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Experimental Study Of Acidic Solution On The Strength, Durability And Characteristics Of Concrete

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Abstract: This research investigates the resilience of concrete when subjected to harsh chemical conditions, particularly in coastal and industrial regions where exposure to sodium chloride and sulfuric acid is prevalent. To address this challenge, M25 grade concrete was utilized, with 8% of the cement replaced by silica fume, a substance recognized for enhancing strength and durability. Concrete cubes were produced and cured under various conditions, including standard water and chemical solutions containing 2.5% sodium chloride and sulfuric acid. These specimens were subsequently evaluated after 7 and 28 days to assess their compressive strength, water absorption, and workability through slump testing. The findings provide valuable insights into the impact of chemical exposure on concrete and the protective role of silica fume. Ultimately, this study underscores the significance of incorporating supplementary materials like silica fume and employing rigorous testing protocols to develop more durable concrete for challenging environments.

Keywords- *Compressive Strength, Sodium chloride (NaCl), Sulfuric acid (H_2SO_4), Sillica Fume, Material Testing*

INTRODUCTION

Concrete is esteemed for its remarkable compressive strength, longevity, and adaptability in design, rendering it a favored material in modern construction. It plays a crucial role in a diverse range of infrastructure projects, such as buildings, bridges, highways, tunnels, dams, and factories. The extensive utilization of concrete can be ascribed to its affordability, accessibility & ease of handling. Nevertheless, concrete has its limitations; extended exposure to harsh environmental conditions and chemical substances can result in a gradual deterioration of its strength and stability. Specifically, compounds like sulfuric acid (H_2SO_4) and sodium chloride (NaCl) are known to have harmful effects. This research focuses on examining the influence of 2.5% concentrations of these chemicals on the long-term durability of concrete.

Fig 1: After 28 days curing in sulfuric acid (2.5 % Concentration) concrete cube surface started to rough and porous

Sodium chloride, which is frequently found in groundwater, marine environments, and road de- icing applications, poses a serious threat to reinforced concrete. Chloride ions are released when it dissolves in water, seeping into the concrete and eventually reaching the steel reinforcements. As a result, corrosion begins and the steel's protective coating deteriorates. The concrete nearby cracks as a result of the steel's oxidation and expansion, further weakening the structure and letting more hazardous materials in. This degradation process may result in internal delamination, surface spalling, and catastrophic structural failure.

On the other hand, sulfuric acid, a strong acid that is commonly present in contaminated areas, acid rain, and industrial effluents, reacts with calcium hydroxide and other necessary cement paste ingredients to produce soluble substances like gypsum that are readily removed. The cement matrix is weakened and structural stability is jeopardized by this reaction. Furthermore, expansive products like ettringite are created when sulfate ions interact with other cement constituents like tricalcium aluminate, which worsens cracking and causes additional structural damage. Prolonged exposure to sulfuric acid can lead to erosion, increased porosity, and significant strength loss.

Concrete's natural porosity makes it especially vulnerable to damage in areas with high concentrations of harsh chemicals. Buildings that are close to the coast, in cold climates that use de-icing salts, or in contaminated industrial environments often show signs of deterioration more quickly. As a result, improving concrete's durability has gained significant attention. Adding supplementary cementitious materials (SCMs), like silica fume, to concrete is a practical tactic that helps to increase the material's density and decrease its permeability. Engineers can create concrete that lasts longer and performs at its best even in harsh environmental conditions by using sophisticated mix designs and incorporating specialized materials that increase durability.

LITERATURE REVIEW

1. Ali H. Shalan, and Mohamed M. El-Gohary, (2024)

This research investigates the influence of the binder's chemical composition and the microstructural evolution of alkali-activated paste (AAP) on the sulfuric acid resistance of AAC. A variety of experimental methodologies, such as X-ray diffraction, thermogravimetric analysis, and scanning electron microscopy (SEM), were employed to assess the impact of binder composition. The findings indicate that increased alumina-silicate (Al/Si) ratios and magnesium oxide (MgO) levels facilitate the development of hydrotalcite and CASH, thereby enhancing sulfuric acid resistance. Additionally, AAC specimens containing slag and metakaolin exhibited lower porosity, which significantly bolstered their durability in aggressive environments.

