

# Experimental Study on Fly Ash and TiO<sub>2</sub> Nanoparticle Modified Geopolymer Concrete for Improved Performance

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## ABSTRACT

This study investigates the combined effect of fly ash and nanoscale titanium dioxide (n-TiO<sub>2</sub>) on the mechanical performance of M-25 grade geopolymer concrete (GPC). Fly ash served as the primary binder, while TiO<sub>2</sub> was incorporated in varying proportions (0%, 0.5%, 1.0%, 1.5%, and 2%) to enhance strength and durability. After 28 days of curing, split tensile strength tests were conducted to evaluate the performance. Results indicate that the inclusion of n-TiO<sub>2</sub> significantly improved tensile strength, with optimal enhancement observed at 1.5% TiO<sub>2</sub> content. The study confirms that the synergistic use of fly ash and n-TiO<sub>2</sub> offers a sustainable, durable, and high-performance alternative to traditional cement-based concrete.

**Keywords** — Geopolymer Concrete, Fly Ash, Nano-TiO<sub>2</sub>, Sustainable Construction, Durability, Mechanical Strength.

## I. INTRODUCTION

The incorporation of nano-TiO<sub>2</sub> into cement has been shown to significantly enhance the performance of cementitious composites, primarily by accelerating hydration, reducing processing time, and improving overall material properties due to its nanoscale dimensions. Ongoing applied research supports the growing use of nano-TiO<sub>2</sub> in the construction industry, where its inclusion has proven beneficial. However, the bulk addition of nano-TiO<sub>2</sub> can affect the dimensional stability of cement mixtures, necessitating careful optimization of its particle size and dosage. This review emphasizes the role of titanium dioxide at the nanoscale, especially in the context of rising global demand for concrete in construction. While concrete is valued for its toughness and durability, it also contributes significantly to environmental pollution through high carbon dioxide emissions. To mitigate this, the substitution of conventional cement components with additives like zinc oxide and titanium dioxide has been found to enhance the formation of C-S-H gel, improve adhesion, and reduce porosity. These nanoparticles not only

strengthen the material but also contribute to air purification and better indoor air quality. Moreover, poor-quality cement can compromise structural integrity, making the strategic use of nanomaterials an effective way to improve performance without adverse effects. Current research efforts aim to enhance traditional concrete formulations with sustainable additives, thereby increasing efficiency and reducing environmental impact.

Many researchers have shown that mineral and chemical additives alter the functionality and characteristics of materials. Nanomaterials are another type of addition that influences the characteristics of cement. Using the correct amount of nanoparticles boosts the materials' strength and durability even after ageing. Nanomaterials and paints containing these elements are used to cleanse the air and increase indoor pollution removal. It also absorbs UV rays emitted by the sun, making the house more beautiful. As a result, nanoparticles like zinc oxide and titanium dioxide have provided a platform for numerous researchers and scholars to undertake studies on concrete properties.

Cement is widely used as a building material all over the world, and concrete is well-known. The

qualities of cement-based materials have grown more essential in modern design as they have evolved. The cement industry, particularly Portland cement, is regarded as a major source of CO<sub>2</sub>. According to studies, one tonne of Portland cement produces 0.8 tonnes of carbon dioxide. Several initiatives have been launched to minimize emissions and energy usage in the cement industry. In addition to the foregoing, regularly used concrete contains other flaws that can compromise its design and durability. Replace Portland cement with additive cement to reduce CO<sub>2</sub> emissions and energy and resource usage (ACM). Fly ash (FA), fumed silica (SF), granulated blast furnace slag (GGBS), limestone dust (LSP), rice hull ash, and other minerals are also utilised in concrete.

## II. TESTS CONDUCTED FOR CONCRETE

### Split Tensile Test

#### Procedure

- For the cylindrical exemplar, the first step is to mix the concrete. Oil the inside of the mould and layer the mixture inside it.
- Compact each layer with a compacting rod. Each layer should be tapped a total of 30 times. Beat the concrete mix evenly to remove any excess concrete.
- After that, the moulded sample should be immersed in water at 27 degrees Celsius for 24 hours.
- After that, start by removing the specimen from the mould and immerse it in freshwater.
- After 28 days of curing, concrete splitting tensile strength should be tested.
- Remove the specimen from the water and dry it before starting the test. Write down the dimensions and weight of the specimen. Use a piece of plywood to cover and protect the specimen. After that, the samples should be placed on the testing apparatus.
- Then, at a rate of 0.7 to 1.4 MPa/min (1.2 to 2.4 MPa/min according to IS 5816 1999), gradually increase the stress. Write down the load at which the specimen fails.



