

PERFORMANCE COMPARISON OF OPTIMIZED SCM-BASED CONCRETE MIXES IN MARINE ENVIRONMENTS OVER VARYING DESIGN LIVES

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ABSTRACT

Coastal bordering countries like Bangladesh, concrete is commonly used for infrastructure development. Concrete performance is significantly impacted by corrosion in coastal regions due to chloride attack, which results in reinforcement deterioration, reduced durability, and increased maintenance costs over time. A sustainable method to mitigate high resource consumption and long-term environmental impacts is to extend the service life of concrete structures with most optimized mix design. Partially replacing cement with Supplementary Cementitious Materials (SCMs) can significantly reduce the carbon footprint and also improve durability by resisting chloride attack, extending service life. To determine the cost-effective and environmentally friendly design life (50 years vs 100 years), this study investigates concrete mixes for a 5 sq.m slab having 200 mm thickness and 50 mm clear cover that incorporate 40% locally available SCMs, such as class F fly ash, ground granulated blast-furnace slag (GGBS) and silica fume. Life-365TM (v1.0.0, online) software is used to predict the service life (durability performance) and life cycle cost of each mix under chloride exposure and the EcoConcrete Calculation Tool (v2.01) is used to evaluate the environmental impact of the design mix by performing simplified Life Cycle Assessment (LCA). Taking 40% OPC replacement by SCMs, multiple trial concrete mixes for 50 and 100 years design life were simulated to identify optimal mix combinations that maximize durability and minimize environmental impact and life cycle costs for each design life scenario. The optimal SCM replacement levels are projected by considering service life environmental impact reductions and life cycle cost altogether for each design life. These mixes minimize the carbon footprint and increase service life when compared to ordinary Portland cement concrete. Here, models show variable trend for service life, life cycle cost and environment impact reduction. Various methods are implemented to have a better optimization to develop a weightage equation, which leads to service life of 51.58 years and 9.64% environment impact reduction for 50 years design life. But for 100 years design life, 104.92 years service life and 1.33% environment impact reduction was found, having almost equal life cycle cost for both cases. This work demonstrates that optimized eco-concrete mixtures can simultaneously meet extended durability requirements and environmental impact reduction, guiding to appropriate design life selection for resilient and sustainable coastal infrastructure.

Keywords: *Supplementary Cementitious Materials(SCMs), Chloride Exposure, Life Cycle Assessment, Life Cycle Cost, Life-365TM*

1. INTRODUCTION

Reinforced concrete structures in coastal regions experience serious durability challenges due to chloride-induced corrosion of reinforcing steel, making it a critical engineering criterion. This deterioration problem is severe and faster in coastal areas of Bangladesh, as tidal flooding and seawater spray are common (Bertolini, 2008; Srinivasan & Gibb, 2019). Chloride concentrations on concrete surfaces in marine areas can reach 4–6 kg/m³, while the corrosion threshold for steel is only 0.4–0.6 kg/m³ (Bertolini, 2008). Chloride ions penetrate through the concrete cover, attack the reinforcement rebars, and lead to crack, spall of concrete and reduce load-bearing capacity, which results in premature serviceability failures and shorter structural lifespans.

It is a common design practice to consider a 50-year design life for buildings in Bangladesh. But for service structure like Hospital, Schools etc. a higher design life should be considered for long-term uninterrupted service. In coastal areas of Bangladesh, chloride penetration depths of 50–60 mm within the first decade of service, significantly reducing structural lifespan (Srinivasan & Gibb, 2019). However, to achieve and maintain a larger lifespan in aggressive marine environments often requires high cement content, which significantly increases carbon emissions. Cement manufacturing contributes nearly 7% of global CO₂ emissions (Cheng, 2023), creating the need for sustainable solutions. This establishes a critical dilemma: the pursuit of durability through conventional means directly undermines efforts toward environmental sustainability.

