Influence of Fly Ash Properties on Performance Geopolymer Concrete

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***Abstract*— A geopolymer is a new type of material that is frequently utilized in the building sector. It's the sustainable one, where cement is partially or entirely replaced by waste materials from thermal power plants to eliminate carbon dioxide emissions from cement production enterprises. Fly ash-based geopolymer concrete (FBGC) derived from two distinct fly ash sources was tested for compressive strength. The primary factors were the weight ratio of sodium silicate to sodium hydroxide (Na2SiO3/NaOH), the weight ratio of alkaline activator to fly ash content (AL/FA), and the concentration of NaOH. When the Na2SiO3/NaOH ratio and NaOH concentration increased, the compressive strength of the FBGM mixed with various fly ashes responded differently.**

***Index Terms*— Geopolymer, Fly ash, Alkaline activator.**

1. INTRODUCTION

The production of Portland cement contributes to global warming and greenhouse gas emissions as it generates a significant quantity of dust and carbon dioxide. Portland cement manufacture contributes 5% of global carbon dioxide output, or about 1.5 gigatons annually, making it one of the biggest sources of combustion and chemical process-related carbon dioxide emissions worldwide. The development of alternative cementitious binders is one strategy to lessen the environmental effect of Portland cement production. When compared to the production of OPC, the production of fly ash-based Geopolymers uses around 60% less energy and emits at least 80% less CO2. About 110 million tons of fly ash are produced nationwide each year by coal-powered thermal power plants, with 30% of that amount going toward filling, embankments, construction, blocks, and tiles. Coal Because fly ash is made up of tiny, glass-like particles that are easily dispersed by the wind, it can contaminate the air and lead to respiratory illnesses like asthma and chronic bronchitis. Nanoscale dimensions of solid materials, like CSH particles, or voids, such the gel porosity in the cement matrix and the transition zone at the cement paste-aggregate interface, have a significant impact on the performance of concrete. To improve the qualities like strength, durability, shrinkage, and bonding, fly ash must be treated close to cement facilities, much like cement. The primary components of these coal fly ash particles are Si, Al, O, Fe, and Ca, along with contaminants from the fly ash's synthesis and processing. Due to the fact that coal combustion technology is used all over the world to produce energy, fly ash (FA), a by-product of coal combustion that is abundant in alumina silicate, is readily available.

2. MATERIAL

2.1 Fly ash

A fine, powdery by-product of burning pulverized coal in power plants is fly ash. It takes the place of conventional cement as the main binder in geopolymer concrete. Alumina (AlO_3) and silica (SiO_2), two essential components for geo-polymerization, are abundant in fly ash. These substances dissolve and produce robust, stable polymer chains (Si-O-Al-O linkages) when combined with alkaline activators such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The low calcium concentration of Class F fly ash makes it more durable over the long term and more resistant to chemical assaults, which is why it is frequently chosen. By eliminating landfill trash and CO2 emissions related to cement manufacture, fly ash use in concrete further improves sustainability.

2.2 Alkaline Solution

In order to start the chemical process that binds the components together, alkaline activators are necessary in geopolymer concrete. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) are common activators. The geo-polymerization process is started when fly ash's silica and alumina are broken down by the OH^- ions produced by sodium hydroxide. By adding more silica to the process, sodium silicate strengthens and bonds the bonds. The concrete's performance is greatly impacted by the molarity and ratio of these activators. For better heat resistance or specific performance needs, potassium hydroxide (KOH) or potassium silicate (K_2SiO_3) are occasionally utilized as substitutes.

2.3 Fine Aggregate (sand)

In geopolymer concrete, fine aggregates—such as manufactured sand (M-sand) or natural river sand—are essential for enhancing workability, completing gaps, and producing a smooth finish. They add to the overall stability and density of the concrete. To guarantee a homogeneous mixture and attain the required strength, proper grading and particle size distribution are crucial. Additionally, fine aggregates strengthen the link between the aggregate structure and the geopolymer matrix and lessen shrinkage.

