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Durability of Limestone-Filler Based Concrete in Acidic Environment

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***Abstract:** Concrete structures exposed to acidic environments are highly susceptible to deterioration due to chemical attack, resulting in strength reduction, increased permeability, and reduced service life. The present study investigates the influence of limestone powder as a partial replacement for cement on the durability and mechanical performance of concrete subjected to acidic conditions. Limestone powder was incorporated at replacement levels of 0%, 5%, 10%, and 15% by weight of cement. Concrete specimens including cubes and cylinders were cast and tested for compressive strength and split tensile strength at 28 and 56 days. Durability performance was evaluated by immersing specimens in diluted hydrochloric acid solution and monitoring mass loss and strength reduction. Results indicate that partial replacement of cement with limestone powder improves particle packing, reduces permeability, and enhances resistance against acid attack up to an optimum level. Among all mixes, the 5% replacement level demonstrated superior performance in terms of strength and durability. The study highlights the potential use of limestone powder as a sustainable and economical supplementary material for durable concrete production.*
***Keywords:** Durability, Acidic environments, sustainability, limestone-filler.*

I. INTRODUCTION

Concrete is the most widely used construction material because of its strength, durability, versatility, and economic advantages. However, concrete structures exposed to aggressive environments such as industrial zones, sewage systems, and marine regions are vulnerable to chemical deterioration. Acid attack is one of the major durability problems affecting concrete structures. Acids react with hydration products such as calcium hydroxide and calcium silicate hydrate, resulting in leaching, increased porosity, and loss of structural integrity.

To improve durability and sustainability, researchers have explored the use of supplementary cementitious and filler materials as partial replacements for cement. Limestone powder has emerged as a promising material due to its filler effect, improved particle packing, lower cost, and environmental benefits. The incorporation of limestone powder can refine pore structure, reduce voids, and improve the interfacial transition zone between aggregates and cement paste.

The present study focuses on evaluating the mechanical and durability properties of limestone-filler-based concrete under acidic exposure. Concrete mixes containing different percentages of limestone powder were prepared and tested to identify the optimum replacement level for structural applications.

II. OBJECTIVES

1) To investigate the mechanical and durability performance of limestone-filler-based concrete when exposed to a 1% Hydrochloric Acid (HCl) solution.
2) To evaluate the effect of different limestone filler replacement levels on the mass loss and acid resistance of concrete.
3) To examine the microstructural characteristics of concrete specimens using Scanning Electron Microscopy (SEM) and relate them to durability performance.
4) To determine the optimum limestone filler content that enhances the durability and long-term performance of concrete in acidic environments.

III. LITERATURE REVIEW

1) *Gunjal, S. M., Turkane, S. D., Patankar, S. V., & Kondraivendhan, B. (2023). Effect of magnesium sulphate and sulphuric acid attack on limestone calcined clay cement concrete.*

This study investigates the durability performance of ground calcined clay–limestone (GCCL) cement concrete as an eco-friendly substitute for conventional Ordinary Portland Cement (OPC) concrete. An experimental program was conducted to evaluate the behavior of GCCL concrete under aggressive environments, specifically magnesium sulphate and sulphuric acid exposure.

The results indicate that GCCL concrete exhibits improved resistance to sulphate and acid attacks compared to OPC concrete, with relatively lower strength and weight loss under exposure conditions. Although strength reduction was observed over time in aggressive environments, GCCL concrete demonstrated superior durability performance.

2) *Chauhan, A., & Santhanam, M. (2026). Impact of low-grade limestone on mechanical and durability performance of binary blended cementitious systems. Gomasa, R., Talakokula, V., Jyosyula, S. K. R., & Bansal, T. (2025).*

This study investigates the development and performance of innovative cement-based materials incorporating supplementary constituents and optimized mix design strategies. An experimental approach was adopted to evaluate the influence of material composition and microstructural evolution on the overall performance of the composite. The findings reveal that optimized material combinations significantly improve mechanical performance and durability, attributed to enhanced bonding, reduced porosity, and refined internal structure. Overall, the study demonstrates that advanced cementitious systems can achieve superior performance while contributing to sustainability goals, making them suitable for modern construction applications requiring durability and environmental efficiency.

