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Review On Performance Evaluation and Analysis of Cement Stabilized Fly Ash–GBFS Mixes As A Highway Construction Material

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Abstract

Constructing an adequate network of pavements, especially in backward areas, is very important for the socio-economic development of the India. However, challenges are faced many times, while constructing roads in the areas with problematic soils or when the subgrade is having poor strength. In such cases, Subgrade improvement is a feasible and economic solution. Fly ash, lime and cement are the commonly used materials for ground improvement. Geosynthetics, Geotextiles and Geo-grids are also used nowadays in roads for subgrade improvement in pavement construction. On the other hand, the waste materials such as coconut coir, rice husk, marble dust, rubber shreds, plastic strips, flyash, etc. have emerged as a solution for subgrade improvement, besides solving the problem of disposal of these materials and consequential environmental issues. The present work has investigated the use of Flyash (waste material of coal based thermal power plants) in Subgrade Improvement and to evaluate the effects of mixing of various percentages of flyash on the Bearing Capacity of saturated and unsaturated soil by conducting California Bearing Ratio test on the Sandy soil of poor gradation.

Keywords: Pavement, flyash, OMC, MDD, CBR, compaction

I. INTRODUCTION

The socio-economic development of a country like India is dependent on roadways to a large extent. With the development of diverse road construction activities, there is a pressing need to reduce construction costs and improve the quality of pavements. This can be accomplished by utilizing certain industrial by-products, such as fly ash, ground granulated blast furnace slag (GGBS), and steel slag, which are commonly disposed of in landfills after being produced by steel production industries and thermal power plants. Furthermore, there is significant concern over the depletion of traditional materials, such as natural aggregates, which are widely used in road construction. As a result, substituting waste materials for natural resources would be beneficial for environmental stability (Pai et al., 2020). Keeping this in mind, various studies have been undertaken to utilize fly ash and GGBS for soil stabilization purposes and pavement construction.

The most common pavement type for constructing roads and highways is a flexible pavement, which is used all around the world [1]. Flexible pavements make up around 95% of all roadways and comprise four layers specifically subgrade, subbase, base, and surface course. Flexible pavement requires a significant amount of natural aggregates, the extraction of which generates a large amount of waste. Additionally, laying these building materials produce pollution. Thus, resource depletion, environmental degradation, material waste, and rising material costs drive the demand for alternative materials that may be employed in flexible pavement [2], [3].

CEMENT-STABILIZED FLY ASH

Cement-stabilized fly ash is a method used in soil stabilization to improve the engineering properties of soil. This technique involves the use of cement as a binder and fly ash, a by-product of coal combustion, as a supplementary material. When combined with soil, these materials enhance the strength, durability, and load-bearing capacity of the soil. Here's an overview:

Key Components

1. **Cement**:
    - Acts as a primary binder.
    - Provides strength and durability by forming a hard matrix when hydrated.
2. **Fly Ash**:
    - A pozzolanic material that reacts with calcium hydroxide in the presence of water to form additional cementitious compounds.
    - Improves workability and reduces the overall cost of stabilization.
3. **Soil**:
    - The material to be stabilized, which can vary from soft clays to granular soils.

Benefits of Using Cement-Stabilized Fly Ash

1. **Improved Strength**:
    - The combination increases the unconfined compressive strength (UCS) of the soil.
2. **Cost-Effectiveness**:

- Fly ash reduces the amount of cement required, lowering overall costs.

3. **Environmental Benefits**:
   - Utilizes fly ash, which is an industrial waste product, reducing landfill usage.
4. **Reduced Swelling and Shrinkage**:
   - Stabilization minimizes volume changes in expansive soils.
5. **Increased Durability**:
   - Enhances resistance to water erosion and weathering.

Applications

- **Road Base Construction**: Provides a strong foundation for roads.
- **Embankments and Dikes**: Stabilized soil is used for slope stability.
- **Landfills**: Improves the bearing capacity of soil in landfill construction.
- **Pavement Subgrades**: Enhances subgrade properties in pavements.

Process of Stabilization

1. **Soil Preparation**:
   - Remove debris and break down large soil clumps.
2. **Material Mixing**:
   - Mix soil with cement and fly ash in appropriate proportions.
   - Typical mix ratios depend on the specific application and soil type.
3. **Moisture Addition**:
   - Add water to facilitate chemical reactions and ensure proper compaction.
4. **Compaction**:
   - Compact the mixture using rollers or rammers to achieve desired density.
5. **Curing**:
   - Allow the stabilized soil to cure for a specified period to develop strength.

Factors Influencing Performance

1. **Type and Proportion of Materials**:
   - The quality and proportion of cement and fly ash affect stabilization effectiveness.
2. **Soil Type**:
   - Clayey soils benefit the most due to their high plasticity.
3. **Moisture Content**:
   - Adequate water is crucial for the hydration of cement and activation of fly ash.

