ACI Technical Committee 243 – Seawater Concrete

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Motivation

Conserving fresh water and natural aggregates is a **global goal** in concrete technology**.** ACI Committee 243 will facilitate the development of knowledge and documentation necessary to attain this goal, as well as motivate improvements to the service life and resilience of concrete in saltwater environments

Committee Mission

Develop and report information on concrete made with brackish, saline, and brine water and associated aggregates and improve the material, ecological and geomorphological integration of these concretes in saltwater environments[1]

[1] = modified, needs committee vote & TAC approval

ACI Committee 243 Membership

(as of October 9, 2024)

Voting members: 27

Associate members: 13

Total: 40

Affiliations

Academics: 25

Practitioners (engineers/contractors): 5

Material suppliers/manufacturers: 6

Users (agencies, DOTs, etc.): 4

ACI 243 - Liaison Activities

ACI 243 has established outreach on three fronts:

1. Collaboration with the Asian Concrete Federation (ACF) via its Technical Committee on Seawater and Sea-sand Concrete (TC-SCC). Chair Tao Yu (https://www.asianconcretefederation.org/technicalcommittee)
2. Collaboration with NovusCrete Consortium recently established in the Kingdom of Saudi Arabia
3. Interaction with ASTM Subcommittee C09.40 - Ready-Mixed Concrete. Colin Lobo and Michelle Wilson (responsible for: C1602/C1602M-22 Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete)

ACI 243 First Task

State-of-the-art Report on Seawater-Mixed Concrete

PROPOSED TABLE OF CONTENTS

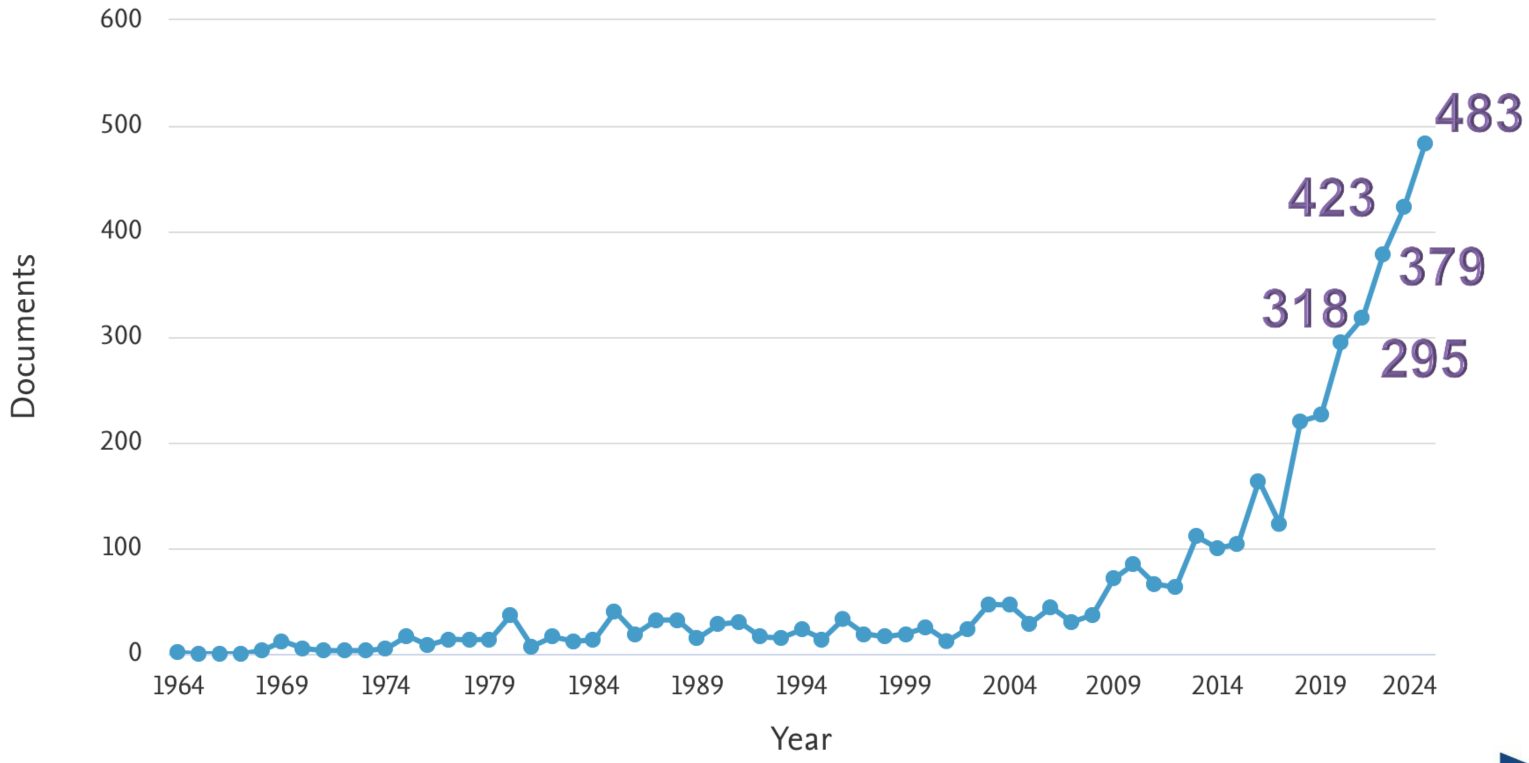
A Look at the Current Knowledge on Seawater Concrete[1]

