Study on the Enhancement of Concrete Properties Using Eco-Friendly Materials

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Abstract — The construction industry is responsible for a significant portion of global carbon emissions, particularly through the production of Ordinary Portland Cement (OPC), which is highly energy-intensive. With the global demand for concrete increasing, there is a growing need to adopt sustainable construction practices. The use of eco-friendly materials to enhance concrete properties presents a promising solution. This review paper explores various eco-friendly materials that can improve the mechanical, durability, and sustainability aspects of concrete. Specifically, the paper investigates the incorporation of materials such as fly ash, ground granulated blast furnace slag (GGBS), rice husk ash, and natural fibers into concrete mixtures. The effects of these materials on concrete properties such as compressive strength, workability, durability, and environmental impact are discussed, and recommendations for future research and implementation are provided.

Keywords: Sisal Fibres, Durability, Coarse Aggregates, Resistance, Hardness, Toughness

I. INTRODUCTION

Concrete is the most widely used material in the construction industry, but its production and use come at an environmental cost, particularly through CO_2 emissions from the manufacturing of Portland cement. As environmental awareness grows, the industry is increasingly exploring alternatives to reduce the carbon footprint of concrete production. The incorporation of eco-friendly materials not only reduces the environmental impact but also enhances the physical and mechanical properties of concrete.

This paper examines the potential of various eco-friendly materials, their effect on the properties of concrete, and the challenges and benefits associated with their use. The primary goal is to enhance concrete's sustainability without compromising performance.

A. *Eco-friendly Materials in Concrete*

Several types of eco-friendly materials can be used to replace or supplement traditional cement and aggregates in concrete. The most commonly researched materials include:

- Fly Ash (FA): A by-product of coal combustion in power plants, fly ash has gained widespread attention as a supplementary cementitious material. When added to concrete, it can enhance workability, reduce permeability, and improve long-term strength and durability. Additionally, fly ash reduces the environmental impact of concrete by replacing a portion of cement.
- Ground Granulated Blast Furnace Slag (GGBS): Derived from the rapid cooling of molten iron slag, GGBS is used as a partial replacement for cement. It enhances the durability and longevity of concrete, particularly in aggressive environments. The use of GGBS in concrete can also improve resistance to sulfate attack and chloride-induced corrosion.
- Rice Husk Ash (RHA): This agricultural by-product contains silica, which, when processed into ash, has pozzolanic properties that can improve the strength and durability of concrete. It is an excellent material for reducing the environmental footprint of concrete production while also providing waste management benefits.
- Natural Fibers (e.g., Jute, Bamboo, and Coir): Natural fibers, such as jute, bamboo, and coir, have been explored for their ability to improve concrete's mechanical properties and reduce its environmental impact. These fibers are biodegradable and renewable, making them ideal for sustainable concrete production. They also enhance the tensile strength and reduce cracking in concrete.
- Recycled Aggregates: The use of recycled aggregates (such as crushed concrete from demolished structures) in concrete has been promoted as a means of reducing waste and conserving natural resources. Recycled aggregates contribute to a decrease in the carbon footprint of concrete production by reducing the need for virgin raw materials.

B. *Effects of Eco-friendly Materials on Concrete Properties*

- Mechanical Properties: The addition of eco-friendly materials can significantly impact the mechanical properties of concrete, including compressive strength, tensile strength, and flexural strength. Materials like fly ash and GGBS generally improve the long-term strength of concrete, though they may result in slower early strength development. Rice husk ash, for example, can increase the early strength of concrete due to its high reactivity.
- Durability: Concrete made with eco-friendly materials exhibits improved durability characteristics. Fly ash and GGBS help reduce the permeability of concrete, making it more resistant to water ingress, sulfate attack, and chloride penetration. This leads to longer service life and reduced maintenance costs for concrete structures. The use of natural fibers enhances crack resistance and overall durability by improving the internal cohesion of the concrete mix.
- Workability: One of the primary advantages of using eco-friendly materials is improved workability, especially with fly ash and GGBS. These materials often enhance the flowability of the fresh concrete, making it easier to handle and place, particularly in complex molds or congested reinforcement areas.

