

Performance of Concrete in Chemically Aggressive Environment by Using Cementitious Materials in Concrete

Priya Mishra*

Abstract

This study investigates the performance and durability of sustainable concrete incorporating industrial and agricultural waste materials specifically Fly Ash, nano silica and Graphene Oxide when subjected to chemically aggressive environments. Traditional Ordinary Portland Cement (OPC) concrete often suffers from micro-structural degradation, sulfate attack, and acid penetration in harsh conditions. However, the integration of pozzolanic wastes creates a synergistic effect that densifies the concrete matrix through secondary C-S-H (Calcium Silicate Hydrate) gel formation. Experimental results indicate that the hybrid mix achieves superior mechanical properties, with a 28-day compressive strength of 29.6 MPa compared to 26.6 MPa for plain OPC. In terms of durability, the hybrid mix demonstrated significantly lower water absorption (4.5%) and a marked resistance to mass loss (3% vs. 8% in OPC) under aggressive testing. Graphene oxide will give more superior result when adding in the minimum amount in concrete approx. 1% will give greater result as compare to plain OPC Concrete. It will increase approximately 40-50% concrete strength and durability when using 15-20% fly ash, 5% nano silica. The spherical geometry of fly ash particles improves workability (slump of 85 mm), while the fine particles of nano silica fill micro-pores, reducing permeability and limiting the ingress of harmful ions. These findings suggest that substituting cement and natural aggregates with waste materials not only mitigates environmental impact but also produces a high-performance concrete with enhanced longevity and chemical resistance, making it an ideal solution for infrastructure in contaminated soils or industrial zones.

Keywords: Sustainable concrete, graphene oxide, fly ash, nano silica, chemical durability, pozzolanic activity, microstructural densification

INTRODUCTION

The construction industry has to promote the challenge of reducing CO₂ emissions from Ordinary Portland Cement (OPC), as well as the challenge of enhancing the durability of the material in chemically aggressive environments. Cement is in high demand in the construction industry, and its production generates a large amount of carbon dioxide, which contributes to environmental problems.

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The cement industry is the primary contributor to climate change, accounting for 8% of global carbon dioxide emissions. Alternative materials and sustainable production techniques have been developed to reduce carbon dioxide emissions; however, the widespread use of these strategies is hampered by functional shortcomings and financial difficulties. However, the widespread implementation of these strategies is limited by functional shortcomings and financial difficulties. It has developed into a sustainable substitute that can replace a significant portion of cement when

combined with limestone, calcined clay, gypsum, and clinker. However, a mixture with ordinary Portland cement can save carbon dioxide emissions by 40-50%. LC3 research has increased dramatically over the last ten years. Beyond these environmental advantages, LC3 improves mechanical and durability qualities, making it appropriate for construction in harsh environments. Researchers studying concrete have investigated several methods to improve the material's qualities [1–4].

The modern building sector requires environmentally friendly materials that maintain their quality over their anticipated lifespan. The material should be aesthetically beautiful, limit waste, and preserve the ecological balance of the environment in order to take care of it. One such material that completely satisfies all requirements is concrete, and a great deal of research has been done to predict how it will behave under different environmental circumstances. Pollutants such carbon dioxide, NOX, sulfur oxides, and suspended particulate matter can have an impact on concrete [5–7].

Cement is the most utilized binder in the building sector because of its widespread availability and efficacy as a building material [1]. However, its production is resource-intensive, requiring significant quantities of raw materials and consuming high amounts of energy. In addition, 7 % of all anthropogenic CO₂ emissions occur in the cement industry annually [2]. In response to these environmental concerns, researchers have investigated numerous strategies to minimize the ecological footprint associated with cement production [3]. In concrete, a hybrid mix usually refers to a combination of two or more waste materials, usually combining a supplementary cementitious material (SCM) (such as fly ash or silica fume) with a waste aggregate (such as recycled concrete aggregates or plastic aggregates).

This "hybrid" technique is better in a chemically harsh environment because it simultaneously solves two weaknesses: the waste aggregate replaces a natural resource, and the SCM densifies the paste [8, 9].