Why do we need to act:

- High annual production of concrete (cement production could reach to 4 billion tons annually by 2030)
- High freshwater consumption for concrete production
- Increasing demand for construction of marine projects
- Scarcity of freshwater in marine regions
- Need for decreasing offshore construction costs
- **Conserve freshwater resources**
- Support the long service life and resilience required of saltwater concrete in coastal infrastructure to mitigate damage to marine ecology and shoreline environments

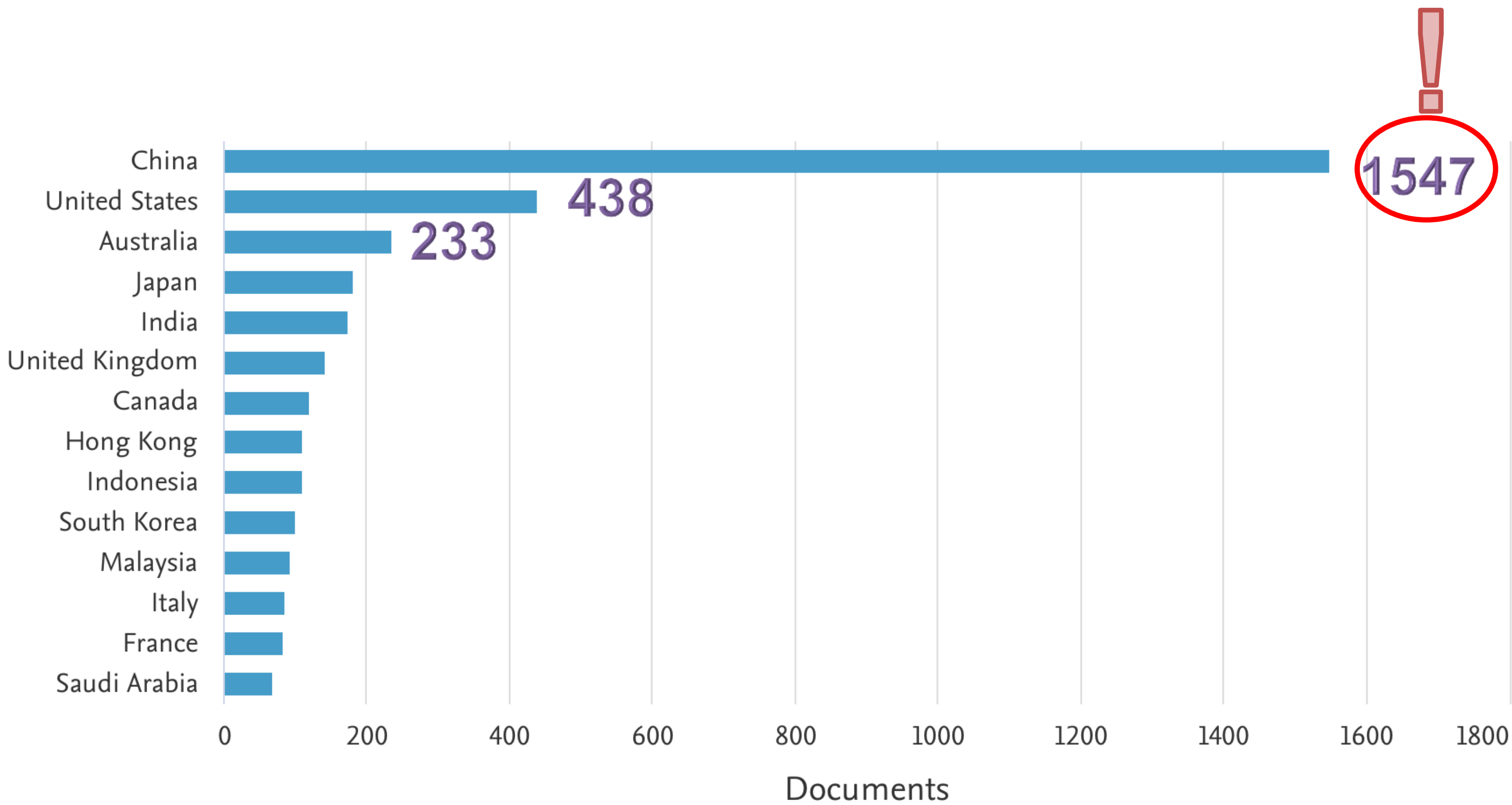
[1] = Contributions by ACI 243 members: Nima Khodadadi, Iman Aghajanzadeh, Prannoy Suraneni and Marie Jackson