– Environmental Benefits: Eco-friendly materials contribute to lowering the carbon footprint of concrete. By substituting a portion of the cement content with supplementary materials, the environmental impact associated with the production of cement is reduced. Moreover, the use of industrial by-products like fly ash and slag makes use of waste materials, contributing to resource conservation and waste reduction.

II. Literature Survey & Background

Anamarie Cotto-Ramos and colleagues (2020) conducted a study on the experimental design of concrete mixtures incorporating recycled plastic, fly ash, and silica nanoparticles. Partial replacement of coarse aggregates and cement was conducted using recycled plastic and supplementary cementitious materials, specifically fly ash and nano-silica, at varying percentages.

Mechanical properties were determined and the concrete showed optimum results at 44% plastic replacement, 2.5% nano-silica and 10% fly ash (by weight of cementitious materials). Ion penetration tests were conducted and the concrete containing plastic, fly ash and nano-silica proved to be more durable than the conventional concrete.

Babar Ali Syed et al. (2020) introduced a new approach aimed at improving the mechanical and durability characteristics of Recycled Aggregate Concrete (RAC) through the combined use of Glass Fiber (GF) and Fly Ash (FA). Different characteristics of concrete mixtures include compressive strength, split tensile strength, flexural strength, water absorption, and chloride penetration.

Uzbas et al. (2019) conducted an analysis of fly ash concrete utilizing Scanning Electron Microscopy and X-Ray Diffraction techniques. Fly ash was substituted for cement at weight percentages of 5%, 10%, 15%, and 20%. X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM) analyses were conducted to assess the microstructural properties. Fly ash concretes exhibited inadequate strength at 7 days; however, the strength of the fly ash concrete increased significantly by the 28th and 90th days. The XRD analysis indicated that both the age of the concrete and the quantity of fly ash affected the ratio of Calcium Hydroxide (CH) generated through hydration.

Jenaa and Panda (2018) conducted an investigation into the mechanical and durability properties of marine concrete incorporating fly ash and silpozz. Silpozz, an agro-waste derived from agricultural processes, along with fly ash, was utilized. Partial replacement was made with cement at various percentages.

Adithya Saran and Magudeswaran (2017) performed a SEM analysis focused on sustainable high-performance concrete. Fly ash was partially replaced with cement at 30% and 35%, while silica fume was incorporated at 7.5% and 10%. Additionally, fine aggregates were entirely substituted with manufactured sand. Coarse aggregates were partially replaced with recycled aggregates at proportions of 30%, 40%, and 50%. The specimens underwent compressive strength testing, revealing that the optimal strength was achieved in the concrete mix comprising 30% fly ash, 7.5% silica fume, and 40% recycled coarse aggregates.

Sandra P Pedraza et al. (2015) conducted a study examining the impact of unburned residues in fly ash additives on the mechanical properties of cement mortars. The effects of varying proportions of fly ash on the microstructural and mechanical strength characteristics of Portland cement mortars were analyzed. The study examined the effects of incorporating fly ash in its original state as industrial waste versus the effects of incorporating fly ash with a reduced content of unburned residues. Mortar cubes were prepared, and the compressive strength was assessed at intervals of 1, 3, 7, 28, 56, and 118 days.

Qingxin Zhao et al. (2015) studied the effect of curing temperature on the creep behaviour of fly ash concrete. Concrete specimens with fly ash replacement levels of 20% and 40% and a water-binder ratio of 0.33 were cast and cured under 20 °C, 50 °C and 90 °C. The specific creep of the concrete was determined. The parameters such as porosity, pore size distribution, Scanning Electron Microscope (SEM) morphology and X-ray diffraction (XRD) analysis and the influence of curing temperature on the creep of fly ash concrete were analyzed based on the amount of non-evaporable water.

Sridhar Kumaar & Saravanan (2015) conducted an experimental study on fly ash blended cement concrete with partial replacement of quarry sand. M25 grade concrete was used, and concrete specimens were cast with 10%, 20%, 30%, 40% cement replacement with fly ash and 10%, 20%, 30%, 40% fine aggregates were replaced by quarry dust. Workability, mechanical and micro structural properties of the concretes were determined. The workability of concrete was found to be decreased with the increased percentage of fly ash. Mechanical properties were observed to be greater for concretes with 30% cement replacement with fly ash and 30% fine aggregate replacement with quarry dust.

