

Behaviour of Ternary Blended Concrete Containing fly ash and Perlite Powder

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Abstract - The global demand for blended cement has been steadily increasing due to growing environmental concerns, technical advancements, and economic benefits. This study investigates the behavior of ternary blended concrete in which cement is partially replaced by fly ash and perlite powder. Perlite powder, a naturally occurring volcanic glass that expands when heated, is lightweight, highly porous, and exhibits excellent thermal and acoustic insulation properties. Its pozzolanic nature allows it to function as a supplementary cementitious material, enhancing concrete performance while reducing its overall density. When used alongside fly ash—a material known for improving long-term strength, durability, and workability—the ternary blend demonstrates a synergistic effect, achieving improved sustainability and mechanical balance. Experimental tests such as slump cone, compressive strength, split tensile strength, and density measurements were conducted to evaluate the fresh and hardened properties of the mixes. The results are compared with conventional concrete to assess the influence of these replacements on strength, workability, and weight reduction. The study ultimately aims to develop an optimized ternary mix that maintains sufficient mechanical strength while being lighter, more thermally efficient, and environmentally sustainable through reduced cement consumption and CO₂ emissions.

Key Words: Perlite Powder, Fly ash, workability, Durability and Mechanical properties.

1. INTRODUCTION

Concrete is one of the most widely used construction materials due to its superior compressive strength, durability, and versatility. However, conventional concrete production requires a large amount of Portland cement, which significantly contributes to carbon dioxide emissions and environmental degradation. The cement industry accounts for a notable share of global CO₂ emissions, emphasizing the need for sustainable alternatives in construction practices.

Recent advancements in materials research have focused on developing eco-friendly concrete mixes incorporating supplementary cementitious materials (SCMs). Among these innovations, ternary blended concrete has gained prominence for its ability to partially replace cement with industrial by-products and natural pozzolanic materials, thereby reducing the environmental impact while maintaining or improving performance characteristics.

Fly ash, a by-product of coal combustion, is a reactive pozzolan known to enhance workability, long-term compressive strength, and chemical resistance through secondary hydration reactions. Perlite powder, a material derived from volcanic glass, contributes to reduced density,

improved thermal insulation, and refinement of the concrete microstructure.

The combined use of fly ash and perlite powder in a ternary blended system minimizes cement consumption and enhances the mechanical and durability properties of concrete. This study investigates the effects of incorporating fly ash and perlite powder on the fresh and hardened properties of ternary blended concrete, including workability, compressive strength, density, and durability. The outcomes of this research are expected to support the development of sustainable, lightweight, and durable construction materials suitable for modern infrastructure applications.

2. LITERATURE SURVEY

Shahedan et al. (2024) investigated the potential of fly ash-based geopolymer concrete as a repairing and protective material for reinforced concrete structures. The study demonstrated that fly ash geopolymer concrete exhibited excellent resistance to chloride ion penetration, making it suitable for applications in aggressive environments. The superior early strength and durability were attributed to the chemical composition and refined microstructure of the geopolymer binder.

Girish et al. (2024) examined the thermal properties and performance of fly ash-slag geopolymers enhanced with perlite. Their results indicated that the addition of perlite significantly improved the thermal insulation capability of the geopolymer, making it ideal for applications requiring low thermal conductivity. The incorporation of perlite also promoted sustainability by utilizing industrial by-products.

In a related study, Girish et al. (2024) analyzed the thermal and mechanical behavior of alkali-activated fly ash and ground granulated blast furnace slag (GGBFS) binders, referencing perlite as an additive or aggregate in lightweight mixes. Their findings revealed that combining fly ash with low-density materials such as perlite reduced bulk density and thermal conductivity while maintaining acceptable strength. Optimized ratios of fly ash and perlite achieved a balance between mechanical performance and insulation. Microstructural analysis confirmed that perlite's porous particles created beneficial thermal gaps, while fly ash contributed to the binding matrix.

Tsardaka et al. (2024) conducted an experimental evaluation using ground perlite as a partial cement replacement and compared its behavior with other supplementary cementitious materials (SCMs), including fly ash. Chemical (XRF), thermal, and pozzolanic activity tests showed that finely ground perlite exhibited modest pozzolanicity but contributed significantly as a microfiller. When combined with fly ash, the mixture demonstrated synergistic densification,

with fly ash enhancing C–S–H formation and perlite filling capillary pores, reducing permeability and improving durability. The study suggested limited replacement levels for perlite unless finely milled or chemically activated.

Wang et al. (2024) studied the effects of waste perlite powder (WPP) on paste and mortar properties through hydration, XRD, and SEM analyses. Comparisons with SCMs such as fly ash revealed that WPP decreased workability and accelerated setting; however, when combined with reactive SCMs like fly ash, the mixtures regained workability and long-term strength. Microstructural observations indicated that WPP acted as a filler and nucleation site, and when coupled with fly ash's pozzolanic reaction, it resulted in a denser matrix with improved late-age strength and durability.

Abdelaal et al. (2024) developed a high-density geopolymer incorporating both fly ash and perlite waste as the main solid constituents. Their study evaluated fresh properties, setting time, compressive strength, and sedimentation stability. Microstructural analysis revealed that perlite waste enhanced workability and minimized segregation, while fly ash improved binding and strength development. The combined system produced geopolymer specimens with superior homogeneity and competitive compressive strength compared to fly ash-only mixes, demonstrating the potential of utilizing perlite waste in alkali-activated systems.

