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INVESTIGATING THE INFLUENCE OF SHEAR NUTSHELL AND GUINEA CORN HUSK ASH ON COMPRESSIVE STRENGTH OF CEMENT BLENDS EXPOSED TO HARSH CONDITIONS

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Abstract: Concrete materials are mostly used in Building Construction 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 compressive strength of concrete produced with shear nutshell ash and guinea corn husk ash as a partial replacement of Portland cement should be used in the production of concrete under the above conditions. Replacement for cement in concrete production tested using aggressive chemicals such as Hydrogen Sulphate(H2SO4) and Magnesium Sulphate (MgSO4). 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 results shows that 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.
Key Words. Concrete, Compressive Strength, Guinea Corn Ashe, Shearnut Shell Ashe, Aggressive Environment

Introduction

The Building Construction Industry in Nigeria are critical 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 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, soyabean 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).

Compressive strength is the capacity of a material or structure to withstand loads and the ultimate compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test where uniaxial compressive load is applied till its failure.

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 compressive strength of concrete produced with binary and ternary blended cement in normal and aggressive environments, specifically using shear nut shell ash (SNA) and guinea corn husk ash (GHA) as partial replacements for cement (Agboola et al., 2022).

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 over emphasized. 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.

Aim and Objectives

The aim of this study is to evaluate the rheological properties, chemical composition, and compressive strength of binary and ternary blended concrete incorporating shear nutshell ash (SNA) and guinea corn husk ash (GHA) under normal and aggressive environmental conditions. The following are the specific objectives which are to:
i. determine the Rheological properties of binary and ternary blended concrete using setting time and workability; ii. determine the Chemical Composition of Guinea corn husk ash and Shear nut shell ash; iii. determine the

compressive strength of binary and ternary blended SNA and GHA concrete subjected to normal and aggressive environments.

Scope of the Work

This research explores the potential of using guinea corn husk ash (GHA) and shear nut shell ash (SNA) as partial replacements for cement in concrete production. The study focuses on the compressive strength performance of these blended cements when exposed to aggressive chemical environments. The materials will be sourced from local suppliers in Daniya, Bali Local Government Area (LGA) of Taraba State, Nigeria, which is characterized by a soil pH of 4.5-5.1. This region has an abundant supply of this agricultural waste products (SNA and GHA), making it an ideal location for sourcing our waste material.

The concrete samples will be subjected to environments containing sulphuric acid (H_2SO_4) and magnesium sulphate ($MgSO_4$) at concentrations of 1.2% for both chemicals. These specific concentrations are chosen based on existing literature to provide a robust assessment of the concrete's performance under severe conditions. The study will assess the rheological properties of the concrete mixes, including setting time and workability, to understand how the inclusion of GHA and SNA affects the fresh concrete behavior.

This analysis will help in understanding the interaction between the pozzolanic materials and the cement matrix. Additionally, the compressive strength of the concrete samples will be measured under both normal and aggressive environments to evaluate the mechanical performance and robustness of the blended cement concrete.

By focusing on these aspects, the research aims to contribute to the development of cost-effective, durable, and environmentally friendly construction materials that can withstand harsh chemical environment.

Conceptual Review

Concrete solidness properties infiltration of forceful substances into concrete through smaller scale splits or openings can lead to weakening, hence decreasing its benefit life of structures. This sort of disintegration may take place due to sulphate assault, chloride infiltration, alkali-silica response. However, this can be diminished by including the Complementary Cementitious Materials (CCMs). These CCM's diminish the pores in concrete as well as increment its thickness (Devi, Rao & Srikanth, 2015). Concrete is for the most part made from locally accessible constituents, which are casted into a wide assortment of basic setups, and involves slight upkeep during benefit. It is appealing in numerous applications since it offers significant quality at a moderately less fetched. High quality of concrete is accomplished by lowering the water substance through chemical admixture like water diminishing specialists to concrete. In some cases, a high quality prerequisite isn't adequate indeed for other properties moreover to be improved like strength, low penetrability and great workability (Datok et al. 2018).

For this reason, pozzolanic materials are consolidated into concrete like fly ash, silica, ggbs, saw dust ash, corn cob ash and a lot more. These are called mineral admixtures. Joining of these admixtures not as it were improve the properties of concrete they moreover decrease the cement substance in concrete. The decrease of cement substance implies it minimizes the environmental impacts caused in cement generation prepare and most of these materials are mechanical byproducts, issues with transfer moreover can be unraveled (Michael & Thomas, 2016). This review shall consider the impacts of mineral admixtures on concrete properties in numerous forms like binary, ternary and quaternary mixes and their impacts on workability, quality advancement, and resistance to alkali aggregate responses and sulphate ass

Fig. 1: Images display various mineral admixtures like fly ash, silica, ggbs, sawdust ash, and corn

The Benefits of Concrete in Building Construction

Concrete as a 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. cement, aggregate, water and admixtures (pozzolans) (Mehta & Monteiro, 2016).

Fig. 2: A diagram showing the parts of concrete: cement, aggregate, water, and admixtures (pozzolans).

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 CO_2 emission. For each tone of cement being delivered, a normal of 0.87 tons of CO_2 is being transmitted (Naitik, et al, 2016).

Table 1: CHEMICAL COMPOSITION OF CEMENT

S/no	Parameters	Composition (wt%)
1	CaO	56-64
2	SiO_2	17-25
3	Al_2O_3	3-8
4	Fe_2O_3	3.5
5	IR	4% Max
6	MgO	2-6
7	Total Alkalis as Na_2O	0.5-1.4
8	SO_3	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 (Datok et 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.

