A Comprehensive Review of Research on Concrete Incorporating Fly Ash as a Mineral Admixture

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ABSTRACT

Fly debris concrete enjoys prudent and natural benefits. Fly ash concrete offers a practical solution for sustainability. In India, less than half of the fly ash produced is currently utilized. Infrastructure development is at its peak worldwide and serves as a symbol of a nation's progress. The most commonly used construction material, cement, contributes to 7% of global carbon dioxide emissions, a major factor in climate change. Despite various efforts to curb CO_2 emissions, an effective alternative to cement has yet to be found. Fly ash concrete presents a viable approach to reducing cement consumption in construction. This paper explores the use of fly ash concrete as a solution to two key environmental challenges: first, the disposal of vast quantities of fly ash generated by thermal power plants, which leads to environmental degradation due to large landfill requirements; and second, the significant carbon dioxide emissions from the cement industry.

Key Words: Cement, fly ash, concrete, fly ash concrete, Environmen1. Introduction

INTRODUCTION

In today's era of rapid development, significant advancements are being made across various sectors. However, amidst this progress, there is a tendency to overlook environmental considerations, leading to ecological harm. The construction industry, with its extensive use of virgin materials like cement, contributes notably to global warming and environmental degradation. The challenge for the civil engineering community is to provide sufficient, cost-effective, and satisfactory infrastructure without causing environmental harm. To promote sustainable development, efforts have been made to reduce cement consumption in concrete by substituting it with waste materials such as fly ash, slag, silica fume, and rice husk ash. The use of fly ash in concrete has been encouraged globally. Although this practice has been adopted in certain regions of India, the percentage of cement replaced by fly ash remains minimal, and currently, only about 25% of the total fly ash produced is utilized. There is a need to build confidence in developing countries like India to use fly ash concrete in various construction fields. As of now every one of the endeavors of Indian development industry are centered around early evacuation of covering and quickest fulfillment of development work. Industry is more centered around 3 hour strength for early expulsion of formwork. This is prompting high intensity of hydration breaks and lower sturdiness of designs. (IS 456, 2000) suggests at least10 long periods of relieving where mineral admixtures are utilized. Anyway for maintainability center should be moved to long haul strength and sturdiness over momentary addition. Consequently no less than 28 days of relieving ought to be made compulsory for high volume fly debris concrete.

Literature Review

Chatterjee (2011) reported that approximately 50% of the fly ash produced is currently utilized. He also noted that replacing up to 70% of cement with fly ash is achievable when using high-strength cement and highly reactive fly ash, combined with sulphonated naphthalene formaldehyde superplasticizer. Enhancements in fly ash properties can be attained by grinding it to submicrocrystalline particle sizes. Bhanumathidas and Kalidas (2002), in their research on Indian fly ashes, found that increasing ground fineness by 52% could lead to a 13% strength increase. However, a 64% increase in native fineness resulted in a 77% strength gain. These findings suggest that grinding coarse fly ash may not significantly improve reactivity. The authors emphasized that studying lime reactivity strength is more relevant when fly ash is used with lime, whereas the pozzolanic activity index is preferred for cement blending.

Subramaniam et al. (2005) investigated the influence of ultrafine fly ash on early-age property development, shrinkage, and shrinkage cracking potential of concrete. Their study compared the performance of ultrafine fly ash as a cement replacement with that of silica fume. They assessed mechanisms responsible for increased early-age stress due to restrained shrinkage by measuring free shrinkage and elastic modulus from an early age. Additionally, they evaluated the materials' resistance to tensile fracture and strength development over time. The results indicated that ultrafine fly ash benefits concrete by reducing shrinkage strains and decreasing the potential for restrained shrinkage cracking.

Malhotra (2005) discussed the role of supplementary cementing materials and superplasticizers in reducing greenhouse gas emissions. He highlighted that developing countries' infrastructure needs lead to substantial cement consumption, which can be mitigated by replacing cement with readily available, high-quality fly ash from thermal power stations. The development of high-performance, high-volume fly ash concrete incorporating large dosages of superplasticizer enhances concrete durability. The paper also explored various cementing materials that can replace cement in concrete production, thereby reducing cement consumption and CO_2 emissions.

