



ouronova 

Accelerating DeepTech Innovation

Cement Integrity



Overview

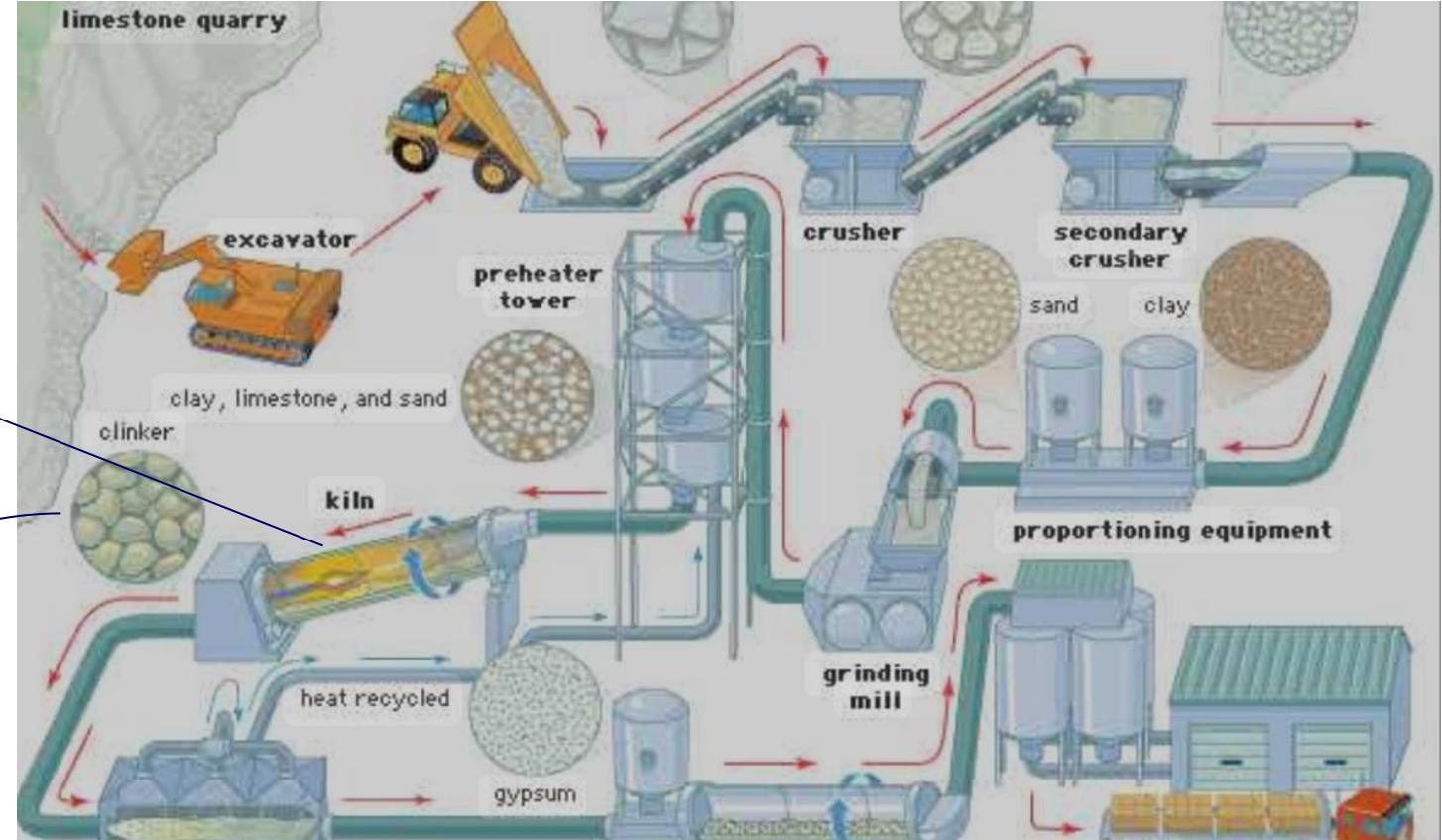
- What Is Cement Integrity?
- Integrity Threats
- Cement Design Approaches
- Cement Integrity Evaluation Tools
- Emerging Technologies
- Final Thoughts

Cement Manufacturing of Portland Cement



Rotary Kiln ($\pm 1450^{\circ} \text{ C}$)

