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MAXIMIZING GEOPOLYMER CONCRETE PERFORMANCE UTILIZING GGBS, SILICA FUME, AND FLY ASH INTEGRATION

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ABSTRACT

Geopolymer concrete is an innovative and sustainable alternative to conventional Portland cement-based concrete. It is produced by activating industrial by-products such as ground granulated blast furnace slag (GGBS), silica fume, and fly ash with alkaline activators. This study aims to maximize the performance of geopolymer concrete by optimizing the integration of GGBS, silica fume, and fly ash. The research investigates the effects of varying proportions of GGBS, silica fume, and fly ash on the fresh and hardened properties of geopolymer concrete. The experimental program includes the evaluation of workability, compressive strength, flexural strength, and durability characteristics of the geopolymer concrete mixtures. To achieve the objectives, a series of geopolymer concrete mixtures with different combinations of GGBS, silica fume, and fly ash are prepared and tested. The mix design is based on a constant alkaline solution-to-binder ratio to ensure a consistent level of activation. The influence of each supplementary cementitious material (GGBS, silica fume, and fly ash) on the mechanical and durability properties of the geopolymer concrete is thoroughly examined. The experimental results will be analyzed and compared to identify the optimal combination of GGBS, silica fume, and fly ash for enhancing geopolymer concrete performance. The findings will provide valuable insights into the synergistic effects of these materials on the fresh and hardened properties of geopolymer concrete, enabling the development of more sustainable and durable construction materials.

INTRODUCTION

Concrete is one of the most widely used construction materials worldwide. However, the production of conventional Portland cement, a key component of concrete, is associated with significant environmental impacts, including high carbon dioxide emissions and depletion of natural resources. In recent years, there has been growing interest in developing alternative cementitious materials that are more sustainable and environmentally friendly. Geopolymer concrete has emerged as a promising alternative to Portland cement-based concrete. It is produced by activating industrial by-products, such as ground granulated blast furnace slag (GGBS), silica fume, and fly ash, with alkaline activators. Geopolymerization is a chemical process that forms a three-dimensional, inorganic polymer network, resulting in a binder with properties similar to traditional cementitious materials. GGBS, silica fume, and fly ash are industrial by-products that have pozzolanic and cementitious properties. GGBS is obtained from the iron industry, silica fume is a by-product of silicon and ferrosilicon production, and fly ash is generated from coal combustion in power plants. By utilizing these by-products as supplementary cementitious materials in geopolymer concrete, the environmental impact of concrete production can be significantly reduced. However, to maximize the performance of geopolymer concrete, it is crucial to optimize the integration of GGBS, silica fume, and fly ash. The proportions and combinations of these materials can have a significant influence on the fresh and hardened properties of the geopolymer concrete, including workability, strength development, and durability characteristics. Therefore, thorough investigation and understanding of the effects of these materials on geopolymer concrete performance are essential. This study aims to address this research gap by systematically evaluating the effects of varying proportions of GGBS, silica fume, and fly ash on the properties of geopolymer concrete. The research will contribute to identifying the optimal combination of these materials to enhance the performance of geopolymer concrete in terms of mechanical strength, durability, and sustainability.

Scope of the Research

The scope of this research is to investigate and maximize the performance of geopolymer concrete through the integration of GGBS, silica fume, and fly ash. The study focuses on optimizing the proportions and combinations of these supplementary cementitious materials to enhance the fresh and hardened properties of geopolymer concrete. The research will involve a comprehensive experimental program, including mix design, specimen preparation, and testing of various properties. The workability of geopolymer concrete mixtures will be assessed using tests such as slump flow, V-funnel, and flow table tests to determine the optimal combination of materials that ensures adequate workability without compromising other performance aspects. The mechanical properties of geopolymer concrete, such as compressive strength and flexural strength, will be evaluated through standardized testing methods. By varying the proportions of GGBS, silica fume, and fly ash, the research aims to identify the optimal combination that maximizes the strength development of geopolymer concrete. The durability of geopolymer concrete will also be assessed, focusing on resistance to chloride ingress and carbonation. These tests will provide insights into the long-term performance and durability of geopolymer concrete mixtures with different combinations of supplementary cementitious materials. The research findings will be analyzed, compared, and optimized to determine the most favorable proportions of GGBS, silica fume, and fly ash for maximizing geopolymer concrete performance. The results will contribute to the understanding of geopolymer concrete technology and support the development of sustainable and high-performance construction materials.