2.4 Coarse Aggregate

A crucial part of geopolymer concrete, coarse particles give the material bulk, strength, and dimensional stability. Typically, broken stones, gravel, or recycled concrete elements make up these aggregates. In order to minimize shrinkage, enhance mechanical qualities, and guarantee durability, their main function is to take up the most volume in the concrete mixture. Coarse aggregates offer dimensional stability and load-bearing capabilities. They increase the mix's cost-efficiency by lowering the amount of binder needed. A mixture of varying sizes, or proper gradation, increases packing density, reduces voids, and increases durability.

2.5 Water

In contrast to conventional Portland cement concrete, water is an essential but different component of geopolymer concrete. Water is essential for reaching the appropriate workability, guaranteeing adequate mixing, and facilitating the even dispersion of components, even though it is not directly engaged in the chemical bonding process. Both potassium hydroxide (KOH) and sodium hydroxide (NaOH) dissolve in water to form a potent alkaline solution.The silica (SiO_2) and alumina (Al_2O_3) found in fly ash and other alumino-silicate minerals must be broken down by this solution. Geopolymer concrete needs very little water to start the reaction, in contrast to conventional concrete, where strength is directly impacted by the water-to-cement ratio.The typical range of w/b ratios, contingent on mix design, is 0.15 to 0.25.While too much water can degrade the geopolymer matrix by diluting the alkaline solution, too little water can result in poor workability and incomplete reactions.

3.Mix Design Procedure

The components of the geopolymer concrete are fly ash (FA), sand, gravel, NaOH (aqueous), and Na2SiO3 (aqueous). In contrast to earlier mix design processes, each ingredient's specific gravity, volume, and air content are taken into account. As a result, the GPC includes the following elements:

GPC = Sand + Gravel + Fly Ash + NaOH + Na2SiO3 + Water

An overall mix design procedure is demonstrated below. The procedure and calculations are explained in more detail below based on 1 Cube specimen of GPC.

3.1 Calculate Total Material Weight

First, the weight of the concrete mixture is calculated in order to determine the material amounts for M20 geopolymer concrete. We must increase the necessary concrete volume of 0.003375 cubic meters (m^3) by the density of geopolymer concrete, which is normally about 2400 kg/m^3. The mass of concrete, comprising the aggregates, binder, and alkaline activator solution, per unit volume is represented by the density value. By completing the computation:

Weight of concrete = 0.003375 × 2400 = 8.1kg

This indicates that the combined mass of all the necessary components for a batch of M20 geopolymer concrete measuring 0.003375 m^3 will be around 8.1 kg. Based on the specified mix proportions, this weight is subsequently divided among several components, including fly ash, fine aggregate (sand), coarse aggregate, and the alkaline activator solution.

3.2 Calculate Proportions of Materials

The next step is to divide the 8.1 kg total weight of the geopolymer concrete across its constituent parts using the mix ratio that was selected. A typical ratio for M20 geopolymer concrete is 1:1.5:3, where:

- 1 part represents the binder (a combination of fly ash),
- 1.5 parts represent the fine aggregate (sand), and
- 3 parts represent the coarse aggregate.

These components add out to 1 + 1.5 + 3 = 5.5. Each component's weight is calculated by dividing the 8.1 kg total weight proportionately by these portions.

- The binder content is calculated as (1/5.5) × 8.1 = 1.47 kg.
- The fine aggregate (sand) is (1.5/5.5) × 8.1 = 2.21 kg.
- The coarse aggregate is (3/5.5) × 8.1 = 4.42 kg.

This process makes sure that the components are distributed appropriately in accordance with conventional mix design guidelines to preserve the geopolymer concrete's strength and structural integrity. Calculating the necessary quantity of the alkaline activator solution, which is essential for joining the components without the use of conventional cement, comes next.