Alaa M Rashad (2015) conducted an exploratory study on high-volume fly ash concrete that incorporates silica fume and is subjected to thermal loads. High-Volume Fly Ash (HVFA) concrete was developed through the partial substitution of Class F fly ash for cement at a ratio of 70% (F70). The F70 formulation was modified by partially substituting Fly Ash (FA) and Silica Fume (SF) with cement, at proportions of 10% and 20% by weight, respectively.

Baboo Rai et al. (2015) performed a study analyzing the effects of fly ash on mortar that utilized quarry dust as a fine aggregate. Quarry dust was employed as a replacement for natural sand at substitution levels of 20%, 50%, and 100% by weight. Modifications were executed by partially replacing cement with 15%, 20%, 25%, and 30% low calcium fly ash. Specimens were prepared, and the compressive strengths were evaluated at 3, 7, 28, and 50 days.

Hong-zhu Quan & Hideo Kasami (2014) performed an experimental study on durability improvement of fly ash concrete with durability improving admixture. Fly ash was replaced partially with cement, and air-entraining water reducing admixtures were added at a rate of 1% of the weight of the binder. The concrete specimens were cast and tests such as compressive strength tests, drying shrinkage tests, accelerating carbonation tests and freezing-thawing tests were carried out

Haneef et al. (2013) experimented with the influence of fly ash and curing on the cracking behaviour of concrete by acoustic emission technique. Plain and fly ash concretes with different curing periods were considered and acoustic technique (AE) was used to study the crack growth behaviour in concretes during the uniaxial compression test. The compressive strengths of both the concrete increased with age till 56 days of curing. AE generated from three distinct stages in the concrete were chosen and attributed to crack closure/microcracking, steady crack propagation and unstable crack propagation. The presence of fly ash in concrete decreased the pores and reduced the microcracking, reducing the amplitude of AE activity. The fly ash concrete proved to withstand higher stress and strain without unstable crack propagation

Aman Jatale et al. (2013) studied the effects of fly ash concrete on compressive strength. High-range superplasticizers such as sulphonated naphthalene formaldehyde with a slump of more than 200mm were used. The admixture dosage was altered to obtain uniform workability. River Sand and Crushed Quarry Sand were combined and used as fine aggregates. A water reduction of 20% was obtained due to the superplasticizers.

Patil et al. (2012) made a technical analysis of the compressive strength of fly ash concrete. Fly ash was replaced at a range of 10% to 50% by the weight of cement. Tests such as consistency, setting time and soundness were carried out for the cement-fly ash blends. A concrete mix proportion of 1:1.5:3 with a water-cement ratio of 0.5 was adopted. Consistency was found to be increased as the fly ash content increased. The initial setting time was recorded at 155 minutes for a mix containing 0% fly ash, while a mix with 50% fly ash exhibited a setting time of 250 minutes. This variation is attributed to the retardation of cement hydration resulting from the inclusion of fly ash. The workability of concrete was observed to improve with the incorporation of 25% fly ash. The maximum strength was achieved at 0% and 5% for durations of 60 days and 21 days, respectively.

In 2012, Jayeshkumar Pitroda and colleagues performed experimental investigations regarding the partial substitution of cement with fly ash in design mix concrete. Ordinary Portland cement classified as 53 grade was utilized. Fly ash was substituted for cement at replacement levels ranging from 0% to 40% by weight. Coarse aggregates were sourced from crushed basalt rock, with particle sizes ranging from 20 mm to 4.75 mm. The river sand and crushed sand were integrated as a fine aggregate, with particle sizes ranging from 4.75 mm to 150 microns.

T Jianglong Yu et al. (2012) analyzed the characteristics of fly ash from coal-fired power stations. Two fly ash samples, namely: Eraring fly ash (EA) and Anshan fly ash (AA), were taken from power stations for analysis. The samples were subjected to tests such as sieve test, magnetic separation and floating test.

Nath & Sarker (2011) studied the effect of fly ash on the durability properties of high-strength concrete. Fly ash was replaced at a rate of 30% and 40% to the weight of cement. Two types of concrete were cast. Series A consisted of a variable water-binder ratio, while series B consisted of a constant water-binder ratio. Various tests were performed. Series A showed higher strength gain at 30% fly ash till 56 days, while series B showed decreased strength in both 28 and 56 days. For Series A, the drying shrinkage increased till 120 days and then started decreasing till 180 days for 30% replacement of fly ash, and for 40% replacement of fly ash, the drying shrinkage increased up to 180 days.