3) *Jiang, Z., Yang, Q., Wang, B., Li, C., Zhang, J., & Ren, Q. (2024). Limestone filler (LF) as a mineral additive on the compressive strength and durability of self-compacting concrete with limestone manufactured sand. Journal of Building Engineering, 94, 109965:*

In this study, a systematically investigated the role of LF as a mineral additive by evaluating its influence on compressive strength, carbonation resistance, chloride ion migration, and drying shrinkage of MS-based SCC across multiple substitution levels. Results demonstrated that increasing LF content progressively reduced compressive strength and weakened resistance to carbonation and chloride penetration, while simultaneously offering an improvement in drying shrinkage — a finding that highlights the dual and contrasting nature of LF's contribution to concrete performance.

4) *Blazy, J., & Blazy, R. (2021). Polypropylene fiber reinforced concrete and its application in creating architectural forms of public spaces. Case Studies in Construction Materials, 14, e00549.*

Fiber-reinforced concrete is a composite material in which dispersed fibers enhance the mechanical and durability properties of conventional concrete. This study focuses on polypropylene fiber-reinforced concrete (PFRC), examining its characteristics and potential applications in architectural forms of public spaces. Polypropylene fibers are categorized into microfibers and macrofibres depending on their size and functional role within the concrete matrix.

The paper presents an overview of selected polypropylene fibers available in the market and evaluates their influence on key physical and mechanical properties of concrete. These include workability, modulus of elasticity, compressive, tensile, and flexural strength, as well as toughness and impact resistance. Additionally, durability-related properties such as resistance to spalling, freeze–thaw cycles, abrasion, water absorption, permeability, and porosity are discussed.

5) Al-Swaidani, A., Soud, A., & Hammami, A. (2017). Improvement of the Early-Age Compressive Strength, Water Permeability, and Sulfuric Acid Resistance of Scoria-Based Mortars/Concrete Using Limestone Filler. *Advances in Materials Science and Engineering*, *2017*(1), 8373518.

A well-recognized limitation of natural pozzolans, such as volcanic scoria, when used as cement replacements is their tendency to produce lower early-age strength and demand prolonged moist curing. This study sought to address that drawback by investigating whether the addition of limestone filler could enhance the compressive strength and durability of mortar and concrete systems incorporating scoria-based binders.

Sixteen binder combinations were formulated with varying scoria replacement levels of 0–30% and limestone filler additions of 0–15%, and specimens were assessed for compressive strength development at 2, 7, 28, and 90 days, water permeability, and resistance to 5% sulfuric acid solution after 90 days of exposure. The experimental outcomes demonstrated that limestone filler positively enhanced early-age strength and reduced water penetration depth across the tested mixtures.

IV. MATERIALS

A. Cement

Ordinary Portland Cement (OPC) 43 grade conforming to IS 8112 was used throughout the study. Cement is a finely powdered material that undergoes hydration when mixed with water, forming compounds responsible for strength development.

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TABLE I: CEMENT PROPERTY

SR NO.	CEMENT PROPERTY	VALUE
1.	Specific gravity	3.10
2.	Soundness	1.20 mm
3.	Initial setting time	30 mins
4.	Final setting time	600 mins

B. Fine Aggregate:

In this study, M-Sand conforming to IS 383:2016 was used as the fine aggregate in concrete preparation. The material was clean, well graded, and free from harmful impurities such as clay, organic matter, and silt.

TABLE II: FINE AGGREGATE PROPERTY

SR NO.	FINE AGGREAGATES PROPERTY	VALUE
1.	Specific gravity	2.6
2.	Water Absorption	1.2 %
3.	Bulk Density	1550 kg/m³
4.	Grading Zone	ZONE II

C. Coarse Aggregate

The coarse aggregates are deprived from deep quarry or river beds due to which the shape, size, hardness, texture and various properties can vary based on different locations. Accordingly, these aggregates can be identified as smooth or angular or rounded. Natural well graded gravel used in this report study as coarse aggregates with a nominal size of 20 mm. This material in testing process act as a filler material, provide strength, volume stability and durability to construction projects. Crushed angular aggregates of maximum size 20 mm were used, conforming to IS 383:2016.