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3.3 Calculation of Alkaline Activator Solution

The alkaline activator solution in geopolymer concrete chemically reacts with the binder (fly ash) to create a robust, long-lasting matrix, taking the place of conventional cement. Usually, 40% of the binder weight of this activator is needed. The activator solution is ascertained as follows since the binder content was computed as 1.47 kg above, the activator solution is determined as:

$0.4 \times 1.47 = 0.588$ kg

Typically, the alkaline activator is a mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions at a weight ratio of 1:2. This indicates that NaOH makes up one-third of the activator solution, while Na_2SiO_3 makes up the other two-thirds. Consequently:

- The NaOH solution required is (1/3) × 0.588 = 0.196 kg.
- The Na_2SiO_3 solution required is (2/3) × 0.588 = 0.392 kg.

In order to dissolve the aluminosilicate compounds in the binder and create a firm geopolymer matrix, these activator solutions are essential. The concrete's strength, workability, and setting time are all influenced by the exact ratio and concentration of NaOH and Na_2SiO_3. We can get the required M20 grade strength and durability in the geopolymer concrete mix by making sure that the activators are proportionately right.

3.4 Calculation of Water

The alkaline activator solution in this instance (NaOH + Na_2SiO_3) weighs 0.588 kg in total, which already includes some water. The water content of sodium silicate solution is normally between 50 and 55 percent, whereas sodium hydroxide solution is usually made with a certain molarity (usually 8 to 12 m) and contains a regulated amount of water. Water may be added at a rate of 5–10% of the binder weight (fly ash + GGBS) to increase workability. Considering the 1.47 kg weight of the binder, the anticipated extra water required is:

Water required $= 0.05 \times 1.47 = 0.0735$ kg (or 73.5 mL)

This tiny bit of additional water helps to achieve the appropriate flowability and installation ease without sacrificing the geopolymer concrete's strength and longevity. Excess water, however, might weaken the activator solution and have a detrimental effect on the ultimate strength and setting time. Because of this, the water content of geopolymer concrete needs to be carefully regulated according to the mix design and environmental factors.

Table
Amount of each ingredient per 1 Cube Specimen

Ingredient	Amount (g)
Fly Ash	1470
NaOH	196
Na2SiO3	392
Sand	2210
Gravel	4420
Water	73.5

3.5 Casting and Curing

The first step involves combining the dry ingredients (fly ash, sand, and coarse aggregate) either by hand on a clean mixing platform or in a concrete mixer. Following the attainment of a consistent consistency in the dry mix, the alkaline activator solution (pre-mixed NaOH and Na_2SiO_3) is added gradually while being constantly stirred. A tiny bit more water (about 5–10% of the binder weight) is added if necessary to increase workability. After three to five minutes of mixing, a homogenous, flowable mixture is achieved. The mix is kept from adhering by cleaning and applying a mold release agent to concrete molds (such as cubes, cylinders, or slabs). Following preparation, layers of the geopolymer concrete mix are poured into the molds. A vibrating table or tamping rod is used to crush each layer in order to release trapped air and guarantee adequate densification.

Geopolymer concrete doesn't need water to cure as regular concrete does. Rather, heat is applied to cure it, speeding up the polymerization process. The molds are kept in a chamber or oven set between 60 and 80 degrees Celsius for 24 to 48 hours. Although it could take 7–14 days for the concrete to reach its maximum strength, it is feasible to cure it at room temperature if oven curing is not an option.

Once the concrete has cured, the specimens are gently taken out of the molds. After hardening, the geopolymer concrete is left to air cure for even more strength. It is now prepared for testing or structural use, depending of the casting's intended use.