Concrete Exposure to Environmental Pollution and Acidic Atmosphere and its Adverse Effects ***Concrete Exposure to Environmental Pollution***

Exposure: Concrete structures are frequently subjected to a variety of environmental conditions, ranging from mild to severe, including industrial zones, wastewater/sewer lines and treatment plants, coastal environments, and other acidic and alkaline environments. These circumstances cause deterioration and negatively affect the strength, durability, and general performance of concrete. In acidic environments, chemical reactions can accelerate the deterioration of cementitious materials and affect their structural integrity. When combined with industrial waste, the OPC Hybrid mix can offer greater sustainability and resistance under harsh environmental circumstances without sacrificing its mechanical strength and long-term durability, as shown in Figure 1 [10–15].

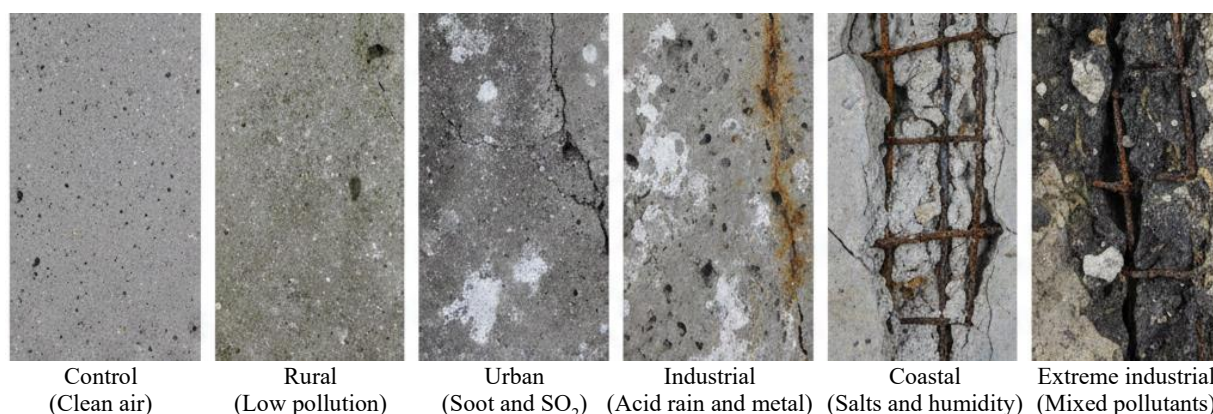


Figure 1. Impact of environmental pollution on concrete structures.

Table 1. Sources of chlorides, sulfates, and acids.

Sources of Chlorides in concrete	Through salty water, contaminated sand, admixtures, moisture, low dampproof course.
Sources of Sulfates in concrete	Through ground water, sewage, acid rain, increase amount of gypsum in cement. Sulfates react with C ₃ A cause ettringite
Sources of acid in concrete	Heavy pollution, acid rain.

Effect of Environmental Pollution on Concrete

The entry of CO₂ into concrete structures initiates a chemical reaction will starts a process called carbonation, which is the main cause of concrete deterioration in contaminated situations. The internal alkalinity of concrete is successfully neutralized as carbon dioxide diffuses through its pore structure and interacts with calcium hydroxide to create calcium carbonate, lowering the pH from approximately 12.5 to less than 9. The embedded steel reinforcement is weakened as a result of this chemical change, and the steel experiences electrochemical oxidation once the alkaline barrier is damaged. Delamination and structural spalling are the results of severe internal tensile strains caused by the resultant iron oxide or rust, which occupies a much larger volume than the original metal. Simultaneously, industrial pollutants such as nitrogen oxides (NO_x) and sulfur dioxide (SO₂) cause chemical erosion through acidic deposition. These acids react with the cement paste to change calcium hydroxide into gypsum (CaSO₄.2H₂O), a much softer mineral that forms degrading crusts and increases surface porosity, ultimately speeding up material loss and structural deterioration. Table 1 and Figure 2 [16–19].

Aggressive Environment

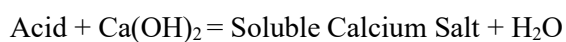
Areas with strong acids (hydrofluoric acid, sulfuric acid), bases, or high salt concentrations. A chemically aggressive environment contains high concentrations of corrosive gases, liquids, or solids, such as acids, alkalis, salts, or industrial chemicals, that cause the rapid deterioration and degradation of concrete.

Problems

- Sewage pipes are frequently exposed to sulfuric acid and sulfate-rich fluids.
- Environments with high salt content (chlorides) lead to rapid corrosion in concrete.
- Rising traffic loads and chemical degradation from H₂S gas and acid attacks damage underground sewage pipes and cause accidents.

