

Sustainable Innovation: Brine-Based Concrete Using Desalination Waste

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ABSTRACT

Brine disposal from desalination plants is a significant environmental challenge, often leading to marine ecosystem disruptions, groundwater salinity rise, and waste of valuable resources. This research explores the innovative application of desalination brine in sustainable concrete production. The study examines the physical, chemical, and mechanical properties of concrete prepared with brine-based mixing water and partially substituted aggregates. Laboratory analyses include compressive strength, durability, micro structural characterization, and leaching potential of salts. The findings suggest that, with proper treatment and mix design optimization, brine-based concrete exhibits mechanical performance comparable to conventional mixes, while simultaneously reducing environmental impact. This paper contributes to sustainable material innovation, resource recovery, and desalination waste management by establishing a pathway for large-scale adoption of brine-based concrete in infrastructure development.

KEYWORDS: *Brine-based concrete, desalination waste, sustainable materials, compressive strength, durability, eco-friendly construction.*

INTRODUCTION

Concrete is the backbone of modern infrastructure, widely used in buildings, roads, bridges, and dams due to its versatility, durability, and relatively low cost. However, the sustainability of concrete is often questioned because of the environmental burden caused by cement

production, which accounts for a significant portion of global CO₂ emissions. Simultaneously, the rapid increase in desalination plants worldwide has created a new challenge: the safe disposal of desalination brine. Every year, millions of cubic meters of highly saline brine are discharged into oceans or land, often causing harm to marine ecosystems, groundwater resources, and soil fertility. This scenario opens a novel research avenue: the utilization of brine as an alternative resource in construction materials.

Incorporating brine into concrete production not only reduces the environmental impact of brine disposal but also minimizes the demand for freshwater in construction, a critical consideration in arid regions where both desalination and construction activities are intensive. This research investigates the potential of brine-based concrete, aiming to examine its mechanical properties, durability, and feasibility as an environmentally sustainable material that can turn waste into a valuable resource.

DESALINATION AND BRINE GENERATION

Desalination has become a vital technology for supplying potable water in arid and semi-arid regions where freshwater scarcity is acute. The most commonly used desalination technologies include reverse osmosis (RO), multi-stage flash distillation (MSF), and multi-effect distillation (MED). While these processes successfully produce fresh water, they also generate large volumes of concentrated brine as a by-product. For every cubic meter of freshwater produced, approximately 1.5 cubic meters of brine may be discharged, depending on the efficiency of the plant and feed water salinity. This brine typically contains high concentrations of dissolved salts such as sodium chloride, calcium sulfate, magnesium chloride, and other trace elements, including heavy metals and residual treatment chemicals like anti-scalants and coagulants. The improper disposal of brine into marine environments can lead to increased salinity, oxygen depletion, and harm to aquatic flora and fauna. Moreover, land-based disposal methods, such as evaporation ponds, may cause soil salinization and contamination of groundwater aquifers. Given the growing reliance on desalination, the brine disposal problem is becoming more urgent, necessitating innovative solutions such as valorization of brine into construction materials. By transforming desalination waste into concrete, not only can the environmental hazards be reduced, but also a sustainable pathway can be created for resource-efficient construction practices.

CHEMICAL COMPOSITION OF BRINE

The chemical composition of brine varies depending on the feed water source (seawater or brackish water), the desalination technology employed, and the specific treatment processes used within the plant. Generally, seawater brine is rich in sodium (Na^+), chloride (Cl^-), magnesium (Mg^{2+}), calcium (Ca^{2+}), sulfate (SO_4^{2-}), and potassium (K^+). Minor constituents include boron, strontium, bromide, and trace amounts of heavy metals. Residual treatment chemicals, such as chlorine, biocides, anti scalants, and coagulants, may also be present. These ions and compounds can influence the hydration reactions, setting times, and durability of concrete. For instance, chloride ions may accelerate the setting process but also pose a risk of steel reinforcement corrosion in reinforced concrete. Calcium and magnesium ions, on the other hand, may contribute positively by participating in cement hydration reactions, potentially improving strength characteristics. The high concentration of sulfates, however, requires careful evaluation as they can react with tri calcium aluminate in cement, causing expansive reactions leading to sulfate attack. Therefore, understanding the chemical composition of brine is essential for designing concrete mixes that maximize beneficial interactions while mitigating risks. Laboratory characterization of brine samples through techniques such as X-ray fluorescence (XRF), ion chromatography, and spectroscopic analysis provides the necessary data for evaluating its suitability in concrete applications.