2. Tareg Abdalla Abdalla et al (2024)

This research examines the impact of partially replacing Ordinary Portland Cement (OPC) with processed bagasse ash (PBA) at proportions reaching 50% and incorporating silica fume at 5%. The study evaluates the resistance to sulfuric acid & the extent of drying shrinkage. The results indicate that although an increased amount of PBA can weaken strength, the pozzolanic reactions play a significant role in improving durability by optimizing the pore structure of the concrete. These findings underscore the benefits of using supplementary cementitious materials (SCMs) in minimizing the environmental impact associated with OPC.

3. Jana Renuka, Konda Rajasekhar (2024)

Rapid urbanization has intensified concrete usage, raising concerns about its environmental footprint, including contributions to climate change, resource exhaustion, and ecological degradation. As concrete is vulnerable to aggressive environmental exposures, especially in acidic and marine environments, researchers have explored various material innovations to enhance its performance and sustainability. Nanotechnology has emerged as a promising domain, with nano Silica is increasingly recognized for its pozzolanic reactivity and its ability to refine pore structure. An important study evaluated how concrete's acid resistance was affected by colloidal silica (SYCOL-TX, which contains 30% nanosolids).. The study involved the addition of various amounts of colloidal silica 0%, 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% to the concrete mixture to ascertain the ideal dosage for enhanced performance. Following a curing period of 28 days in standard water, the specimens underwent compressive strength testing to determine the most beneficial dosage. The optimal mixture was then subjected to sulfuric acid solutions at concentrations of 1.5%, 3%, 4.5%, and 6% over extended durations of 28, 56, 90, and 180 days.

4. Rashmi M P et al. (2021)

This article provides a comprehensive review of the strength and durability of geopolymer concrete, which utilizes Fly Ash, GGBS, and rice husk ash as substitutes for cement. The review emphasizes the superior strength and acid resistance of geopolymer concrete in comparison to traditional concrete, especially when cured at elevated temperatures ranging from 60°C to 80°C.

5. **Kasım Mermerdaş et al.**

This experimental study highlights the potential of fiber-reinforced High-Performance Cementitious Composites (HPCC) in resisting sulfuric acid attacks. Fourteen distinct mix designs incorporating steel and glass fibers were subjected to acid immersion for up to two months. Findings revealed that steel fibers significantly boosted compressive strength and acid durability due to their bridging effect, which helped resist crack propagation. Conversely, the inclusion of glass fibers showed a reduction in strength, possibly due to chemical degradation or poor bond strength. This research offers practical insights into optimizing fiber type and dosage for acid-resistant structural elements.

6. Shripad Umale and G.V. Joshi (2019)

Concrete has become increasingly popular in the last century for usage in a wide range of construction projects, including infrastructure, water storage, industrial, and residential projects. This material can be manufactured to have exceptional mechanical qualities, like strong compressive and flexural strengths, and is often quite durable. The manufacturing process (curing techniques, finishing, etc.) and the materials used have a significant impact on concrete's longevity in terms of resistance to various chemicals. It's a commonly known that concrete deteriorates in acidic environments because of chemical attack.

7. G. Mounika Naidu, M. Rathna Chary (2018)

This study assesses the resistance of concrete to sulfuric acid by incorporating silica fume (10%), ground granulated blast-furnace slag (GGBS) (10%-15%), and volcanic ash (10%-15%). Concrete samples submerged in a 15% sulfuric acid solution revealed that the combinations of GGBS and silica fume exhibited markedly enhanced durability in comparison to the control mixtures.

8. Dr Mahomoud Al Khazalah et al. (2017)

This investigation focuses on the durability properties of High-Strength Concrete (HSC) that includes red mud, nano clay, and silica fume as partial cement substitutes (60%75% replacement). The results revealed that the optimized blend exhibited a 20% increase in resistance to acids and chlorides compared to traditional concrete formulations.