Clinker

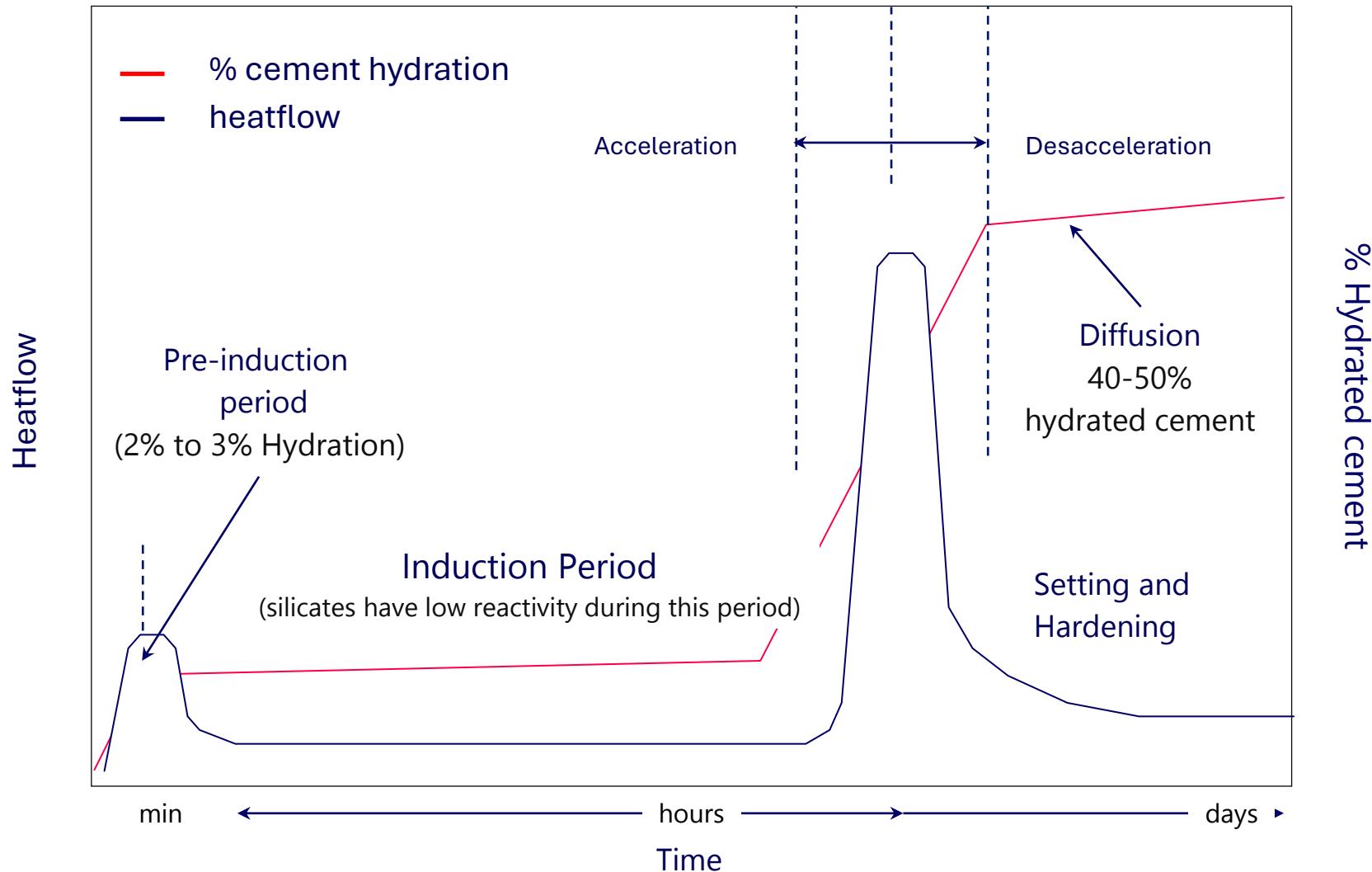


Class G Cement Clinker Composition

| Compound | Abbreviation | Chemical Formula | % | Contribution on performance |
|--------------------------------|-------------------|--|----------|---------------------------------|
| Tricalcium Silicate (Alite) | C ₃ S | 3 CaO. SiO ₂ | 45 - 60% | Durability and total resistance |
| Dicalcium Silicate (Belite) | C ₂ S | 2 CaO. SiO ₂ | 15 - 30% | Long term durability |
| Tricalcium aluminate | C ₃ A | 3 CaO. Al ₂ O ₃ | 5 - 12% | Durability and early setting |
| Tetracalcium aluminoferrite | C ₄ AF | 4 CaO. Al ₂ O ₃ Fe ₂ O ₃ | 6 - 12% | No effect on durability |
| Gypsum (added during grinding) | CSH ₂ | CaSO ₄ 2H ₂ O | 2 - 10% | Prevents early setting |



Heatflow During Cement Hydration



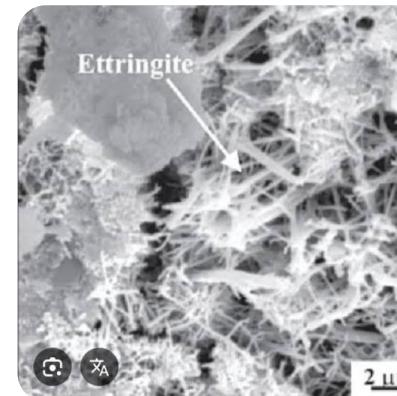
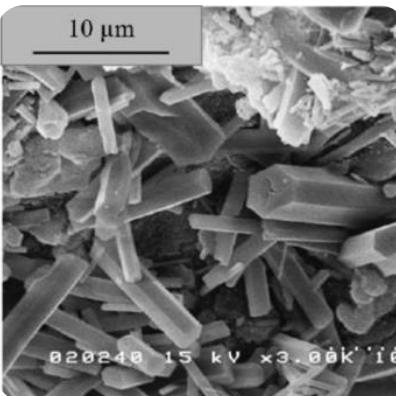
What is Set Cement?

Ettringite is formed during the initial hydration of cement when C₃A reacts with gypsum (CaSO₄.2H₂O) in the presence of water:

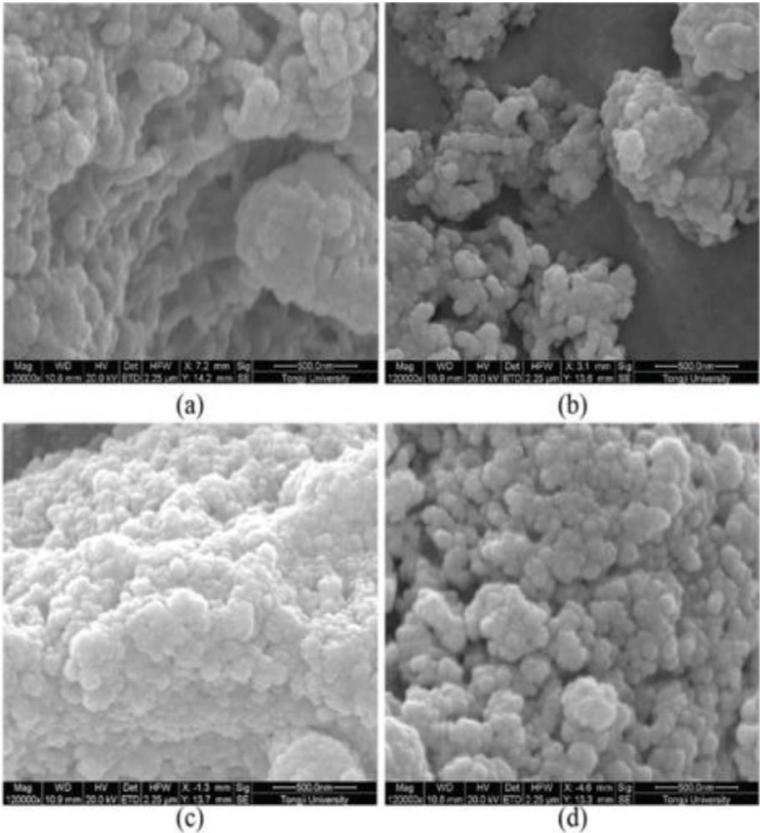


It controls thickening time and cement setting time.

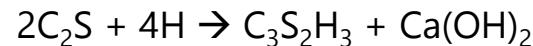
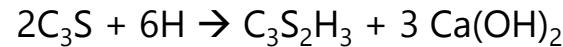
| Compound | Chemical formula | Abbreviation | Typical Mass (%) | Contribution on performance |
|----------------------|-------------------------------------|------------------|------------------|------------------------------|
| Tricalcium aluminate | 3CaO·Al ₂ O ₃ | C ₃ A | 5 -12% | Durability and early setting |



What is Set Cement?



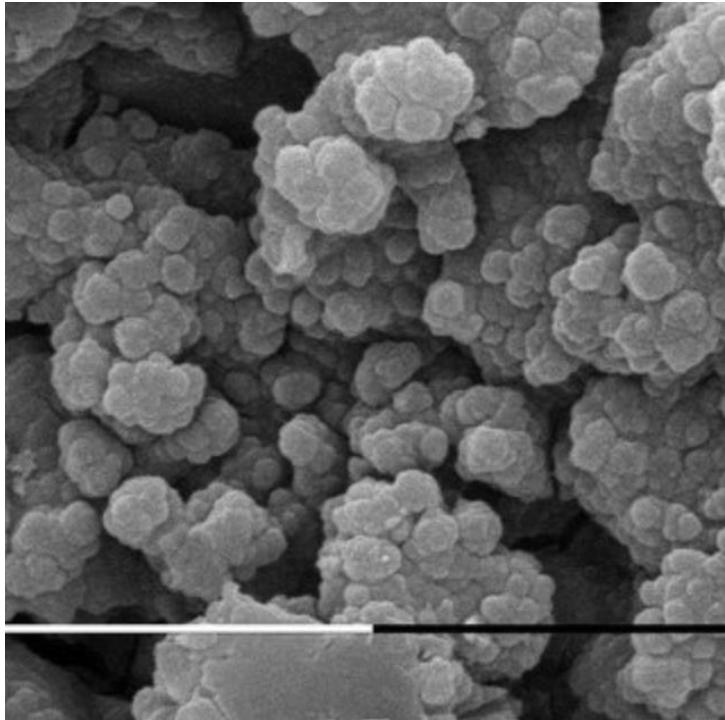
C-S-H (Calcium Silicate Hydrate) is the main phase which keeps the cement particles banded together, providing cohesion and resistance. It does not have a defined chemical formula and is amorphous. It is formed from the hydration of Portland cement silicate phases:



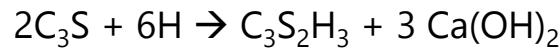
It controls cement permeability (gelled structure which fills the pore spaces), besides resisting to chemical attacks, and improve cement durability over cement long term life.

| Compound | Abbreviation | Chemical Formula | Typical Mass (%) | Contribution on performance |
|-----------------------------|----------------------|--------------------------------|------------------|---------------------------------|
| Tricalcium silicate (Alite) | C_3S | $3\text{CaO}\cdot\text{SiO}_2$ | 45–60% | Durability and total resistance |
| Dicalcium silicate (Belite) | C_2S | $2\text{CaO}\cdot\text{SiO}_2$ | 15–30% | Long term durability |

What is Set Cement?