Documents by Year on Seawater Concrete (1964-2024)



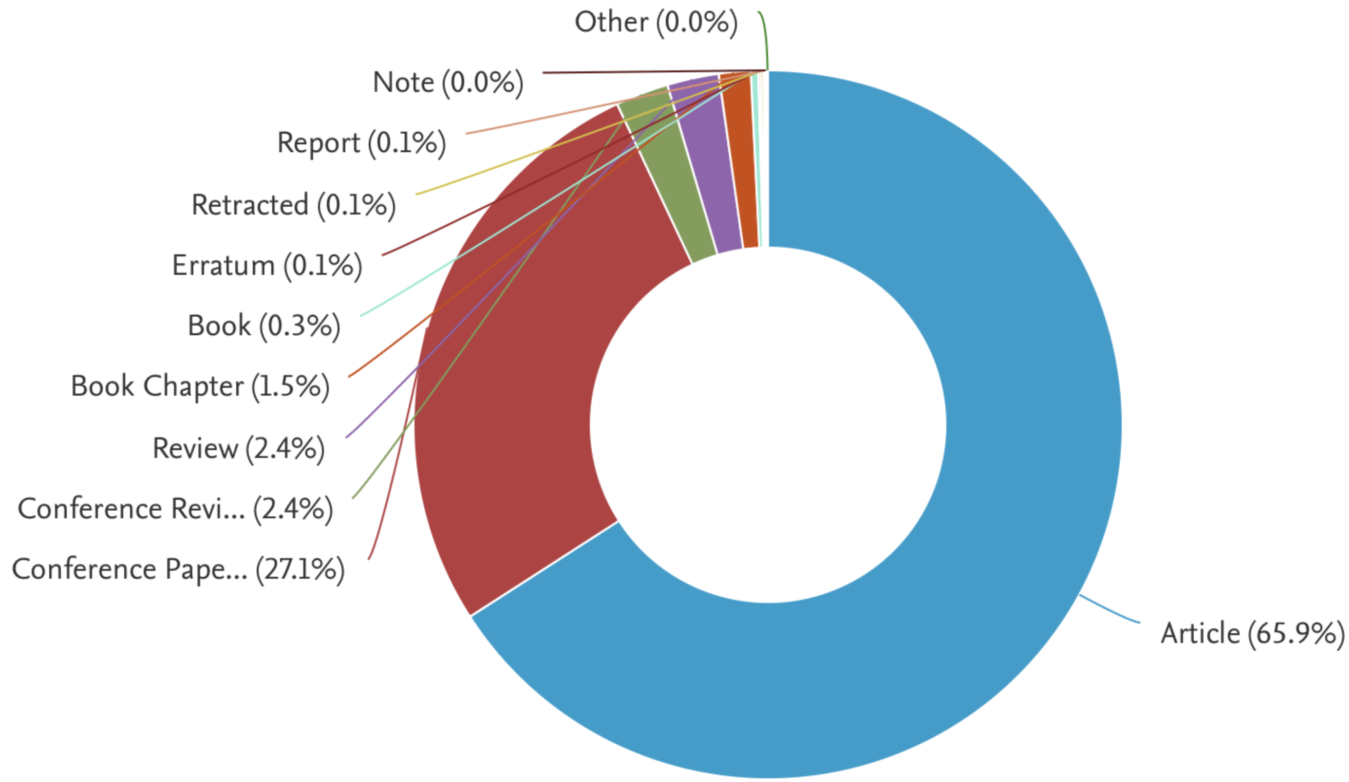
Keyword: Saltwater OR Seawater AND Concrete

Documents by Country on Seawater Concrete (1964-2024)



