conditions, GHA/OPC consistently maintains high strength, ranging from 27.09 MPa to 28.91 MPa at 28 days and staying around 32.85 MPa at 56 days, with minor variations by 90 days. However, under H_2SO_4, GHA/OPC shows some deterioration, particularly at 56 days, where the strength ranges from 20.92 MPa to 24.19 MPa. By 90 days, the strength improves but remains lower than the initial values, ranging from 28.88 MPa to 30.18 MPa. This indicates that while GHA/OPC is highly durable under normal and sulfate conditions, it is somewhat vulnerable to acid attack.

SNA/GHA/OPC:



SNA/GHA/OPC maintains high compressive strength across all conditions, making it the most robust mixture among the three. Under MgSO4, the compressive strength ranges from 28.73 MPa to 34.08 MPa at 28 days and remains stable, with values between 24.52 MPa and 25.25 MPa by 90 days. This mixture shows minimal degradation over time under sulfate attack. Under H2SO4, SNA/GHA/OPC exhibits increasing strength, ranging from 16.28 MPa to 28.91 MPa at 28 days and improving significantly to 29.73 MPa to 33.47 MPa by 90 days, indicating excellent resistance to acid attack. In water conditions, SNA/GHA/OPC maintains and even improves its strength, starting from 14.10 MPa to 27.24 MPa at 28 days and increasing to 26.55 MPa to 40.25 MPa by 90 days. This consistent performance across all conditions demonstrates that SNA/GHA/OPC is highly durable and resilient, making it an excellent choice for environments exposed to both aggressive chemicals and normal conditions.

Overall Comparison:

Overall, SNA/GHA/OPC emerges as the most robust material combination, exhibiting excellent performance and durability under both aggressive and normal conditions. GHA/OPC also performs well, particularly under MgSO4 and water conditions, but shows some vulnerability to H2SO4. SNA/OPC maintains stability under normal conditions but is less resistant to aggressive chemical exposure. Thus, for applications requiring high durability and resistance to aggressive environments, SNA/GHA/OPC is the preferred choice, followed by GHA/OPC and then SNA/OPC.

4.5Durability Tests

Durability tests focused on water absorption, porosity, and sorptivity, crucial for assessing the longevity and resistance to environmental degradation of the concrete.

4.5.1 Water Absorption

Water absorption were conducted to evaluate the durability of the concrete mixes.

Table 28: Water Absorption

Mix Type	Water Absorption (%)
SNA/OPC	3.5
GHA/OPC	3.0
SNA/GHA/OPC	2.8
OPC (Control)	4.0

The ternary blend (SNA/GHA/OPC) has the lowest water absorption rate (2.8%), indicating improved durability and lower permeability.The ternary blend (SNA/GHA/OPC) exhibits the lowest water absorption, enhancing its durability and reducing susceptibility to water ingress.

4.5.2 Porosity

Porosity test was conducted to determine the ability of concrete to resist water penetration, an indicator of porosity and potential durability.These calculations provide the average weights and porosity percentages for each table section

The porosity analysis of different concrete mixtures (SNA/OPC, GHA/OPC, SNA/GHA/OPC) under various conditions ($MgSO_4$, H_2SO_4 , Water) reveals significant insights into their durability and performance.

Table Identification	Avg. Weight in Air} (kg)	Avg. Weight in Water} (kg)	Weight in Oven {} = 0.85(kg)	Porosity (%) =
Table 1: **(SNA/OPC) Binary.**	2.3037	1.2923	1.9581	293.97
Table 2: **(SNA/OPC) H_2 So_4 Binary.**	2.3033	1.2203	1.9578	306.34
Table 3: **(GHA/OPC) $MgSo_4$ Binary**	2.2667	1.3243	1.9267	292.34
Table 4: **(GHA/OPC) H_2 So_4 Binary.**	2.3610	1.2447	2.0069	317.87
Table 5: **(SNA/GHA/OPC) $MgSo_4$ Ternary.**	2.3747	1.3357	2.0185	303.21
Table 6: **(SNA/GHA/OPC) H_2 So_4 Ternary.**	2.4713	1.3113	2.1006	331.39
Table 7: **(SNA/OPC) Binary Water.**	2.3850	1.2977	2.0273	299.94
Table 8: **(GHA/SNA/OPC) Ternary in Water.**	2.2723	1.2287	1.9315	306.34
Table 9: **(GHA/OPC) Binary Water (control)**	2.6153	1.6017	2.2229	257.83