TABLE III: FINE AGGREGATE PROPERTY

SR NO.	FINE AGGREAGTE PROPERTY	VALUE
1.	Maximum Size	20mm
2.	Specific gravity	2.85
3.	Water Absorption	1.2
4.	Bulk Density	1450 kg/cm^3

D. Limestone Powder

Limestone powder is a finely ground material primarily composed of calcium carbonate ($CaCO_3$) and is widely used as a mineral additive in concrete. It is obtained through the crushing, grinding, and processing of natural limestone rocks. The physical and chemical properties of limestone powder may vary depending on its source, purity, and particle size distribution.

TABLE IV: LIMESTONE POWDER PROPERTY

SR NO.	LIMESTONE POWDER PROPERTY	VALUE
1.	Size	< 75 microns
2.	Specific gravity	2.35
3.	pH	8.2
4.	Colour	Light Pink

E. Chemical Admixture (Superplasticizer)

A high-range water-reducing admixture, FOSROC CONPLAST SP-430, was used to improve workability.

FIG 1: FOSROC Conplast SP430

V. METHODOLOGY

The methodology adopted in this study focused on evaluating the durability of limestone-filler-based concrete in an acidic environment. Initially, the physical properties of cement, fine aggregate, coarse aggregate, and limestone powder were determined in accordance with relevant IS codes. Concrete mixes were designed as per IS 10262:2019, with limestone powder used as a partial replacement of cement at replacement levels of 0% (control mix), 5%, 10%, and 15%.

Concrete cube and cylinder specimens were casted and directly placed in acidic environments with a 1% hydrochloric acid (HCl) solution and exposed for durability evaluation. The performance of the concrete was assessed at 28 days and 56 days of acid exposure to study the effect of prolonged acidic conditions on the concrete.

The durability characteristics were evaluated through compressive strength testing, split tensile strength and mass loss measurements. In addition, Scanning Electron Microscopy (SEM) analysis was carried out on selected specimens to investigate the microstructural changes caused by acid attack. The results obtained from different replacement levels and exposure periods were compared to determine the optimum limestone powder content for enhancing the durability of concrete in acidic environments.

VI. RESULTS AND DISCUSSION

The experimental investigation revealed that limestone powder significantly influences the mechanical and durability properties of concrete. The 5% replacement mix exhibited the highest compressive and tensile strength among all mixes, indicating improved particle packing and reduced permeability.

A. Compressive Strength Results in Cubes (150X150X150 cm)

TABLE V: Compressive Strength Results

Replacement Level	28-Days Compressive Strength (MPa)	56-Days Compressive Strength (MPa)
0%	35.85	34.51
5%	30.89	30.82
10%	34.51	34.05
15%	37.63	37.50

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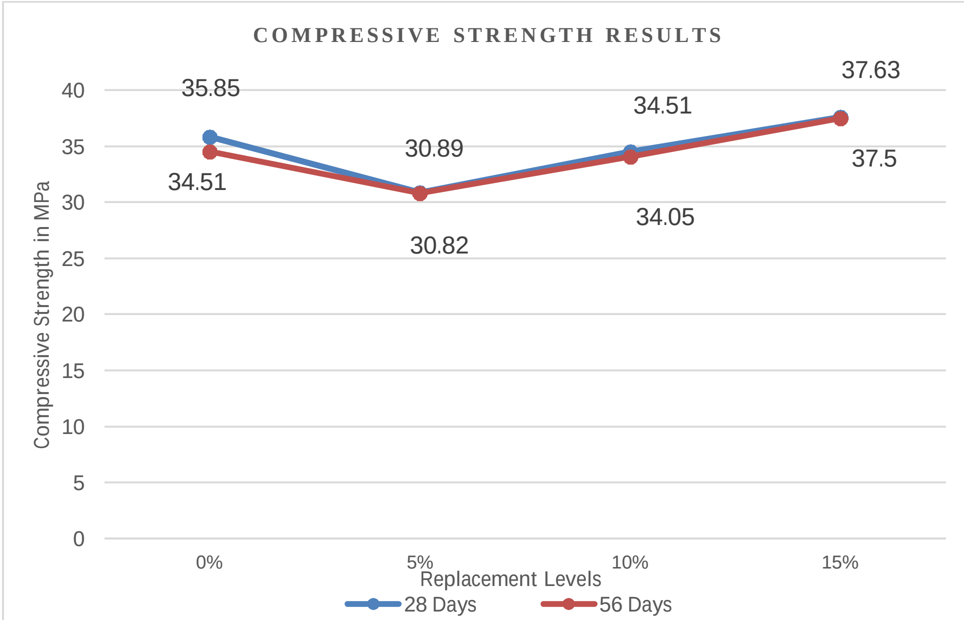