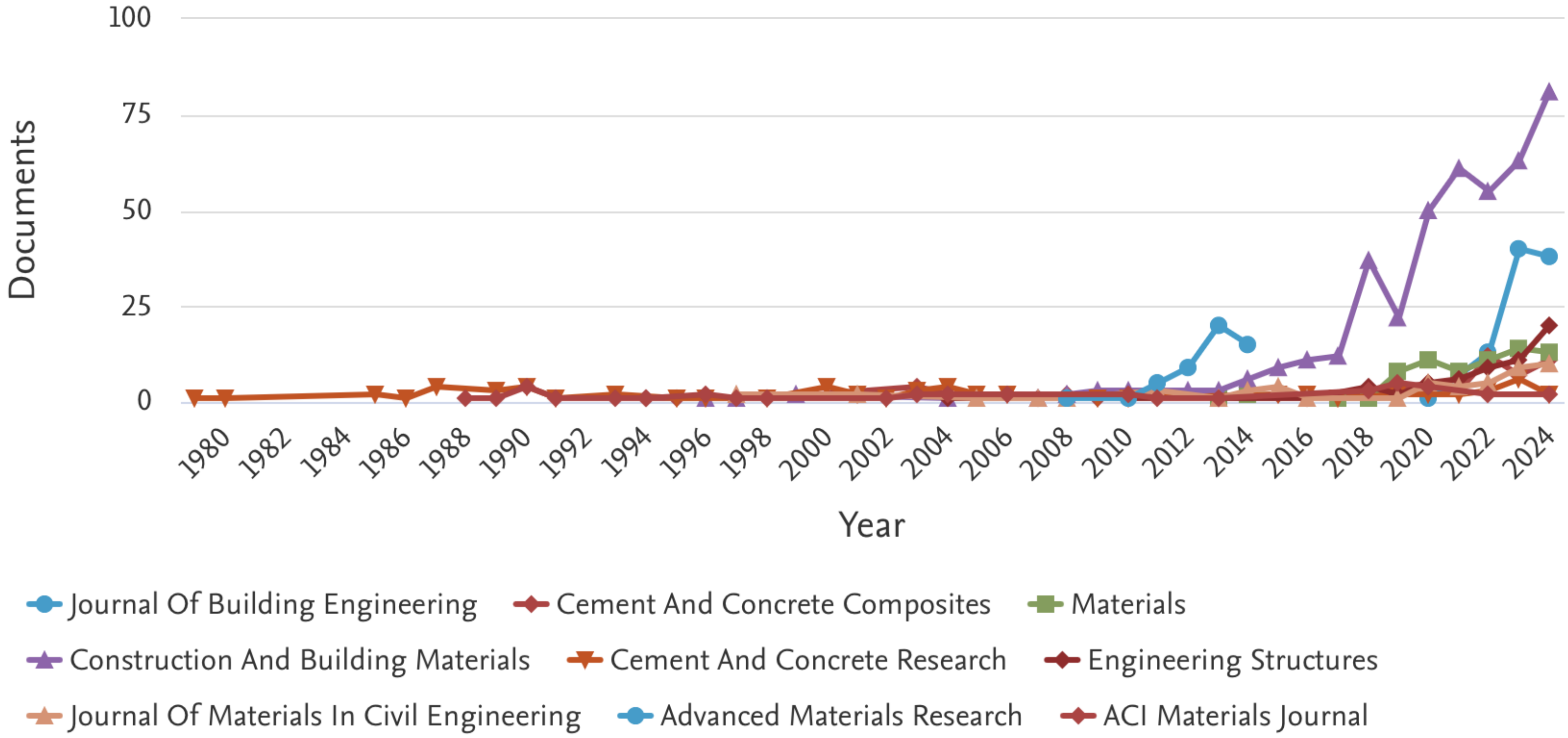
Keyword: Saltwater OR Seawater AND Concrete

Documents by Type on Seawater Concrete (1964-2024)



Keyword: Saltwater OR Seawater AND Concrete

Journal Papers on Seawater Concrete per Year by Source (1978-2024)



Keyword: Saltwater OR Seawater AND Concrete

What do we know: typical effects of seawater on cement hydration

- Promotes the early age hydration of OPC
- Greater silicate peak height, acceleration of the silicate peak time and higher 3-day heat release in isothermal calorimetry (IC) results
- Largest difference with the hydration behavior of freshwater-mixed cement paste occurs in the first day
- After the first day the freshwater mixture catches up with the seawater mixture in terms of hydration rate
- Higher autogenous shrinkage in seawater-mixed concrete