Poloju et al. (2023) analyzed the rheological characteristics of fly ash-based geopolymer concrete and found that the inclusion of fly ash improved workability and reduced viscosity. The rheological properties were influenced by the molarity of the alkaline activator and curing conditions, emphasizing the importance of optimized mix design.

Isnin and Noor (2023) examined the use of perlite as a lightweight aggregate in seawater–fly ash concrete. Their research indicated that adding perlite enhanced workability and reduced density, while the inclusion of fly ash improved durability, making the mixture suitable for marine environments.

Gandage and Ram (2023) conducted experimental research on strengthening perlite concrete with fly ash. Their results revealed that incorporating 10% fly ash improved compressive strength, making the mixture viable for structural applications. However, increasing fly ash content beyond this level did not yield further strength improvement, highlighting the need for optimal dosage.

Karakaş et al. (2023) evaluated lightweight geopolymer mortars using raw and expanded perlite as aggregates within fly ash-based matrices. Tests on compressive strength, thermal conductivity, and microstructure showed that perlite aggregates substantially reduced density and thermal conductivity. When used with reactive fly ash binders, the mortars achieved adequate strength for non-structural to semi-structural applications. SEM images showed well-bonded interfacial transition zones where geopolymer binders penetrated the porous perlite surface.

Leong et al. (2023) investigated lightweight composites incorporating fly ash cenospheres (FAC) and perlite microspheres (PM). The results showed that FAC and PM mixtures produced low-density composites with satisfactory mechanical strength and improved thermal insulation. Fly ash contributed to matrix strength through pozzolanic reactions, while perlite microspheres reduced density. The combination effectively balanced mechanical and thermal properties.

Shehata (2002) explored ternary blends containing silica fume and fly ash to mitigate alkali-silica reaction (ASR) in

concrete. The study concluded that the synergistic use of silica fume and fly ash effectively suppressed ASR expansion and enhanced durability by forming a stable microstructure through pozzolanic reactions.

Celikten et al. (2022) evaluated perlite by-products as pozzolanic materials in cement-based pastes. The inclusion of perlite improved workability and durability, forming additional calcium silicate hydrate (C–S–H) gel, which enhanced overall strength.

Çelikten et al. (2022) also studied how varying the perlite-to-fly ash ratio and curing conditions affect the mechanical and microstructural behavior of geopolymer mortars. Their findings indicated that optimal proportions and curing regimes enhanced compressive strength and microstructural integrity, emphasizing the significance of mix design in maximizing performance.

Celikten et al. (2020) examined alkali-activated mortars made from ground perlite and Class F fly ash under various ratios and curing regimes. Results showed that specific perlite-to-fly ash ratios achieved the best balance between strength and thermal resistance. Elevated temperature tests demonstrated improved residual strength and thermal stability, confirming the suitability of ternary blends for fire-resistant applications.

Castillo et al. (2021) reviewed the synergy between fly ash and ground granulated blast furnace slag (GGBS) in geopolymer concrete. The combination enhanced mechanical strength, durability, and microstructural compactness while reducing porosity compared to single-component systems.

Grzeszczyk et al. (2021) examined reactive-powder lightweight concretes incorporating expanded perlite and supplementary materials like fly ash. Their research showed that perlite decreased density and thermal conductivity, while fly ash compensated for strength losses through improved particle packing and pozzolanic reactivity. The authors emphasized the need for careful proportioning to balance insulation and mechanical performance.

Sicakova (2020) reviewed the use of perlite powder in ternary blended systems containing cement, fly ash, and GGBFS. The study reported that although perlite blends typically show lower compressive strength than traditional SCMs, they provide improved freeze–thaw resistance, thermal insulation, and sustainability. The author concluded that perlite performs best as a minor component in ternary blends where fly ash provides reactivity and perlite enhances durability.

Esfandiari et al. (2019) investigated the combined effects of perlite powder and silica fume on the compressive strength and durability of concrete mixtures. The inclusion of both materials improved strength, durability, and resistance to environmental deterioration, confirming their synergy in producing long-lasting concrete.

Demirboğa and Gül (2003) studied the thermal conductivity and compressive strength of expanded perlite aggregate concrete containing mineral admixtures such as fly ash. Their findings revealed that the inclusion of perlite aggregates reduced thermal conductivity, making the concrete suitable for insulation applications, while the mechanical strength depended on mix proportions and curing conditions.

3. CONCLUSIONS

Ternary blended concrete containing fly ash and perlite powder provides a sustainable and high-performance alternative to conventional concrete. The incorporation of fly ash enhances long-term strength and durability through pozzolanic reactions, while perlite powder reduces density, improves thermal

insulation, and refines the concrete microstructure. When used in optimal proportions, typically with fly ash ranging from 10 to 30 percent and perlite powder from 10 to 20 percent, these materials exhibit a synergistic effect that improves compressive strength, workability, and durability. Microstructural studies have shown that such blends produce denser matrices with reduced porosity and improved bonding between components. Overall, the use of fly ash and perlite powder in ternary blended concrete contributes to the development of environmentally friendly, lightweight, and durable construction materials suitable for both structural and non-structural applications, effectively balancing mechanical performance and sustainability.

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