FIG 2: GRAPHICAL REPRESENTATION OF COMPRESSIVE STRENGTH

The control mix (0% limestone powder) achieved a compressive strength of 35.85 MPa at 28 days and 34.51 MPa at 56 days. The 5% replacement mix recorded the lowest strength, with 30.89 MPa at 28 days and 30.82 MPa at 56 days. For 10% replacement, the compressive strength was 34.51 MPa at 28 days and 34.05 MPa at 56 days, showing performance close to the control mix. The highest strength was obtained at 15% replacement, reaching 37.63 MPa at 28 days and 37.50 MPa at 56 days. A slight reduction in strength was observed in all mixes after 56 days of acid exposure.

However, the 15% limestone powder replacement showed the best performance, indicating improved resistance to hydrochloric acid attack and enhanced durability.

B. *Split Tensile Results in Cylinders*

Table VI: Split Tensile Results of Cylinders

Limestone Replacement Level	28-Days Split Tensile (MPa)	56-Days Day Split Tensile (MPa)
0%	3.13	3.05
5%	3.46	3.80
10%	3.09	3.43
15%	2.9	3.58

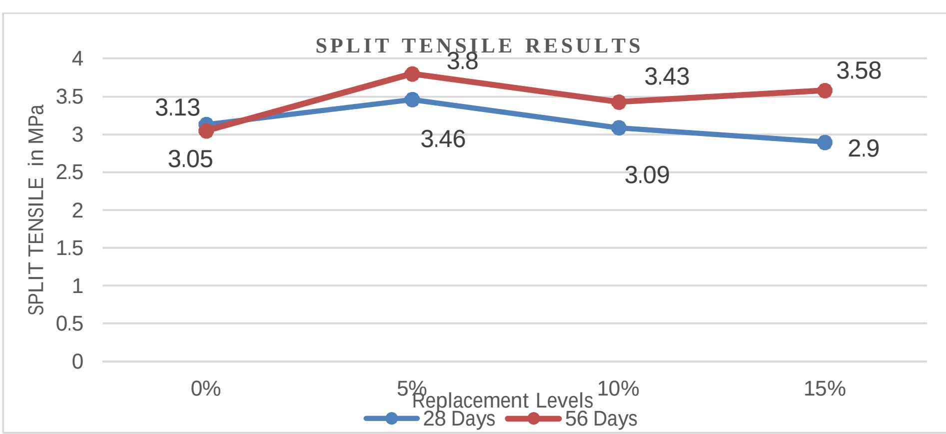

FIG.3: GRAPHICAL REPRESENTATION OF SPLIT TENSILE RESULTS

The control mix (0% limestone powder) achieved a split tensile strength of 3.13 MPa at 28 days and 3.05 MPa at 56 days. The 5% replacement mix showed the highest tensile strength, recording 3.46 MPa at 28 days and 3.80 MPa at 56 days. For 10% replacement, the tensile strength increased from 3.09 MPa at 28 days to 3.43 MPa at 56 days. Similarly, the 15% replacement mix exhibited a significant improvement, increasing from 2.90 MPa at 28 days to 3.58 MPa at 56 days.

Among all mixes, the 5% limestone powder replacement demonstrated the highest split tensile strength, indicating improved crack resistance and bonding within the concrete matrix. The results suggest that limestone powder positively influenced the tensile performance of concrete under acidic exposure, with 5% replacement identified as the optimum level for tensile strength development.

