

# Sustainable Nano-modified Seawater Concrete with Enhanced Service Life (NanoSeaCon)

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## ABSTRACT

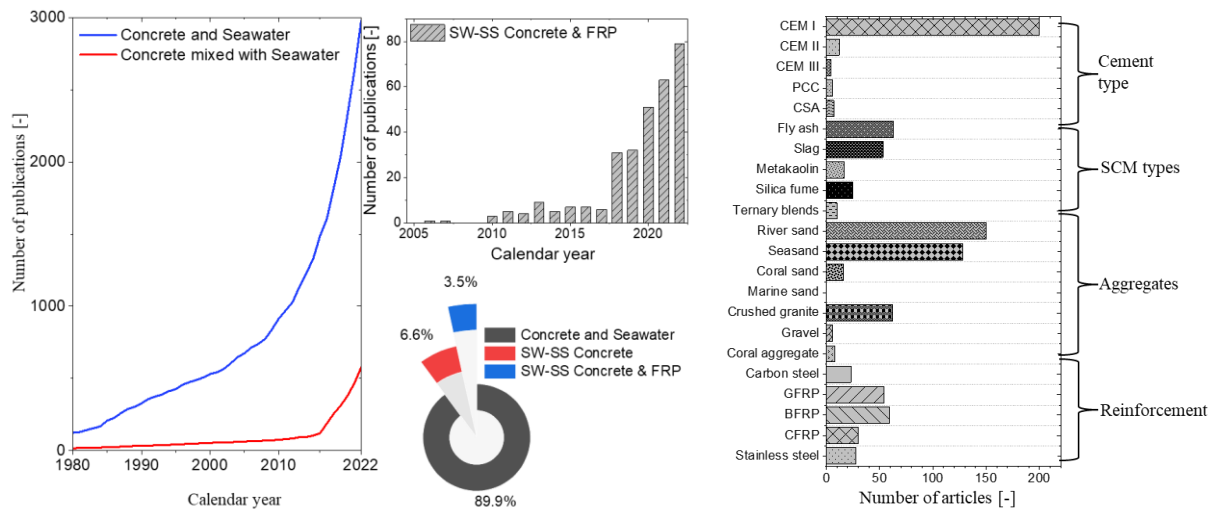
Countries facing extremely severe water-stress are looking for an alternative source of water for industrial purposes including concrete production. The United Nations General Assembly proposed measures to avert a global water crisis by proposing the Water Action Decade between 2018 and 2028. Aligning with this global cause, a significant increase in the research on concrete produced with seawater-mixing has been carried out in the past few years. Researchers focused on understanding the interaction of ions in seawater with hydrated cement phases in OPC and blended cementitious systems. However, a systematic assessment of the long-term strength and durability of seawater-mixed concrete (SWC) is unavailable. NanoSeaCon focuses on evaluating these long-term properties on ternary-blended concretes with nano-SiO<sub>2</sub> (nS) and nano-Al<sub>2</sub>O<sub>3</sub> (nA). The presence of metakaolin and slag in concrete contributed to the active binding of chloride ions and thus reduced the availability of free chlorides in cementitious matrix, which could be detrimental for embedded steel in concrete. The early-age hydration behaviour and the role of seawater ions in reducing the setting time of the cementitious systems were evaluated with isothermal calorimetry studies. Also, the fresh properties and hardened properties of SWC were evaluated to elucidate the role of ions in seawater on reduction in flow and improvement in early-age strength development, respectively. Moreover, the long-term durability of SW-mixed concretes was assessed through resistivity, sulphate attack, and bulk diffusion tests. Based on the durability assessment, the service life of SWCs was calculated, and the feasibility of adapting SWCs for niche applications is discussed.

**KEYWORDS:** *Concrete, seawater-mixing, durability, and service life*

## 1. Introduction

Seawater-mixed concrete (SWC) is a novel approach recommended to produce concrete for niche applications with alternative reinforcement for regions facing extremely severe water stress (Ebead et al., (2022)). Project NanoSeaCon aims to develop sustainable nano-modified concrete with enhanced service life by evaluating the performance of concrete mixes in recent literature. As a first step, a systematic analysis of the literature was carried out and the research gaps were identified to make a significant contribution to this fast-growing area of research (Rathnarajan and Sikora, (2023)). Figure 1 shows the increase in the research interest in SWC in recent years, and primarily more studies are focused on using seawater as a mixing agent and sea sand as an alternative to conventional aggregates. However, meta-analysis of the literature reveals that very limited works are available on understanding the seawater-mixed concretes made with supplementary cementitious materials, as indicated in Figure 1. The research articles considering the ternary blended cementitious materials in SWC are less than 10, and this work intends to contribute significantly to that gap in the literature. The role of supplementary cementitious materials (SCMs) in enhancing the chloride binding ability of cementitious matrix is key to achieve a durable SWC. Also, a preliminary investigation was conducted to evaluate the suitability of the seawater-mixing for producing lightweight aggregate concrete with nano-SiO<sub>2</sub>, waste glass, dune sand, and quartz (Sikora et al., (2023)). A significant reduction in the water footprint was observed in the novel light-weight aggregate mixes. These contributions impacted the formulation of the research objectives of the NanoSeaCon project,