Ca(OH)_2 (Calcium Hydroxide) is byproduct of Portland cement silicate phases hydration:



It is also called hydrated lime or portlandite.

It provides alcalinity (high pH) to the pore solution, helping metal protection against corrosion in harmful environments. It is also one of the main reactants to CO_2 attack (carbonation reaction).

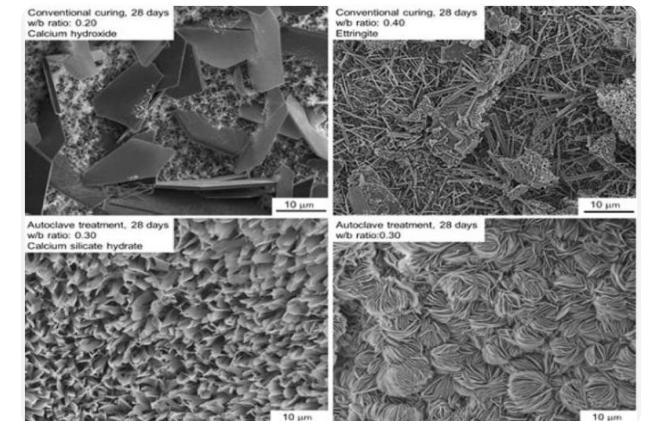
| Compound | Abbreviation | Chemical Formula | Typical Mass (%) | Contribution on performance |
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What is Set Cement?

The main products generated by the cement hydration process are the Calcium Silicate Hydrate gel – CSH – and the Calcium Hydroxide – $\text{Ca}(\text{OH})_2$.

CSH is semi-amorphous material, similar to a gel, which make up approximately 70% in weight of hydrated cement and is the main particles binder.

$\text{Ca}(\text{OH})_2$ is crystalline and make up approximately 15 to 20% in weight of hydrated cement.



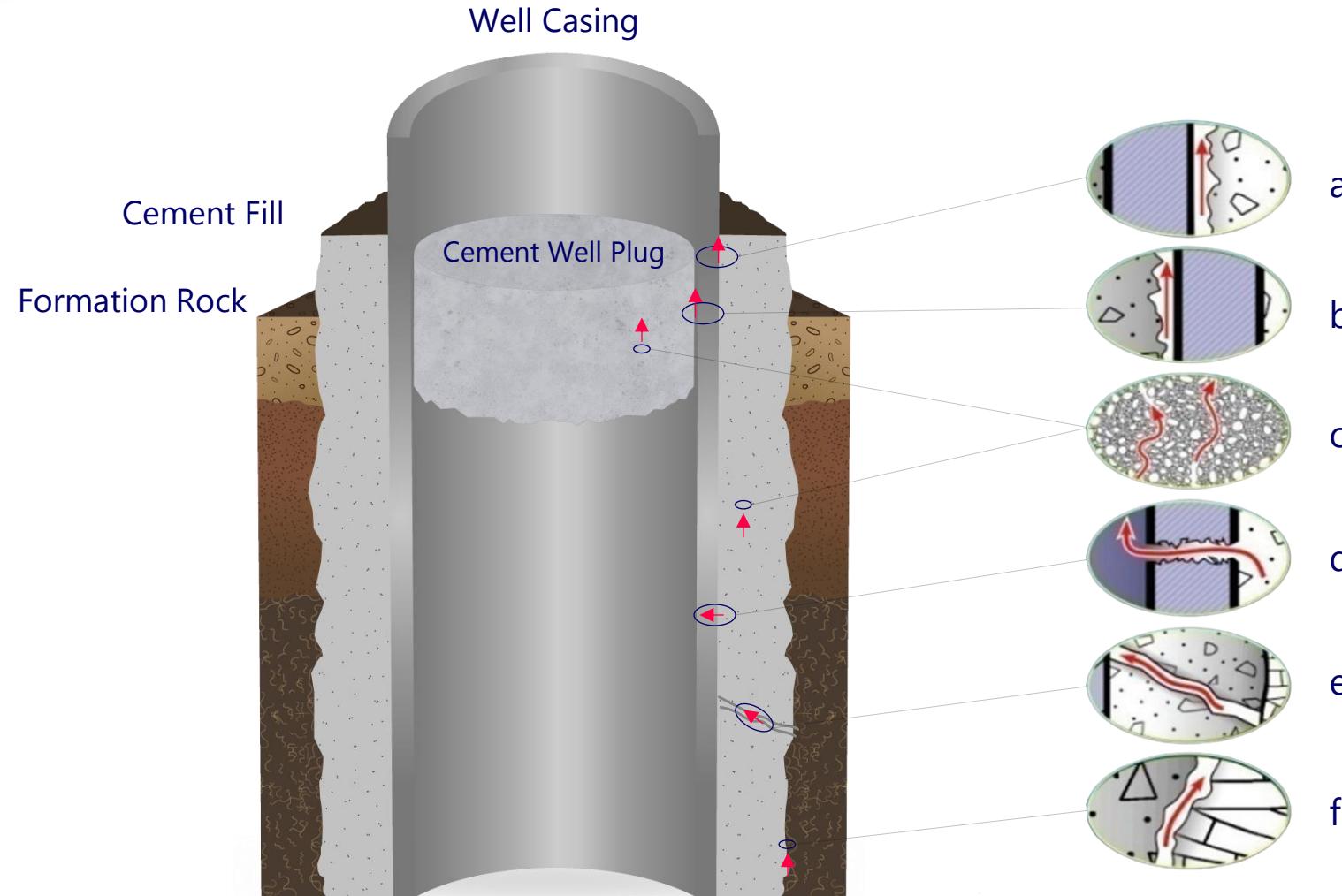
What Is Cement Integrity?

- Key Aspects:
- Mechanical strength
- Bonding (casing and formation)
- Resistance to downhole environments
- Long-term chemical durability

Key Integrity Threats

- Key Chemical Degradation (CO₂, H₂S, Salts)
- Microannuli and Stress-Induced Cracks
- Gas Migration and Fluid Channels
- Cement Aging and Retrogression
- Poor Mud Removal and Placement Practices

Integrity Tests: Potential Leakage Pathways



Gasda et al., 2004 and 2005

Integrity Threat : HPHT Conditions

- Mitigation: Silica, pozzolans, optimized W/C ratio
- Standards: API RP 10B-5, ISO 10426-5

Integrity Threat : HPHT Conditions

1

$\text{C}_3\text{S}_2\text{H}_3$ becomes unstable and transforms itself in a hydrated C_2S of low resistance.

2

The crystallization degree of the hydrated byproducts is limited, and the dehydration of crystals further deteriorate the compressive strength of cement.

3

Increase of porosity and formation of microcracks compromise the structural integrity of set cement.