Acidic Environment

Concrete is naturally alkaline (pH = 12.5-13.5). When exposed to acidic environments, chemical reactions occur that deteriorate the cement matrix and reduce its strength and durability. This applies to conventional OPC concrete and also to OPC HYBRID MIX concrete, although their resistance levels differ (the fundamental reaction can be simplified as



Acidic environments are common in concrete structures found in chemical plants, sewage systems, industrial zones, and coastal regions. Because concrete is naturally alkaline, chemical processes that dissolve calcium compounds and degrade the cement matrix occur when acids penetrate its surface. This causes the steel reinforcement to deteriorate on the surface, lose its compressive strength, crack, and corrode.

Conventional Ordinary Portland Cement (OPC) concrete is more reactive to acid attack. Because of its denser microstructure and reduced calcium hydroxide content, the OPC hybrid mix (OPC+FA+NS+GO) is said to have better durability; however, a thorough assessment of its performance in different acidic conditions is necessary.

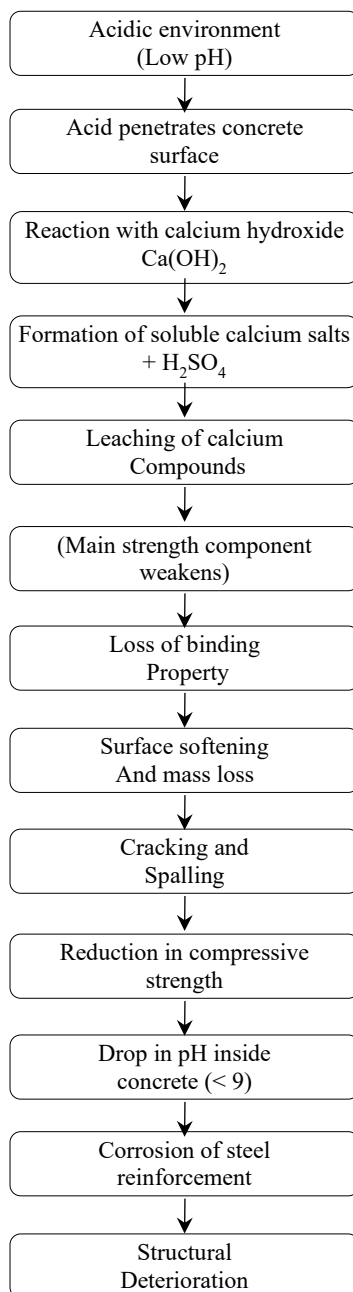


Figure 2. Mechanism (flow chart).

Thus, it is necessary to compare the durability performance of LC3 cement concrete with that of ordinary concrete and investigate the impact of acidic exposure on various grades of concrete. To select better materials and extend the service life of concrete structures in harsh environments, it is crucial to comprehend the strength loss, mass loss, and durability behavior of concrete under acidic conditions (Sahith Reddy, S., & Achyutha Kumar Reddy, M. et al.2021).

Objective

1. Investigate the packing density achieved by combining fine mineral waste (such as Silica Fume) with coarse recycled aggregates.
2. Mass Loss and reduction in compressive strength after exposure to acidic solutions (H₂SO₄ at pH 3.0) were evaluated.
3. Comparative analysis of OPC and Hybrid OPC for chemically aggressive environment.

RESEARCH METHODOLOGY

Research Methodology

The current study aims to examine the mechanical properties of OPC concrete mixes designed to incorporate with fly ash, Nano, and Graphene oxide. The mixes designed in the current study were M-25 mixes. The specimens were cured for 7, 14, and 28 days. This study follows IS 456 and IS 516 standards, as shown in Tables 3–9.

Fly ash and nano-silica were mixed in varying proportions. OPC replaced by fly ash in 70% Nano Silica was added in a proportion of 8% and GO of 0.08 in the concrete mix.

To assess the durability and resistance of the OPC Hybrid concrete, samples were subjected to harsh environments by immersing them in 5% H₂SO₄ (Sulfuric Acid) solution for 7, 14, and 28 d. Result analysis described in tables.

Table 3. Properties of fly ash, nano silica and graphene oxide.

Property	Fly ash	Nano-silica	Graphene oxide
PHYSICAL STATE	Fine powder	Nano powder	Nano sheets
Colour	Grey	White	brownish
Particle size	1 micron-100 micron	10-100 nano micron	1 nano micron
Specific gravity	2.1-2.6	2.2-2.4	1.8-2.2

Table 4. Material dosages in concrete.