Fig. 3: Natural Pozzolan in Concrete

Table 2: CLASSIFICATION OF POZZOLANAS

CHEMICAL REQUIREMENTS	**MINERAL ADMIXTURE CLASS**		
	N	**F**	**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 (Fineness, maximum (%) retained on 325Mesh (44um) sieve)	34	34	34

(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

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.

Fine-Aggregate

Prerequisites of ASTM C 33 or AASHTO M 6/M 43 allow a moderately wide range in fineaggregate 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 in Table 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.

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.

Coarse-Aggregate

The coarse aggregate evaluating pre requisites of ASTM C 33 (AASHTO M 80) allow a wide run in evaluating and an 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 watercement 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.

AGGRESSIVE CHEMICAL EXPOSURE

Concrete will perform palatably when uncovered to different atmospheric conditions, to most waters and soils containing forceful chemicals, and to numerous other sorts of chemical exposure. There are, however, some chemical environments beneath which the valuable life of indeed the finest concrete will be brief, unless particular measures are taken. An understanding of these conditions licenses measures to be taken to anticipate disintegration or diminish the rate at which it takes place

SULPHATE ATTACK

Sulfates respond with hydration items of tri-calcium aluminate (C3A) stage of portland cement and with calcium hydroxide ($Ca(OH)_2$) to make broad items called ettringite and gypsum. Arrangement of ettringite can result in an increment in strong volume, causes tensile stresses to create in the concrete, leading to extension and splitting.

These splits permit simple ingress for more sulfates into the concrete and disintegration quickens. Formation of gypsum can lead to softening and misfortune of concrete quality. A few of the sulfate-related forms can harm concrete without extension too. For example, concrete subjected to dissolvable sulfates can endure softening of the glue matrix or an increment in the generally porosity, either of which decreases solidness.
Sulphate assault decreases the strength of concrete by changing the chemical nature of the cement glue and the mechanical properties of concrete. The degree of assault may be assessed from the quantity of C3A show in the cement and $Ca(OH)_2$ liberated during the hydration of cement. **Sodium sulfate assault**

$Na_2SO_4 + Ca(OH)_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + 2NaOH$

Due to the arrangement of sodium hydroxide as a by-product of the response, the system remains exceedingly alkaline which is an essential condition for the solidness of C-S-H.

Magnesium sulfate attack

When the assaulting sulfate arrangement contains magnesium sulfate, brucite [$Mg(OH)_2$, magnesium hydroxide] is produced in expansion to ettringite and gypsum. During the particle exchange response between magnesium sulphate and calcium hydroxide/calcium silicate hydrate, transformation of calcium hydroxide to gypsum is went with by arrangement of magnesium hydroxide which is generally insoluble and poorly alkaline. In the nonappearance of hydroxyl particles in the arrangement, C-S-H is not steady and is additionally assaulted by the sulphate arrangement. Whereas both shapes of assault will lead to harm by gypsum arrangement, magnesium sulfate attack is considered to be more extreme since it'll also compromise the steadiness of the C-S-H.

$MgSO_4 + Ca(OH)_2 + 2H_2O \rightarrow CaSO_4.2H_2O + Mg(OH)_2$. $3MgSO_4 + 3CaO .2SiO_2 .3H_2O + 8\ H_2O$
$\rightarrow 3CaSO_4.2H_2O + 3Mg(OH)_2 + 2SiO_2.H_2O$

within the world. Without it, the development industry that utilizes huge tonnages of which are casted into a wide assortment of basic setups, and involves slight upkeep during benefit. It is appealing in numerous applications since it offers significant quality at a moderately less fetched. High quality of concrete is accomplished by lowering the water substance through chemical admixture like water diminishing specialists to concrete. In some cases, a high quality prerequisite isn't adequate indeed for other properties moreover to be improved like strength, low penetrability and great workability (Datok et al. 2018).
For this reason, pozzolanic materials are consolidated into concrete like fly ash, silica, ggbs, saw dust ash, corn cob ash and a lot more. These are called mineral admixtures. Joining of these admixtures not as it were improve the properties of concrete they moreover decrease the cement substance in concrete. The decrease of cement substance implies it minimizes the environmental impacts caused in cement generation prepare and most of these materials are mechanical byproducts, issues with transfer moreover can be unraveled (Michael & Thomas, 2016). This review shall consider the impacts of mineral admixtures on concrete properties in numerous forms like binary, ternary and quaternary mixes and their impacts on workability, quality advancement, resistance to alkali-aggregate responses and sulphate assaults et

Methodology

The research design, materials, and methods used in assessing the Rheological properties of binary and ternary blended cement and the compressive strength of concrete produced with binary and ternary blended cement, incorporating shear nut shell ash (SNA) and guinea corn husk ash (GHA) as partial replacements for cement. The experimental procedures for evaluating the compressive strength are as follows **Materials**

The materials utilized for the research facility tests were sourced from the nearby environment and accommodate to significant benchmarks. The materials chosen for this consider were chosen based on their accessibility, quality, and similarity to significant measures 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 (GHA) processed to meet the requirements of ASTM C618.
- Chemicals: Sulphuric Acid (H_2SO_4) and Magnesium Sulphate ($MgSO_4$) at 1.2% concentration, prepared according to ASTM C267.
- **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 legitimate merchant inside Bauchi metropolis. OPC is known for its great binding properties, providing the vital quality and strength for concrete structures. Its choice was based on its broad accessibility and steady execution in construction applications.

Aggregates

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

- **Fine Aggregates**: The fine aggregate, essentially sand, was sourced from the Yelwa Riverflow 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.