Supplementary cementitious materials (SCMs) i.e., fly ash, ground granulated blast-furnace slag (GGBS), and silica fume can help to increase service life in aggressive marine environment. These materials improve pore structure, reduce permeability, and enhance chloride resistance while reducing cement demand and environmental impact (Lothenbach, Scrivener, & Hooton, 2011; Joseph, et al., 2017). Concrete containing 30–50% SCM replacement can extend the time to corrosion initiation by three to four times compared to conventional mixes (Thomas & Bentz, 2002). Fly ash improves long-term strength and workability, extending design life by 1.5–2 times while cutting CO₂ emissions by 20–30% (Van den Heede, Van Belleghem, Van Tittelboom, & De Belie, 2017). GGBS provides even better chloride resistance and can reduce global warming potential (GWP) by 30–45% (Orozco, Tangtermsirikul, Sugiyama, & Babel, 2023). Silica fume is a fine non-crystalline silica by-product from elemental silicon or alloy manufacturing. Silica fume is highly effective in improving strength and reducing chloride diffusivity, often increasing compressive strength by 10–20%, but its production process is energy-intensive and can raise environmental impact (Hossain, Poon, & Dong, 2018).

The study compares mixes designed for 50- and 100-year lifespans with goal to identify the optimal design period and SCM added mix that ensures strength, durability, and environmental balance, contributing to more sustainable coastal infrastructure in Bangladesh. To achieve this, the analysis will focus on key performance indicators as model targets, including the predicted time to corrosion initiation, the Global Warming Potential (GWP) in kg CO₂-eq, and Total life cycle cost. These targets will allow for a quantitative comparison to determine the most eco-efficient solution for sustainable coastal infrastructure in Bangladesh.

2. MODEL AND MATERIAL DESCRIPTION

2.1 Model Description

In this study we considered a reinforced concrete slab with surface area 5 sq. m (53 sq. inches) and thickness of 200 mm (8 inches). A typical reinforcement depth of 50 mm (2 inches) is considered. In Life-365TM software, to create this model, we considered the Florida Tampa region (Marine spray zone) for the analysis as this environment is close to our Cox's Bazar region.

The model determines a maximum surface chloride concentration, C_s , and the build-up time required to reach that maximum concentration, based on the type of structure, its geographic location, and exposure, as input by the user. For this study, default values of C_s and temperature profile were utilized, as this software includes these inputs based on ASTM C1556 data calculations. Figure 02 shows the

boundary condition, assuming a linear build-up period of 10 years to reach maximum concentration, where figure 03 shows the temperature profile of Tampa, Florida.



Figure 1: Model of slab at Life-365TM

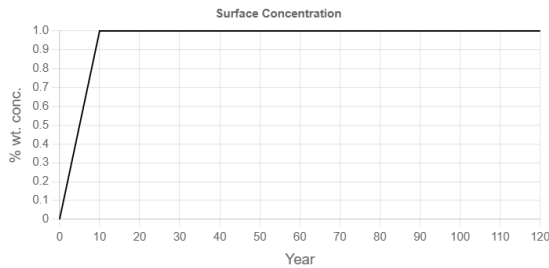


Figure 2: Surface Chloride Concentration graph

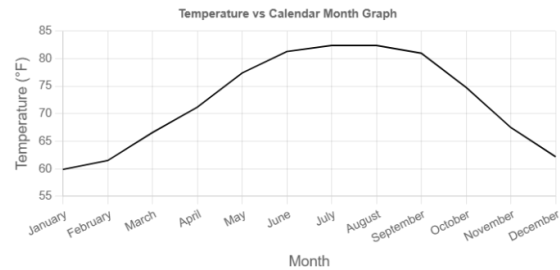


Figure 3: Temperature profile at every month

2.2 Material Description

2.2.1 Material Selection

Materials were chosen considering Bangladesh's context for both the base case scenario (BCS) and the alternate case scenario (ACS). A water-cement ratio of 0.4 is maintained for all mixes. For BCS, the unit mass of fresh concrete is 2345 kg/m³, with nominal maximum aggregate size of 19mm. Aggregates include stone chips and sand, with study showing that stone chip content can be economically and sustainably used up to about 30% of the total aggregate volume (Sarker, Arifa, Hossain, Ishaque, & Chowdhury, 2018). The specific SCMs investigated in this study include Class F Fly Ash, Ground Granulated Blast Furnace Slag (GGBS) and Silica Fume, selected for their availability in our country. While the BCS mixture maintained a conventional composition without any substitution, the ACS mixture involved replacing 40% of the cement with these SCMs to improve durability and reducing environment impact (Neville, 2012). Table 1 gives us a comprehensive breakdown of the mixture proportions to produce a one cubic meter concrete slab.