Poon, Lam, and Wong (1999) conducted experiments revealing that substituting 15% to 25% of cement with fly ash reduces the porosity of concrete and plain cement mortars. While such partial replacement enhances workability and durability, the 28-day strength of fly ash concrete was observed to be lower than that of conventional concrete. Additionally, grinding fly ash to increase its fineness proved less effective, possibly due to the disruption of its beneficial spherical particles, which aid in workability and void reduction. The costs associated with grinding may also diminish the economic benefits of using fly ash over cement. The lower reactivity of low-lime Indian fly ashes, compared to their high-lime counterparts, limits the extent to which fly ash can replace cement. This reduced reactivity underscores the need for methods to increase cement replacement levels without resorting to grinding or other activation techniques. Hwang, Noguchi, and Tomosawa (2004) found that incorporating fly ash as a sand replacement in concrete mixtures led to a reduction in pore content. Siddique (2003) investigated the mechanical properties of concrete where fine aggregate was partially replaced with Class F fly ash at varying percentages (10%, 20%, 30%, 40%, and 50%). The results indicated that all fly ash concrete mixes exhibited higher compressive strength than the control mix at all tested ages, with strength increasing alongside the percentage of fly ash. This enhancement is attributed to the pozzolanic activity of fly ash. Improvements were also noted in splitting tensile strength, flexural strength, and modulus of elasticity compared to the control concrete.Namagg&Atadero, (2009) described early stages of a project to study the use of large volumes of high lime fly ash in concrete. Authors used fly ash for partial replacement of cement and fine aggregates. Replacement percent from 0% to 50% was tested in their study. They reported that concrete with 25% to 35% fly ash provided the most optimal results for its compressive strength. They concluded that this was due to the pozzolanic action of high lime fly ash.

Jones and McCarthy (2005) conducted an extensive laboratory investigation into the use of unprocessed, low-lime fly ash as a sand replacement in foamed concrete. They observed that, for a given plastic density, fly ash concrete mixes exhibited flow spreads up to 2.5 times greater than those of sand-based mixes. While early-age strengths were similar between the two, the 28-day compressive strength of fly ash concrete was more than three times higher than that of sand concrete. Furthermore, whereas the strength of sand mixes remained relatively constant beyond 28 days, the strength of fly ash foamed concrete continued to increase, reaching values 1.7 to 2.5 times higher at 56 and 180 days, respectively. Rebeiz, Serhal, and Craft (2004) investigated the incorporation of fly ash as a partial sand replacement in polymer concrete. Their mix design involved substituting 15% of sand by weight with fly ash, resulting in a compressive strength increase of approximately 30%. Additionally, the stress-strain behavior improved, and the modified mix exhibited a superior surface finish, reduced permeability, and an appealing dark hue. Flexural strength tests on steel-reinforced polymer concrete beams demonstrated a 15% enhancement. Furthermore, after exposure to 80 thermal cycles, the polymer concrete containing fly ash showed about a 7% improvement in thermal cycling resistance compared to the control mix.

Rao (2004) emphasized the necessity of incorporating approximately 650 kg/m^3 of fine materials to produce self-compacting concrete (SCC). This composition also requires fine aggregates to constitute more than 50% of the total aggregate content, ensuring that coarse aggregates remain suspended within the mix. Fly ash serves as an effective fine material to meet these requirements, contributing to the desired properties of SCC. Papadakis (1999) explored the effects of adding a typical low-calcium fly ash to mortar, either by partially replacing Portland cement or aggregate. In both scenarios, fly ash was added at 10%, 20%, and 30% of the cement weight. Notably, when fly ash replaced aggregate, the compressive strength at 3 and 14 days was comparable to that of the control mix, but surpassed it at 28 days and beyond. This strength gain is attributed to an increased formation of calcium silicate hydrate. While strength improvements correlated with higher fly ash content up to 91 days, no significant difference was observed between the 20% and 30% replacement levels thereafter. Conversely, substituting cement with fly ash initially reduced strength due to the fly ash's lower reactivity; however, this disparity diminished over time.