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 (GHA). 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 village in 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 (GHA):** Comparable to SNA, GHA was also sourced from Daniya village in 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. GHA was chosen for its high silica content, which is crucial for its pozzolanic activity. The processing ensured that GHA 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_2SO_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.

Laboratory 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 and compressive quality for both ashes and strength . 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 (GHA). These tests form the foundation investigates, 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 (GHA). Here's a detailed elaboration on each test:

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 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 GHA, 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.

PROCEDURES

Sieve analysis is conducted to determine the particle size distribution of the aggregates and SCMs. The procedure involves:

1. **Sample Preparation:** A representative sample of the material (aggregates or SCMs) is dried in an oven at a standard temperature of 110°C (230°F) to remove moisture. This temperature is commonly used because it effectively removes moisture from the sample without altering its composition.
2. **Sieving Process:** The dry sample is then placed on the top sieve of a stack arranged from largest (at the top) to smallest (at the bottom). Standard sieve sizes used are 4.75 mm, 2.4 mm, 1.2 mm, 600 µm, 300 µm, 150 µm, and 75 µm.
3. **Shaking:** The sieve stack is mechanically shaken for approximately 10-15 minutes to allow particles to pass through the sieves.
4. **Weighing:** Material retained on each sieve is weighed, and the percentage retained and passed is calculated for each sieve to determine the grading of the material.
5. **Data Analysis:** This data is crucial for understanding the aggregate's suitability for concrete mix, affecting the density, workability, and strength of the final concrete.

Coarse and Fine Aggregate Tests

These include several evaluations to assess the physical and mechanical properties of the aggregates. The Flakiness and Stretching Record tests are critical assessments utilized to decide the shape characteristics of aggregates utilized in concrete blends. The shape and dimension of aggregates essentially influence the workability, mechanical solidness, and toughness of the concrete. Legitimately formed aggregates help in accomplishing a higher thickness and quality of concrete whereas decreasing the cement demand and progressing workability.

Flakiness Index Test: This includes measuring the thickness of individual aggregates and identifies those that are considered too thin for optimal concrete performance. Particles that pass through the desired opening are considered flaky. The flakiness index is the weight of flaky particles separated by the entire weight of the sample, expressed as a rate. This test was conducted in agreement with BS EN 933-3 (2017).

PROCEDURE

Here’s a detailed step-by-step procedure:

1. **Sample Preparation:** A representative sample of aggregates is selected and washed to remove dust and then dried to a constant weight at 110°C (230°F).
2. **Sieve the Aggregates:** The aggregates are sieved using standard sieves to separate sizes between 63mm and 6.3mm. Only aggregates within this size range are tested for flakiness.
3. **Thickness Measurement:** Each aggregate piece is then passed through a slot of specific thickness gauges. For example, each gauge slot could be set at dimensions such as 10mm x 6.3mm, based on the maximum and minimum sizes of the aggregates.
4. **Weighing Flaky Aggregates:** Aggregates that pass through the slots are collected and weighed. These are considered flaky because their thickness is less than the minimum dimension of the slot.
5. **Calculation:** The flakiness index is calculated as the total weight of flaky aggregates divided by the total weight of the aggregates tested, then multiplied by 100 to express the result as a percentage.

Elongation Index Test: Similar to the flakiness test, this measures the length of aggregatesand identifies those that are considered too long for optimal use in concrete. Particles that pass lengthwise through a specified gauge (e.g., length gauge of 180 mm x width of 6.3 mm) are considered elongated. The elongation index is calculated by dividing the weight of the elongated particles by the total sample weight, expressed as a percentage. Elongation Index test was conducted in accordance with ASTM D4791-19 (2019)

PROCEDURES

Here's how this test is conducted:

1. **Sample Preparation:** Use the same initial sample that was prepared for the flakiness index.
2. **Sieve the Aggregates:** The same sieved aggregates used in the flakiness test are utilized here.
3. **Length Measurement:** Each aggregate is then individually tested to see if it can pass lengthwise through a specific gauge with a slot of defined dimensions, for instance, a length gauge of 180mm x 6.3mm.
4. **Weighing Elongated Aggregates:** Aggregates that pass through this slot lengthwise are collected and weighed. These are considered elongated because their length exceeds the maximum allowed by the slot.
5. **Calculation:** The elongation index is determined by dividing the total weight of elongated aggregates by the total weight of the aggregates tested and then expressing this as a percentage.

Specific Gravity Test

The Specific Gravity Test is a critical procedure utilized to decide the thickness of aggregates relative to water. This test is essential for assessing the quality of the aggregates and their suitability for utilize in concrete blends, as specific gravity values impact the quality, durability, and volume solidness of the concrete. Using a pycnometer, the particular gravity of the aggregates is decided. Specific gravity test on all aggregates was carried out in accordance with ASTM C12715 (2015) and ASTM C128-15 (2015) whereas the specific gravity test carried out on the Ashes (GHA and SNA) were in accordance to ASTM D546-17 (2017). The aggregate is weighed in air, at that point in water, and the specific gravity is calculated based on the weight difference.

PROCEDURES

The test can be conducted using a pycnometer or through the water displacement method, and it generally follows these detailed steps:

1. Sample Preparation

- **Drying:** Initially, the aggregate sample is thoroughly washed to remove any dust or particles and then dried to a constant weight in an oven at 110°C (230°F). This ensures that moisture does not affect the weight measurements.
- **Cooling:** Once dried, the aggregate is allowed to cool to room temperature in a desiccators to prevent moisture absorption from the air.