RESEARCH METHODOLOGY

MATERIALS USED

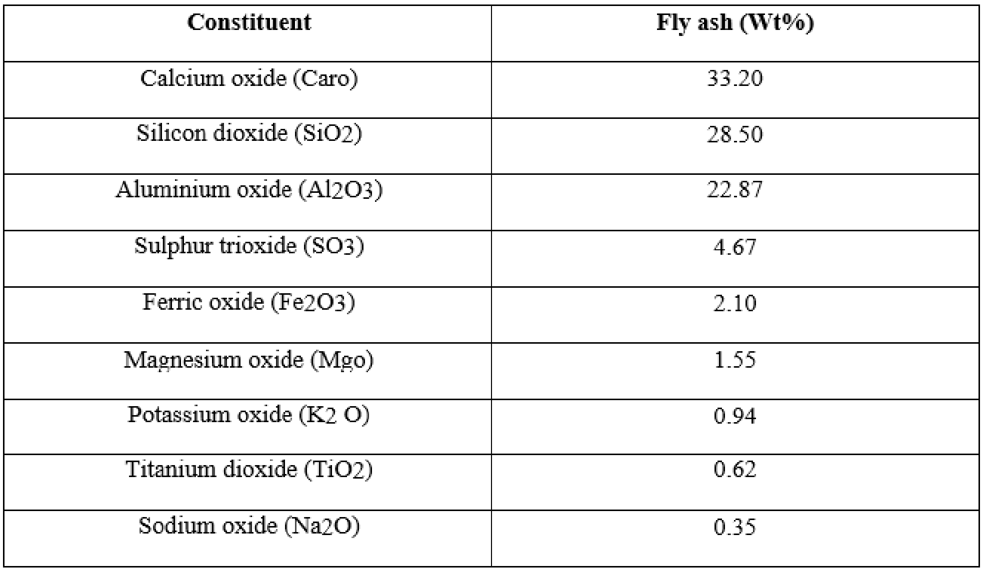
Cement

Cement is a crucial component in the construction industry and serves as the binding agent in concrete, mortar, and other building materials. It is a fine powder that, when mixed with water, undergoes a chemical reaction known as hydration, resulting in a solid matrix that hardens and provides strength to the final product. Portland cement, the most commonly used type of cement, is produced by grinding clinker, which is a mixture of limestone, clay, and other minerals, and adding a small amount of gypsum. During the hydration process, compounds such as calcium silicates, calcium aluminates, and calcium sulfates are formed, contributing to the strength and durability of the resulting concrete. Cement plays a critical role in construction due to its ability to bind aggregates and other materials together, forming a solid and durable structure. It provides the necessary compressive strength to withstand loads, such as those imposed by buildings, bridges, and infrastructure. However, the production of cement is associated with significant environmental impacts. The extraction of raw materials, high energy consumption during the manufacturing process, and the release of carbon dioxide (CO2) contribute to greenhouse gas emissions and climate change.

Fly ash

Fly ash is a fine, powdery by-product generated from the combustion of pulverized coal in thermal power plants. It is collected from the flue gases using electrostatic precipitators or bag filters before being transported to storage silos. Fly ash consists of small, spherical particles that are primarily composed of silica (SiO2), alumina (Al2O3), and iron oxide (Fe2O3), with varying amounts of calcium oxide (CaO) and other trace elements. Due to its pozzolanic properties, fly ash is commonly used as a supplementary cementitious material in the production of concrete. When mixed with water and cement, it undergoes a chemical reaction known as pozzolanic reaction, resulting in the formation of additional calcium silicate hydrate (C-S-H) gel. This reaction improves the strength, durability, and workability of concrete. The utilization of fly ash in concrete offers several benefits. Firstly, it reduces the demand for cement, thereby reducing the consumption of natural resources and carbon dioxide emissions associated with cement production. Secondly, it improves the long-term durability of concrete by reducing the permeability, enhancing resistance to chemical attack, and mitigating the potential for alkali-silica reaction.