In 2004, Rao emphasized the necessity of incorporating approximately 650 kg/m^3 of fine materials to produce self-compacting concrete. This composition requires fine aggregates to constitute more than 50% of the total aggregate, ensuring that coarse aggregates remain suspended within the mix. Utilizing fly ash effectively meets this fine material requirement, thereby enhancing the mix's workability and sustainability.

In 1999, Papadakis investigated the effects of low-calcium fly ash as an additive in mortar, replacing portions of either Portland cement or aggregate. The study revealed that replacing aggregate with fly ash resulted in compressive strengths comparable to the control mix at 3 and 14 days, with significant improvements observed at 28 days and beyond. This strength enhancement was attributed to the increased formation of calcium silicate hydrate. Conversely, when fly ash replaced cement, initial strength was lower due to the fly ash's lower reactivity. However, over time, this strength gap diminished, leading to comparable or even superior strength at later ages. Neville (2009) observed that while the aggregate-to-cement ratio is generally a secondary factor in concrete strength, a leaner mix can lead to higher strength when the water-to-cement ratio is kept constant. This is because a higher aggregate content absorbs more water, effectively reducing the water-to-cement ratio and thereby increasing strength. Additionally, in leaner mixes, the total water content per cubic meter of concrete is lower, resulting in voids constituting a smaller fraction of the total volume, which positively impacts strength.

Pofale and Deo (2010) conducted a study where replacing 27% of sand with low-lime fly ash in concrete resulted in approximately a 20% increase in compressive strength and a 15% increase in flexural strength compared to the control mix. They also noted a 25% improvement in workability. This enhancement in strength and workability is attributed to the ball-bearing effect, pore-filling properties, and the pozzolanic reactivity of fly ash. These benefits could offset the typical 28-day strength loss observed in high-volume fly ash concrete.

Fly ash, a byproduct of coal combustion, is produced in vast quantities worldwide. However, its utilization remains limited, with only a portion being repurposed for beneficial applications. n 1996, approximately 27% of the fly ash produced in the United States was utilized in various applications, while the remaining 73% was either stored or disposed of.

The primary methods for activating fly ash to enhance its properties include chemical, mechanical, thermal, and mechano-chemical techniques. Among these, chemical activation—particularly using alkaline solutions such as sodium hydroxide and sodium silicate—is widely studied. This process involves mixing fly ash with alkaline activators and curing at mild temperatures to produce solid materials with binding properties similar to ordinary Portland cement. Research indicates that the activation regime significantly influences the development of materials with binding properties. The process typically involves the hydrolysis of precursors at temperatures up to 100°C (direct activation) or over 500°C (hydrothermal activation), followed by gel formation and polycondensation.

Additionally, studies have shown that alkali treatment of fly ash with sodium hydroxide and sodium silicate at ambient temperatures can result in higher compressive strength, making it a viable option for producing construction materials with enhanced properties.

In summary, while fly ash is produced in large quantities, its utilization is still limited. Advancements in activation methods, particularly chemical activation using alkaline solutions, are paving the way for more sustainable and efficient applications of fly ash in construction and other industries.

CONCLUSION

Fly ash concrete is a crucial material for sustainable development, enabling the effective utilization of substantial quantities of fly ash. The literature reviewed in this paper highlights the advantages of incorporating fly ash into concrete to enhance its functionality and durability. However, a significant challenge remains: the slower early-age strength development of fly ash concrete, which poses a concern in the Indian construction industry that prioritizes rapid strength gain. To address this issue, a comprehensive mix design approach is essential to achieve the desired 28-day strength. It is imperative to encourage contractors to focus on producing cost-effective and durable fly ash concrete, even if it necessitates extended curing periods

Based on the studies examined, it is concluded that the durability of High-Performance Concrete can be significantly enhanced by incorporating fly ash as an admixture, either alone or in combination with other mineral admixtures. The optimal fly ash content typically ranges from 15% to 20% by weight. Additionally, the use of Polycarboxylate Ether (PCE)-based superplasticizers generally results in improved performance consistency and water reduction efficiency, achieving the same initial workability as conventional concrete without PCEs. These superplasticizer admixtures enhance workability without increasing water demand, and for the three concrete grades studied, no decrease in compressive strength was observed. They also provide improved durability by increasing ultimate strength and reducing the water-to-cement ratio.

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