*And., Intl.,J., Appl Sci., Eng., Tech, Vol 03, No 03, November 2023*
*e-ISSN: 2797-0442*

# Effect of Glass Powder on Durability Performance of Hardened Concrete in Aggressive Environment

**Odero Frank Onyango*), Benard Omondi, Chrispinus Wamalwa**
[1]Department of Civil and Structural Engineering, Masinde Muliro University of Science and Technology, Kakamega, Kenya
*Corresponding author, e-mail: oderofrank7@gmail.com

**Abstract** – Supplementary Cementitious Materials have been widely researched for application in concrete works, primarily to reduce dependence on cement as a binding medium. This research sought to add to that knowledge base by determining the effect of crushed waste glass powder on the durability performance of hardened concrete in an aggressive environment. Crushed waste glass powder was added to the concrete mix at 10%, 20% and 30% respectively by weight of cement. Fresh concrete was subjected to slump test while hardened concrete was subjected to compressive strength, water absorption, sulphate attack and electrical resistivity tests. The results were then compared to the control mix as well as previous studies. Optimal results were obtained at 30% addition of crushed waste glass powder into the concrete mix, noting an increase in compressive strength by 32.5%, water absorption reduced by 5.9%, sulphate attack effect was low while electrical resistivity reduced by 14.7%.

*Keywords: Absorptivity, Crushed Waste Glass, Durability, Electrical Resistivity, Pozzolanic Activity, Sulphate Attack.*

*This article is licensed under the CC–BY-SA license.*

## 1. Introduction

The quality of concrete is primarily affected by the quality of constituent aggregates which ultimately affect its durability [1]. Factors that affect concrete durability period include but are not limited to its constituents, proportioning of the constituents, interaction between the constituents, placing of concrete, curing technique and service environment exposure conditions [2]. Determination of concrete durability is subject to performance parameters such as exposure conditions, permeability and abrasion resistance among other factors as indicators of its properties [3]. Concrete subjected to an aggressive environment tends to deteriorate by spalling, cracking, weathering and abrasion among other means thereby allowing further ingress and exposing concrete to further degradation [4], [5].

Improper packing of concrete microstructure and use of a higher water binder ratio results in development of voids, increased permeability, risk of bleeding and segregation. Supplementary Cementitious Materials (SCM) such as crushed waste glass powder and modification of mix design have been adopted as a measure to mitigate such degrading effects. Proper packing of the microstructure of concrete and enriching of cementing paste reduces the permeability of concrete by minimising the void ratio hence increasing the durability performance of concrete. [6], [1].

Performance of glass powder in concrete has been well documented through various researches. Glass has been used as a Supplementary Cementitious Material (SCM) and as an aggregate in concrete development [7], [8] [9]. Chemical analysis between clear and coloured glass has been noted to have

*Received: October 29, 2023, Revised: November 24, 2023, Accepted: November 25, 2023*
*https://doi.org/10.25077/aijaset.v3i3.106*

similar properties as per requirements of the American Society for Testing and Materials (ASTM) hence classification as a pozzolanic material [10].

Glass powder has emerged as a promising contender to be employed as a partial alternative to cement or as a filler substance in the fabrication of cement concrete, with special focus on the particle dimensions. It has been ascertained that glass powder could potentially serve as a viable substitute for silica fume, particularly at a maximum replacement percentage of 70%, while maintaining a mean particle size of 38 μm. Notably, a discernible enhancement in workability as well as a reduction in heat flow were observed upon incorporating glass powder at a replacement level of 30% in place of silica fume. Such findings provide valuable insights into the potential applications and benefits of utilizing glass powder in cementitious materials [11].

Glass particle size of ≤ 25 mm at an optimum of between 10% to 20% was noted to cause a decrease in workability, strength, durability and increased risk of Alkali-Silica Reaction (ASR). Particle size of ≤ 4.75 mm at an optimum of 40% had a micro-filling effect resulting in decreased workability but with increased density, strength and durability. Particle size of ≤ 0.75 μm induced pozzolanic reaction, had a micro-filling effect and resulted in increased density, strength and durability at an optimum of between 10% to 20%, [6].