Integrity Threat : HPHT Conditions

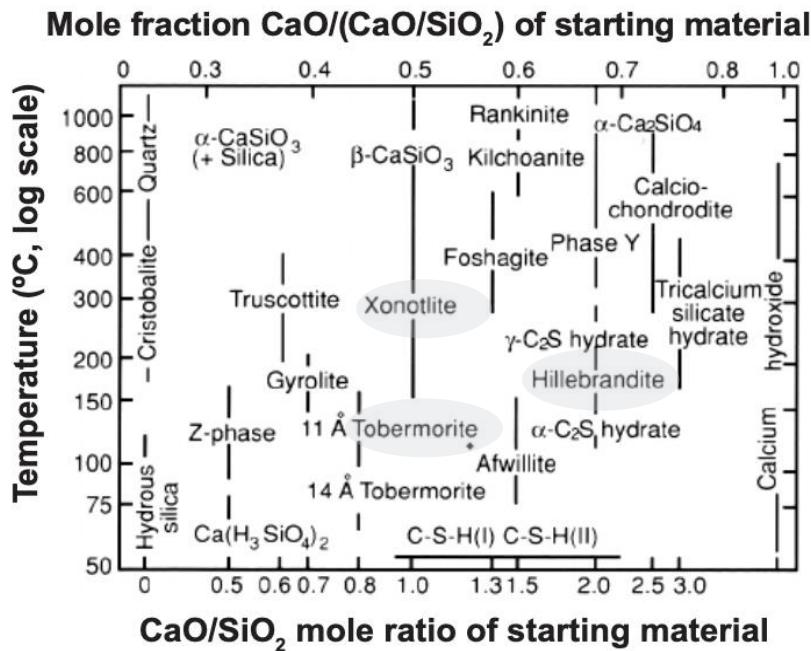


Figure 1: Phase changes in Portland cement submitted to elevated temperatures.

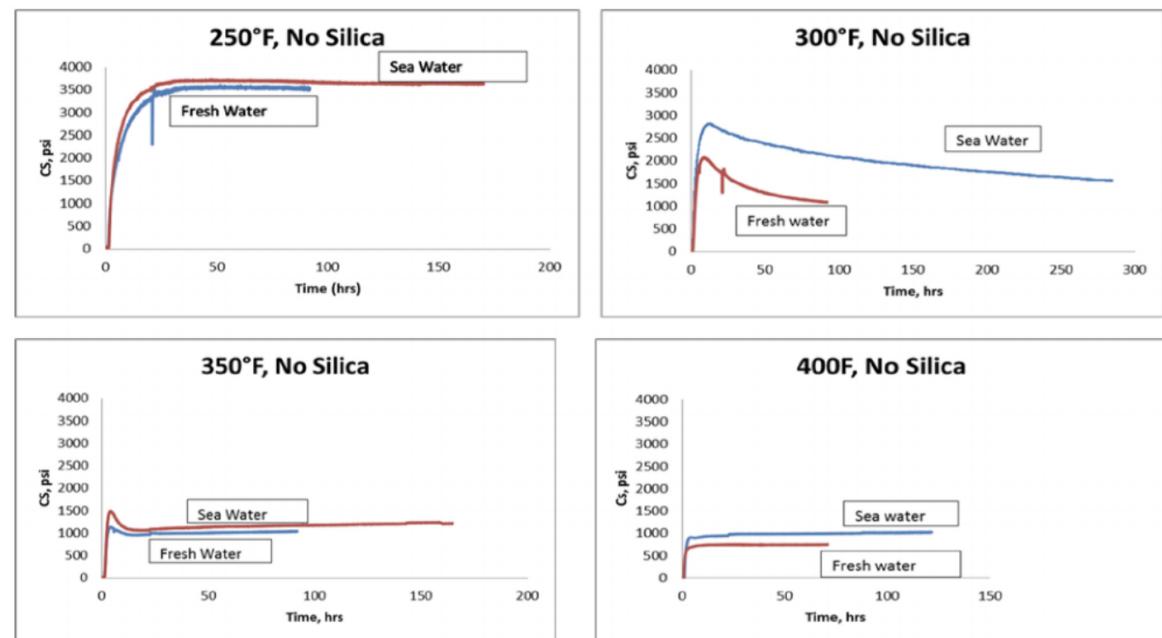
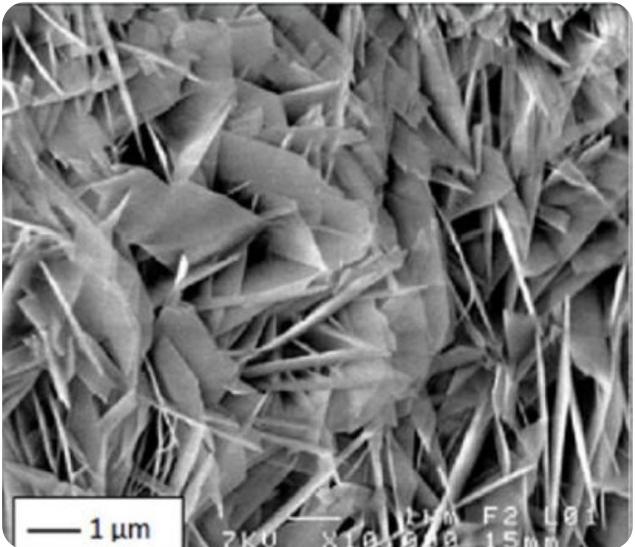


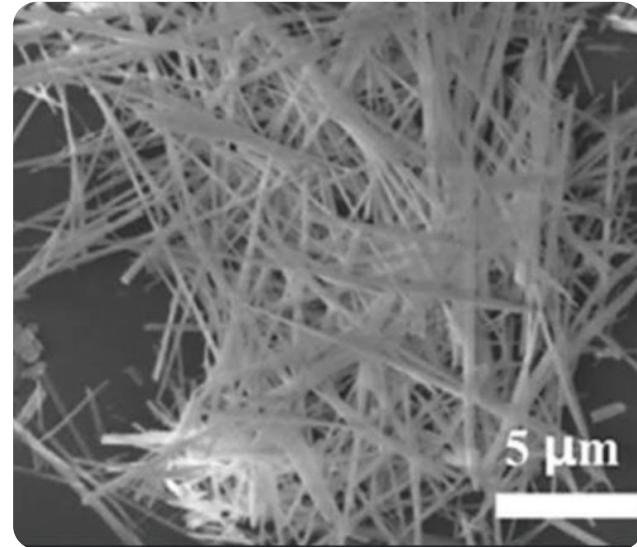
Figure 2: Early strength development patterns for fresh and sea water formulations without silica flour.