Table 1 Chemical composition of fly ash



Constituent	Fly ash (Wt%)
Calcium oxide (Caro)	33.20
Silicon dioxide (SiO2)	28.50
Aluminium oxide (Al2O3)	22.87
Sulphur trioxide (SO3)	4.67
Ferric oxide (Fe2O3)	2.10
Magnesium oxide (Mgo)	1.55
Potassium oxide (K2 O)	0.94
Titanium dioxide (TiO2)	0.62
Sodium oxide (Na2O)	0.35

GGBS

GGBS, which stands for Ground Granulated Blast Furnace Slag, is a by-product of the iron and steel industry. It is obtained by rapidly quenching molten slag from the blast furnace with water or steam, which results in its granulation and subsequent grinding into a fine powder. GGBS is composed primarily of silicates and aluminates, with a high content of glassy material. GGBS is widely used as a supplementary cementitious material in the production of concrete. It is known for its pozzolanic and latent hydraulic properties, which contribute to the enhancement of concrete performance. When GGBS is added to concrete, it reacts with calcium hydroxide to form additional calcium silicate hydrate (C-S-H) gel and calcium aluminate hydrate (C-A-H) gel. This reaction leads to improved strength, durability, and other desirable properties of concrete.

Silica Fume

Silica fume, also known as microsilica, is a highly reactive pozzolanic material that is used as a supplementary cementitious material in concrete. It is a by-product of the production of silicon and ferrosilicon alloys in high-temperature electric arc furnaces. Silica fume consists of very fine, non-crystalline particles with a high content of amorphous silicon dioxide (SiO2).

Here are some important physical properties of silica fume:

Particle Size: Silica fume particles are extremely small, with an average particle size ranging from 0.1 to 0.3 micrometers. This fine particle size contributes to its high reactivity and ability to fill in gaps in the cementitious matrix of concrete.

Specific Surface Area: Silica fume has an exceptionally high specific surface area, typically ranging from 15,000 to 30,000 square meters per kilogram (m^2/kg). The large surface area enables increased pozzolanic reactivity and enhances the bonding and densification of the concrete matrix.

Bulk Density: Silica fume has a high bulk density, typically ranging from 200 to 700 kilograms per cubic meter (kg/m^3). The compact nature of silica fume particles allows for efficient packing in concrete mixtures, resulting in improved strength and reduced permeability.

Color: Silica fume is a dark gray or black powder due to its high carbon content. The color can vary slightly depending on the specific source and production process.

Specific Gravity: The specific gravity of silica fume is approximately 2.2 to 2.3, which is significantly higher than that of conventional cementitious materials. This density contributes to the improved mechanical properties of concrete, such as increased compressive strength.

Moisture Content: Silica fume has a low moisture content, typically less than 3%. The low moisture content ensures better handling and storage characteristics.

It is worth noting that the physical properties of silica fume can vary depending on factors such as the source, production process, and specific manufacturer. However, these properties collectively contribute to the unique reactivity and performance benefits that silica fume offers when used as a supplementary cementitious material in concrete.