9. Ramin Andalib et al. (2014)

This research examines the use of bacterial concrete to enhance acid resistance. Different grades of structural concrete (40, 45, and 50 MPa) were exposed to 5% solutions of sulfuric acid (H_2SO_4) and hydrochloric acid (HCl) for durations of 60, 90, and 120 days. The results demonstrated that bacterial concrete showed reduced strength loss and improved durability, which can be linked to the precipitation of calcite that helps to prevent the ingress of sulfates and chlorides.

10. N. K. Amudhavalli, Jeena Mathew (2012)

This research examines M35 grade concrete with varying levels of silica fume as a cement substitute (0%, 5%, 10%, 15%, 20%). The findings indicate that the incorporation of silica fume enhances both the strength and durability of concrete, while also minimizing weight loss when subjected to acidic environments.

AIM: Experimental study of acidic solution on the strength, durability & characteristics of Concrete.

OBJECTIVES

1. Investigate how sulfuric acid (H_2SO_4) and sodium chloride (NaCl) influence the porosity and compressive strength of standard M25 concrete.
2. Analyze the degradation, water absorption behaviour & compressive strength of concrete subjected to chemical exposure in controlled lab environments.
3. To evaluate the role of 8% silica fume as a supplementary cementitious material in enhancing chemical resistance and long-term performance.
4. Compare the performance and strength of concrete with and without silica fume through compressive strength testing at 7 and 28 days.

METHODOLOGY

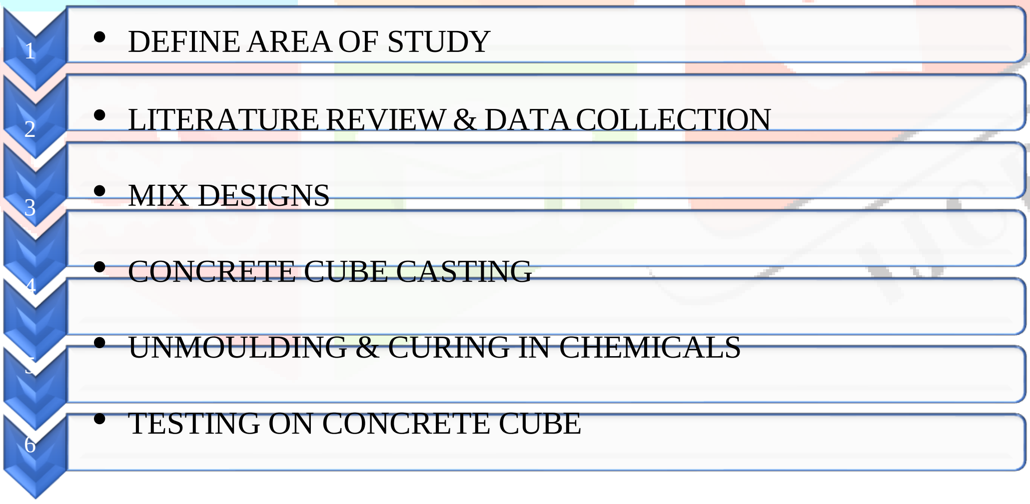


Fig 2: Methodology

1. Literature Review and Data Collection:

The initial phase of the study involved an examination of pertinent literature to comprehend the effects of deleterious chemicals such as sodium chloride (NaCl) and sulfuric acid (H_2SO_4) on concrete. These agents pose significant risks to concrete integrity, particularly in marine and industrial settings. The literature explored the mechanisms by which chloride ions induce corrosion of steel reinforcement within concrete and the manner in which sulfates compromise its structural integrity.Furthermore, the review examined the use of silica fume, a fine powder employed to improve the strength and durability of concrete by reducing porosity. Relevant standards such as IS 10262, IS 456, ASTM, and BS were referenced to gain insights into mix design, curing techniques, and testing procedures.

2. Materials and Mix Design: (IS Code 10262. 2009)

Materials Employed

All materials were chosen in accordance with Indian (IS) and American (ASTM) standards: Cement: Ordinary Portland Cement (OPC) of 53 Grade, serving as the primary binder.

Sand: River sand characterized by a fineness modulus range are from 2.5 to 3.0.