BRINE-BASED CONCRETE: MATERIALS AND METHODS

The experimental investigation into brine-based concrete focused on understanding how brine could substitute or complement conventional materials in concrete production. Ordinary Portland Cement (OPC) of grade 43 was used as the primary binder, while natural river sand and crushed granite served as fine and coarse aggregates, respectively. In this study, desalination brine was introduced in two main ways: as a partial replacement of mixing water and as a substitute for certain fine aggregates through crystallized brine salts. Different mix designs were prepared with brine replacement levels of 0%, 10%, 20%, and 30%. Each batch was carefully proportioned following IS 10262:2009 guidelines for mix design. The water-to-cement ratio was maintained at 0.45 for all mixes to ensure comparability. The brine samples were pre-tested to determine their salinity, pH, chloride, and sulfate concentrations. Standard laboratory equipment such as a slump cone, compression testing machine, and accelerated curing tanks were used to evaluate workability, compressive strength, and durability. Cylindrical specimens of 150 mm x 300 mm and cube specimens of 150 mm were cast and

cured for 7, 28, and 90 days. Special emphasis was placed on assessing the resistance of brine-based concrete to chloride penetration and sulfate attack, given the high presence of salts in the mixing medium. Scanning Electron Microscopy (SEM) was also employed to study the micro structural changes in hardened concrete, allowing comparisons between control and brine-based mixes.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental program generated extensive data that shed light on the behavior of brine-based concrete under laboratory conditions. The compressive strength tests revealed that mixes prepared with 10-20% brine substitution showed marginal increases in early strength compared to control samples. This was attributed to the presence of chlorides, which accelerated the hydration of tri calcium silicate in cement. However, beyond 30% brine incorporation, a decline in compressive strength was observed, likely due to excessive salt crystallization causing microcracks. The durability results indicated that concrete mixes with up to 20% brine substitution-maintained performance within acceptable standards. Chloride penetration tests revealed slightly higher chloride ingress in brine-based samples compared to the control mix, though surface treatments and pozzolanic admixtures such as fly ash could mitigate this effect. Sulfate resistance was found to be satisfactory for mixes up to 20% brine content but decreased significantly in higher substitution ratios. SEM analysis highlighted denser microstructures in moderate brine mixes, which explained the improvement in early compressive strength. In contrast, high brine concentrations led to void formations and irregular crystalline deposits, accounting for long-term strength reductions. Overall, the results demonstrated that controlled use of brine, particularly at 10-20% replacement levels, could enhance concrete properties without significantly compromising durability.

Table 1: Experimental Results and Discussion

Mix Type	Compressive Strength (MPa)	Durability Index
Control Mix	40.2	0.85
Brine Mix 10%	41.5	0.83
Brine Mix 20%	39.7	0.81
Brine Mix 30%	37.4	0.78