Table 1: Material Used for Base Case Scenario and Alternate Case Scenario

Materials	Standard	Base Case Scenario (BCS)	Alternate Case Scenario (ACS)
		Quantity (kg/m ³)	Quantity (kg/m ³)
Cement	ASTM C150 [22]	419	251.4
Fly Ash (Class F)	ASTM C618 [23]	0	167.6
Slag Cement	ASTM C595 [24]	0	(in total, which is 40% cement replacement)
Silica Fume	ASTM C1240 [25]	0	
Fine aggregate-SSD	ASTM C33 [26]	853	853
Coarse aggregate-SSD	ASTM C33 [26]	995	995
Water	ASTM C1602 [27]	167.6	167.6
Void		-	-
Total		2434.6	2434.6

2.2.2 Material Sourcing

For the life cycle assessment of the concrete mixes, materials were sourced locally from suppliers within Bangladesh. Ordinary Portland Cement (OPC), the primary binder with a specific gravity of 3.15 complying with ASTM C150, chosen for its exceptional resistance to cracking and shrinkage, as well as its rapid setting rate, enhancing overall strength. OPC was sourced from Confidence Cement Limited in Bhatiyari, Chattogram.

Fly ash is a by-product from coal-fired power plants and is finer than Portland cement. Fly ash can improve durability of concrete while lowering environmental impact and resource consumption (Islam, Akter, & Islam, 2011). It was procured from the Payra 1320MW Thermal Power Plant in Patuakhali, Bangladesh.

Up to 15% silica fume in the binder can fully consume calcium hydroxides and lowers chloride ion permeability in concrete, thereby protecting reinforcing steel from corrosion (Choi, Yeon, & Yun, 2016). Due to the lack of local suppliers, silica fume maintaining ASTM C1240 was sourced from Vista Chemtech Private Limited in Kolkata, India.

Ground granulated blast-furnace slag (GGBS), a by-product of iron production is derived from processing slag. Although energy-intensive, GGBS impacts the environment far less than OPC. Like silica fume, GGBS was also obtained from Nirvan Ispat Udyog, Kolkata, India.

Natural aggregates consist of coarse river sand (fine aggregate) from Sunamganj, Sylhet, conforming to ASTM C33, has specific gravity of 2.65 and fineness modulus of 3.00, while crushed stone chips (coarse aggregate) sourced from Volaganj, Sylhet, with specific gravity of 2.7, crushing value of 23%, and a Los Angeles abrasion value of 23%.

Tap water from the Cox's Bazar batching plant was used with a water-to-binder ratio of 0.4. This study prioritized the use of sustainable, locally available materials without sacrificing quality by incorporating SCMs to partially replace conventional cement, thereby enhancing concrete durability and environmental performance. Table 2 shows the transportation distance from the source of the materials to batching plant.

Table 2: Location Scenario of materials for both Base Case Scenario and Alternate Case Scenario

SCM	BCS Mixture (LS1)			ACS Mixture (LS2)		
	Roadway (km)	Waterway (km)	Railway (km)	Roadway (km)	Waterway (km)	Railway (km)
Cement	125	0	0	125	0	0
Fly ash	565	0	0	125	270	0
Silica fume	625	0	0	125	360	0
GGBS	625	0	0	125	360	0
Fine aggregate	545	0	0	30	630	0
Coarse aggregate	545	0	0	30	630	0

To estimate the environmental impact using Eco Concrete Calculation Tool v2.01, two location scenarios were considered, LS1 and LS2. For BCS mix, LS1 is adopted considering no waterway. But in ACS mix, LS2 is adopted considering waterway and railway transportation.

3. ANALYSIS METHODS AND OPTIMIZATION OF MIX DESIGN

3.1 Analysis Methods and Optimization Parameters

3.1.1 Service Life Analysis

Service Life Analysis was conducted using Life-365TM (v1.0.0, online) software which predicted the service life of both BCS and ACS mixture considering chloride ingress and temperature of specific site.