Coarse Aggregate: Crushed stone of sizes 10 mm and 20 mm, with a specific gravity between 2.65 and 2.75.

Silica Fume: To increase strength and durability, silica fume is added as an 8% cement substitute.

Testing Chemicals:

NaCl solution (2.5%) – utilized to replicate salt exposure conditions. H_2SO_4 solution (2.5%) employed to simulate acid attack.

Cement:

Cement functions as the binding agent in concrete, ensuring the cohesion of all components. Ordinary Portland Cement (OPC) of grades 43 or 53 is generally employed in M25 concrete.

Its chemical makeup primarily includes:

Tricalcium Silicate (C_3S) – $3CaO \cdot SiO_2$ (Gives early strength)

Dicalcium Silicate (C_2S) – $2CaO \cdot SiO_2$ (Contributes to long-term strength) Tricalcium Aluminate (C_3A) – $3CaO \cdot Al_2O_3$ (Highly reactive to sulfates) Tetracalcium Aluminoferrite (C_4AF) – $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$ (Influences color and hydration heat)

Gypsum ($CaSO_4 \cdot 2H_2O$) (Controls setting time)

Fine Aggregates (Sand):

Fine aggregates, which are usually river sand or manufactured sand, occupy the voids in the mix and enhance the workability of concrete. The sand recommended for M25 concrete should comply with Zone II of IS 383-2016, featuring: Particle size: Less than 4.75 mm

Silica (SiO_2) content: High to enhance bonding Specific gravity: 2.6-2.7

Coarse Aggregates:

Coarse aggregates play a vital role in imparting strength and volume to concrete mixtures. For M25-grade concrete, the preferred materials are crushed stone or gravel with a nominal size of 20 mm. The typical aggregate composition consists of:

Quartz (SiO_2) – The primary constituent

Feldspar ($KAlSi_3O_8$ – $NaAlSi_3O_8$ – $CaAl_2Si_2O_8$) – Durability

Limestone ($CaCO_3$) – May affect chemical interactions

Water:

Water is essential for the hydration of cement, and its quality significantly influences the ultimate strength of the concrete. It must be devoid of impurities and comply with IS 456-2000 standards, exhibiting a pH level above 6 and low organic content.

Silica Fume (SiO_2):

Silica fume is a very fine byproduct of the production of silicon and ferrosilicon alloys.It is mostly made up of amorphous silicon dioxide (SiO_2), which improves concrete's mechanical properties by

- Decreasing permeability
- Increasing strength through the formation of additional calcium silicate hydrate (C-S-H)
- Improving resistance to sulfate attacks and chloride ingress
- Improving the area where the paste and aggregate interfacial transition

When incorporated as an 8% replacement for cement, silica fume refines the microstructure, diminishes porosity, and enhances resistance to chemical degradation.

Chemical Reactions and Their Impact on Concrete:

Impact of Sodium Chloride (NaCl):

Sodium chloride exhibits high solubility in water, facilitating the infiltration of chloride ions into concrete, which subsequently reach the steel reinforcement. Corrosion results from this process's compromise of the passive protective layer:

Chemical Reaction:

$NaCl \rightarrow Na^{+} + Cl^{-}$

$Fe + 2Cl^{-} \rightarrow FeCl_2$

$4FeCl_2 + O_2 + 6H_2O \rightarrow 4Fe(OH)_3 + 8Cl^{-}$

The formation of iron hydroxide (rust) results in expansion, which can lead to cracking and spalling of the concrete, ultimately causing significant structural damage.

Impact of Sulfuric Acid (H_2SO_4)

Sulfuric acid reacts vigorously with calcium hydroxide present in cement paste, resulting in the formation of gypsum and ettringite, which contribute to expansive damage:

Chemical Reaction:

$H_2SO_4 \rightarrow 2H^{+} + SO_4^{2-}$

$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4 \cdot 2H_2O$ (Gypsum) $+ H_2O$

$3CaO \cdot Al_2O_3 \cdot 6H_2O + 3(CaSO_4 \cdot 2H_2O) + 20H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$

Mix Design:

For M25 grade concrete:

Mix Ratio (C:S: A): 1:1:2

Water-Cement Ratio: 0.45

Silica Fume: 8% substitution of cement

Concrete Cube dimensions: 150 mm × 150 mm × 150 mm Material

Calculation:

Qty of Cement = (1.54 X 0.003375 X 1) / (1 + 1 + 2)
= 0.001299/0.035
= 0.037125 X 50
= 1.860 Kg

Qty of Sand = (1.54 X 0.003375 X 1) / (1 + 1 + 2)
= 0.001299 X 35.28
= 0.037125 X 45
= 2.060 Kg

Qty of Aggregate = (1.54 X 0.003375 X 2) / (1 + 1 + 2)
= 0.0 X 35.28
= 0.037125 X 40
= 3.670 Kg

Qty of Sillica Fume = 8 % of Cement Qty
= (8 / 100) X 1.860
= 0.150 KG

∴ After Replacing Sillica Fume to the Cement, Cement qty will be reduced by 8 %

Qty of Cement for Sillica Fume Blocks = Std Qty of Cement – Qty of Sillica Fume (8%)
= 1.860 – 0.150
= 1.710 Kg

3. Concrete Testing: (IS Code 516. 1959)

A. Compressive Strength

Objective: To evaluate the concrete's ability to retain strength after being exposed to chemicals. Cubes measuring 150 mm on each side serve as the specimen. Days of Testing: 7 and 28 days.

Equipment: A 3000 KN capacity compression testing machine.

Method: Remove the cubes out of the curing tanks. Weigh and clean every cube. After placing each cube inside the testing apparatus, gradually increase the load. Note the load at which the failure takes place.

Formula:

Strength (MPa) = Failure Load (N) / 22500 mm²

Fig 3: Compression Testing

B. Water Absorption Test:

Purpose: This test evaluates the water absorption capacity of concrete, which serves as an indicator of its porosity.

Steps:

1. Immerse the cubes in water for 24 hours and subsequently record the wet weight (W_2).
2. For a full day, place the concrete cube in an oven set to 110°C. Note the dry weight, or W_1.
3. Utilizing the subsequent formula to determine absorption:

   Absorption (%) = $(W_2 - W_1) / W_1 \times 100$.

Fig 4/5/6: Curing in Water/Sodium Chloride/Sulfuric Acid

C. Slump Test:

This test objective is to find out the workability of freshly mixed concrete.

Steps to follow:

1. Start by adding three different layers to the slump cone and tamping each layer 25 times.
2. Measure the droop, or height drop, after the cone has been properly removed.

Slumps Types:

When the drop is even and consistent, it is called a true slump. Shear slump is a tilt to one side that indicates an inadequate mix. The combination collapsed when it was not properly prepared or too wet.

1. True Slump
2. Shear Slump
3. Collapsed Slump

RESULT:

COMPRESSIVE STRENGTH

Table 1: Standard Blocks Compressive Strength

Standard Block	Sr No	After 7 Days Curing Strength of Compressive Strength (N/mm^2)		Sr No	After 28 Days Curing of Compressive Strength (N/mm^2)	
Cured in Water	1	17.1	17.36	1	26	26.5
	2	18		2	27.1	
	3	17		3	26.5	
Cured in Sodium Chloride (NACL)	1	16.5	16.5	1	25.5	25.03
	2	16		2	25	
	3	17		3	24.6	
Cured in Sulfuric Acid (H_2SO_4)	1	16	15.8	1	24	23.93
	2	15.8		2	23.2	
	3	15.6		3	24.6	

Table 2: Sillica Fume Blocks Compressive Strength

Sillica Fume	Sr No	After 7 Days Curing Strength of Compressive Strength (N/mm^2)		Sr No	After 28 Days Curing of Compressive Strength (N/mm^2)	
Cured in Water	1	18	18.53	1	28	28.16
	2	18.6		2	29.5	
	3	19		3	27	
Cured in Sodium Chloride (NACL)	1	17	18.16	1	26	26.16
	2	17.5		2	25.5	
	3	20		3	27	
Cured in Sulfuric Acid (H_2SO_4)	1	17	16.5	1	25.5	25.8
	2	16.5		2	26	
	3	16		3	25.9	

