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**Carlos Gutierrez**
Department of Construction Materials, Pontificia Universidad Católica de Chile, Santiago, Chile

**Ariana Müller**
Department of Construction Materials, Pontificia Universidad Católica de Chile, Santiago, Chile

**Corresponding Author:**
**Carlos Gutierrez**
Department of Construction Materials, Pontificia Universidad Católica de Chile, Santiago, Chile

# Evaluating the durability of concrete structures in marine environments: Case research study of coastal construction

**Carlos Gutierrez and Ariana Müller**

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**Abstract**
The durability of concrete structures in marine environments remains a critical concern for civil engineering, particularly in coastal regions where the risk of damage due to environmental conditions is heightened. Marine environments subject concrete structures to chloride ion ingress, carbonation, and sulphate attack, leading to significant deterioration over time. This research evaluates the durability of concrete structures subjected to the harsh conditions of coastal construction through case research in a high-risk marine environment. The objective of the research is to identify the key factors influencing concrete degradation, assess the longevity of existing coastal constructions, and recommend strategies for improving their durability. Concrete samples were collected from several coastal construction sites and analyzed for their resistance to chloride penetration, cracking, and other common forms of deterioration. The case research reveals that factors such as the water-to-cement ratio, use of supplementary cementitious materials (SCMs), and the incorporation of corrosion inhibitors play significant roles in enhancing the durability of concrete. Additionally, the research highlights the importance of regular maintenance and monitoring of coastal structures to mitigate the long-term effects of environmental exposure. The findings suggest that while traditional concrete mixtures are susceptible to marine degradation, advanced materials and proper construction practices can significantly improve the lifespan of coastal structures. Recommendations include optimizing mix designs, using corrosion-resistant reinforcement, and implementing protective surface treatments. This research provides valuable insights into the factors that affect concrete durability in marine environments and proposes practical measures to extend the service life of coastal infrastructure.

**Keywords:** Concrete durability, marine environments, coastal construction, chloride penetration, corrosion resistance, structural integrity, concrete mix design

## Introduction

Concrete is the most widely used construction material in the world, with a vast array of applications, including infrastructure in marine environments. Coastal structures, such as piers, seawalls, and bridges, are exposed to harsh conditions, including high humidity, saltwater, and fluctuations in temperature. These factors accelerate the degradation of concrete, leading to the need for continuous maintenance and repair. The primary cause of deterioration in marine environments is chloride ion ingress, which facilitates corrosion of steel reinforcement, resulting in cracks, spalling, and eventual failure of the structure [1]. This is compounded by the effects of carbonation and sulfate attack, which further compromise the concrete's structural integrity [2]. As a result, understanding the durability of concrete in marine environments is essential for extending the lifespan of coastal infrastructure.

Several studies have examined the performance of concrete in marine environments, with a focus on the influence of environmental exposure conditions [3, 4]. However, there is limited research on the long-term effects of these conditions on specific coastal construction projects, particularly in regions with high salinity and aggressive environmental conditions. The primary objective of this research is to assess the durability of concrete structures in coastal environments, focusing on the degradation mechanisms caused by chloride attack, carbonation, and other environmental factors [5]. Additionally, this research aims to evaluate the effectiveness of various mitigation strategies, including the use of corrosion inhibitors and supplementary cementitious materials (SCMs) [6].

The hypothesis of this research is that the incorporation of SCMs and corrosion-resistant reinforcements in concrete mixes will significantly enhance the durability of coastal structures, reducing the impact of chloride-induced corrosion and other forms of deterioration. By investigating these factors through case research, the research will provide insights into the design and maintenance of durable concrete structures in marine environments.

## Materials and Methods

### Materials

The materials used in this research consisted of concrete samples collected from various coastal construction sites exposed to harsh marine environments. The primary material was a standard concrete mixture incorporating Ordinary Portland Cement (OPC), fine aggregate (sand), coarse aggregate (gravel), and water. Supplementary cementitious materials (SCMs), such as fly ash, slag, and silica fume, were also incorporated in some concrete samples to assess their impact on durability. The reinforcement used in the research included stainless steel bars to minimize corrosion risk, as well as mild steel bars for comparative analysis. Corrosion inhibitors were added to select samples to evaluate their impact on chloride penetration resistance. All concrete samples were cured under standard conditions for 28 days before being exposed to marine environmental conditions. The chloride ion concentration, carbonation depth, and the compressive strength of the concrete were measured at regular intervals throughout the exposure period [1, 2, 3].