Md. Moinul Islam & Md. Saiful Islam (2010) studied the strength behaviour of mortar using fly ash as a partial replacement for cement. Ordinary Portland Cement and Class F Fly ash were used. Cement and fly ash were used at the ratio of 90:10, 80:20, 70:30, 60:40, 50:50 and 40:60. The mix ratio of cementitious material and sand was used at 1:2.75 for compressive strength and 1:3 for tensile strength. About 400 mortar specimens were cast and kept at 27°C temperature and 90% relative humidity for 24 hours.

III. LITERATURE STUDY ON MICRO SILICA-BASED CONCRETE

Arunabh Pandey & Brind Kumar (2020) conducted a comprehensive investigation on the application of Micro Silica (MS) and Rice Straw Ash (RSA) in the rigid pavement. Investigations were made with the proportions of RSA (5%–30%), MS (2.5%–10%) and a combination of RSA (5%, 10%) + MS (5%, 7.5%) by weight of cement in the paste and mortar.

Rakesh Choudhary and colleagues (2020) conducted a study to investigate the surface water absorption properties of High Strength Self-Consolidating Concrete (HSSCC). A total of sixteen HSSCC mixes were prepared to examine the impact of Marble Waste Powder (MWP), Fly Ash (FA), and Micro-Silica (MS) as partial substitutes for cement on the characteristics of surface water absorption.

Naga Gowthami et al. (2018) conducted an experimental investigation on the behaviour of micro silica in concrete. M25, M30, M35 and M40 grades of concrete were considered. Various proportions of micro silica, at 5%, 10%, 15%, and 20%, were added to the cement. Compressive and split tensile strengths were conducted for the concrete specimens and the results were compared with the conventional concrete. The results were found to be optimum for the specimens with 10% micro silica. The use of micro silica reduced the weight of cement and improved the fresh and hardened properties of concrete.

Aladdin M Sharkawi et al. (2018) investigated the efficiency of using micro silica and nano-silica mixture in concrete. Micro silica and nanosilica were used as cement partial replacement and the effects of the cementitious materials on corrosion protection and sulphate resistance on concrete were examined. Based on the maximum mortar compressive strength, 10% micro silica and 2% nano-silica were observed to be the optimum cement replacement ratios. Concrete corrosion protection

Nayana & Rakesh (2018) investigated the properties of cement mortar made with crushed ceramic waste and micro-silica by partially replacing sand and cement, respectively. Mortar mixes were prepared by replacing cement with 5% and 10% micro silica and sand was replaced with 15%, 30% and 50% ceramic waste. Compressive strength tests and durability tests such as rate of water absorption, sorptivity test and sulfate attack test were carried out.

Maciej Szelag (2018) studied the development of cracking patterns in a modified cement matrix with micro silica. The cracking patterns on the surface of the micro silica-modified cement matrix that was exposed to elevated temperatures were evaluated. The stereological parameters in the cracks were observed using image analysis techniques.

Li et al. (2017) conducted an investigation into the combined effects of micro silica (MS) and nano silica (NS) on the strength and microstructure of mortar. The study involved mortar mixes with varying contents of water, MS, and NS, while maintaining constant workability for the purposes of cube strength measurement and microstructure imaging. The test results demonstrated that a minimal NS content of merely 1–2% significantly enhanced the cube strength and microstructure, albeit with a considerable requirement for superplasticizer. The combined addition of MS and NS demonstrated significant impact. synergistic effects on strength and microstructure. These results suggested the combined use of NS and MS for better results.