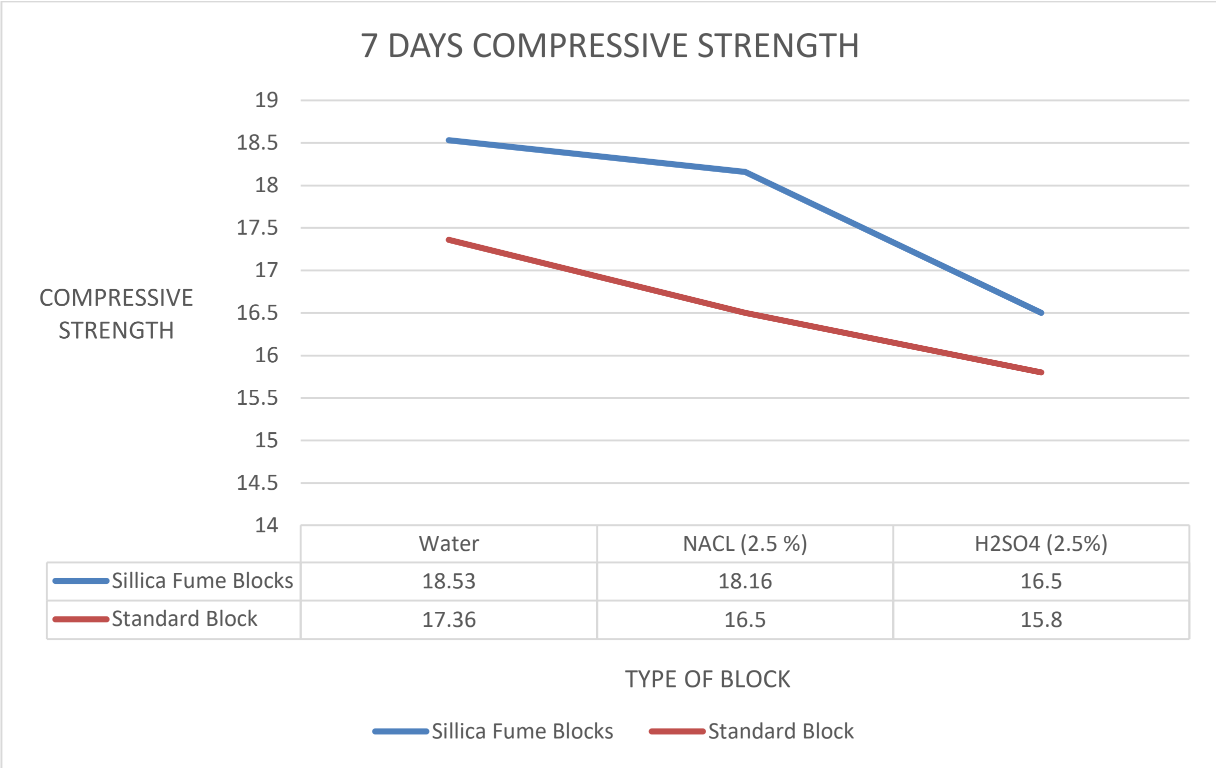


Chart 1: 7 Days Compressive Strength

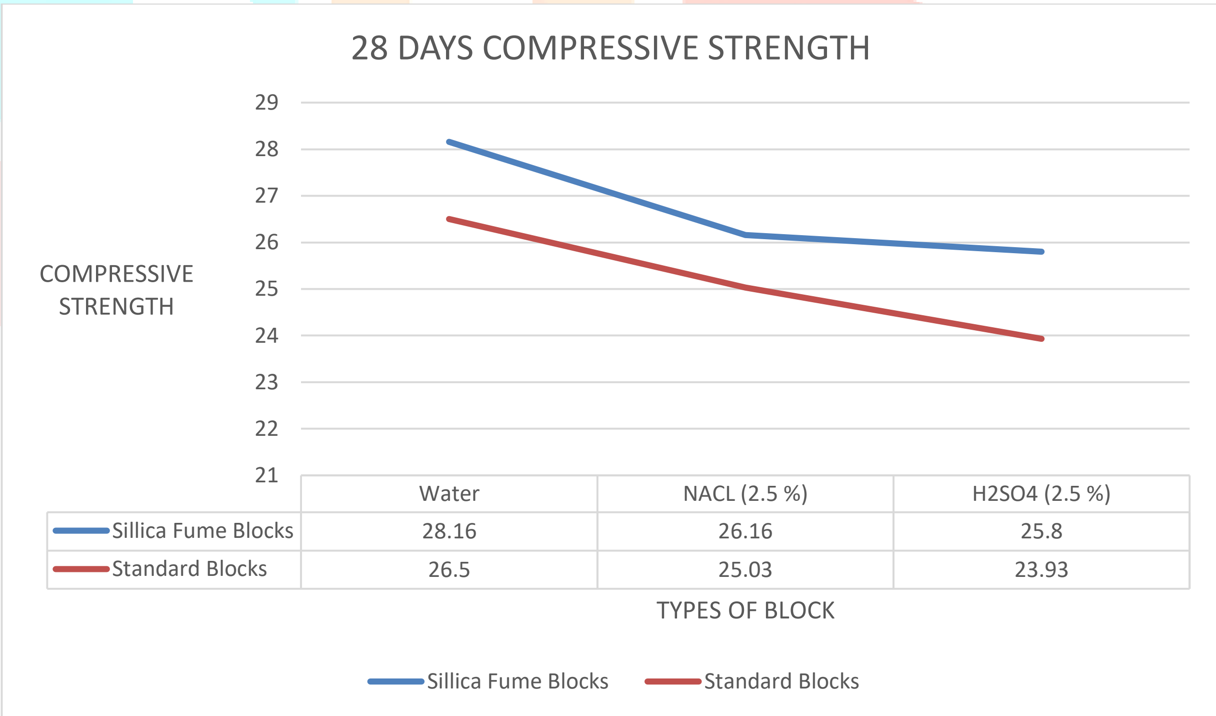


Chart No.2 (28 Days Compressive Strength)