2. Weighing in Air

- **Initial Weighing:** The dried aggregate sample is weighed using a precise balance to obtain its dry weight, often referred to as the mass in air.

3. Pycnometer Method:

- **Filling:** The pycnometer, a specialized flask, is filled with water at a controlled temperature, and its weight is recorded.
- **Adding Aggregate:** The aggregate sample is then added to the pycnometer, and any air bubbles are removed by agitating or by using a vacuum.
- **Weighing:** The filled pycnometer is weighed again with the aggregate and water.
- **Calculations:** The specific gravity is calculated based on the weight of the aggregate in air and the weight of the aggregate in water, using the formula:

$$\text{Specific Gravity} = \frac{Weight\ of\ dry\ aggregate\ in\ air}{\text{Weight of dryaggregate in air} - (\text{Weight of pycnometer with aggregateWeight pycnometer and water} - \text{of with water})}$$

4. Repeatability: The test is often repeated to ensure consistency and accuracy of the results. Multiple samples may be tested to calculate an average specific gravity for the batch.

son equation $P=100 \times (\frac{d}{D})^n$

1.

where;

P is the percentage passing, d is the diameter of the sieve, D is the maximum particle size,

n is an empirical coefficient (usually taken as 0.5 for aggregates)

2. **Optimal Mix Determination:** Adjust the proportions of different aggregate sizes to match the Fuller's curve as closely as possible, indicating the ideal gradation for maximum packing density.
3. **Trial Batching:** Prepare concrete mixes based on the determined proportions and test them for workability and compressive strength to validate the mix design.

Workability Tests

Slump Test

The Slump Test is a simple measure of the consistency of fresh concrete before it sets. It is primarily used to check the workability and water content of the mix, which are indicative of its ease of placement and compaction without reducing its strength:

1. **Preparation:** Gather all equipment, including the slump cone, a non-absorbent surface plate, a tamping rod, and a measuring scale.
2. **Filling the Cone:** Place the slump cone on the surface plate. Fill the cone with fresh concrete in three layers, each approximately one-third of the cone's height.
3. **Compaction:** Compact each layer with 25 strokes of the tamping rod, distributed evenly over the cross-section.
4. **Lifting the Cone:** After filling and tamping, carefully lift the cone vertically upwards in one swift motion without disturbing the concrete.
5. **Measuring the Slump:** Measure the vertical distance between the top of the slumped concrete and the top of the original height of the cone. This measurement is the slump.

A higher slump indicates higher workability, suitable for structures with congested reinforcement and complex shapes, where a stiffer mix would be difficult to work into place.

Cement Setting Time Test

This test, conducted using a Vicat apparatus, measures the time it takes for the cement glue to set, which influences the working time available for concrete arrangement and wrapping up. The test includes bringing down a needle onto a sample of cement glue at standard intervals to determine when it no longer penetrates to a indicated depth

Mix Design

The mix design for this study was developed to explore the potential benefits of using SNA and GHA as partial replacements for OPC in concrete. The inclusion of these pozzolanic materials aimed to enhance the durability and strength of the concrete, particularly under aggressive environmental conditions. The detailed methodology ensured that the concrete mixes were prepared and tested in a consistent and scientifically rigorous manner, providing valuable insights into the performance of sustainable concrete materials. The concrete mixes for this study were prepared with varying percentages of Shear Nut Shell Ash (SNA) and Guinea Corn Husk Ash (GHA) as partial replacements for Ordinary Portland Cement (OPC). The mix designs were developed based on the guidelines provided by ACI 211.1 for normal concrete and adjusted for the incorporation of pozzolanic materials. The following sections elaborate on the specific mix designs used in this study with a mix ratio 1: 2: 4 being adopted using a water cement ratio of 0.5. SNA and GHA as partial replacement of cement with 0% as control and 2, 4 and 6% as replacement.

Mix Proportions

The mix proportions were carefully calculated to ensure the desired workability, strength, and consistency of the concrete. The mixes included binary blends (OPC with SNA and OPC with GHA) and a ternary blend (OPC with both SNA and GHA). The following percentages of SNA and GHA were used as partial replacements for cement:

- **Control Mix:** 0% replacement (100% OPC)
- **Binary Mixes:**
- 2% SNA / 98% OPC
- 4% SNA / 96% OPC
- 6% SNA / 94% OPC
- 2% GHA / 98% OPC
- 4% GHA / 96% OPC
- 6% GHA / 94% OPC
- **Ternary Mixes:**
- 2% SNA + 2% GHA / 96% OPC
- 4% SNA + 4% GHA / 92% OPC
- 6% SNA + 6% GHA / 88% OPC

These proportions were chosen based on previous studies and preliminary tests that indicated these levels of replacement could provide significant benefits in terms of durability and strength Gambo (2014).

3.4.2 Preparation of Mixes

The preparation of concrete mixes followed these steps:

a. **Weighing of Materials:** All materials (cement, aggregates, pozzolanic materials, and water) were accurately weighed according to the mix proportions.

b. **Mixing:** The materials were mixed in a mechanical mixer to ensure uniformity. The dry materials (cement, SNA, GHA, and aggregates) were mixed first, followed by the gradual addition of water until the desired consistency was achieved.

c. **Casting:** The mixed concrete was cast into standard cube molds (100mm x 100mm x 100mm) for compressive strength testing and cylindrical molds for other durability tests.

d. **Curing:** The molds were covered with plastic sheets and left to cure for 24 hours. After demolding, the concrete specimens were cured in water, 1.2% H_2SO_4 solution, and 1.2% $MgSO_4$ solution for specified periods (28, 56, and 90 days) Gambo (2014) and Sunday et al. (2020).