Integrity Threat : HPHT Conditions

Tobermorite



Xonotlite



Xonotlite is formed at higher temperatures than Tobermorite

Integrity Threat : CO₂ and H₂S and HCl Attack

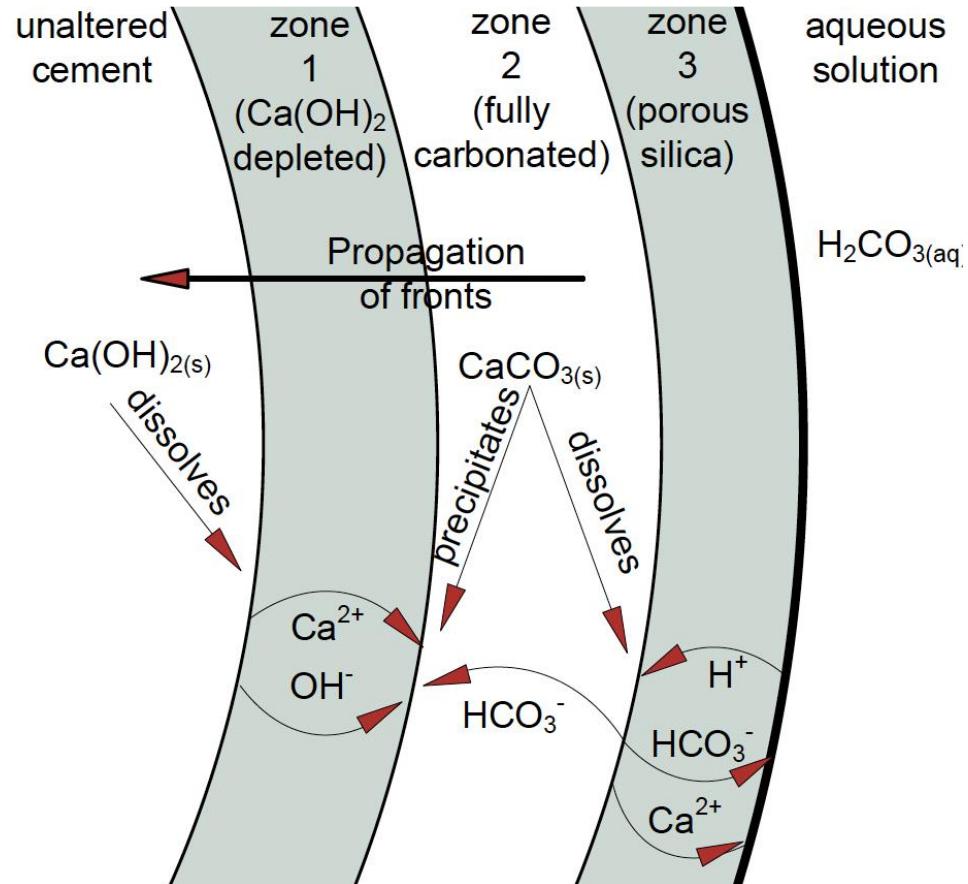
- Reactions: CH + CO₂ → CaCO₃, then leaching
- Mitigation: CO₂-resistant cements, Sulfate resistant cements, fly ash, geopolymers, MgO, latex-modified

Integrity Threat : CO₂ Attack

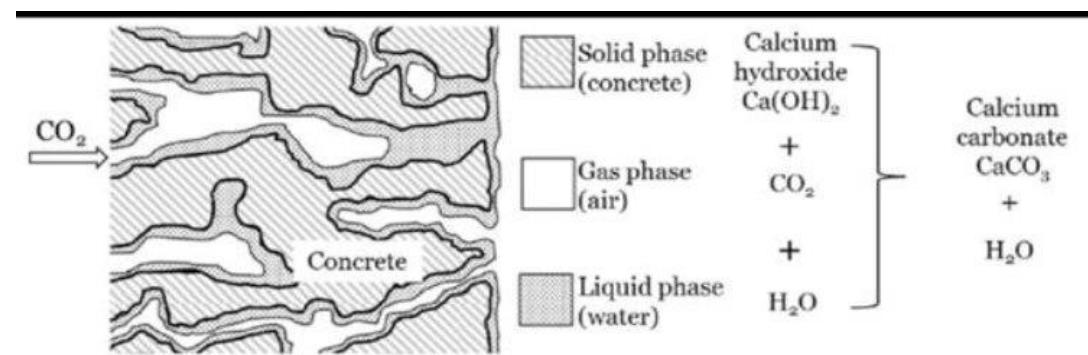
1. CO₂ + H₂O → H₂CO₃ (carbonic acid)
2. H₂CO₃ + Ca(OH)₂ → CaCO₃ + 2H₂O
3. C-S-H and/or crystalline phases + H₂CO₃
→ CaCO₃ + SiO₂ (gel) + H₂O
4. CaCO₃ + H₂CO₃ → Ca(HCO₃)₂



Integrity Threat : CO₂ Attack



The dissolution and calcium migration and formation of distinct zones in the set cement.

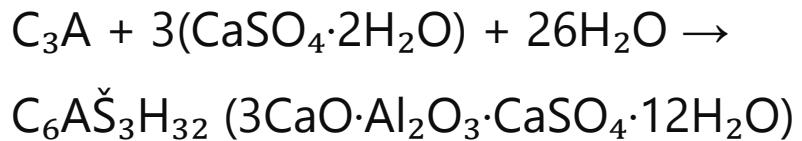


| Step 1: | Step 2: | Step 3: |
|------------------------------------|--|--|
| Diffusion inwards of CO_2 | Reaction between CO_2 and water molecules | Reaction between resultant H_2CO_3 and the $\text{Ca}(\text{OH})_2$ of concrete resulting in calcium carbonate (CaCO_3) and water |

Integrity Threat : H₂S Attack

1. $\text{H}_2\text{S} + \text{Ca(OH)}_2 \rightarrow \text{CaS} + 2\text{H}_2\text{O}$
2. $\text{CaS} + 2\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{S}\uparrow$
3. Monosulfates react with C₃A, forming expansive crystals:

- Ettringite:

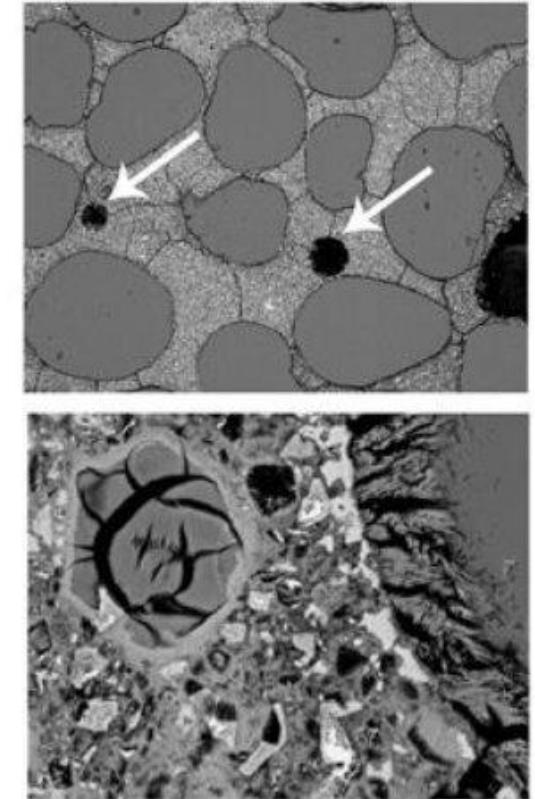
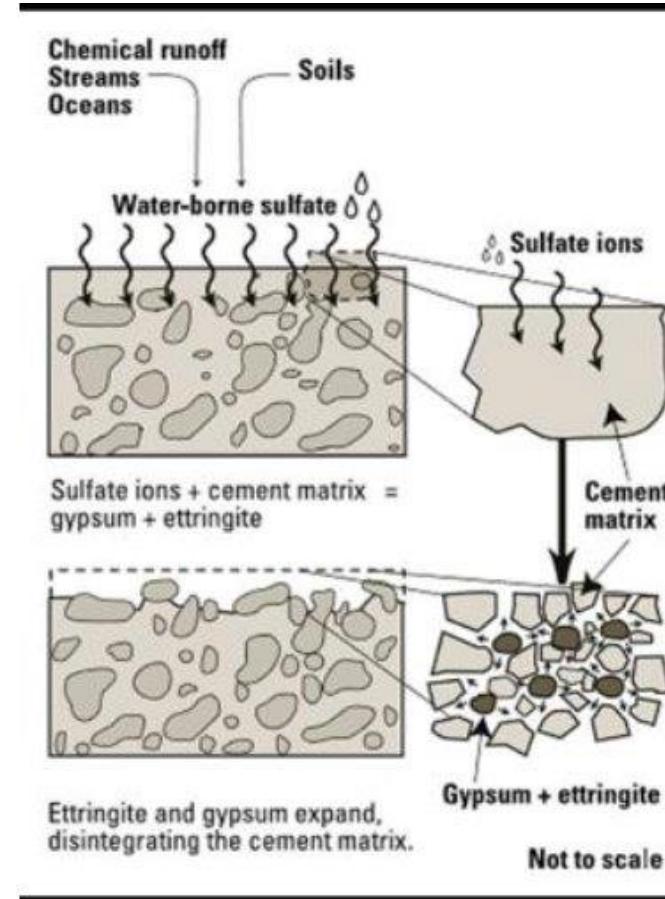
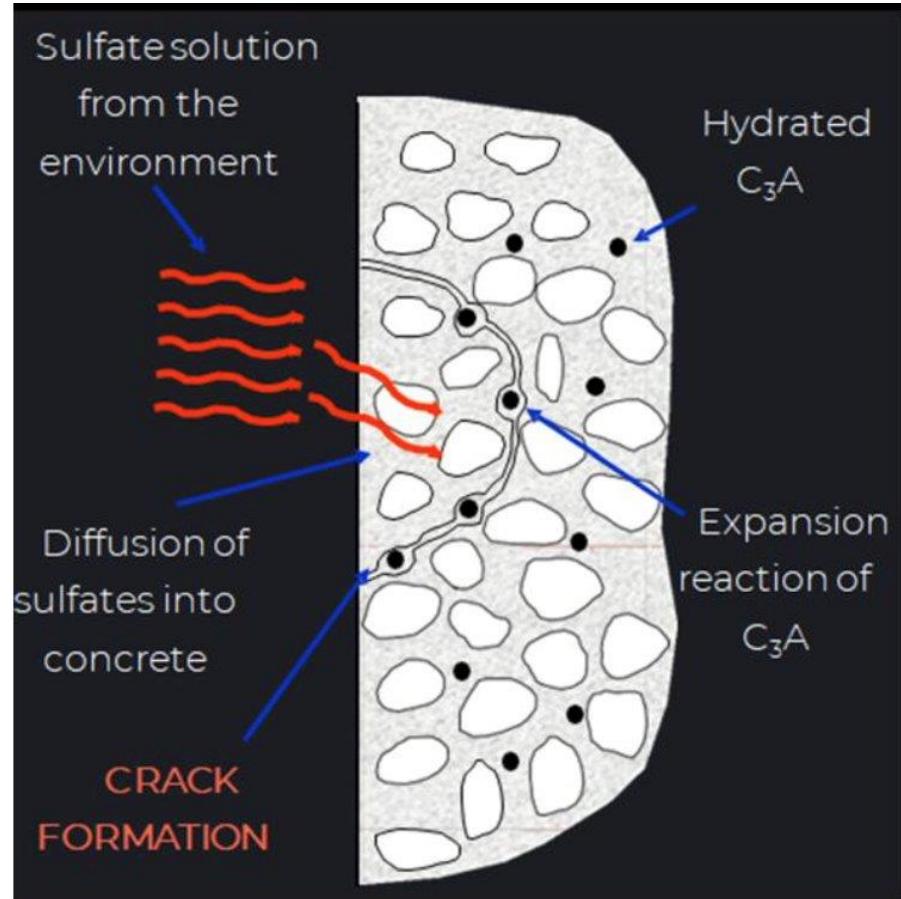


- Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$):

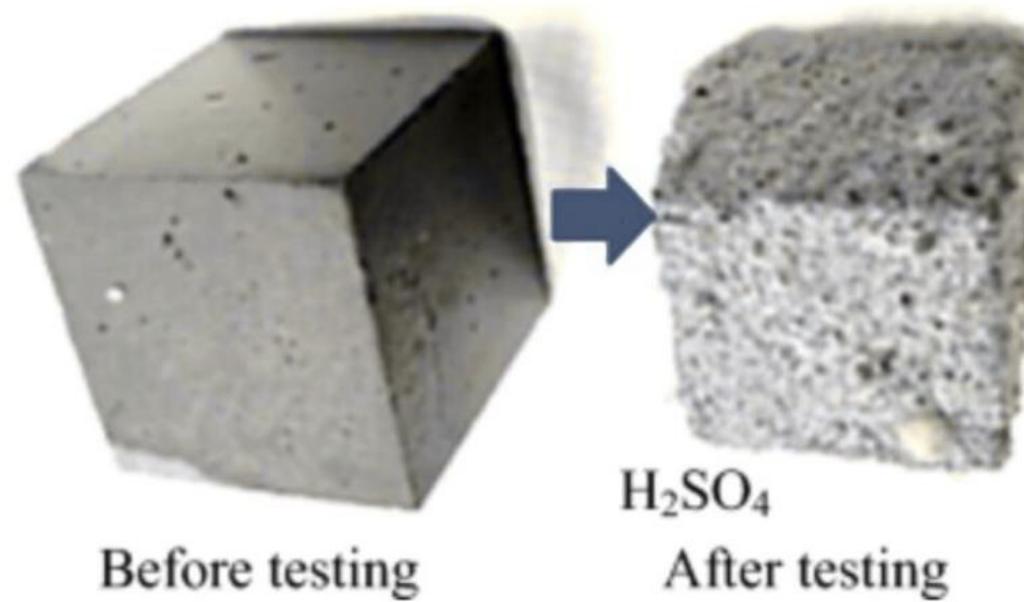
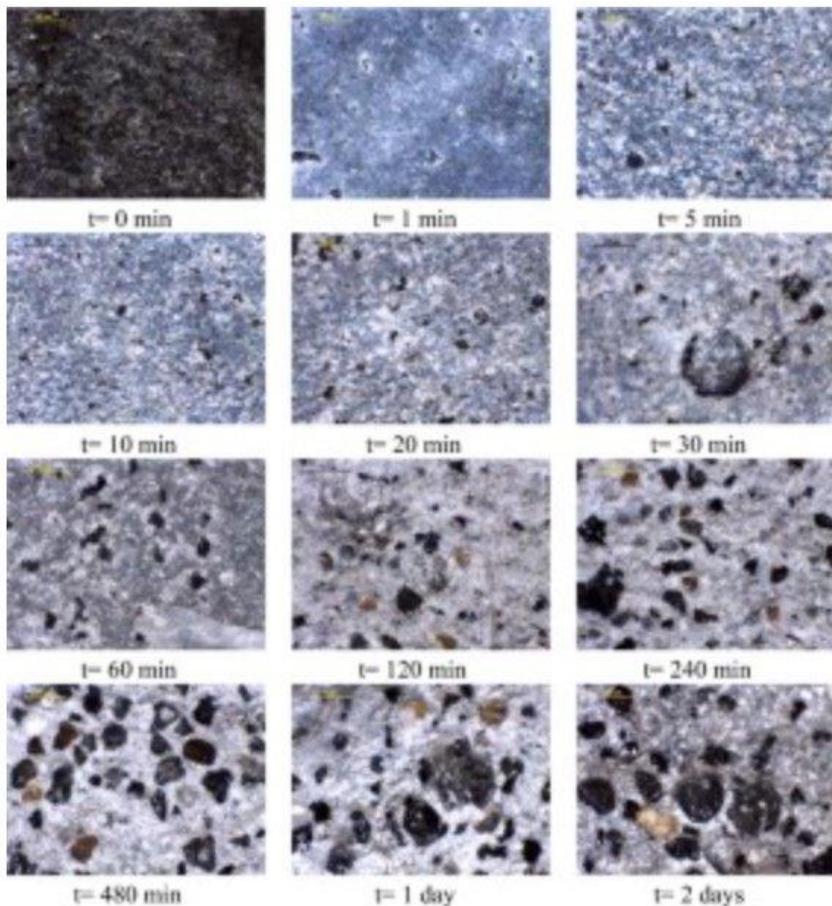
Can also form if excess sulfate reacts with calcium hydroxide (portlandite)