Davood Mostofinejad et al. (2016) utilized micro-silica, blast furnace slag and limestone powder in concrete. Cement was replaced partially with various ratios and exposed to magnesium sulphate environments with different concentrations of 5%, 10% and 14.7%. The influence of different water-cement (w/c) ratios and the parameter of time on reducing the compressive strength and increasing the volume of the concrete were studied. A total of 36 mix designs were evaluated, incorporating concretes with 0%, 15%, and 30% limestone powder as a substitute for cement. These designs were analyzed under four conditions of cement replacement: 10% micro-silica, 10% blast furnace slag, 20% blast furnace slag, and a control group with no cement replacement using slag or micro-silica. A total of 864 concrete cubes, each measuring 70 mm × 70 mm × 70 mm, were produced using three water-to-cement ratios: 0.3, 0.4, and 0.5. The compressive strength of the specimens was evaluated at 140 and 280 days of sulfate exposure. Additionally, volume variations were measured at 70, 140, 210, and 280 days of sulfate exposure to assess the durability of various sulfate-submerged concrete types. A durability index was developed to facilitate the comparison of the concretes' performance in each environment, leading to the identification of the most durable concrete. A 5% magnesium sulphate solution was identified as the most destructive environment. Concrete with a water-to-cement ratio of 0.3, containing 15% limestone powder and 20% slag, was recognized as the most durable concrete.

Akshaykumar Hirapara et al. (2016) conducted a study on the application of micro silica in concrete. M25 grade concrete was utilized. Micro silica was incorporated into cement at varying percentages of 3%, 5%, 7%, 9%, 11%, 13%, and 15%. Tests for workability and compressive strength were performed on the specimens. Micro-silica has been observed to enhance the consistency of concrete owing to its superior fineness. The compressive strength of concrete was enhanced with the inclusion of 11% micro silica.

Mohammed Salah Nasr et al. (2016) conducted an investigation into the durability characteristics of concrete containing micro silica and nano-silica. Replacement ratios of 5%, 10%, and 15% were evaluated for micro silica, while nano-silica was substituted at levels of 0.5%, 1.5%, 3%, and 5%. Durability tests, including water absorption, chloride content, and pH tests, were performed. The chloride content test was performed under two distinct exposure conditions: wetting-drying and full immersion in a 6% sodium chloride (NaCl) solution. The findings indicated that the mixtures containing 5% micro silica and 5% nanosilica exhibited reduced chloride levels under both wetting-drying and full immersion exposure conditions, respectively.

N. Midhuna and Chandrasekeran (2015) conducted a study on the mechanical and durability properties of micro silica concrete reinforced with sisal fibers. M40 grade concrete was utilized, with varying percentages of micro silica incorporated into the cement at levels of 0%, 5%, 10%, 15%, and 20%. Superplasticizers were incorporated as high-range water-reducing agents.

Anil Kumar et al. (2014) conducted an experimental investigation of the influence of micro silica on high-strength concrete properties. Micro silica was replaced partially with cement at rates of 0%, 5%, 10% and highstrength concrete specimens were cast and cured. Mechanical properties such as compressive and flexural strengths were determined. The results showed increased compressive strength for higher micro silica replacements.

Magudeaswaran and Eswaramoorthi (2013) performed experimental investigations to assess the mechanical properties of micro silica and fly ash utilized as partial replacements for cement in high-performance concrete. Preliminary investigations were conducted by subjecting micro silica, fly ash, and cement to physical and chemical analyses, which confirmed compliance with the applicable standards. T

Janina Setina and colleagues (2013) investigated the influence of pozzolanic additives on the structural integrity and chemical durability of concrete. Silica and biomass ashes of micro and nano sizes were utilized as pozzolanic additives. The concrete samples underwent casting and curing processes, followed by the execution of X-ray diffraction, Hg absorption porosimetry, and optical microscopy tests on the specimens. The pozzolanic additives were noted to facilitate the mineralization process and functioned as both a cementitious admixture and a fine filler, resulting in a reduction in pore quantity.

Verma Ajay and colleagues (2012) conducted a study on the influence of micro silica on the strength properties of concrete. Concrete cubes were produced using a mix ratio of 1:1.5:3, accompanied by a water-to-cement ratio of 0.50. Specimens containing ordinary Portland cement and ordinary Portland cement with varying levels of silica fume at 0%, 5%, 10%, and 15% were cast and subjected to testing at intervals of 7, 14, and 28 days.