Fly Ash – Glass powder blend used to partially substitute cement resulted in an increase in workability and compressive strength at an optimum of 10% by weight of cement, [12]. This was supported by findings of [1] when glass powder was used as a substitute of cement in concrete resulting in an increase in workability, compressive strength and improved durability at an optimum of 4% by weight of cement. Similar increase in workability and compressive strength was noted when cement was partially replaced with 20% waste glass, [10].

An increase in compressive, split tensile and flexural strength by 16.56%, 7.16% and 6.57% respectively was noted when cement was replaced with waste glass powder at 10% however, replacement of up to 20% gave satisfactory results. The researchers concluded that the use of waste glass powder can prove to be economical as opposed to cement and reduce disposal challenges associated with environmental hazards posed by waste glass. Due to the filler effect and pozzolanic properties of finely ground glass powder, it can also be used to partially replace cement hence reducing energy and carbon (IV) oxide produced during cement manufacture [9].

Based on the trend, it's noticeable that the focus has been on waste glass powder being used as a partial replacement of cement or aggregates with attention majorly on the physical and mechanical properties of concrete. This research, therefore, aimed to explore alternative use of crushed waste glass powder as an additive to concrete mix matrix as opposed to partial replacement with primary objectives to evaluate the performance of resulting hardened concrete against resistance to sulphate attack, water and chloride ion permeability.

## 2. Methodology

### 2.1 Materials

#### 2.1.1 Mixing Water

Mixing water was sourced from the Nairobi city supply mains to the research laboratory, which was used in the mix design for making concrete at a constant water-cement ratio of 0.35 for all mixes.

#### 2.1.2 Cement

The cement used in this research was Portland Pozzolanic Cement (PPC) CEM IV 32.5R cement, conforming to [13] with chemical properties as shown in Table 1.

**Table 1.** Chemical Composition of Cement and Crushed Waste Glass Powder

| Compound | Composition (%) | |
|---|---|---|
| | Cement | CWG Powder |
| Silicon Oxide ($SiO_2$) | 43.662 | 83.383 |
| Aluminium Oxide ($Al_2O_3$) | 7.419 | 0.703 |
| Calcium Oxide (CaO) | 40.585 | 10.553 |
| Potassium Oxide ($K_2O$) | 2.64 | 0.272 |
| Magnesium Oxide (MgO) | 0 | 4.583 |
| Phosphorous Pentoxide ($P_2O_5$) | 0.191 | 0.116 |

#### 2.1.3 Coarse and Fine Aggregates

Coarse and fine aggregates for this research were locally sourced, cleaned to reduce silt content and oven-dried to reduce moisture content. Coarse aggregates used were of sizes 3.18 mm, 6.35 mm and 9.5 mm. Fine aggregates were sieved through 4.75 mm and retained on 150 µm sieves. The aggregates shown in Figure 1, were then subjected to preliminary laboratory tests with the results shown in Table 2.

**Table 2.** Properties of Concrete Aggregates

| Materials | Water Absorption (%) | ACV (%) | AIV (%) | Silt Content (%) | Fineness Modulus |
|---|---|---|---|---|---|
| Coarse Aggregate | 2.6 | 18.4 | 13.4 | - | - |
| Fine Aggregate | 2.4 | - | - | 6.9 | 2.52 |

9.5 mm Agg. 6.35 mm Agg. 3.18 mm Agg. Sand

**Figure 1.** Concrete Aggregate

#### 2.1.4 Crushed Waste Glass Powder (CWGP)

Clear waste glass was locally sourced cleaned, air dried, crushed and sieved through a 150 µm sieve via the process shown in Figure 2 to obtain crushed waste glass powder.

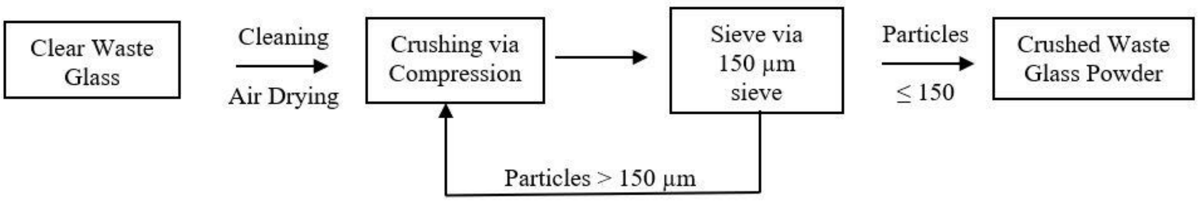


**Figure 2.** Crushed Waste Glass Powder Preparation Process

### 2.1.5 Mix Design and Batching

Mix design for this research was developed based on the principle of Densified Mixture Design Algorithm (DMDA) that proposed maximum packing of larger aggregates with smaller aggregates successively until maximum dry density was achieved. Based on the maximum dry density, quantities of paste contents were determined via prescribed the procedure to obtain concrete aggregate quantities per unit volume of concrete [14]. Batched proportions were determined for the respective mixes and tabulated in Table 3.