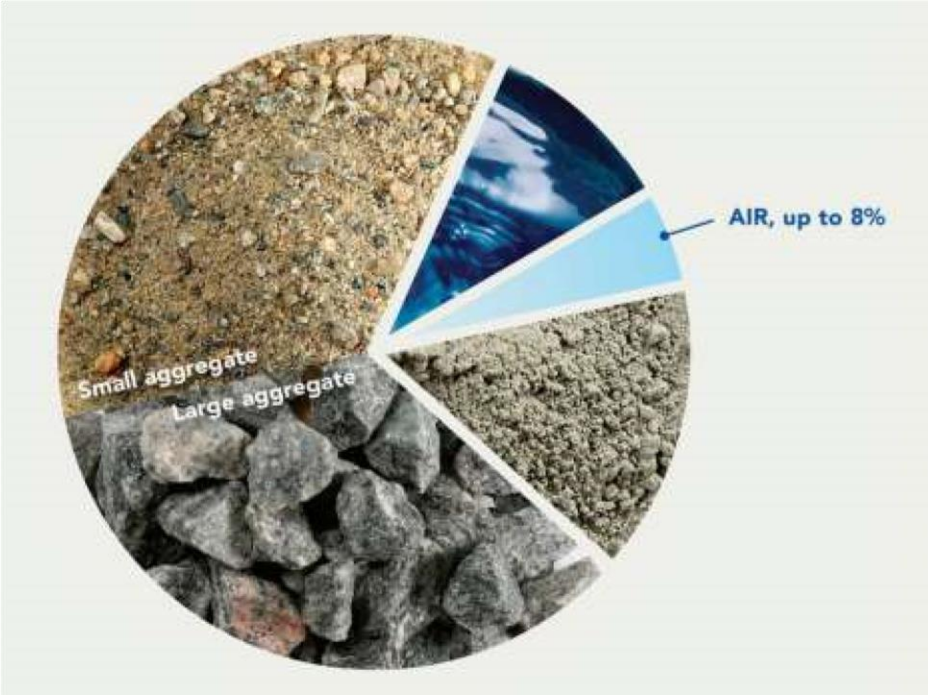

Fig. 14: Mix Design of Concrete

RESULTS AND DISCUSSION

The results and discussion of the various tests conducted on the concrete mixes incorporating Shear Nut Shell Ash (SNA) and Guinea Corn Husk Ash (GHA) as partial replacements for Ordinary Portland Cement (OPC). The tests include preliminary tests, rheological properties, compressive strength. The performance of binary (SNA/OPC and GHA/OPC) and ternary (SNA/GHA/OPC) blends in aggressive environments (H_2SO_4 and $MgSO_4$) and normal water conditions are analyzed.

PRELIMINARY TESTS

The preliminary tests were conducted to determine the physical and chemical properties of the materials used in the concrete mixes. These tests include sieve analysis, specific gravity, aggregate impact value, aggregate crushing value, and tests on the ashes and cement.

Sieve Analysis

Sieve analysis was performed to determine the particle size distribution of the coarse and fine aggregates, as well as the supplementary cementitious materials (SCMs) utilized in the blend.

Table 4.1: 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 4.2: 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 4.3: 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 4.4: 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.

