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Optimization and Evaluation of Alkali Activated Fly Ash for Lightweight Aggregate Production

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Abstract: *This study investigates the utilization of solid waste, specifically fly ash, and other materials to produce aggregates through geopolymerisation. The research aims to explore the properties of fly ash aggregates and assess their viability in concrete production. The objectives of the study encompass the preparation of aggregates using different proportions of fly ash and alkali activator such as sodium hydroxide and sodium silicate, alongside the casting of concrete cubes utilizing the artificial aggregate. The methodology employed involves the preparation of alkali activator, mix proportioning, and the subsequent processes of mixing, casting, crushing, and curing. Various ratios of fly ash to activator (2.5:1, 3:1, and 3.5:1) were investigated, with corresponding results obtained for properties such as abrasion value, impact value, bulk specific gravity, and water absorption. The findings reveal that the properties of the fly ash aggregates vary with different ratios, with notable differences observed in abrasion value, impact value, bulk specific gravity, and water absorption. For 2.5:1 abrasion value is 26.02%, impact value is 19.32%, bulk specific gravity 1.821 and water absorption 9.61%.For 3:1 abrasion value is 37.14%, impact value is 25.15%, bulk specific gravity 1.78 and water absorption 10.58%.For 3.5:1 abrasion value is 46.5%, imapct value is 32.87%, bulk specific gravity 1.648 and water absorption 12.83%. Casting cude using ratio 2.5:1, 28 day strength is 20.46 N/mm^2.. This research project offers an eco-friendly solution for utilizing fly ash in the production of high-performance aggregates, contributing to sustainable construction practices. The implications of the findings include reduced environmental impact, enhanced resource efficiency, and the potential for resilient and environmentally conscious built environments. Further research and development in this area could lead to broader adoption of geopolymerized fly ash aggregates in the construction industry, paving the way for a more sustainable and Greener future.*

Key Word: *Artificial Aggregate, Flyash, Geopolymerisation.*

I.INTRODUCTION

The burgeoning global urbanization and industrialization have triggered a surge in the demand for construction materials, particularly aggregates, essential for producing concrete, asphalt, and other building essentials. However, the extraction and processing of natural aggregates have posed significant environmental challenges due to resource depletion and carbon emissions. In response, researchers have turned their attention to sustainable alternatives, with a notable focus on repurposing industrial wastes. Notably, the utilization of fly ash and other byproducts from coal-fired power plants has emerged as a promising avenue for environmentally friendly aggregate production. Numerous studies, including those by Xiao et al. [1] and Bimo Brata Adhitya et al. [2], have investigated the synthesis of artificial aggregates from fly ash, revealing variations in physical properties based on different production techniques. Beyond fly ash, researchers have explored alternative industrial wastes and innovative manufacturing methods, such as fly ash cenosphere, sintered fly ash aggregate, and polymer matrix materials [6][7][8]. These endeavors have demonstrated the feasibility of integrating substitute aggregates into concrete mixes, achieving comparable mechanical properties to conventional concrete while mitigating waste disposal issues and preserving natural resources. Moreover, efforts to enhance the mechanical properties and sustainability of artificial aggregates through approaches like geopolymerization and the utilization of local industrial waste materials have shown promise [5][9]. The main goal of this research is to explore the possibility of creating artificial aggregates using fly ash as a starting material. This involves using a process called geopolymerization to convert fly ash into aggregates that are both strong and functional for use in concrete. The study aims to investigate how different ratios of fly ash to alkaline activator affect the properties of the resulting aggregates. These properties include things like particle size distribution, density, compressive strength, and porosity. By understanding how these factors interact, the research aims to determine the optimal conditions for producing high-quality artificial aggregates from fly ash.

II.MATERIAL AND METHODS

In the realm of artificial aggregate production, various manufacturing techniques have been explored to harness different materials and processes. The following sections delineate the methodologies employed by different studies in the field.

Fly Ash: Fly ash is a fine, powdery residue produced by the combustion of pulverized coal in thermal power plants. Fly ash exhibits a complex chemical composition, with silica (SiO_2) and alumina (Al_2O_3) being the predominant constituents. These compounds contribute to the pozzolanic reactivity of fly ash, enabling it to react with calcium hydroxide ($Ca(OH)_2$) in the presence of water to form additional cementitious compounds, such as calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H). Iron oxide (Fe_2O_3) imparts color to fly ash and can influence its reactivity and pozzolanic properties. Other minor constituents, including calcium oxide (CaO) and magnesium oxide (MgO), may affect the setting and hardening characteristics of concrete containing fly ash.