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4. **Curing Time**:
    - Longer curing periods generally result in higher strength.

Challenges

- **Variability in Fly Ash**:
    - Properties of fly ash can vary depending on its source.
- **Environmental Concerns**:
    - While fly ash utilization is beneficial, cement production has a high carbon footprint.
- **Quality Control**:
    - Ensuring consistent mixing and compaction is critical.

II. GROUND GRANULATED BLAST FURNACE SLAG (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a by-product derived from the manufacturing of iron in a blast furnace. It is a fine, powdery material obtained by rapidly cooling (quenching) molten slag with water or steam, followed by grinding it into a fine powder. GGBS is widely used in construction as a supplementary cementitious material (SCM) because of its pozzolanic and latent hydraulic properties.

How GGBS is Produced

1. **Blast Furnace Operation**:
    - Iron ore, limestone, and coke are charged into a blast furnace.
    - The intense heat melts the iron, and slag forms as a by-product on top of the molten iron.
2. **Quenching**:
    - The molten slag is rapidly cooled with water or steam, transforming it into a granulated form to preserve its amorphous (non-crystalline) structure, which is reactive.
3. **Grinding**:
    - The granulated slag is dried and ground into a fine powder, resulting in GGBS.

Properties of GGBS

1. **Color**:
    - Light gray to off-white, contributing to aesthetic benefits when used in concrete.
2. **Chemical Composition**:
    - Rich in calcium, silica, alumina, and magnesium.

3. **Latent Hydraulic Behavior**:
    - Reacts with water and calcium hydroxide (from cement hydration) to form cementitious compounds.
4. **Fineness**:
    - Typically ground to a similar or finer particle size than Portland cement.

Benefits of Using GGBS

1. **Improved Durability**:
    - Increases resistance to sulfate attack, alkali-silica reaction (ASR), and chloride ingress.
2. **Strength Development**:
    - Provides higher long-term strength compared to ordinary Portland cement (OPC).
3. **Reduced Heat of Hydration**:
    - Ideal for large structures to prevent thermal cracking.
4. **Environmental Sustainability**:
    - Reduces the carbon footprint by partially replacing cement, which is energy-intensive to produce.
5. **Enhanced Workability**:
    - Improves the flowability of concrete mixes.
6. **Aesthetic Appeal**:
    - Reduces efflorescence, resulting in cleaner, lighter finishes.

Applications of GGBS

1. **Concrete Production**:
    - Used as a partial replacement for Portland cement (up to 70% in some mixes).
2. **High-Performance Concrete**:
    - Suitable for marine structures, bridges, dams, and high-rise buildings.
3. **Soil Stabilization**:
    - Enhances the strength and durability of stabilized soils.
4. **Precast Elements**:
    - Used in precast concrete products like blocks, pipes, and panels.

GGBS in Concrete Mixes

- **Typical Replacement Levels**:

  - GGBS can replace 20–70% of OPC in concrete.
- **Blended Cement**:
  - Forms part of CEM II and CEM III (European cement standards).

III. GGBFS ACTS AS A STABILIZING AGENT

Stabilization is a method where the GGBFS acts as a stabilizing agent that alters the properties of a soil chemically to meet the specified engineering requirements based on its field application. Soft clay is always susceptible for settlement and consolidation. Stabilization of soft clay with GGBFS results in increased strength, reduced compressibility and shrinkage. Clay soils provide a challenge to the geotechnical engineer due to their considerable variety in terms of composition and properties and in particular their variation in properties with time and loading. Soil stabilization is used in many areas of the construction industry such as roads, parking lots, airport runways, building sites, landfills etc. The use of soil stabilization for slope protection, dam cores, impervious liners are feasible based on both economical & service life considerations. A the water infiltrate and weaken the underlying soil layer and due to the wheel loads moving on the surface layer will damage the pavement structure, the use of stabilization method in road construction proved to be the one of the best method.to increase the life of the pavement.

IV. LITERATURE REVIEW

Wangwen Huo et al.[1] Recycling waste materials for geopolymer synthesis offers a sustainable solution for reducing environmental impact from construction. In this study, the recycled concrete fine powder (RCFP) and granulated blast furnace slag (GBFS) were used to synthesize geopolymers, and the effects on physical performance, compressive strength, and microstructure were investigated. Building upon the existing results, the quantitative relationships between initial constituent molar ratios (Si/Al, Na/Al, and Si/Ca) and macro-properties of the geopolymers were explored and the influence mechanisms were analyzed. The findings demonstrate that the incorporation of GBFS significantly reduced setting time and increased compressive strength. Additionally, the blending of GBFS effectively enhanced the geopolymerization degree and generated more mixed gelling products of C-(A)-S-H, N-A-S-H and (C, N)-A-S-H, resulting in a refined internal structure of the matrix. The results revealed that the relationships between initial constituent molar ratios and macro-properties were not straightforward and involved multiple models. The initial and final setting times showed complex non-linear correlations with initial component molar ratios, while strong linear correlations were observed between initial component molar ratios and both flowability and compressive strength. A non-linear relationship was found between the setting time and fluidity.