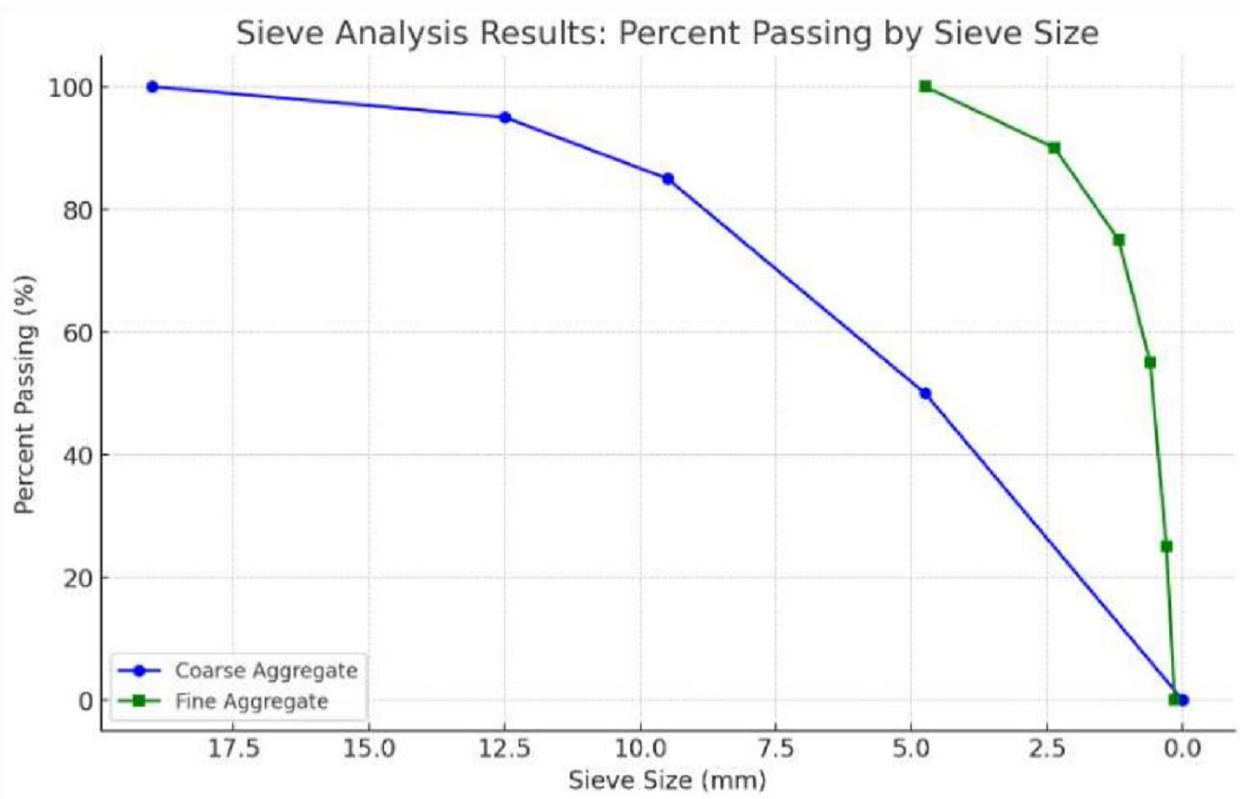

Fig 4.1: The percent passing by sieve size for two types of aggregates: coarse and fine

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).

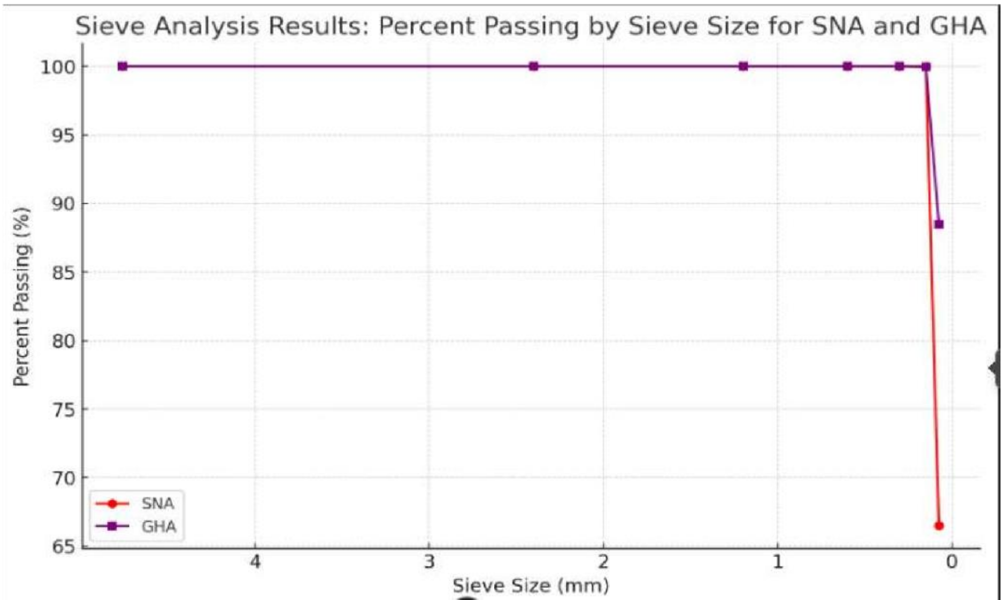

Fig 4.2: The percent passing by sieve size for SNA and GHA materials

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 4.5: Specific Gravity of Materials

Material	Specific Gravity
Coarse Aggregate	2.72
Fine Aggregate	2.62
SNA	2.30
GHA	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 GHA (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 GHA can be effectively used as partial replacements for OPC, contributing to a lighter and potentially more workable concrete mix.

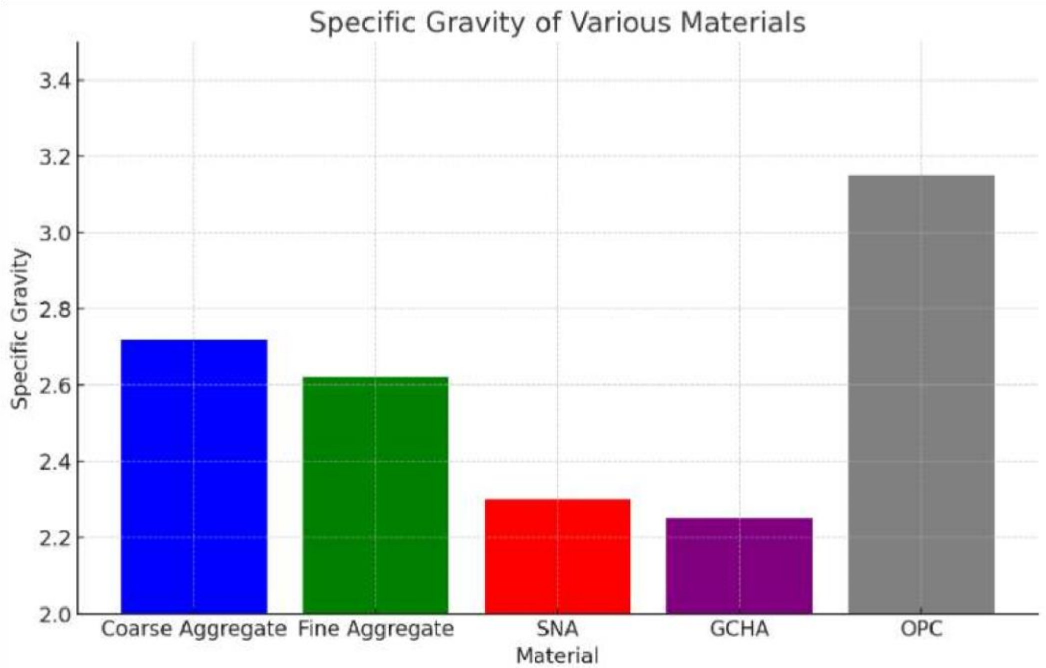

Fig 4.3: The specific gravity of five different construction materials

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 GHA (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.