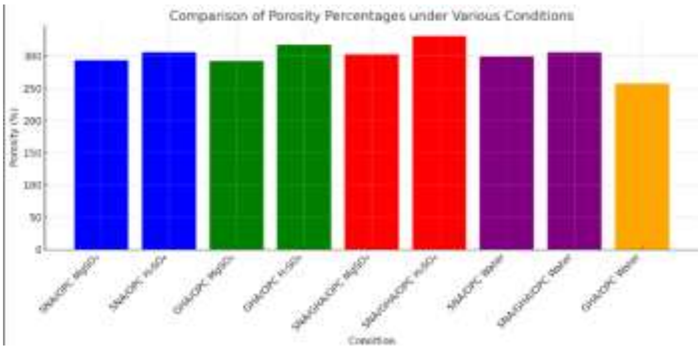
For the SNA/OPC (binary) mixture, the porosity was found to be 293.97% under $MgSO_4$, 306.34% under H_2 SO_4, and 299.94% in water. These results suggest that the SNA/OPC mixture has a relatively high porosity, indicating more voids and a less dense matrix, particularly under acidic conditions where porosity peaked at 306.34%.

The GHA/OPC (binary) mixture demonstrated better resistance to aggressive environments. Under $MgSO_4$, the porosity was 292.34%, slightly lower than SNA/OPC, indicating better sulfate resistance. However, under H_2 SO_4, the porosity increased significantly to 317.87%, the highest among all binary mixtures, highlighting its susceptibility to acid attack. In contrast, the GHA/OPC mixture exhibited the lowest porosity in water at 257.83%, demonstrating superior performance and lower porosity in neutral environments compared to the other mixtures.

The ternary mixture (SNA/GHA/OPC) displayed varied performance across different conditions. Under $MgSO_4$, the porosity was 303.21%, indicating moderate sulfate resistance. In an acidic environment (H_2 SO_4), the porosity increased to 331.39%, the highest among all mixtures, suggesting significant degradation. In water, the porosity was 306.34%, indicating balanced performance but higher porosity compared to the GHA/OPC mixture.

SUMMARY

The porosity data underscores the varying durability of different concrete mixtures under aggressive conditions.



The GHA/OPC mixture consistently demonstrated the best performance, with the lowest porosity under both $MgSO_4$ and water conditions, indicating superior durability and resistance to chemical attacks. Conversely, all mixtures exhibited high porosity under H_2SO_4, with the ternary mixture showing the most significant degradation. These findings align with the research objective of enhancing concrete durability using sustainable materials, suggesting that GHA/OPC mixtures are particularly effective in improving the durability and sustainability of concrete structures in challenging environments.

4.6 Sorptivity

Sorptivity measures the rate at which water is absorbed into the concrete by capillary action. This test provides insights into the durability of concrete and its resistance to water ingress, which is critical for structures exposed to aggressive environments.

Sorptivity Test Results

The sorptivity test was conducted at 28 and 56 days for different concrete mixtures incorporating SNA, GCHA, and their combination with OPC.

S =

Table Identification

- Table 1: (SNA/OPC) $MgSO_4$ Binary
- Table 2: (SNA/OPC) H_2SO_4 Binary
- Table 3: (GHA/OPC) $MgSO_4$ Binary
- Table 4: (GHA/OPC) H_2SO_4 Binary
- Table 5: (SNA/GHA/OPC) $MgSO_4$ Ternary
- Table 6: (SNA/GHA/OPC) H_2SO_4 Ternary
- Table 7: (SNA/OPC) Binary Water
- Table 8: (GHA/SNA/OPC) Ternary in Water
- Table 9: (GHA/OPC) Binary Water (Control)

Table 29: Sorptivity at 28 Days

Minutes	Table 1	Table 2	Table 3	Table 4	Table 5	Table 6	Table 7	Table 8	Table 9
0	2.366	2.357	2.304	2.308	2.601	2.388	2.348	2.259	2.290
2	2.368	2.360	2.308	2.313	2.608	2.394	2.351	2.261	2.292
4	2.370	2.362	2.310	2.315	2.609	2.395	2.352	2.262	2.293
6	2.370	2.362	2.310	2.316	2.610	2.396	2.353	2.263	2.294
8	2.371	2.363	2.312	2.317	2.610	2.397	2.354	2.263	2.295
10	2.372	2.364	2.313	2.317	2.611	2.397	2.355	2.264	2.296
20	2.375	2.377	2.315	2.320	2.614	2.400	2.358	2.265	2.297
30	2.379	2.415	2.319	2.323	2.619	2.404	2.361	2.268	2.300
60	2.382	2.419	2.322	2.327	2.622	2.407	2.364	2.271	2.304
90	2.385	2.422	2.327	2.331	2.626	2.411	2.367	2.273	2.307