**Table 3.** Mix Design

| S/No. ID | Mix Type | Water ($kg/m^3$) | S. Plasticizer ($kg/m^3$) | Cement ($kg/m^3$) | CWGP ($kg/m^3$) | Sand ($kg/m^3$) | 3.18 mm ($kg/m^3$) | 6.35 mm ($kg/m^3$) | 9.5 mm ($kg/m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Mix 1 | 170 | 10 | 486 | 0 | 425 | 191 | 163 | 922 |
| 2 | Mix 2 | 170 | 10 | 486 | 48.6 | 425 | 191 | 163 | 922 |
| 3 | Mix 3 | 170 | 10 | 486 | 97.2 | 425 | 191 | 163 | 922 |
| 4 | Mix 4 | 170 | 10 | 486 | 145.8 | 425 | 191 | 163 | 922 |

## 2.2 Concreting and Casting

Fresh concrete was prepared using a paddle mixer by placing constituent concrete materials in an ascending order, at a constant rate of mixing until uniformity was achieved and slump determined as illustrated in Figure 3.

**Figure 3.** Fresh Concrete Preparation

Fresh concrete was then placed into casting moulds and allowed to set for 24 hours, demoulded and placed into curing tanks until maturity as indicated in Figure 4.

**Figure 4.** Fresh and Hardened Concrete Samples

Test samples for sulphate resistance test as shown in Figure 5, were prepared from fresh mortar paste with equivalent mix ratios as of the concrete mixes and then subjected to curing in 5% Magnesium Sulphate solution for 28 days.

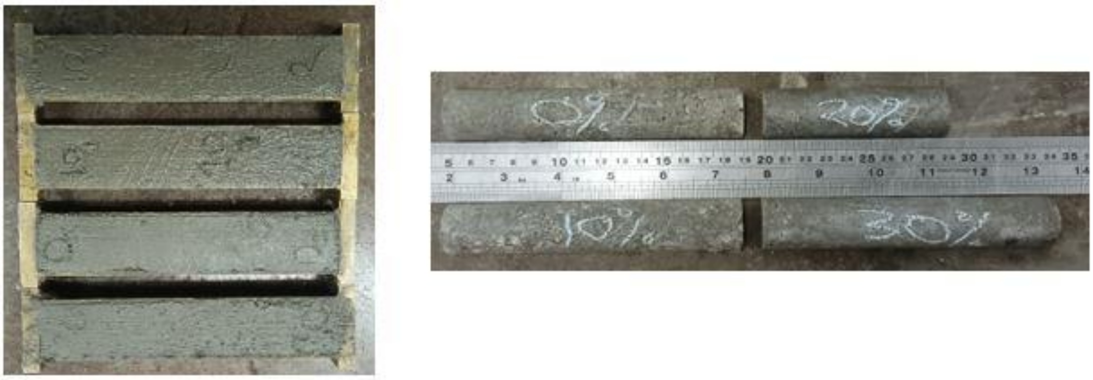


**Figure 5.** Fresh and Hardened Mortar Samples

## 2.3 Laboratory tests

### 2.3.1 Slump test

Slump test was conducted on fresh concrete to determine the workability of the fresh concrete as per the guidelines of [15].

### 2.3.2 Compressive Strength Test

Compressive strength test was conducted on hardened samples at 7, 14 and 28 days respectively across all the mixes to determine the compressive strength performance of the samples conforming to specifications of [16].

### 2.3.3 Water Absorption Test

Water absorption test was conducted on hardened samples after 28 days of curing to determine the rate of absorption of water by the samples as per specifications of [17].

### 2.3.4 Sulphate Attack Test

Hardened mortar samples for the mixes were subjected to curing in 5% Magnesium Sulphate solution for 28 days, variation in mass of the samples was monitored during this period [18].