4.2.4 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.

4.2.5 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 8: 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.

4.2.6 Chemical Composition of Ashes

The chemical composition of the SNA and GHA was determined using X-ray fluorescence (XRF). **Table 4.8: Chemical Composition of SNA**

Component	Concentration (wt.%)
SiO_2	25.494
Al_2O_3	7.861
Fe_2O_3	4.282
Total	37.637

The total combined content of SiO_2, Al_2O_3, and Fe_2O_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 4.9: Chemical Composition of GHA

Component	Concentration (wt.%)
SiO_2	68.520
Al_2O_3	2.645
Fe_2O_3	6.032
Total	77.197

The total combined content of SiO_2, Al_2O_3, and Fe_2O_3 in GHA is 77.197%, meeting the ASTM C618 requirement for a pozzolan. GHA, with a combined oxide content of 77.197%, qualifies as a pozzolan under ASTM C618, making it a viable supplementary cementitious material.

4.2.7 Physical and Chemical Properties of OPC in comparison with BS EN 197-1:2000 Specification

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

Table 4.10.1: Consistency of Cement

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

Table 4.10.2: 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 4.10.3: 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 4.10.4: 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 4.10.5: 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 4.10.6: Fineness of Cement

S/NO.	SAMPLE	FINENESS

1	F-01	320
2	F-02	320
3	F-03	320
Average		**320**

Table 4.10.7: 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 4.10.8: Chemical Composition in 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 4.10.9: Summary of the Physical Properties of OPC in comparison with BS EN 1971:2000 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. **4.2.8 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 in 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:

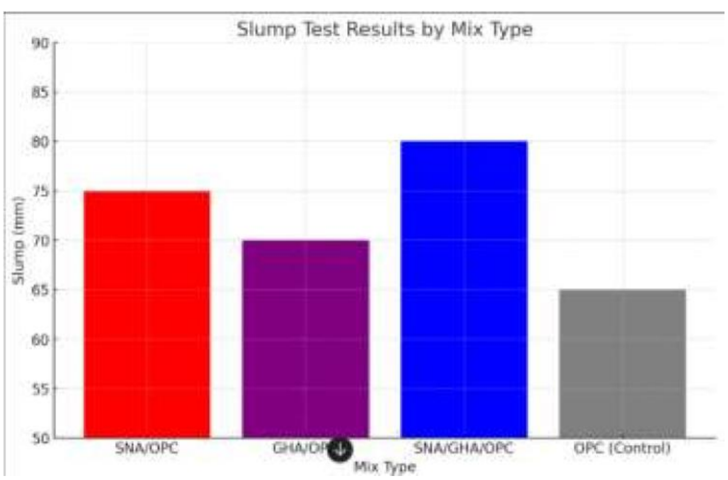

Fig 4.4: The slump test results for different cement mix types

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 strength

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 4.14.1: 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 4.14.2: 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 4.14.3: 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 4.15.1: 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 4.15.2: 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 4.15.3: 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 4.16.1: 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 4.16.2: 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 4.16.3: 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:

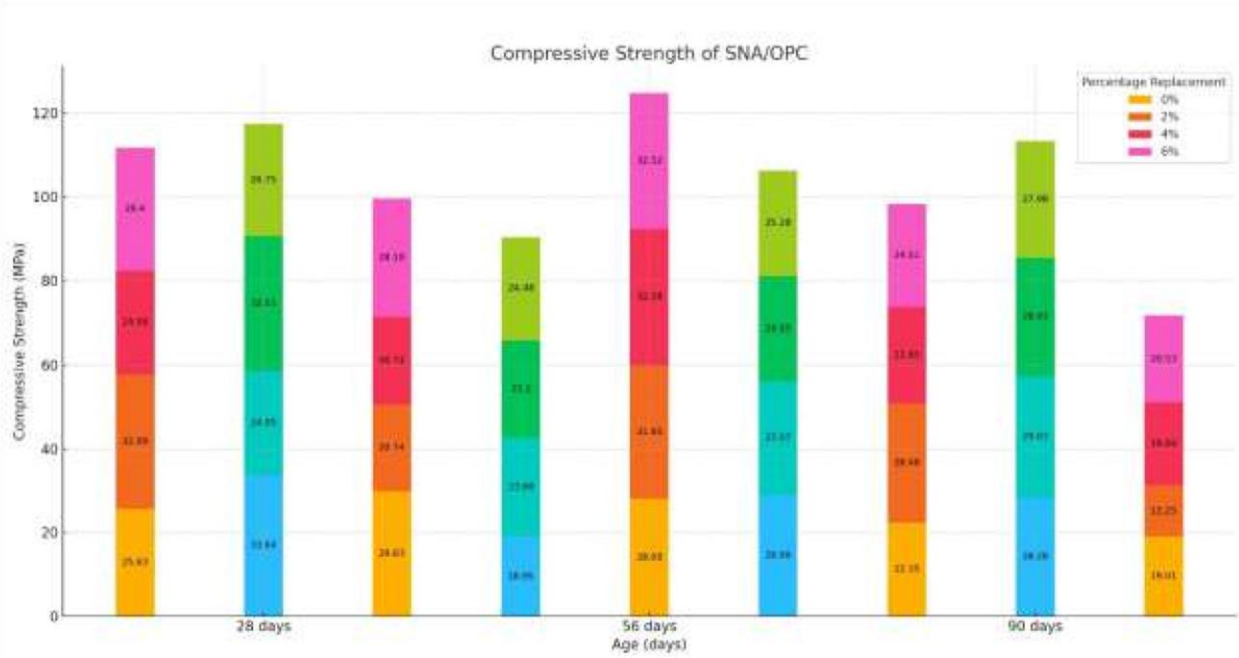

Fig 4.8: Compressive strength of different curing days for SNA/OPC

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

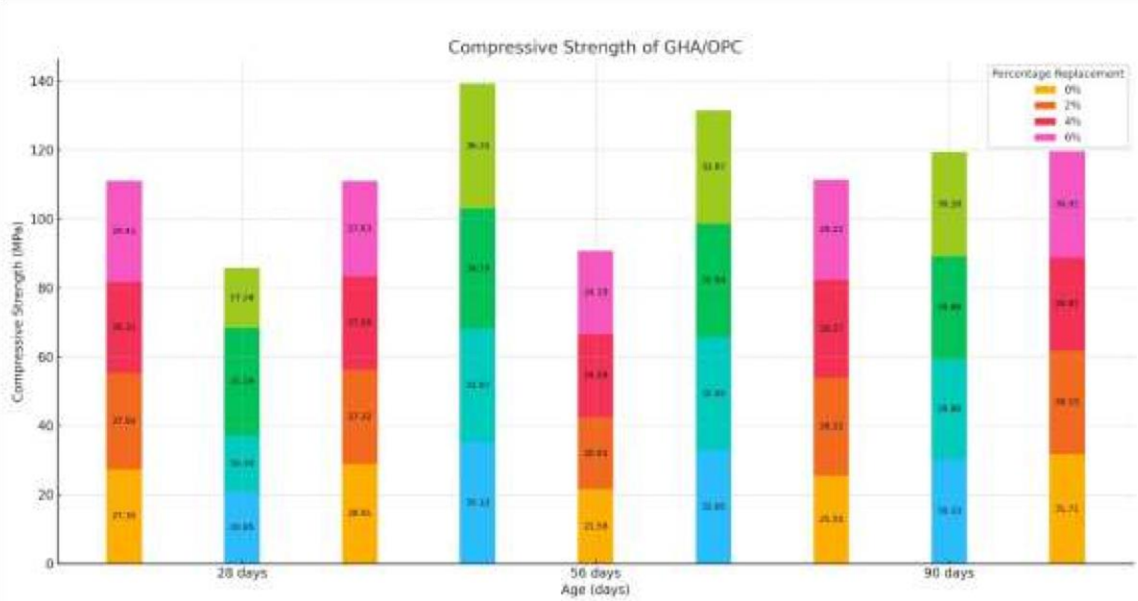

Fig 4.9: compressive strength of different curing days for GHA/OPC

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:

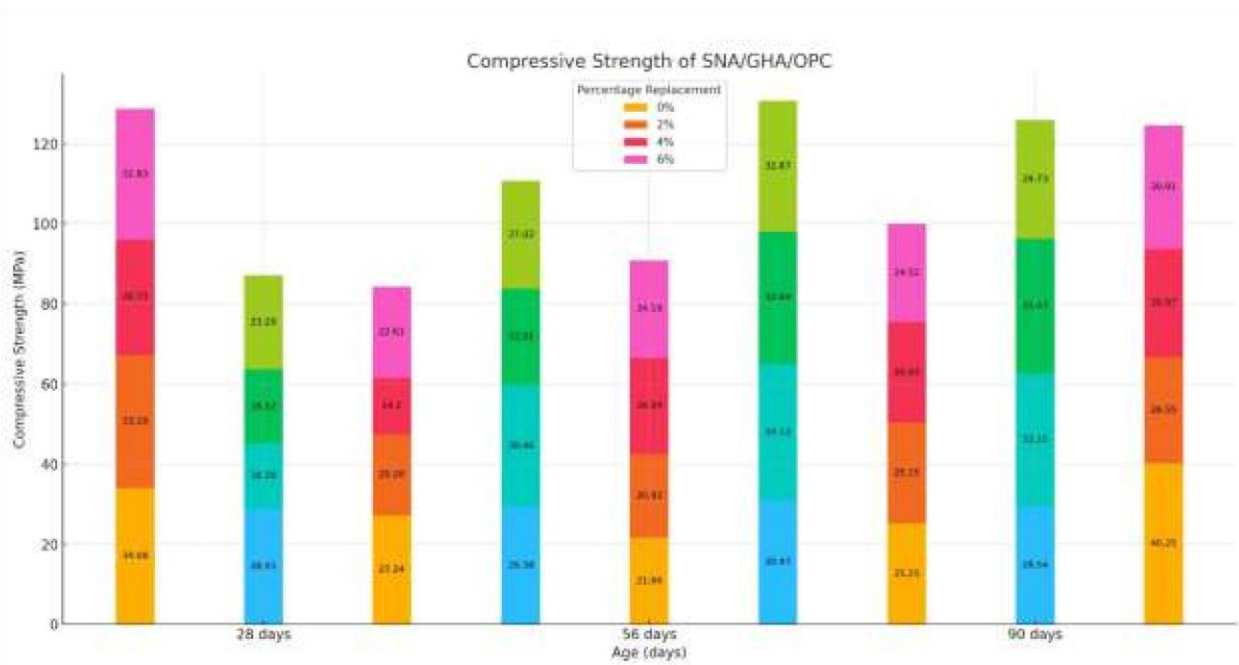

Fig 4.10: Compressive strength of different curing days for SNA/GHA/OPC

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 an4.d 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

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