Simulations were performed for the coastal environment in Cox's Bazar subjected to severe chloride conditions (1% wt. of concrete by weight of concrete, marine spray zone). The whole process of optimization comprised two main phases: firstly, obtaining the service life of BCS model concrete, secondly, evaluating the ACS model performance by incorporating several combinations of SCMs, which is taken in total 40% of cement. Subsequently, the service life was calculated using Life-365TM and service life score was calculated as a percentage of design life using the following Eq 1.

$$\text{Service Life Score} = \frac{\text{Service Life in ACS mix}}{\text{Design Life in ACS mix}} \times 100\% \quad (1)$$

3.1.2 Environmental Impact Reduction Determination

Eco Concrete Calculation Tool v2.01 was used to assess reductions in environmental impact achieved by using SCMs. In this study, LCA was defined as the production of one cubic meter of concrete using eco-friendly constituents, specifically tailored to the marine spray zone conditions of Cox's Bazar, Bangladesh. In this assessment, simplified cradle-to-gate LCA analysis, referring to the evaluation of the environmental impacts from extraction of raw material through to the production phase at the batching plant was applied for five environmental impact categories: Global Warming Potential, Ozone Depletion, Fossil Fuel Depletion, Ecotoxicity, and Carcinogenicity. This approach is often favored as it simplifies the analysis rather than up to material's disposal phase, which is covered in cradle-to-grave analysis. The scope of the cradle-to-gate analysis included the production, transportation, and material extraction procedures used to create the concrete mix. Eq 2 shows the Environmental Impact Reduction (EIR) score calculation procedure.

$$\text{Environmental Impact Reduction (EIR) Score} = \left(1 - \frac{SS_{ACS}}{SS_{BCS}}\right) \times 100\% \quad (2)$$

Where, SS_{ACS} = Single score of Alternative Case Scenario,
 SS_{BCS} = Single score of Base Case Scenario.

3.1.3 Life Cycle Cost Assessment

Life Cycle Cost symbolizes the total cost that is associated with the structural element during the whole design life, that means constructing cost and repair cost. To estimate life-cycle cost, Life-365TM follows the guidance and terminology in ASTM E-917 Standard Practice for Estimating the Life-Cycle Cost of Building Systems. All the cost includes material cost, labor cost, inflation rate, real discount rates etc. all possible elements that can possibly impact the life cycle cost. The life cycle cost assessment was performed using Life 365TM software. The repair area is considered 10% of the total area of the structural element and the interval for the repair is considered 10 years.

The Life Cycle Cost assessment is conducted with a score which is calculated as a percentage of design life using the following Eq 3.

$$\text{Life Cycle Cost Score} = \left(1 - \frac{LCC_{ACS}}{LCC_{BCS}}\right) \times 100\% \quad (3)$$

Where, LCC_{ACS} = Life Cycle Cost Score of Alternative Case Scenario,
 LCC_{BCS} = Life Cycle Cost Score of Base Case Scenario.

3.2 Mix Design Optimization

In this study, the primary objective was to establish an innovative mix design of concrete with maximum service lifespan, minimum environment impact and minimum life cycle cost. After introducing SCMs in the concrete mixture as partial replacement, service life can be increased, and environment impact along with life cycle cost can be decreased simultaneously. To calculate the service life and life cycle cost, Life-365TM was used, and to calculate the environment impact reduction, Eco Concrete Calculation

Tool v2.01 was used for every ACS mix. Both 50-year and 100-year design lives were considered in this study, using the same analytical process for each. Then Statistical Methodology was implemented for defining the most optimized mix design.

3.2.1 Mix Design Dataset Preparation

Here, total percentage of fly ash, silica fume and GGBS was considered 40% in this study. To create an ACS mix design dataset, the percentage of fly ash is selected at first, which was 15%, 20%, 25%, 30%, 35%, and 40%. Now for each percentage of fly ash, GGBS and silica fume are taken in systematically varying proportions such that summation of fly ash, GGBS and silica fume remains 40% for each mix case.

Figures 4-6 represent visualization of the prepared dataset, including service life score, life cycle cost, and environmental impact reduction for both 50-year and 100-year design mixes. Trends are observed among mix ratios, such as service life shows cyclical variation, EIR increases almost linearly, and followed by a sharp declination at a particular interval, and LCC displays substantial fluctuation. Challenges were encountered as different percentage of individual SCMs yield variable results and they follow a variable trend, thus making direct identification of the optimal mix by inspection impractical.