C. Mass Loss%

Mass loss is one of the most important indicators used to evaluate the durability of concrete exposed to aggressive chemical environments. It reflects the extent of material deterioration caused by the dissolution of cementitious compounds and surface degradation under acid attack. In this study, the mass loss percentage of concrete specimens was measured after exposure to a 1% hydrochloric acid solution to assess the effectiveness of limestone powder in improving resistance to acidic conditions.

Here, the mass loss percentage is calculated by:

$$Mass\ loss = Mass_{initial} - Mass_{cured}$$

Table VII: Mass Loss% in Cubes

LIMESTONE REPLACEMENT%	28 DAYS	56 DAYS
0%	5%	5%
05%	5%	7%
10%	5%	4%
15%	6%	6%

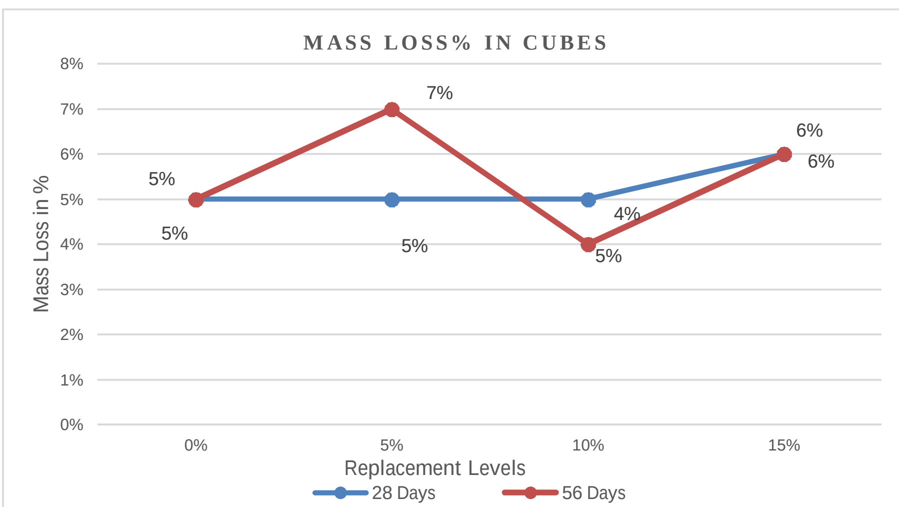

FIG.4: GRAPHICAL REPRESENTATION OF MASS LOSS% IN CUBES

The mass loss test was conducted to evaluate the durability of concrete specimens exposed to a 1% hydrochloric acid (HCl) solution. Mass loss is an important indicator of the extent of deterioration caused by acid attack, as it reflects the dissolution of cementitious compounds and surface degradation of concrete.

The control mix (0% limestone powder) exhibited a mass loss of 5% at both 28 days and 56 days, indicating moderate resistance to acidic exposure. The 5% limestone powder replacement mix showed a mass loss of 5% at 28 days, which increased significantly to 7% at 56 days, suggesting greater susceptibility to acid attack and increased material degradation over time.

The 10% replacement mix recorded a mass loss of 5% at 28 days, which decreased to 4% at 56 days. This result indicates improved durability and better resistance to hydrochloric acid penetration, likely due to a denser and less permeable concrete matrix. The 15% replacement mix showed a mass loss of 6% at both 28 and 56 days, indicating stable performance under prolonged acidic exposure.

Among all the mixes tested, the 10% limestone powder replacement demonstrated the lowest mass loss at 56 days (4%), indicating superior resistance to acid-induced deterioration. In contrast, the 5% replacement level experienced the highest mass loss (7%) and showed the least durability. The results suggest that an appropriate limestone powder content can improve the resistance of concrete to acidic environments by reducing permeability and limiting the ingress of aggressive ions.