Alkaline Activator: Alkaline solutions play a crucial role in geopolymers by activating the precursors like aluminosilicate materials (such as metakaolin or fly ash). Fly ash, a byproduct of coal combustion, is often mixed with an alkaline solution (such as sodium hydroxide or potassium hydroxide) and other additives to form slurry. This slurry is then subjected to a process known as geopolymerization or alkali activation. These solutions provide the necessary conditions for the polymerization reaction, initiating the formation of a three-dimensional polymeric network that contributes to the strength and stability of geopolymers. The high pH of the alkaline solution helps in dissolving and activating the precursors, allowing them to form strong bonds and solidify into the desired material. Alkaline activators commonly used in the production of artificial aggregates include alkali metal hydroxides and silicates. These compounds provide the necessary alkaline environment for the activation of fly ash and the subsequent formation of cementitious bonds. Some of the primary types of alkaline activators used in this process are:

1. Sodium Hydroxide (NaOH): Sodium hydroxide, also known as caustic soda, is a widely used alkaline activator in the production of artificial aggregates. It provides a strong alkaline environment conducive to the dissolution and activation of silica and alumina components in fly ash.
2. Sodium Silicate (Na_2SiO_3) Sodium silicate (Na_2SiO_3) is a compound formed by combining sodium oxide with silica, resulting in a range of products known as sodium silicates. It exists in various forms, commonly as a colorless or white crystalline solid or in liquid form. It’s used in diverse applications such as adhesives, detergents, coatings, and as a key component in geopolymers due to its role in forming the geopolymer matrix. Sodium silicate (Na_2SiO_3) is a compound formed by combining sodium oxide with silica, resulting in a range of products known as sodium silicates. It exists in various forms, commonly as a colorless or white crystalline solid or in liquid form. It’s used in diverse applications such as adhesives, detergents, coatings, and as a key component in geopolymers due to its role in forming the geopolymer matrix.

Optimization of Alkaline Activator Concentration: The concentration of the alkaline activator solution is a critical parameter that influences the activation efficiency and performance of artificial aggregates. The optimal concentration depends on various factors, including the chemical composition of fly ash, curing conditions, and desired properties of the aggregates. Generally, higher concentrations of alkaline activators result in accelerated pozzolanic reactions and higher strength development in the aggregates. However, excessive concentrations may lead to alkali-aggregate reactions (AAR) and detrimental effects on long-term durability.

Laboratory-Scale Pelletization

Preparation of Alkali Activator: Sodium hydroxide pellets were taken and dissolved in water to make it 14M molar concentration. It is strongly recommended that the Sodium hydroxide solution must be prepared 24 hours before prior to use and also if it exceeds 36 hours it terminate from semi-solid state to liquid state. So the prepared solution should be used within the time.

Molarity calculation: The sodium hydroxide pellets must be dissolved in water to make a solution with the required concentration The concentration of Sodium hydroxide solution can vary in different molarity and the mass of NaOH solids in the solution varies depending on the concentration of the solution. For instance, NaOH solution with a concentration of 10M molar consists of 10x40=400 grams of NaOH solids per liter of water, where 40 is the molecular weight of NaOH. Water is the major component in both the alkaline solution.

1. **Mixing-** The activator, usually a solution of alkali metal silicates or hydroxides reacts with fly ash to form a geopolymer binder. Mixing of materials can be done by hand mixing or it can be done with drum mixers.

2. **Casting**: The 75mm cube is used and prepared mix is casted in it. The casting is done in 3 layers with tamping each layer with tamping rod. Casted cube should be well compacted so that no void is present. After that cube is left for curing for 2 days. Mould is removed from cube after 24 hours.

3. **Crushing**: After curing, the cube will be crushed into pieces and the grading of aggregate canbe done by sieve analysis. Take aggregate passing from sieve 20mm and retained on sieve 4.75mm.

4. **Curing**: In the present investigation produced aggregates were subjected to three different curing regimes. They are as follows

Ambient curing: The artificially produced fly ash based coarse aggregates was kept at a temperature of 27 degree Celsius and relative humidity of 80% and were characterised for aggregates properties.

Heat curing: The artificially produced fly ash based coarse aggregates process was allowed in ambient temperature as rest period for 24 hours. After that the fly ash aggregates are subjected to 80°C for 24 hours. Further, aggregates removed after heat curing were kept in ambient temperature conditions until it is tested for their engineering properties. Solution curing: The artificially produced fly ash based coarse aggregates was allowed in ambient temperature as rest for a period of 24 hours. After that produced aggregates are subjected to solution curing in laboratory grade sodium silicate solution for 30 minutes. Further, this fly ash based coarse aggregates are removed and kept in an ambient temperature conditions until it is tested for their engineering properties.

Test Performed

Testing aggregates is crucial in the construction industry to ensure that they meet the required specifications for use in concrete, asphalt, and other construction applications. Various tests assess the physical, mechanical, and chemical properties of aggregates. Here are some common tests performed on aggregates:

1.**Aggregate Impact Test**:
Purpose: The aggregate impact test evaluates the resistance of aggregates to sudden impacts or shocks. It helps assess the toughness and durability of aggregates, which is important in determining their suitability for road construction and other impactprone applications.

2.Water Absorption Test:
Purpose: The water absorption test measures the porosity of aggregates and their ability to absorb and retain water. It provides information on the durability and susceptibility of aggregates to damage from freezing and thawing cycles, chemical reactions, and other environmental factors.

3.Specific Gravity Test:
Purpose: The specific gravity test assesses the density of aggregates, which is crucial for designing concrete mixtures. It helps identify the quality of aggregates and their ability to contribute to the strength and workability of concrete.