Material	Standard dosage (% of weight)	Properties	Dosage of material for maling concrete cube
OPC	65%–80%	Reduces Ca(OH) ₂ and to prevent chemical attack	30%
Fly Ash	15–25%	Improve workability and provides long term sulfate resistance	70%
Graphene oxide	0.01%–0.05%	To block all pores and mitigate all chemical attack	0.08%
Nano silica	1–2%	Accelerate the early age strength by combining with graphene oxide	8%

Table 5. Test for fresh concrete and harden concrete.

1. Fresh Concrete	2. Durability Test	3. Mechanical Properties
Workability: Slump Test Setting Time (Initial & Final)	Water absorption test Acid attack test	Compressive strength Split tensile strength Flexural strength

Table 6. Result for plain OPC.

S. N.	Curing days	Compressive strength (Mpa)	Tensile strength (Mpa)	Flexural strength (Mpa)	Water absorption value	Workability test (slump value)	Durability test
1	7	16.5	1.2	2.12	5.5%	75.5mm	1.5%
2	14	21.64	2	3.3			4%
3	28	26.6	22	3.6			8%

Table 7. Result for concrete mix (OPC+FLY ASH).

S. N.	Curing days	Compressive strength (Mpa)	Tensile strength (Mpa)	Flexural strength (Mpa)	Water absorption value	Workability test (slump value)	Durability test
1	7	20.7	1.7	3.12	4.5%	85mm	0.5%
2	14	26.64	2.29	4.3			1.5%
3	28	29.6	2.7	4.8			3%

Table 8. Result for concrete mix (OPC+FLY ASH+NANO SILICA).

S. No.	Curing days	Compressive strength (Mpa)	Tensile strength (Mpa)	Flexural strength (Mpa)	Water absorption value	Workability test (slump value)	Durability test
1	7	21.5	1.5	2.5	3.2%	80mm	0.2%
2	14	23.2	2.6	3.9			0.5%
3	28	30.2	3.2	4.2			2%

Table 9. Result for concrete mix (OPC+FLY ASH+NANO SILICA+GRAPHENE OXIDE).

S. No.	Curing days	Compressive strength (Mpa)	Tensile strength (Mpa)	Flexural strength (Mpa)	Water absorption value	Workability test (slump value)	Durability test
1	7	25	1.9	3.5	1.2%	80mm	0.1%
2	14	26.2	2.8	4.2			0.2%
3	28	35	4.3	5.6			1%

CONCLUSION

The experimental data indicate a clear and progressive improvement in the mechanical and durability properties of concrete as advanced minerals and nanomaterials are integrated. In the Plain OPC control mix, the 28-day compressive strength reached 26.6 MPa with a relatively high water absorption rate of 5.5%, suggesting a more porous internal structure. The addition of Fly Ash (OPC + Fly Ash) served as an effective pozzolan, increasing the 28-day compressive strength to 29.6MPa and improving workability (slump increased to 85 mm), while simultaneously densifying the matrix to reduce water absorption to 4.5%. This highlights the "ball-bearing" effect of fly ash particles, which enhances the flow of the fresh mix and the secondary hydration that fills capillary pores over time. The performance was further enhanced with the inclusion of Nano Silica, which acted as a high-surface-area filler and catalyst for the hydration process. The OPC + Fly Ash + Nano Silica mix achieved a 28-day compressive strength of 30.2MPa and showed a significant increase in durability, with water absorption decreasing to 3.2%. However, the most substantial leap in performance occurred with the addition of Graphene Oxide. The OPC + Fly Ash + Nano Silica + Graphene Oxide mix outperformed all others across every metric, reaching a peak compressive strength of 35 MPa, tensile strength of 4.3MPa, and flexural strength of 5.6 MPa. Most notably, this mix exhibited superior resistance to environmental ingress, with a remarkably low water absorption of only 1.2% and a durability test value of 1% compared to 8% for plain OPC.

The synergy between the microfilling effect of fly ash and the nano-reinforcement of silica and graphene oxide creates a significantly denser and stronger concrete matrix. Graphene Oxide appears to regulate the growth of hydration products, leading to a more ordered crystalline structure that provides exceptional resistance to cracking and water penetration. While the nanomaterials slightly reduced the workability compared to the fly ash-only mix owing to their high water demand, the trade-off resulted in a high-performance material with superior longevity and structural integrity.

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