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Exploring Novel Applications of Fly Ash Polymer Materials: Analytical Insights

Arif Hussain[1] and Raushan Kumar[2]

Research Scholar, Department of Civil Engineering[1]

Assistant Professor, Department of Civil Engineering[2]

Eklavya University, Damoh M.P, India

Abstract: *In order to demonstrate that fly ash-based geopolymers can be produced under specified conditions and with the necessary compressive strength for use in building, no additional sand, cement, or aggregates are needed. A series of experiments involving at least 73% fly ash shown that, with the right curing conditions, a compressive strength of up to 90 MPa could be achieved. Higher alkalinity produced stronger materials, but without the need of sand and cement, the results shown a 40% reduction in CO2 emissions. These materials are appropriate for construction uses that have little effect on the environment.*

Keywords: Fly Ash, Geopolymer, Compressive Strength, Carbon Dioxide, Construction, CO2 Emissions

I. INTRODUCTION

After water, concrete is the second most used substance worldwide. Ordinary Portland cement (OPC) is the primary ingredient in concrete. It is well known that the manufacturing of cement requires a significant quantity of natural resources, including limestone, and is the second most energy-intensive industry after that of steel and aluminium. The limestone turns into lime and carbon dioxide when heated. These CO2 emissions make for 60–65% of all emissions related to the manufacture of cement. Accordingly, depending on the process, about one tonne of CO2 is released for every tonne of OPC produced. It was estimated that cement plants released 2.2 billion tonnes of CO2 into the sky in 2016. These factors make it essential to develop green concretes are novel varieties of concrete. The need for power rises along with the world's population. While there are plenty of carbon-neutral energy options, coal is inexpensive and widely accessible. Coal combustion produces fly ash as a byproduct, and the amount of waste fly ash produced worldwide is rising. Globally, millions of tonnes of coal ash are produced. About 32.6 billion tonnes of coal ash were produced by coal-fired power plants in South Africa during 2016 and 2017. Because dry fly ash from poorly maintained ash piles contains very fine particles (less than 10 μm diameter), inhaling it can be harmful. Coal fly ash beneficiation could reduce possible hazards while saving enormous tracts of land that would otherwise be lost to landfills and ash ponds. liabilities and pollution from these sources. Applications for fly ash include the production of zeolites and the treatment of acid mine drainage. Because of its pozzolanic qualities and wide availability, it can be used in place of cement when making concrete. According to Yao et al, coal fly ash can be utilised in building with effectiveness. The binder, which is collectively referred to as a "geopolymer," may be created through a polymeric reaction of alkali liquids with silicon and aluminium found in coal fly ash. Davidovits originally coined the word "geopolymer" in 1979 to refer to a group of three-dimensional aluminosilicate polymers made from materials such as fly ash, red mud, and clay. Using flies the naturally high concentration of SiO2 and Al2O3 is utilised by ash in the production of geopolymer; low SiO2 and Al2O3 content is insufficient for alkali-activation. As a general rule, lower calcium ASTM C618 Class F fly ash is preferred over higher calcium Class C fly ash. The amount of iron, silicon, and aluminium oxides combined in the ash determines the distinction between the two types of fly ash. Fly ash is classified as Class F when the sum is more than 70%, and Class C when the sum is between 50% and 70%. Because Class C fly ashes have a high calcium concentration and a low glass content, they react poorly with alkaline activators.

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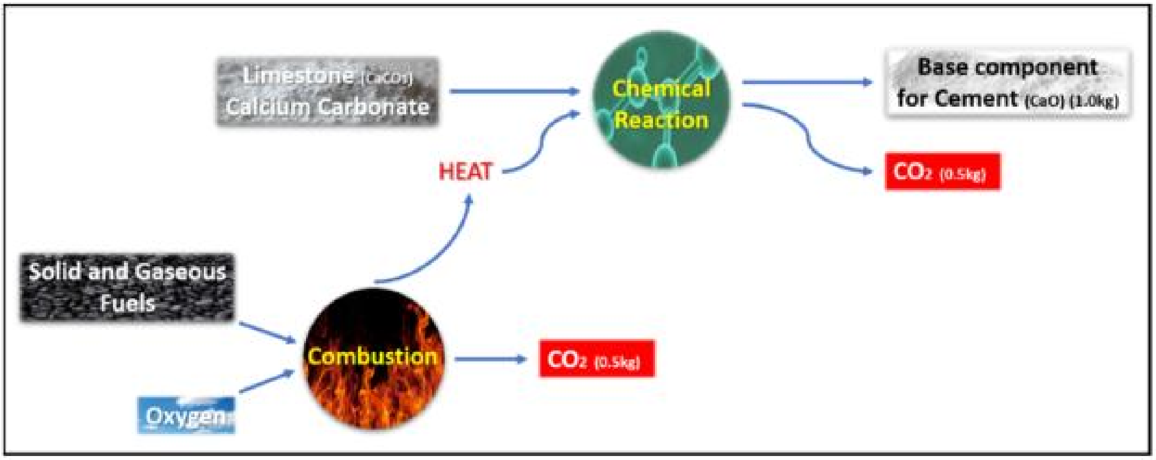