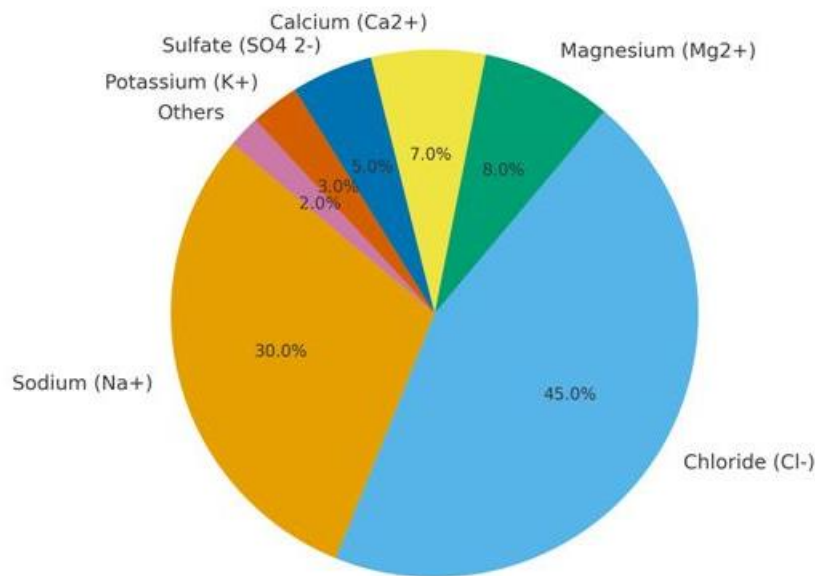


Figure 1: Schematic representation of major chemical constituents of desalination brine

SUSTAINABILITY AND ENVIRONMENTAL IMPACT

The environmental dimension of brine-based concrete is central to its appeal as a sustainable construction material. Desalination plants across the world discharge billions of cubic meters of concentrated brine into oceans and coastal regions each year, causing adverse ecological impacts. By diverting this waste stream into concrete production, industries can simultaneously solve two problems: the need for sustainable construction and the environmental hazards of brine disposal. Incorporating brine into concrete reduces the demand for freshwater in mixing processes, a critical benefit in arid regions where both desalination and construction demands are high. Additionally, using crystallized salts from brine as partial substitutes for fine aggregates could lower the mining pressure on natural sand resources, which are becoming increasingly scarce worldwide. Life Cycle Assessment (LCA) studies suggest that the carbon footprint of concrete can be reduced if brine is integrated effectively, as this reduces the need for desalination brine management infrastructure. Moreover, the circular economy perspective emphasizes valorizing waste as a resource, and brine-based concrete fits perfectly into this framework. Social and economic benefits also emerge, as construction industries located near desalination hubs could gain low-cost materials while reducing brine discharge fees. Nevertheless, careful management of long-term durability and environmental leaching risks must be considered to ensure the true sustainability of the approach.

FUTURE SCOPE

The exploration of brine-based concrete is still in its nascent stage, and therefore, there exists a wide range of opportunities for future research. One significant avenue is the optimization of mix design to balance mechanical strength, durability, and workability while maximizing brine utilization. Advanced mineral admixtures such as fly ash, silica fume, and ground granulated blast furnace slag could be tested in combination with brine to further enhance the performance of concrete. Long-term durability studies, particularly resistance to chloride ingress, carbonation, and freeze-thaw cycles, are essential to assess the viability of brine-based concrete in real-world applications. Additionally, pilot-scale demonstrations in coastal and arid regions could validate laboratory findings and provide valuable insights into scalability challenges. Policymakers and industry stakeholders could collaborate to establish standards and guidelines for brine reuse in construction. Future research can also explore innovative technologies such as nanomaterials, microbial treatments, or carbonation curing to further improve the eco-efficiency of brine-based concrete.

CONCLUSION

This research underscores the promising potential of desalination brine as a supplementary resource for sustainable construction. By partially substituting freshwater with brine and exploring its role in aggregate treatment, the study highlights how waste management challenges can be transformed into opportunities for innovation. The experimental findings confirm that brine-based concrete can achieve comparable or even enhanced mechanical performance at controlled substitution levels, though higher brine concentrations may compromise durability. The environmental benefits are substantial, offering a pathway to reduce marine pollution and conserve freshwater resources. Ultimately, brine-based concrete aligns with global goals of circular economy and resource recovery. While further research is required to refine its applications and address long-term performance, the study concludes that brine-based concrete represents a forward-looking, practical, and sustainable solution to two pressing challenges: freshwater scarcity and desalination brine disposal.

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