### 2.3.5 Electrical Resistivity Test

Electrical Resistivity test was conducted on hardened concrete samples after 28 days of curing to determine the electrical resistivity of the samples as per the specifications of [18].

## 3. Results and Discussion

## 3.1 Workability

Slump test results were recorded and data was used to determine the workability of the fresh concrete as shown in Table 4.

*https://doi.org/10.25077/aijaset.v3i3.106*

**Table 4.** Slump Test Results

| Mix ID | Control | 10% CWG | 20% CWG | 30% CWG |
|---|---|---|---|---|
| **Slump (mm)** | 135 | 200 | 555 | 655 |

An increase in slump was noted across the mixes compared to the control sample, this was similar to observation by [11], [1]. This performance was attributed to the use of superplasticizer which causes dispersion of cement and crushed waste glass powder particles coupled with the crystalline non-porous micro structure nature of the crushed waste glass powder with lower water absorptivity hence free flow of the particles.

### 3.2 Compressive Strength

Compressive strength test was carried out on 7, 14 and 28 days for each mix on the hardened concrete samples and the results were as shown in Figure 4.

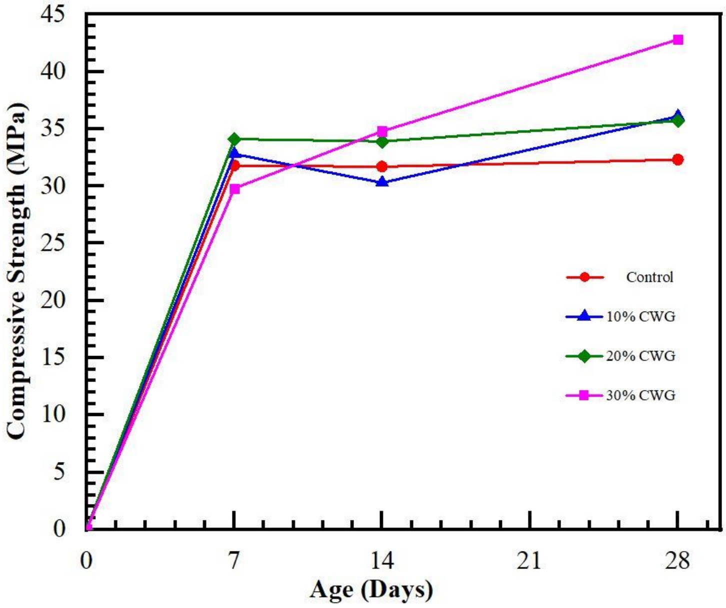


**Figure 4.** Compressive Strength Performance

Compressive strength increased by 11.8%, 10.5% and 32.5% for mix 2, 3 and 4 respectively at day 28 in comparison to mix 1. This performance indicated an increase in compressive strength with an increase in the amount of crushed waste glass powder across the mixes. The trend can be attributed to the pozzolanic reaction of crushed waste glass powder and cement during the hydration process where silica in glass powder dissolves under an alkane environment reacting with calcium ions to form C-S-H gels that reduced porosity and increased compressive strength [19].

### 3.3 Water Absorption

Water absorption test was conducted on hardened mortar after 28 days of curing across all mixes and the result was as indicated in Figure 5.