Figure 1- Simple recipe for cement and CO_2 emissions

DESCRIPTION OF FLY ASH

Thermal power facilities collect fly ash, a combustion waste, and categorise it based on how it was separated. Electrostatic precipitators are used to produce fine fly ash, whereas gravity separation in the boiler's rear passageways produces coarse fly ash. The type of feedstock burned, the method of combustion, and the source of the biomass all have a major role in determining the physical characteristics and chemical makeup of ash. Rich in calcium, potassium, and other minerals, ash is an alkaline material. Ash contains a variety of hazardous materials, organic pollutants, including polyaromatic hydrocarbons in addition to nutrients. Its use is restricted by the presence of dangerous particles and components as well as a high pH. Fly ash can all be utilised as a raw material for the following goods: geopolymerization, embankments, road and mine backfilling, bricks and blocks, and cement and concrete.

(i) Coal Combustion Fly Ash- A byproduct of producing electricity in thermal power stations using pulverised coal as fuel for their boilers is coal fly ash. The coal burns instantly due to the temperature, which is roughly 1500 °C. The leftovers from fuel combustion melt and then quickly cool off while being transported by flue gas. Fine particles sized between 0.1 and 150 µm are formed as a result of this process. The flue gas entangles around 80% of the unburned wastes, which means they need to be removed.

Figure 2- The fly ash generated at the combustion of biomass

(ii) Biomass Combustion Fly Ash- Biodegradable organic matter generated from plants or animals is referred to as "biomass." Wood and wood waste are the most widely used biomass fuels, followed by grain and oilseed straw.

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Additionally classified as biomass are bacteria, cyanobacteria, and fungi. The bulk of the minerals contained in the initial biomass are present in fly ash, which is the inorganic fuel component that is left in the boiler after the organic matter has been burned. 6–10% ash is produced during ideal wood burning (Figure 2).

(iii) Waste Biomass- Crop production waste (residues from primary agricultural production and landscape maintenance, waste from orchards and vineyards, corn straw, rapeseed straw and all other waste and residues from bush clearance) and animal production waste (livestock excrement, feed residues manure, urine, slurry); logging and forestry waste (branches, bark, stumps, roots, trimmings, sawdust, shavings); biodegradable municipal waste (food scraps, paper packaging); biodegradable industrial waste (slaughterhouses).

BIOMASS FLY ASH-BASED GEOPOLYMERS

As per the widely recognised definition, geopolymers are inorganic, aromatic, synthetic aluminosilicate polymers that arise from the synthesis of silicon, aluminium, and minerals taken from geology. Although their chemical makeup is comparable to that of zeolite, their microstructure is amorphous. In this case, the base material could be an inorganic substance with pozzolanic qualities, fly ash, slag, clay, volcanic tuff, or any natural raw material (kaolin, metakaolin, laterite, etc.).

Geopolymer materials have great elasticity, chemical and fire resistance, compressive and flexural strength, and mechanical durability. When compared to concrete made with Portland cement, they may have compressive strengths that are higher or comparable. Bakri and colleagues devised an experimental approach to evaluate the effects of varying flies aggregate and ash affect concrete's compressive strength. In the study, regular Portland cement (OPC) and fly ash-based geopolymer were contrasted. The geopolymer concrete used in this investigation had different ratios of FA 50%: aggregate (AGG) 50%, FA 40%: AGG 60%, FA 30%: AGG 70%, and FA 20%: AGG 80%. For OPC concrete, the same designs have also been used as control references. Compressive strength testing was used to evaluate the material's strength. After 1, 7, and 28 days of testing, the results show that the geopolymer built with 30% fly ash and 70% aggregate has greater compressive strength compared to regular Portland cement concrete. When exposed to temperatures between 1000 and 1200 ◦C, the geopolymer matrix look remains unaltered. Geopolymers exhibit great resistance. to fire and don't release any smoke or dangerous vapours. Additionally, geopolymers may be utilised to coat metal in a fire-resistant manner or to create fire panels. It is possible to develop the coatings to withstand temperatures lower than 550 ◦C. Because the geopolymer material's chemical structure contains little calcium, it has a low thermal conductivity, a high mechanical strength, and exceptional resilience to alkaline and acidic conditions. It can even adsorb hazardous chemical pollutants. Its physical characteristics and performance metrics (strength, mechanical resistance, and thermal conductivity) are enhanced by the addition of various fillers (particles, fibres).