**Figure 1: Split Tensile Test**

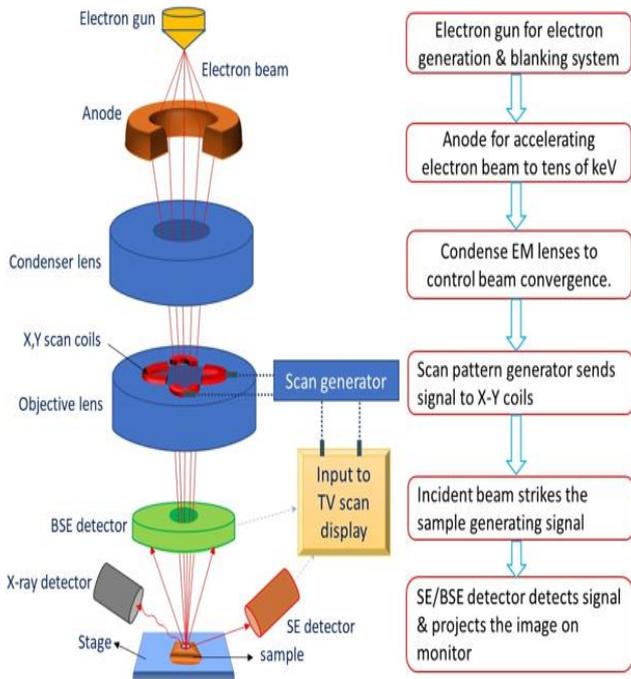
### SEM Analysis

A Scanning Electron Microscope (SEM) is a type of electron microscope that generates detailed images of a sample by scanning its surface with a focused beam of electrons. As the electron beam interacts with the sample, it produces a variety of signals that reveal information about the surface's topography and composition. SEM is particularly powerful when equipped with a microprobe analyzer, enabling techniques such as X-ray fluorescence to determine the chemical composition of hydrated compounds. The high resolution of SEM makes it an effective tool for examining the microstructure of hydrated cement paste in concrete or mortar. However, careful interpretation of the images is essential, as the sample preparation process and the vacuum environment required for SEM analysis can introduce artifacts not present in the original, wet cement paste

#### Working of SEM:

- SEM allows the visualization by using electrons rather than light.
- By heating a metal filament, an electron beam is produced on the microscope's surface.
- The path of the electron beam through the microscope tube is straight. • When it reaches the sample, some electrons (back electrons or secondary electrons) are taken from the sample when it travels through an electromagnetic field that concentrates and directs its light onto the sample.

- To create the image, the detector captures secondary electrons, or backscattered electrons, and transforms them into signals that are relayed to a display comparable to a traditional television.



**Figure 2: Schematic Representation of SEM components**

Accurate topographical and 3D images are only two examples of the many uses for electronic sensing, which may also gather data from various sensors. With the right training and the help of similar software and technological advancements, SEM is simple to use.

The instrument is quick and frequently completes SEI, BSE, and ED tests in less than five minutes. Furthermore, digitization data is now possible because to advances in modern SEM technology. Although all samples must be prepped before being placed in the vacuum chamber, the majority of SEM samples only need minimal prep work.



**Figure 3: Concrete sample testing by Scanning Electron Microscope**



**Figure 4: Concrete Sample Prepared for SEM analysis**



**Figure 5: Measure Electron images on Software**

### III. RESULTS AND DISCUSSION

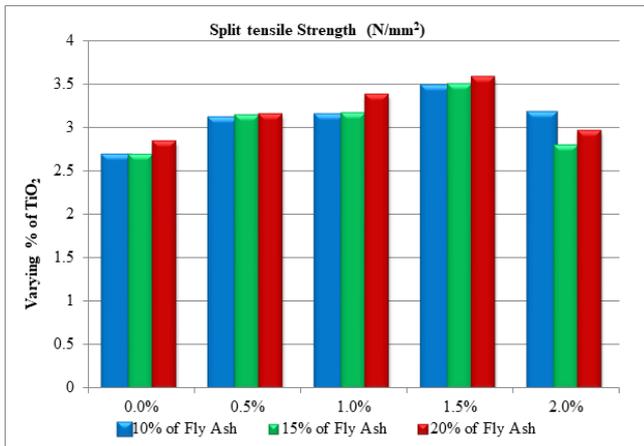


Figure 6: Split Tensile strength with 10%, 15%, and 20% Fly ash and varying % of TiO<sub>2</sub>