5. Result and Discussion

Effects of Fly ash on Compressive Strength:

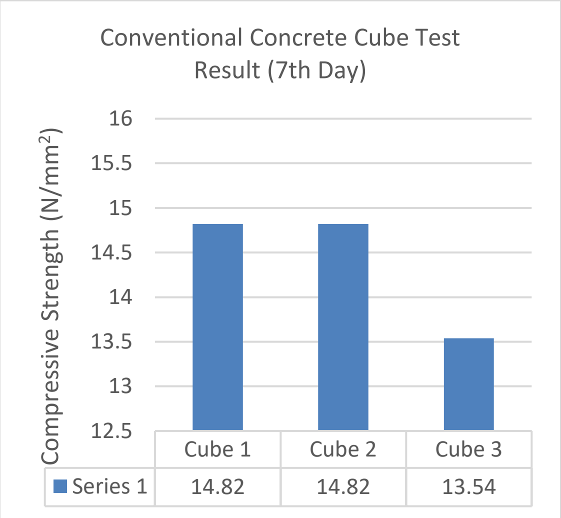
Khaperkheda Power Station Fly ash:

The compressive strength of concrete is decreased to 15.11 N/mm^2 as compared to conventional concrete (19.45 N/mm^2). This reduction could attributed due to the higher percentage of heavy metals and trace element present in the fly ash which is known to altering the hydration process, affecting strength, and potentially impacting durability which leading to lower strength.

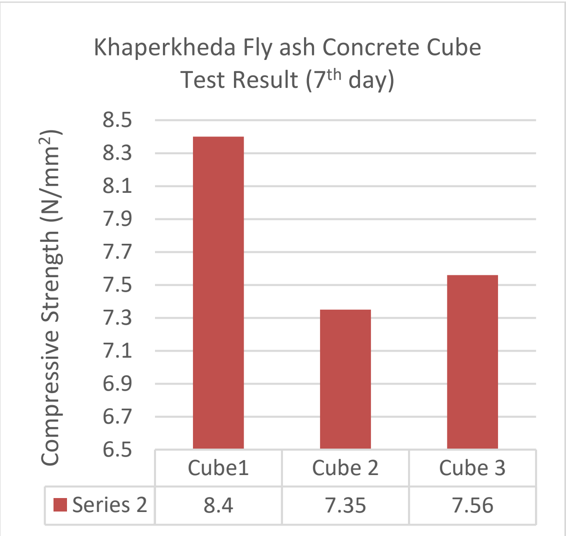
Koradi Power Station Fly ash:

Here, we observed an improvement in compressive strength of concrete to 19.55 N/mm^2 as compared to conventional concrete (19.45 N/mm^2). This enhancement is due to its high pozzolanic activity, fine particle size, and rich amorphous content. Its low carbon and calcium oxide levels support better hydration and ongoing strength gain, making it an effective material for producing durable, high-strength concrete.