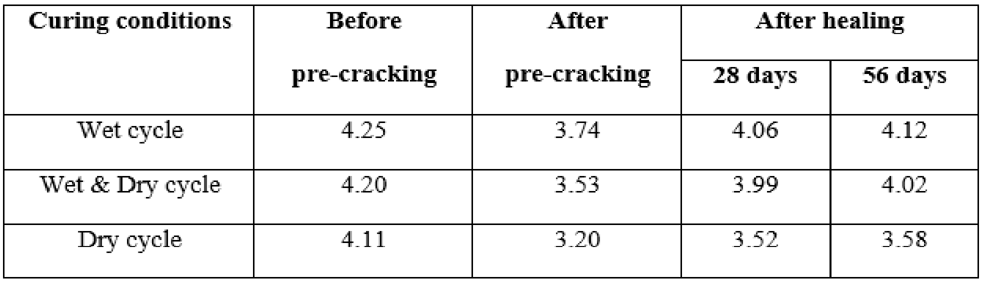
RESULTS AND DISCUSSION

SELF-HEALING OBSERVATION TESTS

Ultrasonic Pulse Velocity

Ultrasonic Pulse Velocity (UPV) is a non-destructive testing (NDT) technique used to assess the quality and integrity of concrete structures. It involves the propagation of high-frequency ultrasonic waves through the concrete and the measurement of the time taken for the waves to travel a known distance within the material.In the UPV testing, a pair of transducers is placed on the surface of the concrete specimen, with one acting as the transmitter and the other as the receiver. The transmitter emits a short ultrasonic pulse, typically in the frequency range of 50 kHz to 500 kHz, which travels through the concrete. The receiver detects the pulse after it has traversed the concrete and measures the time taken for the wave to travel the known path length. The velocity of the ultrasonic pulse is calculated by dividing the path length by the measured time. This velocity is influenced by the elastic properties of the concrete, including its density, modulus of elasticity, and the presence of any defects or anomalies within the material.UPV testing is commonly used for assessing the uniformity, homogeneity, and overall quality of concrete structures. It can help in detecting voids, delaminations, cracks, and other internal defects that may affect the structural integrity of the concrete. Additionally, UPV can be used to estimate the compressive strength of concrete based on empirical correlations

Table 2: UPV test results in km/s



Curing conditions	Before pre-cracking	After pre-cracking	After healing	
			28 days	56 days
Wet cycle	4.25	3.74	4.06	4.12
Wet & Dry cycle	4.20	3.53	3.99	4.02
Dry cycle	4.11	3.20	3.52	3.58

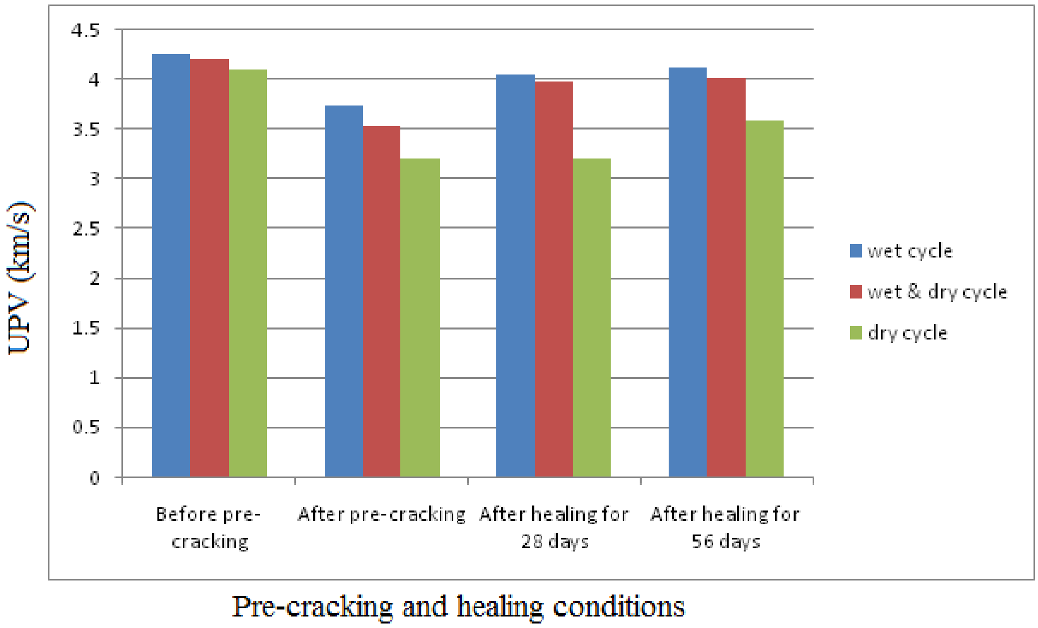


Fig. 1 UPV test results for pre-cracked samples and healed samples (at 28 days & 56 days)