II. MATERIALS AND METHODS

(i) Raw Materials- Fly ash from a coal-fired power plant in the South African province of Mpumalanga was used in this investigation. The alkaline activator mixture that was employed was NaOH plus Na2SiO3. NaOH was 98% pure in pellet form, whereas SiO2 made up 30%, Na2O 9.2%, and H2O 60.8% of the Na2SiO3 in liquid phase. There was also additional usage of deionised water.

(ii) Characterization of the Raw Material- In order to use coal fly ash in the synthesis of geopolymer materials, it was examined. After the bag filters or electrostatic precipitators, coal fly ash was gathered downstream. The fly ash samples were stored in airtight plastic containers that were shielded from moisture and kept in a cool, dark closet to prevent temperature changes. X-ray diffraction (Philips PANalytical instrument with a pw3830 X-ray generator, Bruker UK, United Kingdom), X-ray fluorescence (Philips 1404 Wavelength Dispersive spectrometer, Bruker UK, United Kingdom), and scanning electron microscopy (LEO SEM 1450, ZEISS, Germany) were used to identify the mineral phase, major element compositions, and morphology of coal fly ash, respectively.

(iii) Preparation of Materials and Experimental Procedure- We used 10, 12, 14, and 16 M NaOH solutions. To guarantee the solution's reactivity, an alkaline activator was made by combining Na2SiO3 and NaOH solution (for each molar concentration of NaOH) right before it was mixed with fly ash and water. Either adding additional water to the fly ash or using a more concentrated alkaline activator solution improved the workability and produced a homogenous paste. The extra water to fly ash mass ratios of 0.1, 0.075, 0.05, and 0.025 were adjusted, while all other parameters remained same. First, the excess water was combined with the alkaline activator (Na_2SiO_3 solution) and a predetermined amount of NaOH solution 30 minutes); to create a homogenous paste, this solution was then combined with fly ash in a mixing apparatus consisting of a plastic tank and a mechanical stirrer spinning at 55 rpm. After that, the pastes were put into 100 mm^3 moulds and coated with a high viscosity oil to act as a releasing agent.

(iv) Compressive Strength- The geopolymer samples were tested for compressive strength at 7 and 28 days of age using the SANS method 5863:2006, "Compressive Strength on Concrete Cubes." The ultimate strength of the geopolymer was ascertained using an Automatic Max testing machine (King test auto 2000 model Pat 2001, Cape Laboratory equipment (Pty), Republic of South Africa), which has a load capacity and a load rate of 2000 kN and 40–1000 kN/min, respectively. A load of 180 kN was applied to the samples, with a loading rate of 180 kN/min for a sample with a diameter of 100 mm3. The average of the three samples produced for each condition and formulation was used to report the compression strength values.

(v) Water Absorption- In accordance with ASTM D570-98 standard, a water absorption test was conducted on the geopolymer product samples that were acquired after 28 days of ageing. The purpose of the test was to find out how much water a geopolymer could absorb under the given circumstances. Geopolymer samples cured in an oven at 60 °C for 24 hours and aged for 28 days were used in the water absorption test. The ratios of water to fly ash were 0.025:1, Na_2SiO_3/NaOH was 2.5:1, NaOH to fly ash was 0.1:1, and NaOH solutions were 10, 12, 14, and 16 M. After the samples were weighed, they were submerged for 24 hours in a pail of water that was roughly 23 °C. The samples were then taken out, dried using a lint-free cloth, and weighed. Consequently, the water absorption is measured in weight percentage.

III. CONCLUSION

Numerous issues were answered by the current investigation. The primary source of silica, alumina, and lime coal fly ash allows for the reuse of this waste and answers the issue of how to dispose of trash from coal-fired power plants. The formulations lessened the carbon footprint associated with cement manufacturing because neither cement nor aggregates were required for the geopolymer to function. High-temperature brick kilning was eliminated by mild curing conditions. Geopolymerization provides a way for coal fly ash to be substituted for cement in the building sector. Alkaline activators were added less frequently in the formulations created here. The following could be used to summarise the study's significance:

No cement, sand, or coarse aggregate were employed in any of the formulations created during this investigation.

A series of trials yielded compressive strengths ranging from 13.39 ± 1.42 to 89.32 ± 7.1 MPa.

The product exhibited limited water penetration, with its water absorption ranging from 3.74 ± 0.78 to 7.55 ± 0.17%, as a result of the increased alkalinity throughout the geopolymerization process.

The ideal mixture and conditions for creating a geopolymer with a high strength of 89.32 ± 7.1 MPa were 16 M NaOH, a curing temperature of 80 ◦C, a 28-day ageing period, and a water/fly ash ratio of 0.025:1.

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