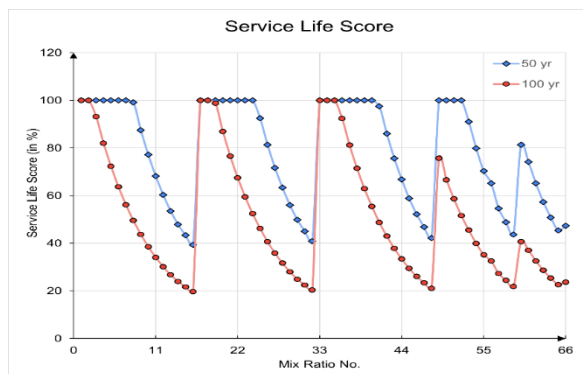


Figure 4: Service Life Score of different Mix Ratio

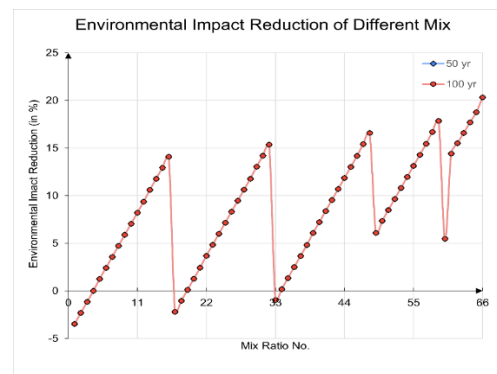


Figure 5: Environment Impact Reduction of different Mix Ratio

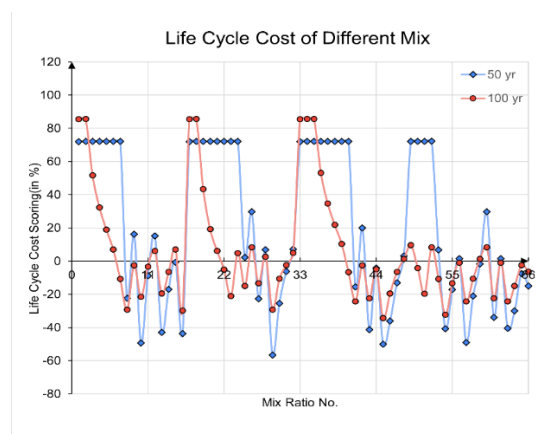


Figure 6: Life Cycle Cost of different Mix Ratio

3.2.2 Mix Design Optimization

To identify the optimal mix formulation, this study employed a quantitative, multi-criteria decision analysis (MCDA) framework. The objective of this framework was to develop a composite performance score for each candidate mix, enabling a robust and objective ranking. The methodology was executed in three sequential phases which are discussed below.

3.2.3 Data Standardization

Raw performance metrics for all candidate mixes were transformed onto a common, dimensionless scale to ensure valid comparison. The analysis evaluated each mix based on three core performance criteria: Durability, Environmental Impact Rating (EIR), and Cost. As these criteria are measured in non-commensurate units, standardization was a necessary prerequisite for aggregation. This was achieved using Z-score normalization, which transforms each criterion's dataset to have a mean (μ) of zero and a standard deviation (σ) of one. The μ and σ values for each metric were derived from the experimental dataset. The transformation for a specific performance value x of a given mix is defined in Eq 4.

$$z = \frac{(x - \mu)}{\sigma} \tag{4}$$

This procedure yielded three standardized variables for each mix: z_D (standardized Durability), z_E (standardized EIR), and z_C (standardized Cost). These standardized scores form the basis for the subsequent composite score calculation.

3.2.4 Criterion Weight Determination and Robustness Analysis

To mitigate subjective bias, weights for each performance criterion were derived using three distinct objective weighting methods. A critical challenge in MCDA is the assignment of relative importance (weights) to each criterion. To ensure the final solution's robustness and avoid dependence on a single, potentially biased perspective, this research implemented three distinct weighting schemes:

- a. **Entropy Weighting Method:** An objective method that assigns weights based on the informational content of each criterion. A criterion exhibiting greater variance (i.e., lower entropy) across the alternatives is considered more informative and is consequently assigned a higher weight.
- b. **Principal Component Analysis (PCA) Method:** A statistical technique that reduces data dimensionality by identifying principal components. The weights are derived from the loadings of the first principal component, reflecting the maximal variance and covariance structure within the dataset.
- c. **Equal Weighting (Baseline):** This "non-informative" method serves as a control scenario, operating under the assumption of equal importance for all criteria ($w = 0.333$ for each).