Visual Observation

The visual observation of the presence of CaCO3 and accompanying photographic images are depicted in Figure 1 below.

Fig. 2 Self-healing of concrete (formation of calcium carbonate)

DURABILITY PROPERTIES

Rapid Chloride Permeability Test

Table 3**:** RCPT results

Mix Designation	Charge Passed (coulombs)
NM	2034
B	2059
B+SF	1992

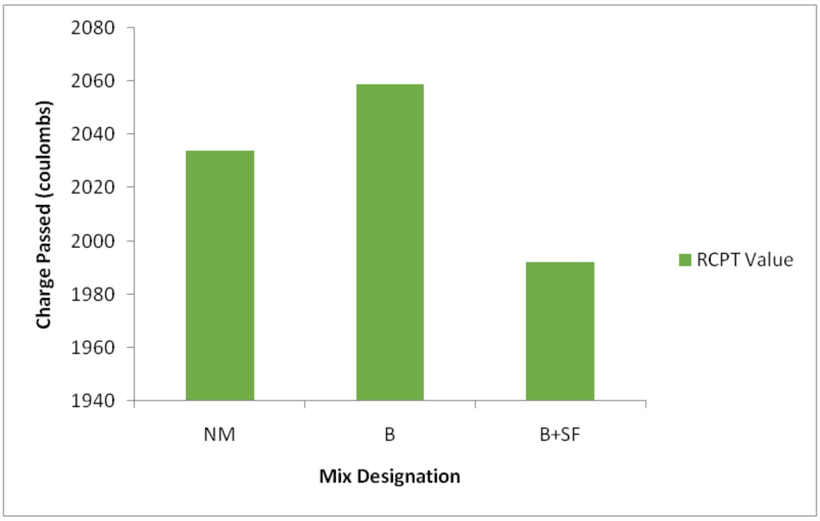


Fig. 3RCPT results

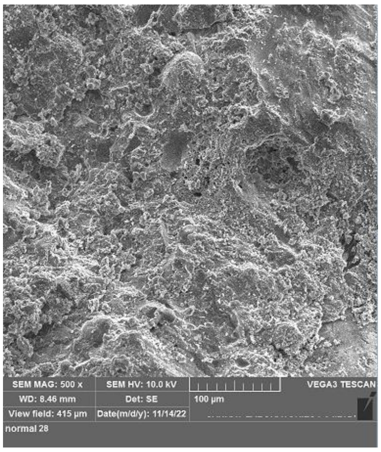
The salt resistance of the specimens was assessed at 28 days using the rapid chloride penetration test (RCPT) according to ASTM C-1202 standards. The specimens had a diameter of 100 mm and a thickness of 50 mm, and were subjected to a 60 V voltage. The chloride permeability of different mixtures was determined by measuring the total charge transmission across the samples.

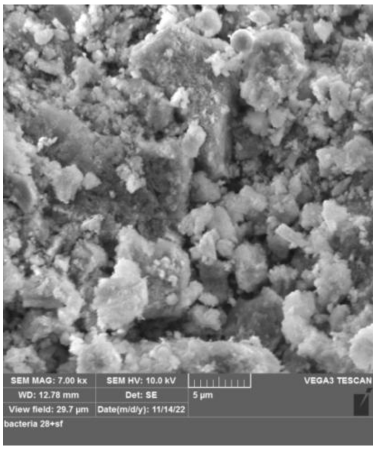
The results of the RCPT test showed favorable outcomes for the bacterial mix. In comparison to the normal mix, a higher amount of charge was transmitted through the bacterial mix. However, in the case of the fiber-reinforced bacterial mix, the addition of fibers resulted in a lower charge transmission. This can be attributed to the increased porosity caused by the addition of fibers, which may lead to reduced resistance to ion penetration compared to the specimens with the normal mix or the mix containing bacteria.