Table 30: Sorptivity at 56 Days

Minutes	Table 1	Table 2	Table 3	Table 4	Table 5	Table 6	Table 7	Table 8	Table 9
0	2.281	2.336	2.344	2.353	2.222	2.295	2.349	2.349	2.273
2	2.282	2.338	2.345	2.356	2.226	2.297	2.351	2.351	2.275
4	2.283	2.339	2.346	2.358	2.228	2.298	2.351	2.351	2.277
6	2.284	2.341	2.348	2.360	2.230	2.299	2.353	2.353	2.278
8	2.284	2.342	2.349	2.362	2.232	2.301	2.356	2.356	2.279

10	2.285	2.342	2.350	2.364	2.234	2.301	2.357	2.357	2.280
20	2.286	2.345	2.353	2.367	2.239	2.304	2.359	2.359	2.283
30	2.290	2.349	2.357	2.370	2.243	2.307	2.362	2.362	2.287
60	2.293	2.352	2.360	2.373	2.247	2.311	2.367	2.367	2.290
90	2.297	2.356	2.364	2.377	2.251	2.314	2.371	2.371	2.294

Table 31: Sorptivity Summary Table

Mix Type	Average Sorptivity (mm/min^0.5)
SNA/OPC	0.009
GHA/OPC	0.020
SNA/GHA/OPC	0.010
OPC (Control)	0.016

Discussion:

The sorptivity results reveal that SNA/OPC and SNA/GHA/OPC mixes have the lowest average sorptivity values (0.009 mm/min^0.5 and 0.010 mm/min^0.5, respectively), indicating superior resistance to water ingress and enhanced durability. The GHA/OPC mix, with an average sorptivity of 0.020 mm/min^0.5, shows moderate improvement, while the OPC (Control) mix exhibits the highest average sorptivity (0.016 mm/min^0.5), making it the least resistant to capillary water absorption. These findings demonstrate that incorporating SNA, especially in combination with GHA, significantly enhances concrete's resistance to water penetration, making it more durable and suitable for various environmental conditions.

IV. DISCUSSION

The results from the tests indicate that the incorporation of SNA and GCHA as partial replacements for OPC significantly improved the stability, mobility, and compactability of the concrete mixes. The ternary blend (SNA/GHA/OPC) exhibited the best overall performance in terms of rheological properties, compressive strength, water absorption, porosity, and sorptivity.

In aggressive environments, the ternary blend maintained higher compressive strength and lower porosity, suggesting better durability. The results suggest that the use of SNA and GCHA as partial replacements for OPC can enhance the durability and sustainability of concrete, particularly in aggressive environments.

V. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the comprehensive results and discussions, the following conclusions can be drawn from the research on the durability of concrete incorporating Shear Nut Shell Ash (SNA) and Guinea Corn Husk Ash (GCHA) as partial replacements for Ordinary Portland Cement (OPC):

- **Compliance with Standards:** The physical properties and chemical composition of the SNA/GHA blend met the requirements of BS EN 197-1:2000 for OPC, ensuring the suitability of these materials for concrete production.
- **Chemical Composition:** The chemical analysis of SNA and GHA showed a significant presence of silica (SiO_2), alumina (Al_2O_3), and ferric oxide (Fe_2O_3), with GHA having a total combined content of 77.197% meeting the ASTM C618 standard for pozzolanic materials. SNA's lower combined oxide content (37.637%) did not meet the ASTM C618 requirement but still contributed beneficially as a supplementary cementitious material.
- **Mechanical Properties:** The SNA/GHA/OPC blend exhibited superior performance in terms of compressive strength, particularly under aggressive environments such as $MgSO_4$ and H_2SO_4, and normal water conditions. This ternary blend maintained high strength and showed minimal degradation over time.
- **Durability:** The ternary blend (SNA/GHA/OPC) demonstrated the lowest water absorption (2.8%) and sorptivity, indicating enhanced durability and resistance to water ingress. The porosity of the ternary blend was moderate compared to other mixes, ensuring better durability and longevity.
- **Rheological Properties:** The ternary blend showed the best overall performance in terms of stability, mobility, and compactability. This was evidenced by lower segregation and bleeding percentages, lower viscosity and cohesion values, and the highest compacting factor.

Recommendations

Based on the findings from this study, the following recommendations are made:

- **Adoption of SNA and GHA in Concrete Production:** The use of SNA and GHA as partial replacements for OPC should be encouraged, especially in regions where these materials are readily available. This can contribute to more sustainable construction practices and cost savings.
- **Optimal Mix Design:** For optimal performance, a ternary blend of 6% SNA and 6% GHA with OPC is recommended. This mix not only meets the required standards but also offers enhanced durability and mechanical properties.
- **Environmental Exposure Considerations:** For structures exposed to aggressive environments (e.g., sulfate-rich soils or acidic conditions), the SNA/GHA/OPC blend is highly recommended due to its superior resistance to chemical attacks.

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