After calculation, we can get the coefficients for the weightage Equation for scoring the mix ratios to have an optimized one shown in Table 3.

Table 3: Weightage equation coefficients

Method	Durability	EIR	Cost
Entropy	0.4563	0.3019	0.2418
PCA	0.5063	0.0000	0.4937
Equal	0.3333	0.3333	0.3333

The Pearson correlation matrix reveals a high degree of agreement (0.82 to 0.97) between the Entropy, PCA, and Equal weighting methods. This strong positive correlation indicates that the final rankings are highly robust. This provides strong confidence that the top-performing alternative mixes are clear winners, independent of the specific analytical approach used. This Pearson correlation matrix is shown in Table 4.

Table 4: Co-relation among weightage coefficient determination methods

Method Name	Entropy	PCA	Equal
Entropy	1	0.884222	0.9728
PCA	0.884222	1	0.823772
Equal	0.9728	0.823772	1

3.2.4.1 Composite Score Formulation and Robustness Analysis

A weighted sum model was used to calculate a composite score for each mix under each weighting scenario. The final selection was based on identifying the mix that demonstrated superior performance consistently across all models.

A composite performance score for each mix j was formulated using a linear equation, shown in Eq 5.

$$Score = a \times z_D + b \times z_E + c \times z_C \quad (5)$$

Where a , b , and c represent the weights for Durability, EIR, and Cost, respectively, as determined by one of the three elicitation methods. This equation was applied to every mix, generating three distinct performance rankings.

The final stage of the analysis involved a comparative assessment of these rankings. The optimal mix was identified not simply as the top performer in a single model, but also taking 2 major points into consideration:

- i. The Environmental Impact Reduction (EIR) must be greater than 0
- ii. The Life Cycle Cost Score Should be Greater than 0

The final stage of the analysis involved a comparative assessment of these rankings. The optimal mix was identified not simply as the top performer in a single model, but as the alternative that consistently achieved a high rank across all three divergent weighting scenarios. This convergence of results demonstrates the solution's robustness, validating that the selected mix's superiority is independent of the specific weighting methodology employed.

4. RESULT AND DISCUSSION

This study developed optimized concrete mixes designed for 50-year and 100-year service lives, substituting 40% OPC with SCMs, balancing durability, environmental impact, and cost. Two optimized concrete mixes, 50-year design mix and 100-year design mix, achieved their targeted service lives with the 50-year design mix lasting almost 52 years and the 100-year design mix lasting almost 105 years, showing successful extension of durability compared to base concrete having only 12 years service life. Generally, for a standard concrete structure, or in cases where the environment impact takes precedence, the mix for 50-year design life is recommended. But, when the structure serves specialized functions where durability dominates by outweighing environmental impacts, then the 100-year design mix may be selected. Details of the design mix are shown in Table 5.

Table 5: Result values of the optimization

Design Life	% of SCM in Concrete			Service Life (yrs)	Environment Impact Reduction (%)	Life Cycle Cost (\$)
	Fly Ash	GGBS	Silica Fume			
50	30	3	7	51.58	9.64	346
100	25	2	13	104.92	1.33	348

4.1 Service Life comparison

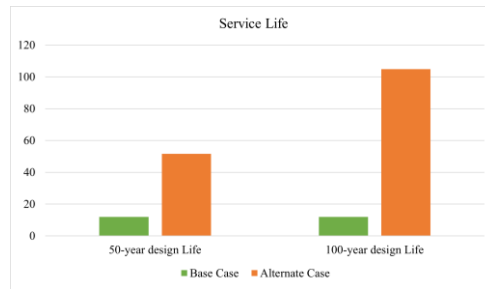


Figure 7: Service Life comparison for both alternate mix

Figure 7 shows the service life comparison of the base case and both alternative cases. The base case shows a significant lower service life, indicating that the durability is achieved by using SCMs.

4.2 Chloride Concentration over time at 50 mm depth

Figure 7 and Figure 8 illustrates chloride concentration versus time at a 50 mm (2 inch) cover depth for both base and alternative cases. This graph shows an increasing trend, close to a parabolic curve. Here the base case shows lower concentration compared to alternate case, which indicated that with the increasing percentage of SCMs, the time required for chloride to reach the specified depth having a particular concentration percentage increased.