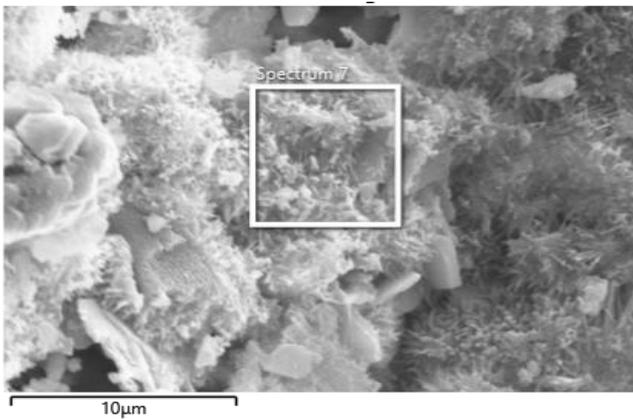


Figure 7: Electron Image of SEM at 0% fly ash + 0% titanium dioxide at 28 days

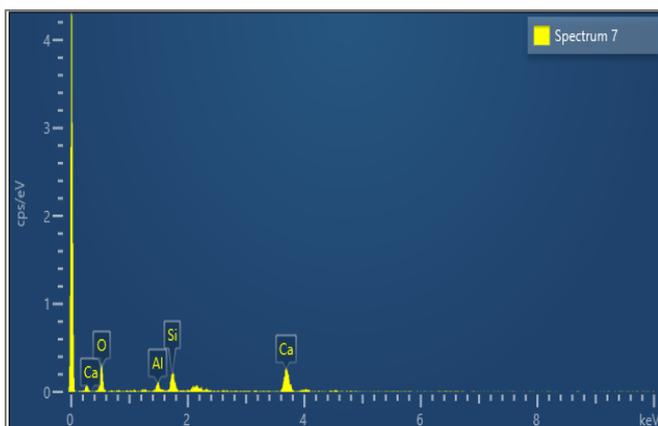


Figure 8: Graphical Representation of Spectrum at 0% fly ash + 0% titanium dioxide at 28 days

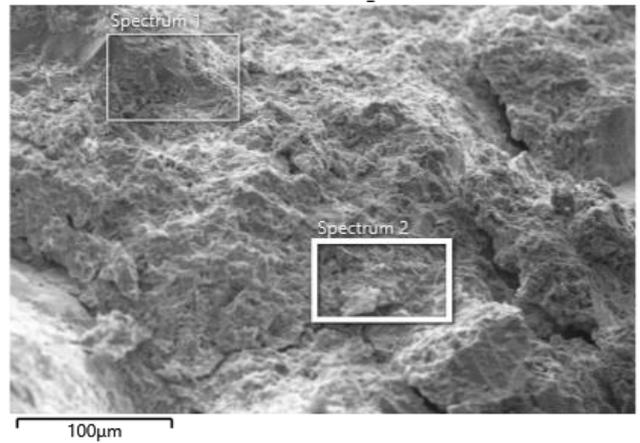


Figure 9: Electron Image of SEM at 10% fly ash + 1.5% titanium dioxide at 28 days

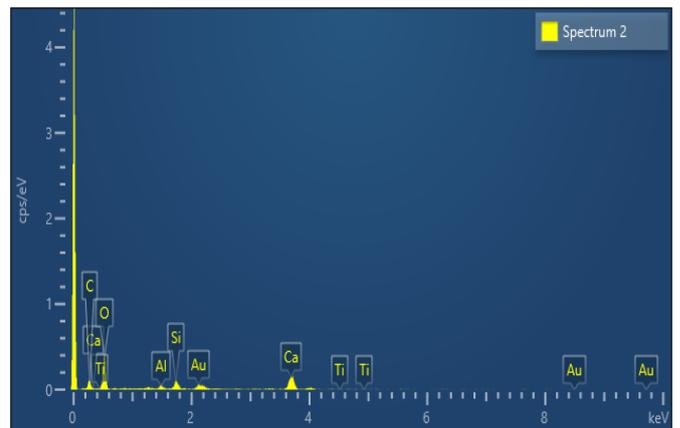


Figure 10: Graphical Representation of Spectrum at 10% fly ash + 1.5% titanium dioxide at 28 days