which focuses on the optimization of blended cementitious systems with mineral admixtures like fly ash, slag, and metakaolin.



**Figure 1 Current state of art: Increase in research interest on seawater-mixed concretes and type of materials used in SWC. [Rathnarajan and Sikora (2023)]**

## 2. Optimization of blended cementitious systems suitable for seawater-mixing

A preliminary investigation was conducted on 35 binder combinations produced with fresh- (FW) and seawater (SW). Table 1 summarises the number of paste mixes produced at a similar water-to-binder ratio to evaluate the tasks mentioned in the project. From the analysis of this wider research task, it is evident that there has been a significant improvement in the early-age hydration and strength development of ternary blended cementitious systems compared to binary or CEM I-based combinations. Rathnarajan et al., (2024) presented the most suitable combinations of CEM I and SCMs for seawater-mixing with a reasonable acceleration in the early-age hydration and maximum strength improvement up to 28 days. Among these mixes, the most suitable 12 binder combinations were selected for producing concrete for evaluating the strength and durability characteristics of seawater-mixed concrete.

**Table 1 Detailed experimental program to understand early age hydration of SW-mixed binder systems**

All concrete mixes are cast with binder content = 550 kg/m <sup>3</sup> and water-to-binder ratio: 0.4			
Binder composition (xx, yy: SCM content)	No. of mixes (FW & SW)	Replacement level % by weight	Remarks
CEM I (PC)	2	0	-
CEM I + Fly ash (PFxx)	8	10 - 40%	Binary
CEM I + Slag (PSxx)	6	30 - 70%	Binary
CEM I + Metakaolin (PMxx)	6	10 - 30%	Binary
CEM I + Limestone (PLxx)	6	10 - 30%	Binary
CEM I + Fly ash + Slag (PSxxFyy)	8	30 - 60%	Ternary
CEM I + Fly ash + Limestone (PFxxLyy)	4	30 - 45%	Ternary
CEM I + Slag + Limestone (PSxxLyy)	4	30 - 45%	Ternary
CEM I + Metakaolin + Limestone (PMxxLyy)	4	30 - 45%	Ternary
CEM I + Slag + Metakaolin (PSxxMyy)	6	30 - 60%	Ternary
CEM I + Fly ash + Metakaolin (PFxxMyy)	6	30 - 60%	Ternary

### 2.1 Mechanical performance of SW-mixed concretes

Based on the preliminary investigation, one CEM I, 4 binary, and 7 ternary binder compositions were selected for producing 24 concretes. The binder content and water-to-binder ratio of the produced concretes were kept constant at 360 kg/m<sup>3</sup>, and 0.45, respectively. Compressive strength of cubes (size: 100 mm)

was measured at 7, 28, and 90 days to understand the effects of seawater-mixing on strength development. Figure 2a summarizes the percentage change in compressive strength between FW-mixed and SW-mixed concretes at the above-mentioned ages. A significant improvement in strength at 7 days was observed in specimens produced with SW-mixing due to acceleration in the hydration process. Despite the reduction in strength at a later age (say the 90<sup>th</sup> day), the mean value of the strength reduction is not less than 10% in the concretes except the CM30 mix. In general, ternary blended cementitious systems have a faster gain in strength at an early age and a lesser reduction in strength at a later age with seawater-mixing. Among the ternary blended systems, CS30M15 comprises 30% slag and 15% metakaolin replacing the CEM I fraction by weight in binder which demonstrates the maximum benefit with seawater mixing. Furthermore, 3% nano-SiO<sub>2</sub> (nS) and 1% nano-Al<sub>2</sub>O<sub>3</sub> (nA) by weight of binder were used in the mix to further enhance the microstructure of the SW-mixed CS30M15. Figure 2b indicates this effect of rapid strength development in SW-mixed concrete at early ages (say 1 and 7) compared to the improvement in strength observed in CEM I concrete (CC).