WATER ABSORPTION TEST

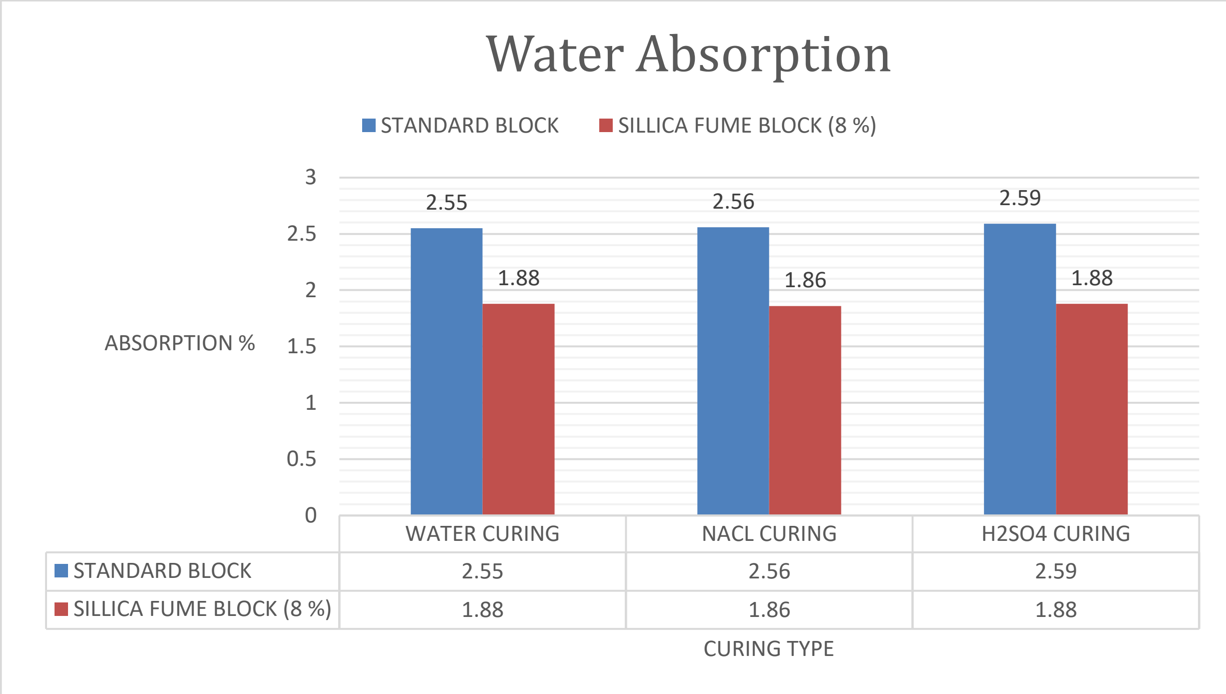
TABLE 3: WATER ABSORPTION TEST

Sr. No.	Curing Method	Type of Block	Dry Weight (W1) (kg)	Wet Weight (W2) (kg)	Absorption (%) = [(W2 - W1)/W1] × 100	Average absorption (%)
1	Water	Standard	7.90	8.10	2.53	2.55
2			7.93	8.13	2.52	
3			7.95	8.15	2.52	
4			7.97	8.17	2.51	
5			8.00	8.21	2.63	
6			8.02	8.23	2.62	
7	NACL		8.05	8.26	2.61	2.56
8			8.07	8.28	2.60	
9			8.10	8.31	2.59	
10			7.92	8.12	2.53	
11			7.94	8.14	2.52	
12			7.96	8.16	2.51	
13	H_2SO_4		7.98	8.18	2.51	2.59
14			8.01	8.22	2.62	
15			8.03	8.24	2.62	
16			8.06	8.27	2.61	
17			8.08	8.29	2.60	
18			8.09	8.30	2.60	
19	Water	8% Silica Fume	7.90	8.05	1.90	1.88
20			7.92	8.07	1.89	
21			7.94	8.09	1.89	
22			7.96	8.11	1.88	
23			7.98	8.13	1.88	
24			8.00	8.15	1.88	
25	NACL		8.02	8.17	1.87	1.86
26			8.04	8.19	1.87	
27			8.06	8.21	1.86	
28			8.08	8.23	1.86	
29			8.10	8.25	1.85	
30			7.91	8.06	1.90	
31	H_2SO_4		7.93	8.08	1.89	1.88
32			7.95	8.10	1.89	
33			7.97	8.12	1.88	
34			7.99	8.14	1.88	
35			8.01	8.16	1.87	
36			8.03	8.18	1.87	

Note: Average Absorption for Standard Blocks: 2.57%

Average Absorption for 8% Silica Fume Blocks: 1.88%

Chart No.3 Water Absorption Testing



CONCLUSION

- After 28 days of submersion in water, concrete containing silica fume demonstrated exceptional strength evaluation performance, achieving a compressive strength of 28.16 MPa, or roughly 6% higher than conventional concrete, which was measured at 26.5 MPa.

- It showed a minor edge over regular concrete blocks even after seven days. Additionally, silica fume blocks exhibited a strong 25.8 MPa in acidic conditions when exposed to harsh chemicals like sulfuric acid (H_2SO_4) and sodium chloride (NaCl), compared to traditional concrete's 23.93 MPa, confirming their durability in challenging conditions.

- In addition, silica fume blocks exhibited a superior resistance to moisture infiltration, with an average water absorption rate of 1.88%, which was significantly lower than that of standard concrete, which was 2.57%.

- According to these results, adding 8% silica fume increases durability against moisture and chemical exposure in addition to compressive strength, making it ideal for infrastructure applications in industrial or maritime environments.

FUTURE SCOPE

- For practical applications, experiment with varying silica fume replacement levels (such as 5%, 10%, and 15%) to determine the ideal ratio of strength, durability, and cost.

- To learn more about how the concrete responds to ongoing chemical exposure and environmental stress, track its performance over a longer time frame, such as 90 to 180 days.

- To achieve a more sustainable and environmentally friendly concrete mix without sacrificing strength, combine silica fume with other environmentally friendly additives like fly ash or GGBS to lower the cement content.

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