Pavlo Kryvenko et al.[2] A critical analysis of alkali-activated cements as sustainable materials demonstrates their advantages compared to traditional Portland cements. It also makes it possible to identify the main drivers of alkaline activation in the production of cements for mortars and concretes used in repairing building construction. These materials are effective for repairing, retrofitting, and rehabilitation of damaged structures (pavement, bridge decks, tunnel structures, highways, airport runways, berths, piers, coast-protecting structures, dams, etc.). *Technical drivers* are based on cements with high physical and mechanical properties and durability, due to a highly effective hydrate composition in cement stone.

Radhikesh Prasad Nanda et al.[3] Construction in weak or soft soil needs soil stabilization. The most popular stabilizers are fly ash, cement, and lime to stabilize a road pavement's base, subbase, and subgrade courses. Cement is a crucial component of many construction materials for the entire world. However, it has particular environmental problems and the long-term durability of soil-cement combinations, which impacts life. The production process of this cement requires a tremendous amount of energy and produces a large quantity of carbon dioxide, resulting in environmental pollution.

Su Lu et al.[4] The objective of this study is to investigate the influence of fly ash (FA), granulated blast furnace slag (GBFS), and a high-efficiency crack-resistant agent (HECRA) on the workability, mechanical properties, hydration heat (HH), adiabatic temperature rise (ATR), and volume stability of mass concrete (MC). Preliminary experiments determined that the total replacement of FA and GBFS in dual blending should be within 35% to 40%, with the GBFS content not exceeding 15%. A total of 16 concrete mix designs (MD) were formulated, including a control mix (comprising only cement (C)) and ternary blends (comprising C, FA, and GBFS), with the HECRA added at 0%, 4%, and 8% of the mass of cementitious materials. The workability of the MC was assessed through tests for air content (AC), bulk density (BD), slump, flow, and setting time. The mechanical strength, HH, ATR, and shrinkage rate of the MC were individually evaluated through compressive strength (CS) tests, HH experiments, ATR tests, and shrinkage measurements.

Nilofar Asim et al.[5] Concerns about the environment, cost, availability of resources, compatibility and performance are always challenges in the construction industry. The development of a new generation of smart materials was in response to the need for advanced materials in modern and sustainable technology applications. These materials respond to a variety of environmental stimuli and exhibit their particular characteristics in a useful and controlled manner. Durability and performance are essential for achieving sustainable development in the construction industry, and green multifunctional smart materials that possess good mechanical properties must be developed. Geopolymers are good, sustainable and green substitutes for new construction materials. The technological and environmental benefits of geopolymer are driving ongoing development as a material for future engineering.

B.A.V. Ram Kumar et al.[6] Red mud, owing to its high alkalinity and presence of hazardous elements, cannot be disposed of in landfills. Sustainable use of red mud is the way to resolve the environmental concerns created by its improper disposal. This study attempts to review the overall applications of red mud as a construction material. Red mud is used in making various construction materials like mortar, bricks, concrete, ceramics, etc. The utilization of red mud in brick manufacturing is said to increase the mechanical characteristics and longevity of bricks. Red mud is also employed in various types of concrete like Lightweight concrete, Ultra high-performance concrete, pervious concrete, and geopolymer concrete.

Thamer Alomayri et al.[7] This research work proposed an economic and eco-efficient idea to supplement the ductility and durability of concrete by the simultaneous incorporation of several processed waste materials i.e., ground blast furnace slag (GBFS), recycled coarse aggregate (RCA), and coconut fibre (CF). Two concrete families were produced containing 0% and 100% coarse RCA. GBFS was incorporated as by 25% replacement for cement. CF was used as a fibre reinforcement at 0.25% volume fraction. The results revealed that the recycled-aggregate concrete (RAC) modified with GBFS, CF, and modified plasticizer dosage can attain similar or higher mechanical performance than unmodified natural-aggregate concrete (NAC).