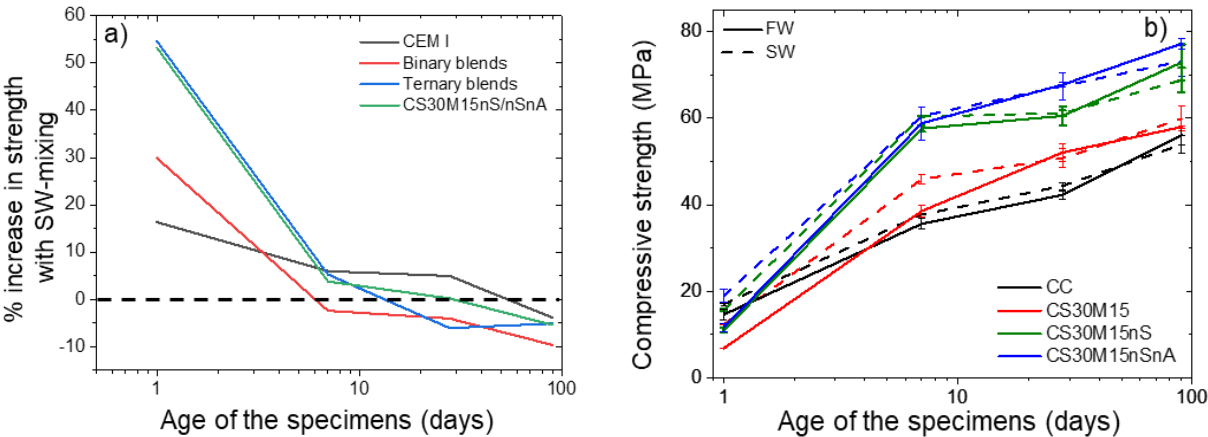


Figure 2 Compressive strength development in SW-mixed concretes: (a) % change in strength with time, (b) compressive strength of concretes with nano-additions

2.2 Durability of SW-mixed concretes

Beyond the assessment of mechanical properties, the durability potential of the SW-mixed concretes was assessed by monitoring the electrical resistivity of the concretes using the Wenner-4-probe method. Cylindrical specimens of diameter 100 mm and height 200 mm. Figure 3 presents the development of surface resistivity in the concretes CC and CS30M15 with and without nano-additives. Compared to the FW-mixed concretes, the ternary-blended cementitious systems mixed with seawater achieved higher resistivity within 7 days of hydration. The presence of nano-additives further accelerated this process with SW-mixing and a resistivity of 50 kΩ.cm which indicates a lower likelihood of corrosion within 7 days.

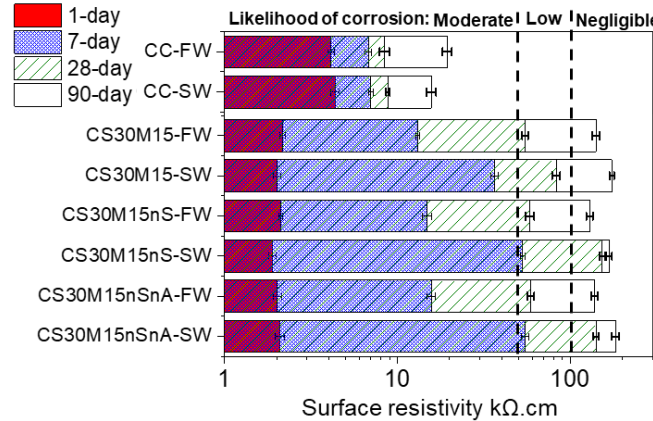


Figure 3 Surface resistivity measurements at 1, 7, 28, and 90 days

The chloride binding in early age hydration and its effect on structural evolution could be attributed to the denser microstructure of SW-mixed concretes (Ji et al., (2024)). A larger study on SW-mixed concretes is being conducted under the exposure of complete immersion in sodium sulphate solution, bulk diffusion, carbonation, and wet-dry cycles of 3.5% sodium chloride to understand their long-term durability in this project. Based on these results, the calculated service life of concretes made with SW-mixing will be presented.

### **3. Conclusions**

NanoSeaCon is a first-of-its kind project that extensively explores the possibilities of using SW-mixing in ternary blended concretes. A significant breakthrough was achieved by identifying the ternary combination of slag and metakaolin at a replacement level of 30% and 15%, respectively being the most optimal for adapting SW-mixing through the assessment of mechanical properties. Furthermore, ongoing durability studies like long-term shrinkage, bulk diffusion, carbonation, sulphate attack, and corrosion studies do not show any rapid deterioration after a few weeks of exposure. These long-term studies are extended further to look at the prospects of adapting CS30M15 concrete with nano-silica and nano-alumina as a durable mix for producing SWC.

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