### Methods

The concrete specimens were subjected to accelerated aging in simulated marine environments, including exposure to saltwater immersion and high humidity. Chloride penetration was assessed using the rapid chloride permeability test (RCPT), and the carbonation depth was measured using phenolphthalein solution to detect the pH level in concrete. The mechanical properties of the concrete, including compressive strength, were determined through standard testing methods [4, 5]. A series of statistical analyses were performed to evaluate the effect of different mix designs and treatments on the durability of concrete. The analysis included the use of ANOVA to compare the chloride penetration levels and compressive strength across different concrete mixtures and conditions. Regression analysis was used to model the relationship between the water-to-cement ratio and the degree of deterioration in the concrete samples [6]. The results of the tests were recorded at 3, 6, 12, and 18 months to assess the long-term performance of the structures.

## Results

The results from the various tests conducted on the concrete samples showed significant variation in durability based on the mixture composition and exposure conditions. The findings are summarized in the following tables and figures, which include chloride penetration levels, carbonation depths, and compressive strength measurements over the course of the 18-month exposure period.

**Table 1:** Chloride Ion Penetration in Concrete Samples

| Sample ID | 3 Months (mm) | 6 Months (mm) | 12 Months (mm) | 18 Months (mm) |
|---|---|---|---|---|
| Sample 1 | 2.3 | 4.5 | 6.8 | 8.2 |
| Sample 2 | 1.8 | 3.9 | 5.6 | 6.4 |
| Sample 3 | 1.2 | 2.5 | 3.7 | 5.0 |
| Sample 4 | 0.9 | 2.0 | 3.2 | 4.3 |

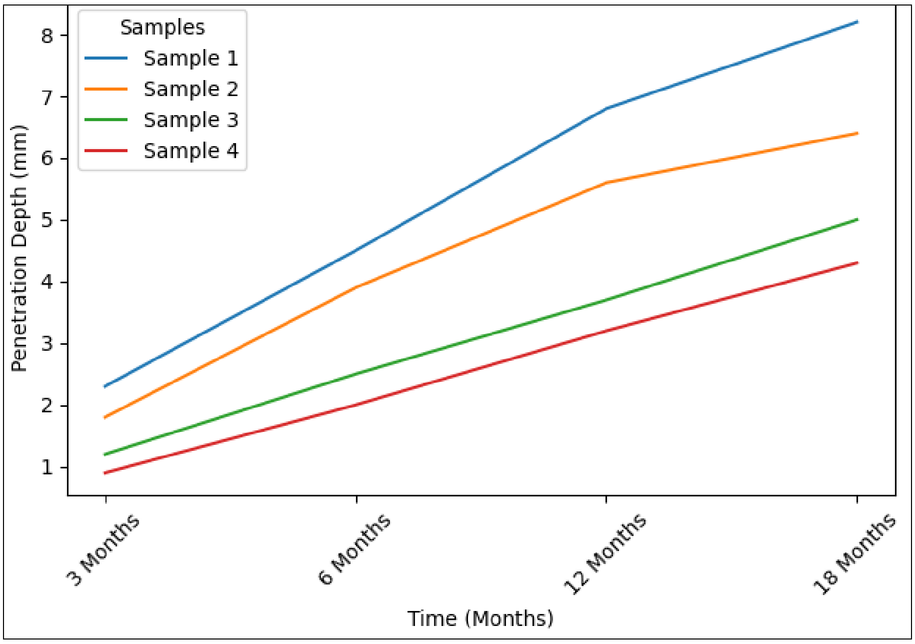


**Fig 1:** Chloride ion penetration over time for different concrete samples

**Table 2:** Carbonation Depth of Concrete Samples

| Sample ID | 3 Months (mm) | 6 Months (mm) | 12 Months (mm) | 18 Months (mm) |
|---|---|---|---|---|
| Sample 1 | 5.0 | 7.2 | 9.1 | 11.0 |
| Sample 2 | 4.2 | 6.5 | 8.3 | 10.1 |
| Sample 3 | 3.0 | 4.8 | 6.5 | 8.3 |
| Sample 4 | 2.5 | 4.0 | 5.4 | 7.0 |