MICRO-STRUCTURAL PROPERTIES

Scanning Electron Microscope (SEM)

The scanning electron microscope (SEM) is a powerful imaging technique used to examine the microstructural properties of materials at high magnification. It provides detailed information about the surface morphology, composition, and structure of the specimens.In SEM analysis, a focused electron beam is scanned over the surface of the sample. The interaction between the electrons and the atoms in the sample generates various signals, including secondary electrons, backscattered electrons, and characteristic X-rays. These signals are detected and used to create an image of the sample. SEM allows for imaging at high magnification, ranging from a few times to several hundred thousand times, providing a detailed view of the microstructure. It enables the visualization of features such as cracks, pores, aggregates, and fiber distribution, allowing for the assessment of material homogeneity, porosity, and interfacial characteristics. Furthermore, SEM can be coupled with energy-dispersive X-ray spectroscopy (EDS) to obtain elemental composition information from specific areas of interest. This capability enables the identification and mapping of different elements or compounds present in the sample.





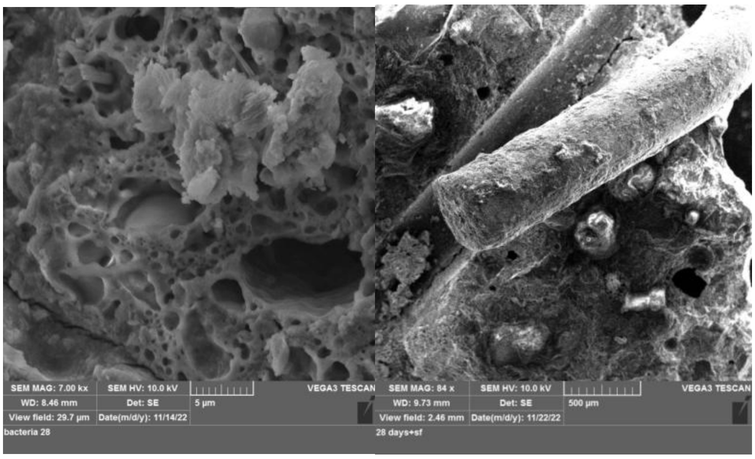


Fig. 4 SEM images of (a)Normal Mix (b)Bacteria+Fiber (c)Bacteria (d)Fiber

CONCLUSION

The integration of GGBS, silica fume, and fly ash in geopolymer concrete offers significant potential for maximizing its performance and promoting sustainable construction practices. This study aimed to investigate the effects of varying proportions of these supplementary cementitious materials on the fresh and hardened properties of geopolymer concrete. Through a comprehensive experimental program, including mix design, specimen preparation, and testing, valuable insights were gained regarding the optimal integration of GGBS, silica fume, and fly ash. The results demonstrated that careful adjustment of the proportions of these materials can lead to improved workability, enhanced mechanical strength, and enhanced durability characteristics of geopolymer concrete. The findings showed that the addition of GGBS, silica fume, and fly ash contributed to the development of a denser and more refined microstructure, resulting in enhanced strength and reduced permeability. The synergistic effects of these materials led to improved chemical resistance, reduced chloride penetration, and mitigated alkali-silica reaction. the incorporation of supplementary cementitious materials resulted in a more sustainable and environmentally friendly geopolymer concrete, reducing the demand for Portland cement and minimizing carbon dioxide emissions. this research highlights the potential of integrating GGBS, silica fume, and fly ash to maximize the performance of geopolymer concrete. The optimized combination of these materials can lead to sustainable, durable, and high-performance construction materials, contributing to the advancement of sustainable construction practices and reducing the environmental impact of concrete production.

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