*https://doi.org/10.25077/aijaset.v3i3.106*

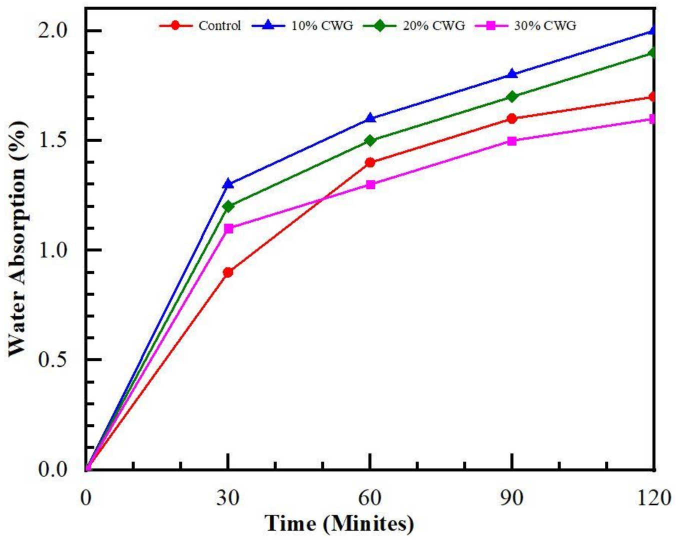


**Figure 5.** Water Absorption Trend

An increase of 17.6% and 11.7% for mix 2 and 3 respectively were noted while a decrease of 5.9% for mix 4 respectively at 120 minutes compared to mix 1. Mix 4 sustained a lower water absorption rate than mix 1. This performance can be attributed to the densification effect of the crushed waste glass powder and cement during the hydration process when pozzolanic reaction occurs leading to the formation of C-S-H gels that densify the pore structure of concrete microstructure which concurs with studies by [19].

### 3.4 Sulphate Attack

Sulphate Attack test was conducted on hardened mortar samples at 7, 14 and 28 days across all mixes and the result was as indicated in Figure 6.

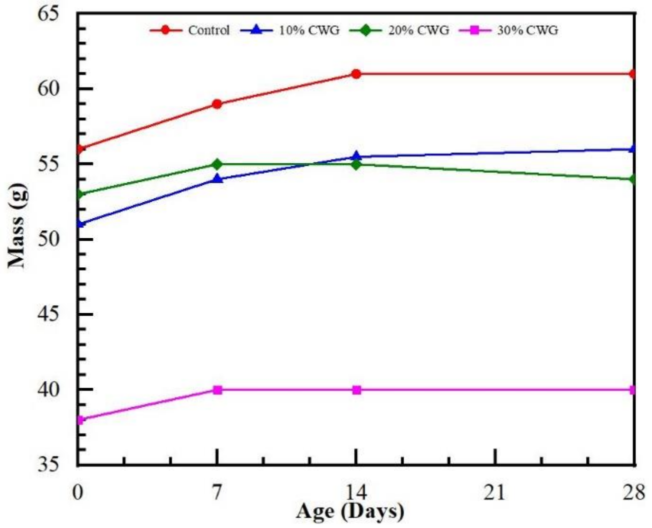


**Figure 6.** Sulphate Attack Trend

Mass increased by 3.4% and 3.7% for mix 1 and 2, a decrease of 1.8% for mix 3 while no change in mass of mix 4. The increase in mass can be attributed to the ingress of the sulphate solution which contributed to the hydration process that resulted in additional compounds in the formation of C-S-H gels densifying the mortar. This performance supports the advantages of the micro-filling effect of the crushed waste glass powder as well as the build-up of C-S-H gels that contribute to the densification of the cementing paste matrix as noted by [19].

### 3.5 Chloride Ion Permeability

Electrical Resistivity test was conducted on hardened concrete at 28 days across all mixes, the result was as indicated in Table 5.

**Table 5.** Electrical Resistivity Results

| Mix ID | Control | 10% CWG | 20% CWG | 30% CWG |
|---|---|---|---|---|
| **Ohm Meter Reading (kΩ/cm)** | 13.6 | 12.8 | 12.3 | 11.6 |

A decrease of 5.9%, 9.6% and 14.7% in electrical resistivity was noted for mix 2, 3 and 4 respectively relative to mix 1 with an increase in the quantity of crushed waste glass powder yet within moderate classification in terms of chloride permeability [18]. This performance could be attributed to the level of porosity, pore structure and pore solution temperature among other varying factors that affect the movement of ions within the concrete microstructure [19].

## 4. Conclusion

Based on the findings of this research, the addition of 30% crushed waste glass powder by weight of cement was found to have satisfactory overall performance noting an increase in compressive strength from 32.3 Mpa to 42.8 Mpa representing an increase of 32.5%. Water absorption reduced from 1.7% to 1.6% within 120 minutes representing a decrease of 5.9%. Sulphate attack test showed a constant mass sustained within 28 days. Electrical resistivity reduced from 13.6 kΩ/cm to 11.6 kΩ/cm representing a decrease of 14.7% yet within a moderate range. Further research should be done to assess the possible cause of the reduction in electrical resistivity when crushed waste glass powder is added to concrete mix as well as possible use of crushed waste glass in concrete beyond the 30% amount by weight of cement.