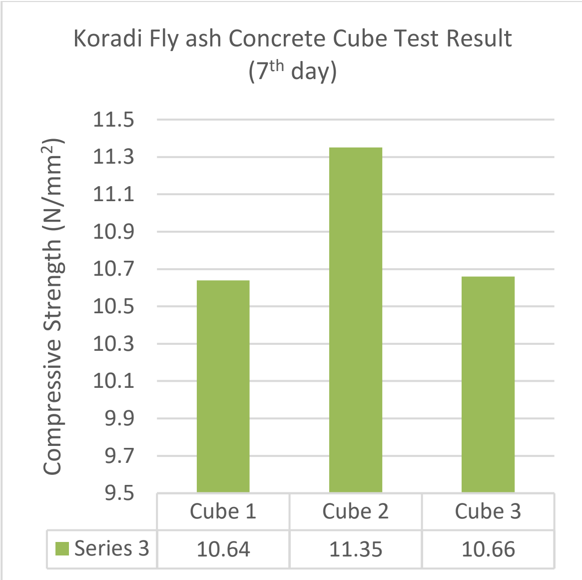
5.1 Compression Test



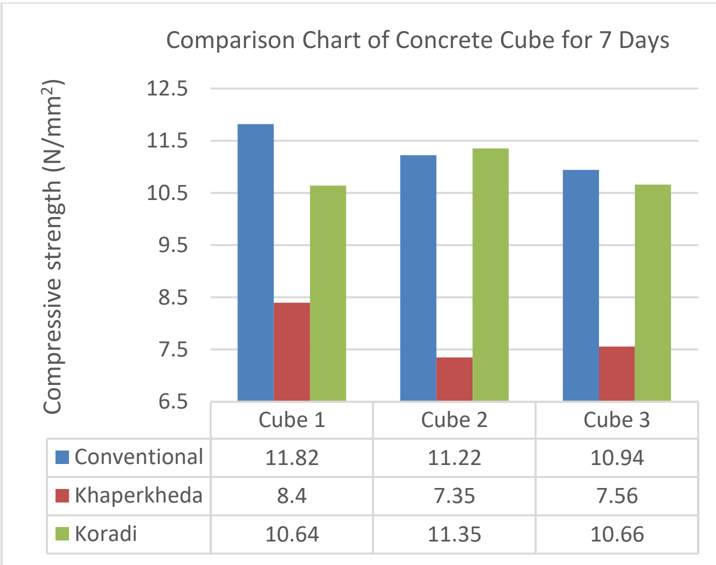
Graph 5.1.1 Conventional Concrete Cube Test Result (7th Day)



Graph.5.1.2. Khaperkheda Fly ash Concrete Cube Test Result (7^{th} day)



Graph 5.1.3 Koradi Fly ash Concrete Cube Test Result (7^{th} day)



Graph 5.1.4 Comparison Chart of Concrete Cube for 7 Days

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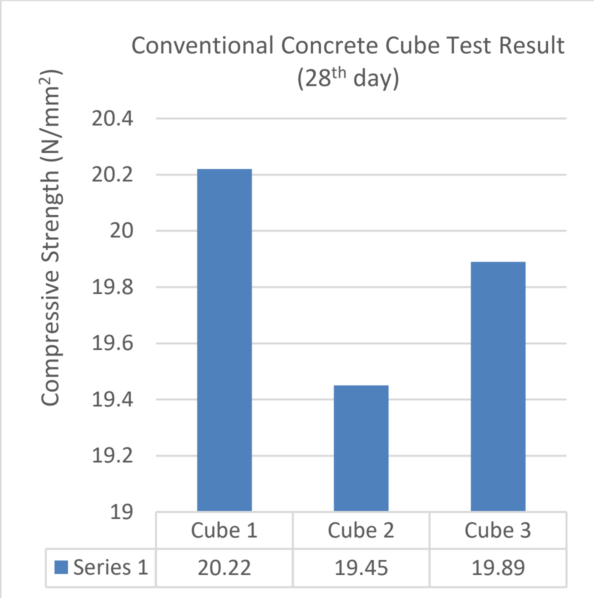
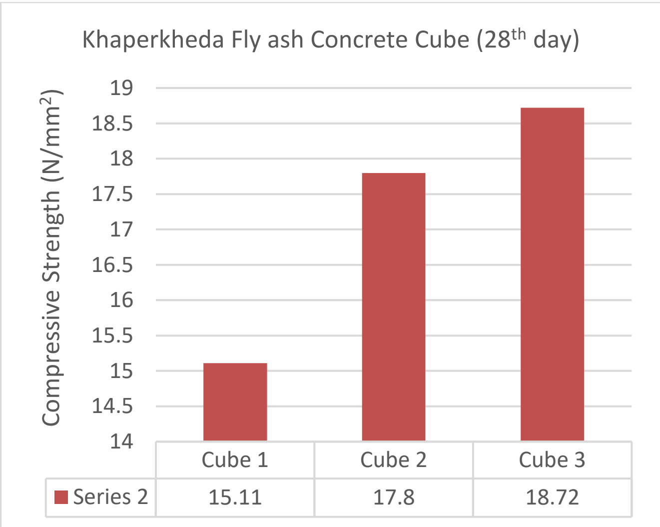
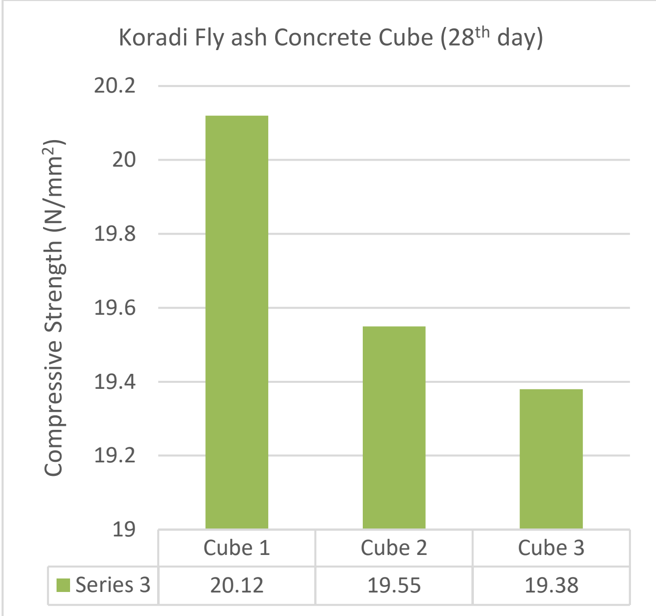