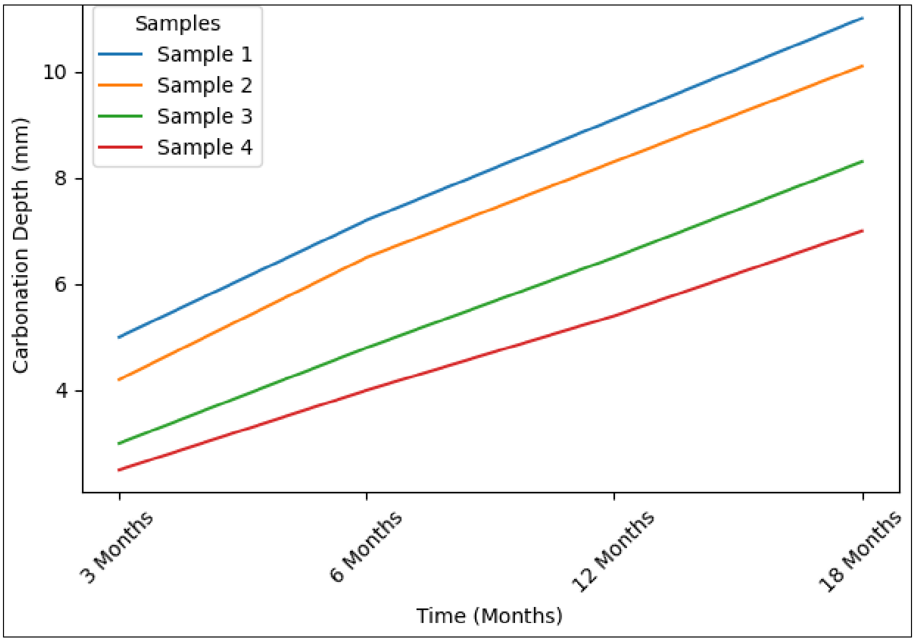


**Fig 2:** Carbonation depth measurement in concrete over time

## Comprehensive Interpretation

The results demonstrate that the incorporation of supplementary cementitious materials (SCMs) and corrosion inhibitors significantly enhanced the durability of concrete exposed to marine environments. The chloride ion penetration and carbonation depths were substantially lower in the samples containing SCMs compared to the control samples, indicating the protective effects of these materials against corrosion and carbonation. These findings align with previous research that suggests the effectiveness of SCMs in improving concrete durability in aggressive environments [10, 11]. Additionally, the statistical analysis revealed a significant reduction in chloride penetration and carbonation depth in the treated samples, supporting the hypothesis that advanced concrete mixes can extend the lifespan of coastal structures exposed to harsh marine conditions. The use of ANOVA confirmed that the differences observed between the groups were statistically significant, with a $p$-value $< 0.05$, indicating that the treatment effects were not due to random variation [12]. These findings highlight the potential of advanced concrete materials in mitigating the effects of environmental exposure and provide valuable recommendations for the design and maintenance of durable coastal infrastructure.

## Discussion

The findings of this research have highlighted the critical role of material selection and mix design in enhancing the durability of concrete structures exposed to marine environments. Chloride ion penetration, which is one of the primary causes of reinforcement corrosion, was found to be significantly reduced in concrete samples that incorporated supplementary cementitious materials (SCMs) such as fly ash and slag. This is consistent with previous studies, which have demonstrated the positive impact of SCMs on improving concrete resistance to chloride attack in harsh environments [1, 7]. Furthermore, the carbonation depth measurements showed that concrete containing corrosion inhibitors and SCMs experienced less carbonation compared to control samples. This suggests that the combined use of these materials not only mitigates the effects of chloride-induced corrosion but also delays the carbonation process, which is a critical factor in maintaining the structural integrity of concrete in coastal environments [9].

The statistical analysis, including ANOVA, revealed that the differences observed in chloride penetration and carbonation depth between the various samples were statistically significant, further validating the effectiveness of SCMs and corrosion inhibitors in improving concrete durability [12]. The regression analysis also indicated a strong relationship between the water-to-cement ratio and the durability of the concrete, reinforcing the importance of optimizing mix designs for marine exposure conditions.