Table VIII: Mass Loss% in Cylinders

LIMESTONE REPLACEMENT%	28 DAYS	56 DAYS
0%	2%	4%
05%	1%	2%
10%	2%	3%
15%	4%	6%

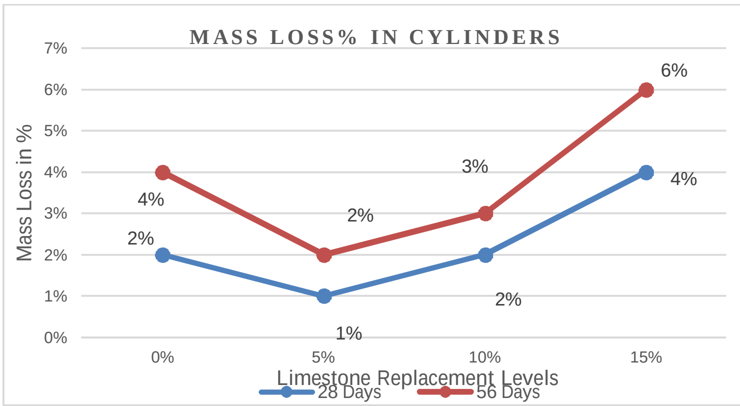

FIG.5: GRAPHICAL REPRESENTATION OF MASS LOSS% IN CYLINDERS

The mass loss test on concrete cylinders was carried out to assess the durability of limestone-filler-based concrete exposed to a 1% hydrochloric acid (HCl) solution. The percentage of mass loss reflects the degree of material deterioration resulting from acid attack. The control mix (0% limestone powder) recorded a mass loss of 2% at 28 days and 4% at 56 days, indicating gradual deterioration with prolonged acid exposure. The 5% replacement mix exhibited the lowest mass loss among all specimens, with 1% at 28 days and 2% at 56 days, demonstrating excellent resistance to acid penetration and material degradation.

For the 10% replacement mix, the mass loss increased from 2% at 28 days to 3% at 56 days. Although some deterioration occurred over time, the values remained lower than those of the control mix, indicating satisfactory durability performance. The 15% replacement mix showed the highest mass loss, increasing from 4% at 28 days to 6% at 56 days, suggesting greater susceptibility to acid attack at higher replacement levels.

Overall, the results indicate that all mixes experienced an increase in mass loss with longer exposure to hydrochloric acid. However, the 5% limestone powder replacement provided the best durability performance, exhibiting the lowest mass loss values (1% and 2%) at 28 and 56 days, respectively. These findings suggest that an optimum limestone powder content can improve the resistance of concrete cylinders to acidic environments by reducing the rate of material degradation and preserving the integrity of the concrete matrix.

D. Scanning Electron Microscopy (SEM) Analysis

The SEM micrograph at 6.26 KX magnification in FIG.6, reveals a highly compact and dense cementitious matrix with well-developed hydration products distributed throughout the observed area. The layered and closely packed morphology indicates the presence of a stable microstructure with strong bonding between the hydration phases. Only a few isolated pores are visible, suggesting a refined pore structure and reduced permeability. The matrix appears continuous with minimal microcracking, demonstrating that the concrete maintained its integrity even after exposure to the acidic environment. The dense arrangement of hydration products indicates that the limestone powder contributed to improved particle packing and matrix densification. Furthermore, the absence of significant deterioration features such as extensive cracking, large voids, or severe surface degradation suggests that the concrete exhibited good resistance to the 1% hydrochloric acid solution.

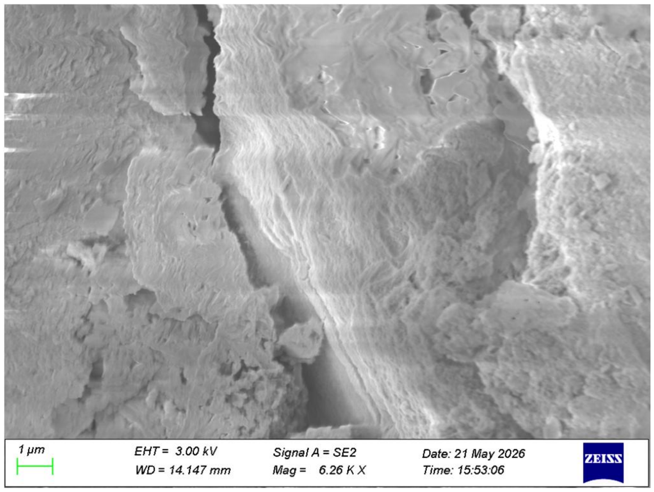

FIG.6: Microstructural Analysis Results of 28 days cured of 05% specimen.