## Acknowledgement

The authors are grateful to the Department of Structural and Construction Engineering of the Technical University of Kenya through the director for facilitating the research and to the staff and students who dedicated their time to assist in various capacities during this research.

## References

[1] D. B. Eme and C. Nwaobakata, "Effect of Powdered Glass as an Admixture in Cement Concrete Block," Nigerian Journal of Technology (NIJOTECH), vol. 38, no. 1, pp. 8 - 14, January 2019.

[2] Portland Cement Association, "Durability," 19 February 2023. [Online]. Available: https://www.cement.org/learn/concrete-technology/durability. [Accessed 19 February 2023].

[3] S. Nanukuttah, K. Yang, J. McCarter and M. Basheer, "Methods of Assessing The Durability and Service Life of Concrete Structures," 2017.

[4] The Constructor, "Concrete Exposed to Sea Water - Effect & Prevention," 25 July 2023. [Online]. Available: https://theconstructor.org/concrete/concrete-seawater-effects-preventions/843/.

[5] L. Nicole, "ENVIROSIGHT," 12 June 2017. [Online]. Available: https://blog.envirosight.com/the-cost-of-sewer-pipe-corrosion.

[6] J. Ahmad, Z. Zhou, K. I. Usanova, N. I. Vatin and M. A. El-Shorbagy, "A Step Towards Concrete with Partial Substitution of Waste Glass (WG) in Concrete: A Review," Materials, no. 15, pp. 1 - 23, 30 March 2022.

[7] Y. Jani and W. Hogland, "Waste Glass in the Production of Cement and Concrete - A Review," Journal of Environmental Chemical Engineering, no. 2, pp. 1767 - 1775, 25 March 2014.

[8] B. S. Shekhawat and V. Aggarwal, "Utilization of Waste Glass Powder in Concrete - A literature Review," International Journal of Innovative Research in Science, Engineering and Technology, vol. 3, no. 7, pp. 14822 - 14826, 2014.

[9] A. Anwar, "The Influence of Waste Glass Powder as a Pozzolanic Material in Concrete," International Journal of Civil Engineering and Technology (IJCIET), vol. 7, no. 6, pp. 131 - 148, November - December 2016.

[10] G. M. S. Islam, M. H. Rahman and N. Kazi, "Waste Glass Powder as Partial Replacement of Cement for Sustainable Concrete Practice," International Journal of Sustainable Built Environment, no. 6, pp. 37 - 44, June 2017.

[11] N. A. Soliman and A. Tagnit-Hamou, "Partial Substitution of Silica Fumes with Fine Glass Powder in UHPC: Filling the Micro Gap," Construction and Building Materials, vol. 139, pp. 374 - 383, 16 February 2017.

[12] V. Verma and H. Varshney, "The Possibility of Replacement of Cement by Fly Ash and Flass Powder," International Journal of Advanced Research in Science and Engineering, vol. 7, no. 03, pp. 516 - 523, January 2018.

[13] Kenya Bureau of Standards (KEBS), Cement-Part 1:Composition, specification and conformity criteria for common cements., Nairobi: Kenya Bureau of Standards (KEBS), 2005.

[14] M. Techman and S. Skibicki, "Use of DMDA Method for Production of Heavyweight Concrete," in MATEC Web of Conferences, Szczecin, Poland, 2018.

[15] British Standards Institution, BS 12350 - 2: Testing Fresh Concrete - Slump Test, London, United Kingdom: British Standards Institution, 2019.

[16] British Standards Institution, BS EN 12390 - 3: Testing Hardened Concrete - Compressive Strength of Test Specimens, London, United Kingdom: British Standards Institution, 2019.

[17] British Standards Institution, BS 1881 - 122: Method for Determination of Water Absorption, July 2011 ed., London, United Kingdom: British Standards Institution, 2011.

[18] AASHTO, AASHTO T358: Standard Test Method for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration, Washington DC, United States of America: American Association of State Highway and Transportation Officials, 2015.

[19] H. Du and K. H. Tan, "Properties of High-Volume Glass Powder Concrete," Cement & Concrete Composites, pp. 1 - 37, 2016.

[20] H. M. Nadir and A. Ahmed, "The Mechanism of Sulphate Attack in Concrete - A Review," Modern Approaches on Material Science, pp. 658 - 670, 2022.