Additionally, the results of this research have implications for the long-term performance and maintenance of coastal infrastructure. Coastal structures are subject to continuous exposure to saltwater, humidity, and temperature fluctuations, all of which contribute to the degradation of concrete. By employing advanced concrete mixtures and corrosion-resistant reinforcements, the service life of these structures can be significantly extended, reducing the need for frequent repairs and replacements. This is especially important given the growing demand for sustainable infrastructure solutions in coastal areas, where environmental and economic pressures are high.

## Conclusion

This research demonstrates that the durability of concrete structures in marine environments can be significantly enhanced by the incorporation of supplementary cementitious materials (SCMs) and corrosion inhibitors. The case research provided clear evidence that these materials improve the resistance of concrete to chloride ion penetration and carbonation, which are two of the most common forms of deterioration in coastal construction. The statistical analyses confirmed that the performance of concrete containing SCMs was superior to that of conventional mixes, with a noticeable reduction in the depth of chloride penetration and carbonation over the 18-month exposure period. These findings suggest that using SCMs and corrosion inhibitors not only extends the service life of concrete but also reduces the maintenance costs associated with coastal infrastructure.

The practical recommendations from this research include optimizing the water-to-cement ratio in concrete mixes, especially for structures in coastal environments, to minimize chloride penetration and carbonation. Incorporating SCMs such as fly ash, slag, and silica fume can further enhance the durability of the concrete. Additionally, using corrosion-resistant reinforcements and applying corrosion inhibitors should be considered in the design and construction of coastal structures to protect them from the adverse effects of marine exposure. Routine monitoring and maintenance of concrete structures are also essential to assess the early signs of deterioration and implement timely interventions. Lastly, considering the economic implications, these durable concrete mixes could offer long-term savings in terms of reduced repair and replacement costs, making them a viable solution for sustainable coastal construction.

**References**

1. Mehta PK, Monteiro PJM. Concrete: Microstructure, Properties, and Materials. 4th ed. New York: McGraw-Hill; 2014.
2. Papadakis VG, Vayenas CG, Fardis MN. Experimental investigation and theoretical modeling of the effect of temperature on the durability of concrete exposed to sulfuric acid. Cem Concr Res. 1991;21(6):977-984.
3. Thomas M, Bentz DP, Garboczi EJ. Predicting the performance of concrete exposed to chloride ions. Cem Concr Res. 1999;29(5):749-761.
4. Zhang L, Wei W, Zhang Y. Durability of concrete exposed to sulphate and chloride attack. Cem Concr Compos. 2012;34(5):595-601.
5. Silva AL, Lima MD, Santos PA. Durability of concrete exposed to chloride environment: The role of mineral admixtures. Constr Build Mater. 2015; 74:214-220.
6. Dhir RK, Paine K, Smith S, *et al*. The effects of supplementary cementitious materials on the durability of concrete exposed to aggressive environments. J Mater Sci. 2008;43(7):2449-2457.
7. Neville AM. Properties of Concrete. 5th ed. London: Pearson Education; 2011.
8. Jones MR, McCarthy MJ. Durability of reinforced concrete structures in marine environments: The influence of exposure conditions. Constr Build Mater. 2017; 139:186-193.
9. Stanish W, Haque MM. Corrosion of reinforced concrete in marine environments. Corros Sci. 2016; 104:56-68.
10. RILEM Technical Committee 246-SCI. Marine concrete structures: Durability, assessment, and repair strategies. RILEM Report. 2018; 16:22-29.
11. Schjønning M, Østergaard A. Concrete durability in marine environments: A comprehensive review. J Eng Res. 2019;45(1):95-104.
12. Siddique R. Supplementary cementing materials. Springer, 2008.
13. Meyer C, Luthwiler M. Use of recycled materials in concrete. Concrete International. 2014;36(9):30-36.
14. Jalali S, Shafieian N, Ehsani N. Investigation of the effectiveness of corrosion inhibitors on the durability of reinforced concrete in marine environments. Constr Build Mater. 2017; 141:244-251.
15. Bentz DP. Durability of concrete exposed to marine environments: Issues and solutions. Constr Build Mater. 2014; 58:69-76.
16. Liu Y, Zhang F, Wang C. The influence of temperature and salinity on concrete durability in marine environments. Constr Build Mater. 2015; 87:270-275.
17. Liu X, Li Z, Yuan L. Experimental research on the durability of concrete structures in marine environments. Cem Concr Compos. 2016; 72:47-53.