Integrity Threat : H₂S Attack



Integrity Threat : H₂S Attack

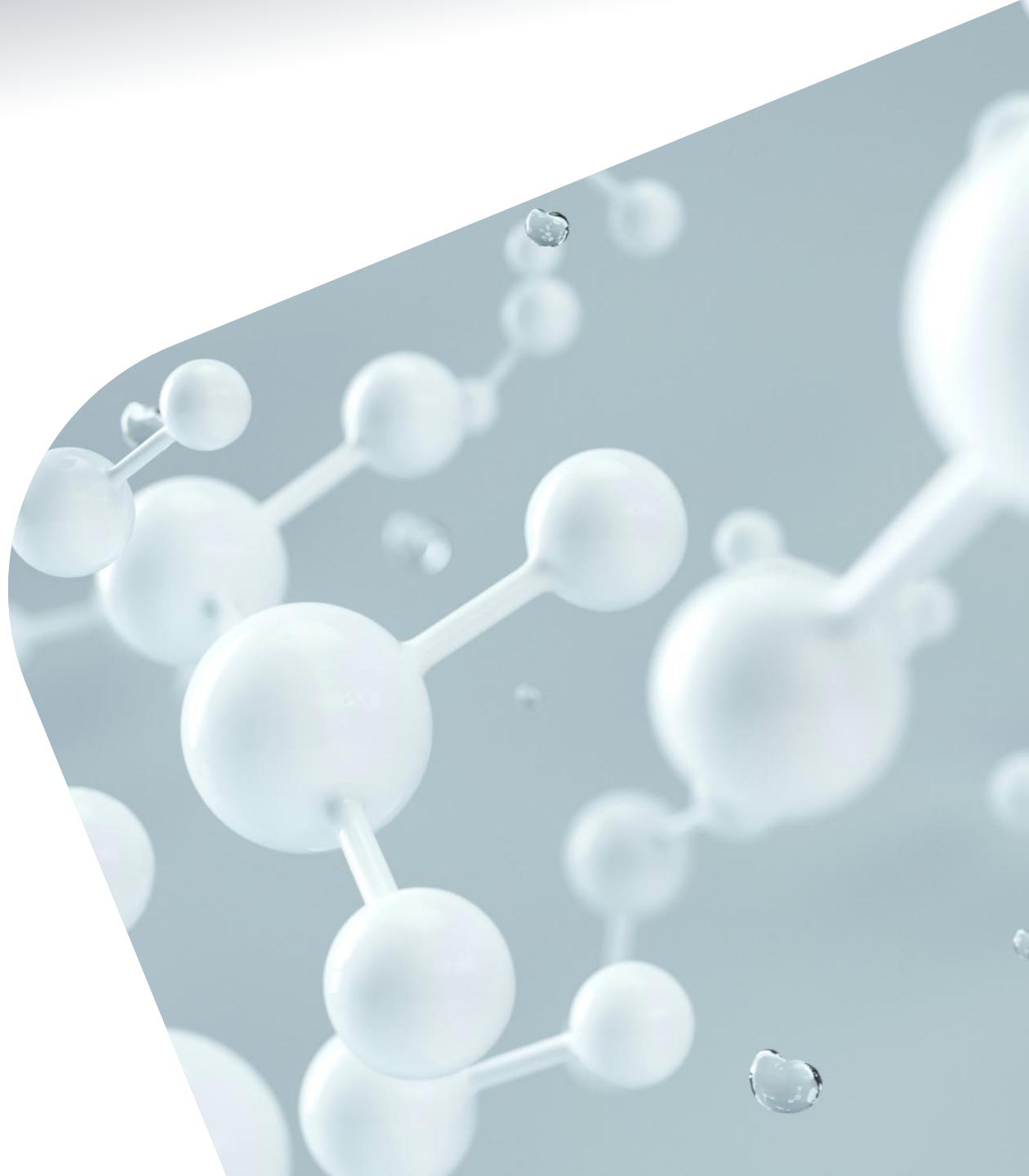


Before testing

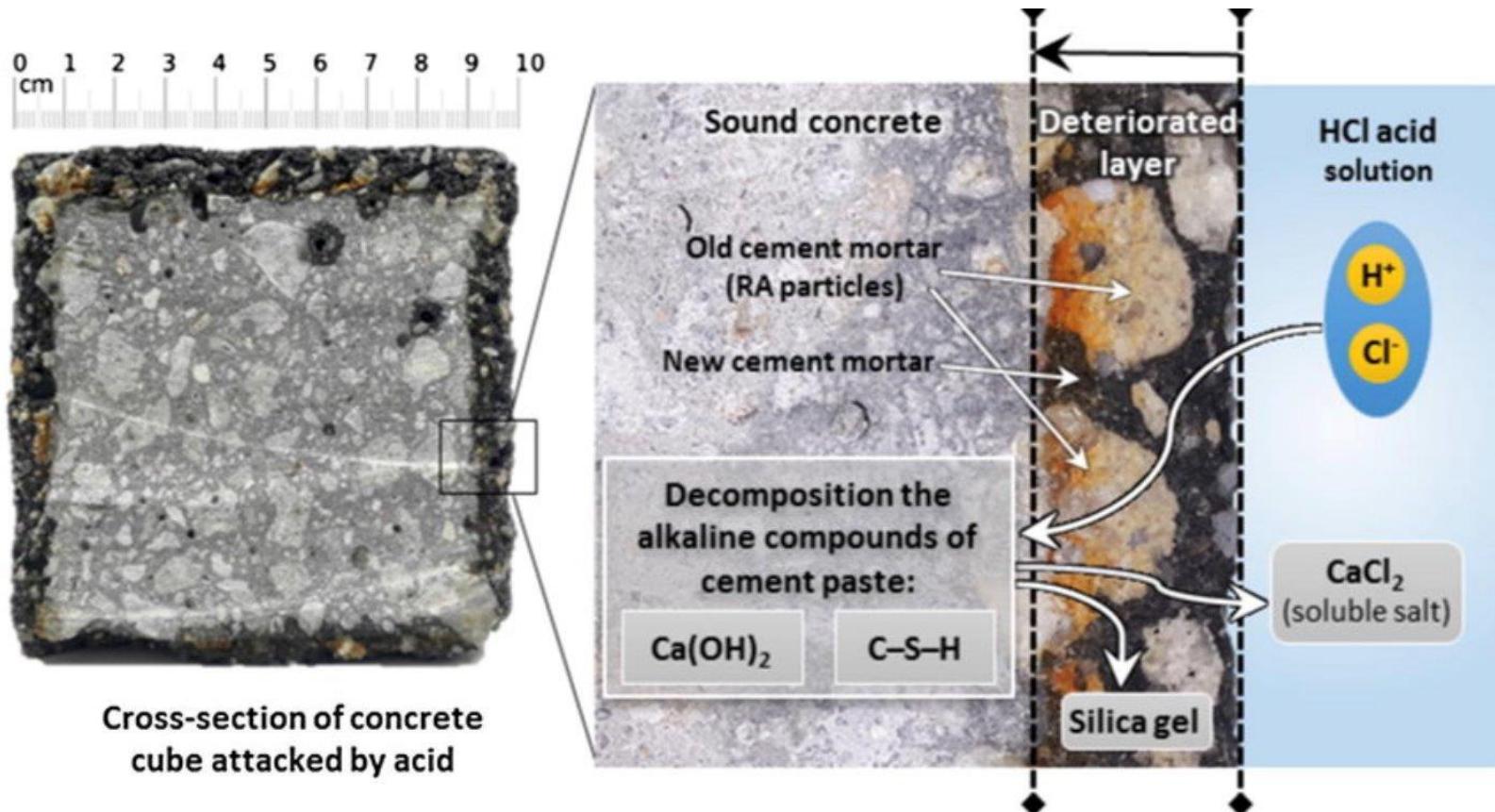
After testing

Integrity Threat : HCl Attack

1. $2\text{HCl} + \text{Ca}(\text{OH})_2 \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O}$
2. $\text{CSH} + 2\text{HCl} \rightarrow \text{SiO}_2 \cdot x\text{H}_2\text{O} \text{ (gel)} + \text{CaCl}_2$
3. Reaction with Ettringite :
 $\text{C}_6\text{A}\ddot{\text{S}}_3\text{H}_{32} + 12\text{HCl} \rightarrow \text{AlCl}_3 + \text{CaCl}_2 + \text{byproducts}$
4. $\text{CaCO}_3 + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{CO}_2 \uparrow + \text{H}_2\text{O}$



Integrity Threat : HCl Attack



Integrity Threat : CO₂ and H₂S and HCl Attack

Dissolution:

Loss of Ca(OH)₂ reduces alcalinity.

Precipitation:

Formation of secondary minerals such as CaCO₃ and CaS.

Structural alterations in high temperature:

Increase of porosity and micro fissures reduce mechanical resistance.

API testing for CO₂ environments

- There is no API RP protocol for testing cement slurries exposed to CO₂;
- API TR 10TR3 covers, however:
 - General view of CO₂ chemical attack (carbonation process);
 - Discussion of strategies on cement designs exposed to CO₂ environment;
 - Orientation on materials selection (for example, pozzolans, silica, special binding materials);
 - Recommendations and considerations on set cement durability, micro-structure analysis, and required chemical additives.

CO₂ testing (other organizations)

AMPP (Association for Materials Protection and Performance)

The screenshot shows the AMPP website's search interface. At the top, there is a navigation bar with links for EDUCATION & CERTIFICATION, STANDARDS & TECHNICAL, QP PROGRAMS, MEMBERSHIP, EVENTS, ADVOCACY, MEDIA, and ABOUT. Below the navigation is a search bar with a placeholder "Search" and a "Shop AMPP" button. On the right side of the search bar are a magnifying glass icon and a red "Login" button.

The main content area displays search results for "CO2". A sidebar on the left lists filters: All Content (8), Communities (1), Q&A Threads (1), and Web Pages (6). The main content area shows 8 results found for "CO2". The first result is a question titled "Effect of dry CO2 on epoxy surface condition" by Andrew Lindsay. It asks if a dry gas mixture (65% methane, 35% CO2) in non-condensed phase operation (199 bar, 30C) would be detrimental to the surface performance of an epoxy flow efficiency coating. The second result is a community titled "Carbon Capture and Storage" by Community. It describes the Carbon Capture and Storage (CCS) Community of Interest as a group of people (both AMPP members and nonmembers) assembled for the aim of investigating phase behavior, corrosion mechanisms and rates, and materials selection in CO2 separation, transport, and storage.

All Content 8

8 results found for "CO2"

Sort By: Relevance

Effect of dry CO₂ on epoxy surface condition

Question

Would you consider a dry gas mixture (65% methane, 35% CO₂) in non-condensed phase operation (199 bar, 30C) to be detrimental to the surface performance of an epoxy flow efficiency coating?

AL Andrew Lindsay

Added 11-06-2023

View Community

More Filters

> Community

> Created

Carbon Capture and Storage

Community