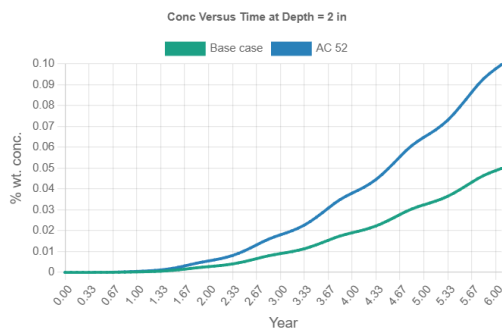


Figure 8: Chloride concentration vs Time at 50 mm depth (for 50-year design mix)

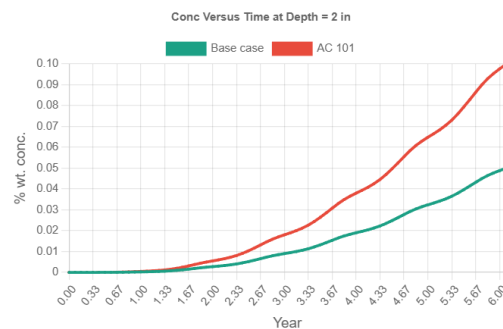


Figure 9: Chloride concentration vs Time at 50 mm depth (for 100-year design mix)

4.3 Surface Chloride Concentration over time

Figure 9 and Figure 10 illustrates the surface chloride concentration versus time. In both base and alternate cases, the graph shows a clear linear increase in concentration over time for the two mixes over the six-year period. The base case shows lower surface chloride concentration graph compared to the alternative one, suggesting that the time required for chloride, suggesting a rapid initial build-up of chlorides at the surface for both alternate mixes, which are designed for extending service life.

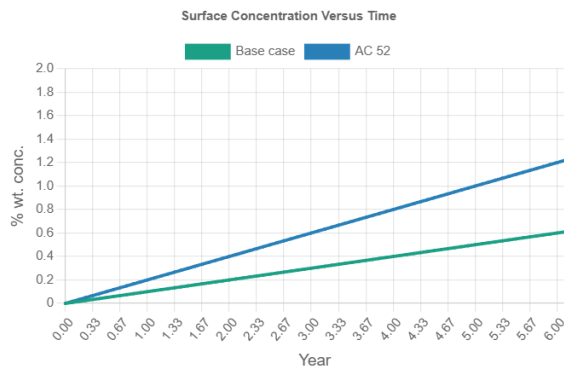


Figure 10: Surface Chloride Concentration vs Time for the initiation phase (50-year design mix)

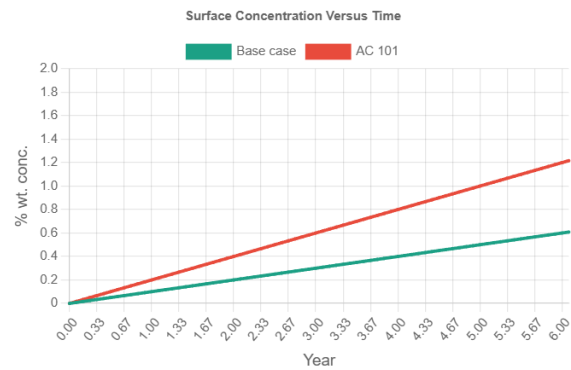


Figure 11: Surface Chloride Concentration vs Time for the initiation phase (100-year design mix)

4.4 Environment Impact considerations

The 50-year mix, containing 30% fly ash, 3% ground granulated blast-furnace slag (GGBS), and 7% silica fume offers the most favourable balance. This mix reduced the total harmful environment impact by 9.7%, notably lowering global warming impact (27.8%) and using less fossil fuel (22.9%). This shows that we can make concrete last much longer while also helping the environment.