Loyford Muchui Mugambi et al.[8] Clay soil is associated with geotechnical problems of swelling and shrinkage, which causes deformations on structures. Ordinary Portland Cement (OPC) which is the most common stabilizing agent for clay soils, remains unaffordable in most developing countries, and its production also contributes about 8 % of global anthropogenic CO_2 emissions. The present study aimed to investigate the effect of Limestone Calcined Clay Cement (LC^3) on the stabilization of clay soils for applications in road construction. Clay soil was mixed with quarry dust to reduce the clay content and save cement. The mixture was stabilized using LC^3 and OPC separately in proportions of 1 %, 3 % and 5 %. The effect of stabilizer dosage on the performance of clay soil was studied by monitoring the changes in Atterberg limits, Proctor test and soaked California Bearing Ratio (CBR). The mineralogical and microstructural investigation was carried out using X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Thermogravimetric Analysis (TGA). Plasticity index (PI), linear shrinkage (LS), and optimal moisture content (OMC) of stabilized soil was found to decrease with increase in the dosage of LC^3 and OPC. The Maximum Dry Density (MDD) and soaked CBR increased with addition of both LC^3 and OPC. Formation of calcium silicate hydrate (C-S-H) in both LC^3 and OPC stabilized clay soil, as well as formation of Hemi-carboalumination in LC^3 stabilized clay soil was responsible for improved properties of the stabilized soil. The performance of LC^3 was found to be comparable to that of OPC, at optimum cement ratio of 5 %.

Leila Farahzadi et al.[9] The construction sector is one of the main contributors to carbon dioxide (CO_2) emission and causes of global warming. CO_2 mitigation solutions are vital. New technologies can facilitate and improve these efforts. Thus, the paper reviews how new technologies of artificial intelligence and machine learning have contributed to CO_2 emissions reduction in construction and what techniques have been applied in the literature to provide significant information that will be beneficial for the construction sector design and management. The paper provides the results of a content review, including their contributions and gaps. A total of 78 papers were identified to develop the dataset. The method was a combination of systematic reviews, including co-occurrence analytical map development of the main keywords, co-authorship network analyses, publication source analyses, and content analysis, including theme identification and review of the selected papers, which were divided into five conceptual clusters based on their scopes: (1) sustainable materials and components design/production, (2) on-site vehicles and equipment, (3) energy and life cycle assessment, (4) optimization, decision-making and solution-based platforms, and (5) real-world monitoring. The content of each cluster of papers was also reviewed, and the potential gaps were identified and discussed. A set of directions for future research investigations were presented that can be a valuable source for researchers in their future research. This paper contributes to the current knowledge base by presenting insights into intelligent techniques in the construction industry to mitigate CO_2 emissions.

Cheng Xu et al.[10] To obtain a green and cost-effective one-part alkali-activated grouting material (OAGM) with good comprehensive performance for subgrade reinforcement and determine its proper mix parameters. In this study, using response surface methodology (RSM), multiple objective particle swarm optimization (MOPSO) algorithm and the technique for order preference by similarity to an ideal solution (TOPSIS) algorithm coupled with entropy weight method, two multi-objective optimization schemes for OAGM were performed, one only considering performance and another considering performance, embodied CO_2 emission (ECO_2e) and cost. Then, the correlation-based feature selection (CFS) algorithm was used to evaluate the importance of various molar ratios as mix parameters on the performance of OAGM. Finally, the effects of key mix parameters on the microstructure and reaction products of OAGM were studied. RSM results show that W/S (water to solid) ratio, borax (BR) content and UCG content chiefly govern the flowability, initial setting time and mechanical strength of OAGM respectively, and the interactions between some factors also significantly affect these properties. MOPSO and entropy-TOPSIS algorithm can be used to optimize OAGM objectively. Two optimal OAGM pastes both have better comprehensive performance and much lower ECO_2e than ordinary Portland cement (OPC) paste. And the optimal OAGM considering performance, ECO_2e and cost even has 7.68% lower cost than OPC paste. But another optimal OAGM has the best comprehensive performance. CFS results show that the molar ratios of Si/Al, Al/Ca, Na_2O/H_2O, B_2O_3/CaO and B_2O_3/Al_2O_3 are the key mix parameters of OAGM. Al/Ca rather than Si/Al is the most important mix parameter to the 28-day compressive strength. And higher Si/Al and Al/Ca deteriorates the microstructure and hinders the formation of C-A-S-H gel, while higher Na_2O/H_2O has the opposite effect. This study provides guidance for objective optimization and the determination of proper mix parameters of OAGM, and promotes the market-oriented application of OAGM.

V. CONCLUSION

It is observed from above researches that with the increase in fly ash content the Optimum Moisture Content (OMC) increases and Maximum Dry Density decreases. Also with the increase in fly ash content CBR value of both soaked and un soaked samples increases up to a certain level after that the value of CBR starts decreasing, therefore indicating us the optimum level of fly ash content. With the increment in CBR values, it can be concluded that it will result in the decrement of the thickness of the pavement during road construction. Overall it can be concluded that fly ash mixed soil can be good subgrade improvement technique especially on weak soils where it can act as additive to increase strength and reducing the overall cost as well as energy.

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