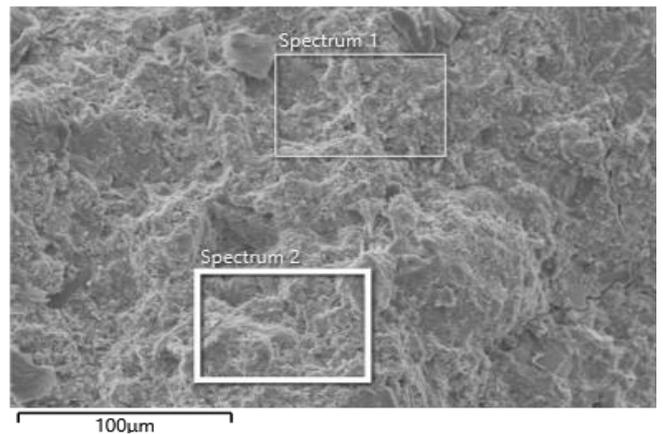
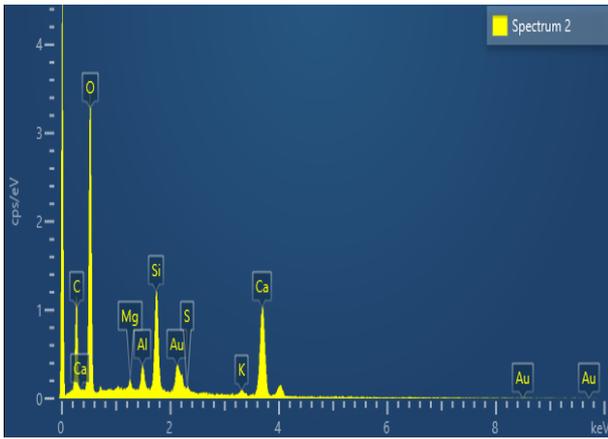
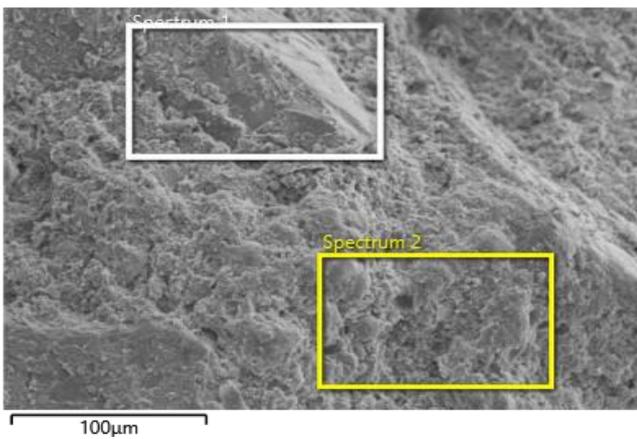


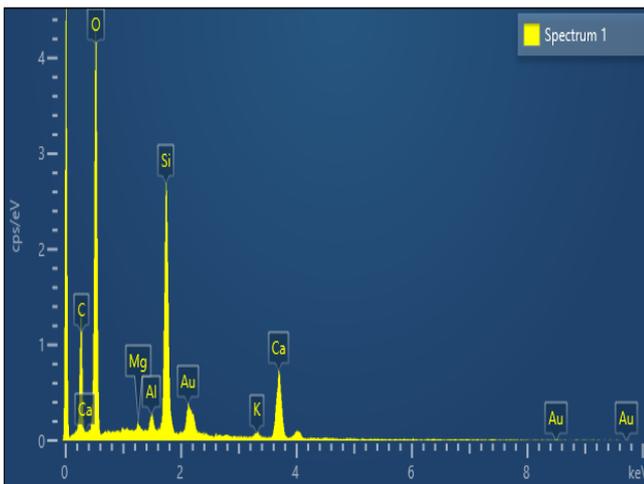
Figure 11: Electron Image of SEM at 15% fly ash + 1.5% titanium dioxide at 28 days



**Figure 12: Graphical Representation of Spectrum at 15% fly ash + 1.5% titanium dioxide at 28 days**



**Figure 13: Electron Image of SEM at 20% fly ash + 1.5% titanium dioxide at 28 days**



**Figure 14: Graphical Representation of Spectrum at 20% fly ash + 1.5% titanium dioxide at 28 days**

#### IV. CONCLUSIONS

This study investigated the mechanical performance and microstructural characteristics of geopolymer concrete (GPC) incorporating fly ash and nanoscale titanium dioxide ( $\text{TiO}_2$ ) as partial replacements for Portland cement. The experimental results from split tensile strength tests and SEM analyses demonstrated the following key findings:

- **Optimal Dosage:** Incorporating 1.5%  $\text{TiO}_2$  nanoparticles consistently resulted in the highest split tensile strength across all fly ash levels (10%, 15%, and 20%), confirming the significant role of nanoscale additives in enhancing concrete performance.
- **Improved Microstructure:** SEM analysis revealed that mixes containing  $\text{TiO}_2$  exhibited a denser and more homogeneous microstructure with reduced porosity, contributing to enhanced durability and strength.
- **Synergistic Effect:** A higher proportion of fly ash (especially 20%) in combination with  $\text{TiO}_2$  showed synergistic benefits, improving the pozzolanic reaction and resulting in superior geopolymer gel formation.
- **Performance Decline Beyond Optimal:**  $\text{TiO}_2$  addition beyond 1.5% showed diminishing returns in strength development, likely due to particle agglomeration and disruption of the matrix.

Overall, the study concludes that a geopolymer concrete mix with 15–20% fly ash and 1.5%  $\text{TiO}_2$  offers an optimal combination for mechanical strength, durability, and sustainability.

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