Table 6: Environment Impact Reduction result for both design life

Impacts categories	Units	Base-Case Scenario	50-year design life		100-year design life	
			Alternate -Case Scenario	Potential environmental impact reduction	Alternate -Case Scenario	Potential environmental impact reduction
Global warming	kg CO ₂ eq	396.736	286.389	27.8%	295.289	25.6%
Carcinogenic	CTUh	5.70E-06	6.58E-06	-15.3%	7.51E-06	-31.7%
Ozone depletion	kg CFC-11 eq	1.91E-05	1.53E-05	19.9%	1.62E-05	15.2%
Ecotoxicity	CTUe	686.043	733.052	-6.9%	822.443	-19.9%
Fossil fuel depletion	MJ	174.912	134.901	22.9%	141.283	19.2%
Average:				9.7%	Average:	1.7%

On the other hand, the 100-year mix needed almost double the amount of Silica Fume (13%). This increased negative impacts on carcinogenicity (-31.7%) and ecotoxicity (-19.9%), despite enhancing service life. Even though this mix helped with other impacts, the total trade-off dampens the net environment impacts, having only only 1.7%.

4.5 Life Cycle Cost considerations

The total life cycle costs for both optimized alternate mixes were nearly identical, approximately \$346 to \$348. This indicated that economic feasibility is not a limiting criterion in choosing between longer or shorter design lives.

The following table shows the summary of whole analysis result for optimized mix design of 50 year and 100 year service life span and their performance comparison:

Performance Metric	Base Case (100% OPC)	50-Year Optimized Mix	100-Year Optimized Mix
SCM Composition	0%	30% FA, 3% GGBS, 7% SF	25% FA, 2% GGBS, 13% SF
Service Life (Years)	12	51.6	104.9
Durability Improvement	-	~4.3x	~8.7x
Global Warming (CO ₂ eq)	396.7 kg	286.4 kg (-27.8%)	295.3 kg (-25.6%)
Avg. Env. Impact Reduction	0%	9.7%	1.7%
Ecotoxicity/Carcinogenicity	Baseline	Slight Increase	Significant Increase
Life Cycle Cost (\$)	\$2,408	\$346	\$348
Recommended Application	Not recommended for marine	Standard Infrastructure	Specialized/Critical Structures

5. SCOPE OF THE STUDY

This study was limited to a reinforced concrete slab of 5 m² area having 200 mm thickness and 0.4 water – to – cement ratio. Florida Tampa (marine spray zone) region was used instead of Cox’s Bazar region due to insufficient data at Life-365TM, though the places are almost similar in chloride surface condition and weather. Only three SCMs were used due to input limitations of Life-365TM. Also, to keep the study brief, we have used only 40% partial replacement of cement. As cradle – to – gate LCA was considered, environment impacts during production, and concrete end life wasn’t taken into account.

6. CONCLUSION

The study investigated the service life, environmental impact and life cycle cost of concrete when 40% of cement is replaced with supplementary cementitious materials (SCMs). Based on the results and analysis, the following conclusions are drawn:

- The cement used in this study was obtained from suppliers located near Cox’s Bazar. However, if materials were collected directly from production plants to the batching plant, the outcomes might be different, as the transportation method significantly influences the life cycle assessment. Future studies could consider incorporating railway transport as a means to mitigate environmental impacts.
- Considering all environmental impacts, it can be said that silica fume increases the service life of concrete significantly owing to its exceptional capability to produce C-S-H gel. However, it also has a greater negative effect on ecotoxicity and carcinogenicity compared to other supplementary cementitious materials.
- This study incorporated supplementary cementitious materials including fly ash, GGBS and silica fume as SCM. Future investigations could explore additional SCMs like rice husk ash, fibres etc to evaluate their effects on service life, environmental impacts and costs.
- The concrete mixtures demonstrated that for a targeted design life of 50 years, a service life of 51.5 years is found in alternate case, corresponding to a service life of 11.92 years in base case. Similarly for the design life 100 years, alternate case showed a service life of 105 years, base case shows a service life of 11.92 years. This indicates a notable improvement in durability for the ACS mix relative to the BCS mix. Additional research with in depth replacement levels could provide deeper insights into the serviceability of the concrete formulations.

- The study focused exclusively on positive values of Environmental Impact Reduction (EIR) and Life Cycle Cost (LCC). If a minimum EIR threshold of 15% were implemented, then the result may vary, leading to a corresponding reduction in the service life.

7. DECLARATION OF USE OF AI

During the preparation of this research work, the author(s) used Perplexity to search and identify relevant research work. Also, Gemini and Grammarly are used for refining grammar and paraphrasing. After using these tools, the authors reviewed and edited the content and take full responsibility for the publication.

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