Overall, the microstructural observations confirm that the incorporation of limestone powder enhanced the durability of the concrete by producing a compact and less permeable matrix capable of resisting acid-induced damage.

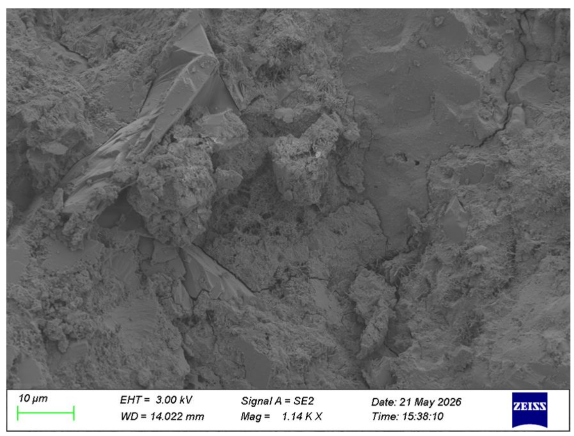

FIG.7: Microstructural Analysis Results of 28 days cured of 05% specimen.

The Scanning Electron Microscope (SEM) image of FIG.7 (Magnification: 1.14 kX, Scale bar: 10 μm) reveals the microstructural characteristics of the tested concrete sample. The micrograph shows a heterogeneous matrix consisting of hydration products, unreacted particles, and void spaces distributed throughout the specimen. The image indicates the presence of a relatively compact cementitious matrix with irregularly shaped hydration products filling portions of the pore structure. Plate-like crystalline formations can be observed in several regions, which are characteristic of hydration products formed during cement hydration. These products contribute to the development of strength by binding the constituent particles together.

Some micro-pores and interconnected voids are visible within the matrix. These pores may have formed due to incomplete hydration, evaporation of excess water, or chemical interactions occurring during exposure to aggressive environments. The existence of such voids can influence the permeability and durability of the concrete by providing pathways for the ingress of harmful substances. Localized microcracks are also observed in certain regions of the image. These cracks may have developed as a result of shrinkage, mechanical loading, or chemical attack. Their presence suggests the initiation of internal deterioration, although the extent of cracking appears limited and does not dominate the microstructure.

VII. CONCLUSIONS

The experimental results demonstrated that acidic exposure affected all concrete specimens by causing gradual deterioration of the cementitious matrix. The interaction between hydrochloric acid and cement hydration products led to leaching, mass loss and minor reductions in mechanical properties over time.

The incorporation of limestone filler improved the overall performance of concrete by refining the pore structure and enhancing the compactness of the matrix. The filler effect reduced void spaces within the concrete and restricted the penetration of aggressive acidic ions. As a result, limestone-filler-based concrete exhibited improved resistance to acid attack compared to conventional concrete. From the study, the limestone powder significantly influenced the strength characteristics of concrete exposed to acidic conditions. The highest compressive strength was achieved at 15% limestone powder replacement, recording 37.63 MPa at 28 days and 37.50 MPa at 56 days, outperforming the control mix. In terms of split tensile strength, the 5% replacement level showed the best performance with 3.80 MPa at 56 days, indicating enhanced crack resistance and improved bonding within the concrete matrix under acidic exposure. The mass loss results showed that limestone powder improved the durability of concrete exposed to a 1% HCl solution. In cube specimens, the 10% replacement mix exhibited the lowest mass loss (4% at 56 days), while the 5% replacement mix showed the highest mass loss (7% at 56 days). In cylinder specimens, the 5% replacement mix performed best with only 2% mass loss at 56 days, whereas the 15% replacement mix recorded the highest value (6% at 56 days). Overall, limestone powder replacement enhanced both strength and durability, with 10% replacement levels providing the most favorable overall performance under acidic exposure conditions. The SEM investigation provided microstructural evidence supporting the mechanical and durability test results. The micrographs revealed dense hydration products, well-developed C-S-H gel, reduced pore connectivity, and satisfactory bonding within the matrix. The overall microstructure remained compact and stable, indicating good durability characteristics. Based on the combined evaluation of compressive strength, split tensile strength, mass-loss behavior under acidic exposure, and SEM microstructural analysis, the 05% to 10% limestone powder replacement level is considered the optimum mix. It provides the best balance between mechanical performance and durability, exhibiting superior resistance to acid-induced deterioration while maintaining adequate strength characteristics for structural applications.