III.RESULT

The increase in the Na2O content and SiO2/Na2O ratio has the significant influence on the engineering properties of fly ash aggregates. Water content has shown aslightly negative and negligible effect on the engineering properties of fly ash aggregates. The engineering properties of the artificially produced fly ash based coarse aggregates are significantly influenced by the factors of geopolymerisation reaction. Statistically designed experiments showed that geopolymerisation factors significantly influenced the production and engineering properties of the fly ash aggregates. The Flyash to Alkaline Aggregate ratio influence the strength of the flyash aggregate concrete. A well-balanced ratio enhances the pozzolanic reactivity, resulting in improved strength and durability. However, careful consideration of workability, setting time, and other practical aspects is essential to achieve good flyash aggregate.

Table no 1: Result of Aggregate properties

Ratio	2.5:1	3:1	3.5:1
Abrasion Value	26.02	37.14	46.5
Impact Value	19.32	25.15	32.87
Bulk specific gravity	1.821	1.78	1.78
Water absorption	9.61	10.58	12.83

IV. DISCUSSION

Creating artificial aggregates from fly ash with sodium silicate and sodium hydroxide as binders is a multifaceted project poised at the intersection of innovation, sustainability, and construction engineering. At its core lies the vision of transforming fly ash, a byproduct of coal combustion often viewed as waste, into a valuable resource for the construction industry. The project begins with a meticulous selection of materials, emphasizing the importance of high-quality fly ash, sodium silicate, and sodium hydroxide. These materials, when combined in specific proportions, have the potential to form durable aggregates through a chemical process known as alkali activation.With materials in hand, the project moves forward to the experimentation phase,where various mix designs are tested to determine the optimal combination for producing artificial aggregates. This process involves careful consideration of factors such as particle size distribution, binder content, curing conditions, and mechanical properties. As the manufacturing process unfolds, a series of controlled steps, including mixing, shaping, and curing, are meticulously executed to ensure the production of high-quality aggregates. Each stage is monitored closely, with an emphasis on quality control and adherence to established standards. Once the aggregates are produced, they undergo rigorous testing and evaluation to assess their engineering properties. These tests encompass a wide range of parameters, including compressive strength, density, absorption, abrasion resistance, and durability, providing valuable insights into the performance and suitability of the aggregates for construction applications. The results of the project affirm the viability of using fly ash with sodium silicate and sodium hydroxide as binders to create artificial aggregates with desirable engineering properties. These aggregates hold promise for various construction applications, offering not only performance benefits but also significant environmental advantages by repurposing industrial byproducts and reducing waste. Looking ahead, the project sets the stage for further exploration and optimization, with future research avenues focusing on refining mix designs, evaluating field applications, and conducting comprehensive environmental impact assessments. Utimately, this project represents a pioneering effort in sustainable construction, demonstrating the potential of innovative materials and processes to shape a more resilient and resource-efficient built environment.

V. CONCLUSION

This research project demonstrates the feasibility and potential benefits of advancing sustainable manufacturing practices in the construction industry through the production of fly ash aggregates using geopolymerization. The utilization of fly ash, a byproduct of coal combustion, as a raw material for manufacturing aggregates aligns with the growing emphasis on eco-friendly construction materials. The innovative geopolymerization process, involving the optimization of key parameters such as activator concentration, curing time, and temperature, has been successfully employed to produce high-strength, lightweight fly ash aggregates. The mechanical characterization tests, including compressive strength, density, and durability, indicate promising results that position these aggregates as viable alternatives for various construction applications. Beyond the technical aspects, the research underscores the environmental significance of repurposing fly ash, contributing to the reduction of industrial waste and minimizing the reliance on traditional, resource-intensive aggregate production methods. The incorporation of fly ash in construction materials not only enhances performance but also aligns with broader goals of resource efficiency and environmental responsibility. The careful selection and optimization of alkali activators, specifically sodium hydroxide and sodium silicate, play a pivotal role in achieving the desired properties of the geopolymeric materials. The strategic use of these activators underscores the commitment to eco-friendly and resource-efficient construction practices, reducing the carbon footprint associated with conventional cement production. The comprehensive manufacturing process, including molding, curing, and testing, has been meticulously executed to ensure the production of high-quality geopolymerized fly ash aggregates. The battery of tests performed, such as specific gravity, loose bulk density, compacted bulk density, water absorption, and impact value, provides a thorough evaluation of the aggregates' physical and mechanical characteristics. The observed results, comparing different molarities of alkali activators, indicate variations in specific gravity, bulk density, water absorption, and impact value. These variations highlight the importance of carefully selecting and optimizing activator parameters to achieve the desired performance characteristics in geopolymeric materials. In conclusion, this research project contributes to the advancement of sustainable construction practices by offering an eco-friendly solution for utilizing fly ash in the production of high performance aggregates. The findings have implications for reducing environmental impact, promoting resource efficiency, and fostering the development of resilient and environmentally conscious built environments. Further research and development in this area could lead to broader adoption of geopolymerized fly ash aggregates in the construction industry, contributing to a more sustainable and greener future.

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