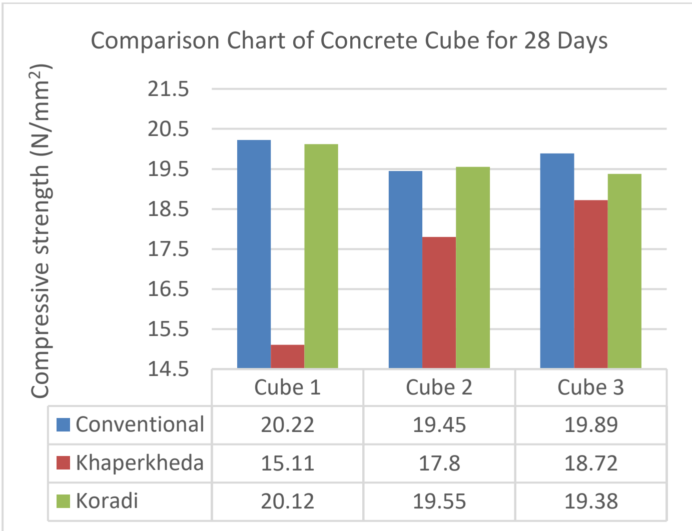
Graph 5.1.5 Conventional Concrete Cube Test Result (28th Day)



Graph 5.1.6 Khaperkheda Fly ash Concrete Cube Test Result (7th day)



Graph 5.1.7 Koradi Fly ash Concrete Cube Test Result (28th day)



Graph 5.1.8 Comparison Chart of Concrete Cube for 28 Days

6. Conclusion

1. Sustainable Cement Substitutes:

The sustainable aspect of using fly ash as an alternative cement substitute in concrete manufacture is highlighted in this study. The varying mixture ratios tested have shown unequivocal effects on the compressive strength, showing it is achievable to utilize a reduction in cement use without compromising strength.

2. Improved Strength from an Optimized Mix

After seven days, the fly ash mixture had the highest compressive strength and was found to be the optimum combination. The mixture is a workable material for building applications as well as enhancing the mechanical properties of concrete.

3. Realistic Possibility in Building:

The enhanced blend's superior performance means that it can be applied to actual construction projects. Since it meets sustainability goals and strength requirements, builders and contractors can employ this blend confidently.

4. Environmental Sustainability Contribution

By utilizing industrial waste products like fly ash, this study promotes environmentally friendly sustainability in the construction sector. The environmental impact of concrete manufacturing is minimized and carbon emissions decreased when there is less use of cement.

5. Promotion of Industry Adoption

These findings promote the utilization of alternative materials to enhance the properties of concrete and provide valuable information to the construction industry. Utilizing industrial waste not only enhances material efficiency but also enables the achievement of sustainable development.

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