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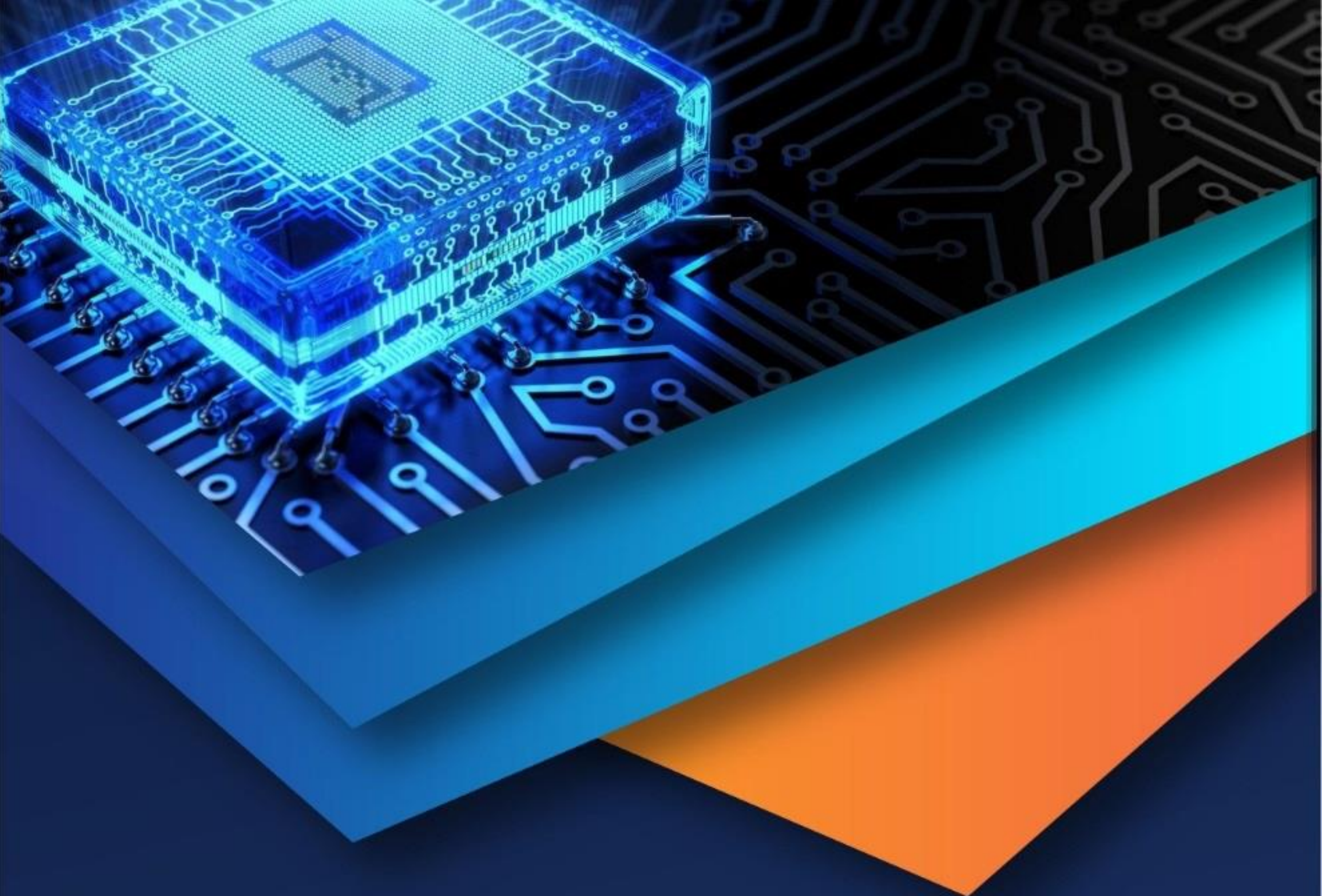

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