IV. LITERATURE STUDY ON QUARRY DUST CONCRETE

Fauzi et al. (2001) conducted a study on the impact of admixtures and quarry dust on the physical properties of freshly mixed high-performance concrete. Silica fume and fly ash were substituted at a rate of 10% based on the weight of the cement. River sand was utilized as a replacement for quarry dust at 20% and 40% concentrations. Superplasticizers and air-entraining admixtures were incorporated to regulate the flowability of the fresh concrete mix. The characteristics of fresh mixes, including slump flow, V-funnel flow, air content, mix temperature, and unit weight, were assessed. The influence of mineral and chemical admixtures on the fresh properties was observed, particularly regarding flow and entrained air content. In the presence of superplasticizer, silica fume demonstrated superior flow properties compared to fly ash. The addition of quarry dust to the concrete mix enhanced the flowability of the concrete.

Ho et al. (2002) conducted a study on the effective utilization of quarry dust in self-compacting concrete (SCC) applications. Limestone powder and quarry dust were integrated into the concrete mix, and the rheological measurements of the pastes yielded a result of 36 when compared.

Anitha Selva Sofia et al. (2013) performed an experimental study on the properties of quarry dust concrete incorporating chemical admixtures. Fine aggregate was replaced with quarry dust at the following percentages: 0%, 10%, 20%, 30%, 40%, 50%, and 100%. In each mix, two dosages of superplasticizer (Conplast SP430) were incorporated: 0.5% and 1% by weight of cement. Multiple specimens were produced through casting. The physical and chemical properties of quarry dust meet the specifications for fine aggregate.

Sakthivel et al. (2013) proposed a novel approach involving the substitution of river sand with quarry dust. The preparation of M35 concrete involved a mix ratio of 1:1.68:2.8 (cement: sand: blue metal jelly), adhering to a water-cement ratio of 0.45, in accordance with the relevant IS codes. River sand was substituted with 10%, 20%, 30%, and 40% of quarry dust. Tests for compressive strength, split tensile strength, and flexural strength were conducted. The results indicated a favorable outcome with up to 10% replacement of natural sand by quarry dust in M35 concrete.

Chandana Sukesh et al. (2013) conducted a study on the impact of partially substituting quarry dust for cement. The M20 grade concrete was utilized, and the mix design was conducted independently for the quarry dust employing the minimum void ratio and maximum density methods. Quarry dust was partially substituted for river sand at different levels, and various tests were conducted, including specific gravity, particle size analysis, bulking, workability, and compressive strength.

Shakir et al. (2014) performed a study to analyze the effects of integrating quarry dust and billet scale on the properties of fly ash bricks. Bricks were formulated utilizing different proportions of quarry dust and billet scale, combined with fly ash and cement. The mixtures were formulated to ensure flowability in their fresh state and were subsequently assessed for various properties, including strength, modulus of rupture, ultrasonic pulse velocity, initial rate of suction, water absorption, and efflorescence. The measured strength values of the bricks ranged from 0.8 MPa to 18.9 MPa. The modulus of rupture was observed to range from 0.13 MPa to 3.7 MPa. Water absorption values ranged from 15% to 32%. The initial suction rate for the bricks ranged from 0.27 to 2.21 kg/m²·min.

Sudheer et al. (2016) conducted a study on the strength of innovative mortar synthesis with epoxy resin, fly ash and quarry dust. Hybrid mortar with epoxy resin, fly ash and quarry dust was replaced with fine aggregate and cement. The compressive strengths of the hybrid mortars at 7 days were determined and found to be greater than that of the conventional concrete. SEM images were taken for fly ash specimens and fly ash containing 30% epoxy resins, and it was observed that the specimens with resin bonded more compactly than the fly ash specimens.

Thushar & Balakrishna Rao (2015) conducted a study on the effect of fineness of quarry dust on the compressive strength of concrete. M20 and M25 grades of concrete were considered. Various percentages of quarry dust were replaced with river sand and the compressive strength, both on the mortar cubes and concrete cubes, was determined.

V. CONCLUSION

The enhancement of concrete properties through eco-friendly materials represents a promising strategy to address the growing environmental concerns associated with traditional concrete production. Materials such as fly ash, GGBS, rice husk ash, natural fibers, and recycled aggregates offer significant improvements in the mechanical properties, durability, and sustainability of concrete. However, challenges related to mix optimization, variability, and regulatory approval must be overcome for widespread adoption. With continued research and technological advancements, eco-friendly concrete materials can play a crucial role in creating more sustainable and durable infrastructure, contributing to a greener built environment.

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