What do we know: effects of seawater mixing on microstructure of cement pastes

- Dissolved ions affect the hydrated phase assemblage
- Chemical combination of aluminate ferrite monosulfate (AFm) phase and chloride ions forms Friedel's (or Kuzel's) salts
- Reaction of chloride ions with monocarboaluminate can convert it into a stable phase as Friedel's (or Kuzel's) salts
- Elevated ettringite occurs in seawater-mixed mortar compared to distilled water-mixed mortar at later curing age
- Denser paste microstructure at early ages but almost the same microstructure at later ages, compared to freshwater-mixed paste
- More diverse hydration products, refined microstructure and possibly higher crystallinity compared to distilled water-mixed pastes

What do we know: effects of seawater mixing on mechanical properties of concrete

- Slightly higher compressive strength at 3 and 7 days compared to freshwater-mixed concrete in freshwater and seawater curing conditions due to smaller pores and accelerated hydration
- 28-day compressive strength slightly lower than that of freshwater-mixed concrete in freshwater and seawater curing conditions due to leaching of hydration products and salt crystallization
- Another study and interpretation: Higher compressive strength when cured in seawater compared to freshwater-mixed concrete cured in seawater, due to smaller differences in ionic concentrations, leading to less leaching of alkalis and calcium hydroxide in the seawater-mixed paste

What do we know: chloride binding

- Steel corrosion: the main durability problem of reinforced concrete structures in marine environments. Chloride penetrates the concrete, breaks down the passivation layer on surfaces of steel bars, and produces corrosion
- Chloride binding 1: can entail capture of chloride ions by hydration products such as Friedel's (and Kuzel's) salts
- Chloride binding 2: Friedel's (and Kuzel's) salts retard penetration of external chloride, fill pores, reduce porosity in the paste (also system already full of Chlorides) – further retarding transport of chloride ions
- Chloride binding 3: may reduce possibility of steel corrosion, but black steel reinforcement remains not recommended

What do we know: chloride binding (continued)

- Chloride in seawater-mixed concrete occurs in the pore solution of concrete, is physically held on the surface of hydration products, or is chemically bound to hydration products
- Higher C3A and C4AF content in cement increases chloride binding of paste
- Reactions among chloride ions and C3A or C4AF or their hydrates leads to chemical binding in Friedel's (or Kuzel's) salts
- C3S and C2S dominate physical binding of chloride ions within C-S-H or complex C-(A, Na, K, Cl, S)-S-H binding phase
- SCMs, including fly ash, metakaolin, and slag, increase chloride binding through sequestration in Friedel's (or Kuzel's) salts
- Silica fume, alone, does not directly increase chloride binding because it contributes little alumina (Al_2O_3)

What do we know: sulfate attack through external seawater ingress

- Definition: Sulfate ions as sodium sulfate (NS) or magnesium sulfate (MS) can react with calcium hydroxide (CH) and form gypsum (CSH2), sodium hydroxide (NH), and magnesium hydroxide (MH)
- Gypsum can react with hydrated calcium aluminates (C4AH13), hydrated calcium sulfoaluminates (C4ASH12), or unhydrated tricalcium aluminate (C3A) to form ettringite (C6AS3H32), possibly leading to expansion and cracking through delayed ettringite formation
- For a freshwater mixed concrete exposed to marine conditions chlorides in seawater decrease sulfate attack because they compete with sulfate to react with C3A and hydration products of C3A to form Friedel's (and Kuzel's) salts
- Seawater exposure of seawater mixed cement paste would not cause sulfate damage under the standard curing condition as shown by low expansion and low ettringite content

What do we know: sulfate attack

- Seawater-mixed sea sand concrete (SWSSC) shows better sulfate resistance than freshwater-mixed desalinated sea sand concrete (FDC)
- This is because Cl- in the seawater and sea sand reacts with AFm, C3A, and calcium hydroxide and forms Friedel's (and Kuzel's) salts, leading to reduced formation of expansion products, AFt and $Mg(OH)_2$
- Damage caused by SO_4^{2-} is also reduced in the SWSSC
- This is because seawater-mixing and sea sand can improve sulfate resistance due to refinement of pore structure and consumption of erodible components (aluminate phase available to react)
- Using high ferrite Portland cement (HFPC) instead of OPC in SWSSC also results in enhanced sulfate resistance

Recommendations for Future Research

- Expand data on durability. Investigate long-term concrete performance, including historic structures, and integrate materials, ecological and geomorphological perspectives to improve resilience in saltwater environments
- Resolve contradictory results. Further clarify response of seawater-mixed concrete by better understanding hydration mechanisms based on different constituents
- Optimize concrete designs by considering interactions of seawater with different types of binders, admixtures, and aggregates, including mix designs without cement
- Develop specifications. Provide guidance on recommended? constituents of concrete mixtures and hydration procedures
- Address use of corrosion-resistant reinforcement, critical for full deployment of seawater-mixed concrete technology

Thanks

Any Question?