The Carbon Capture and Storage (CCS) Community of Interest is a group of people (both AMPP members and nonmembers) assembled for the aim of investigating phase behavior, corrosion mechanisms and rates, and materials selection in CO₂ separation, transport, and storage

Added 05-03-2022

[View All Communities](#)

[View Community](#)

CO₂ testing (other organizations)

CSA GROUP

CSA GROUP

Cart (0) > Login / Register > English > USD > CSA OnDemand™

Search Products

Browse Catalogue > Services >

Home > CSA Group > CSA Z625:16 (R2021)

CODES & STANDARDS - PURCHASE

CSA Z625:16 (R2021)

Well design for petroleum and natural gas industry systems

SKU: 2424656 | Published by CSA Group | Publication Year 2016 | Reaffirmed in 2021 | 48 pages

Product Details

Preface/Scope Updates

Thanks to the financial contribution of the Western Regulators Forum (WRF), CSA Group is providing the CSA Petroleum and Natural Gas standards in a downloadable PDF format for no fee to Canadian customers only ([Click for more detail](#)). If you are not in Canada, please reach out to one of the following licensed CSA Group resellers to purchase these standards or contact your local reseller:

- Accuris: (<https://store.accuristech.com/>)
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GST REG No R119441681
QST REG No R1006017360

- 1.2 This Standard addresses
- a) casing, including casing design for various types of wells, including but not limited to horizontal and directional wells;
 - b) cementing, including cement design and centralization issues and practices; and
 - c) wellhead, including design, and assembly.
- 1.3 This Standard does not apply to
- a) completion;
 - b) operations;
 - c) abandonment;
 - d) remedial cementing;
 - e) interventions;
 - f) suspensions;
 - g) competencies;
 - h) management system requirements;
 - i) drilling operations;
 - j) emerging technologies;
 - k) design tools; and
 - l) offshore and arctic applications.

CO₂ testing (other organizations)

ISO 27916



Standards

Sectors

About ISO

Insights & news

Taking part

Store

The screenshot shows the ISO website's product page for ISO 27916:2019. At the top left is the ISO logo. To its right are navigation links: Standards, Sectors, About ISO, Insights & news, Taking part, and Store. Below this is a large image of the ISO 27916:2019 standard document cover. The cover is white with "INTERNATIONAL STANDARD" at the top left, "ISO 27916:2019" at the top right, and "Edition 1 2019-01" at the bottom right. In the center, it reads "Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO₂-EOR)". At the bottom of the cover image is a "Read sample" button. To the right of the document image, the title "ISO 27916:2019" is displayed in large bold letters, followed by a green leaf icon. Below the title is a descriptive text: "Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO₂-EOR)". A horizontal green line separates this from the publication information: "Published (Edition 1, 2019)".

API testing for H₂S

- There is no API RP or exclusive TR to test cement resistance to H₂S. However, H₂S resistance is indirectly approached through specifications of sulfate resistant cements and general cement testing protocols.
- Service companies, operators and research institutions lean on:
 - Exposure tests in autoclave machines with H₂S rich gas mixtures;
 - Long immersion of set cement in sulfide brines;
 - Petrographic analysis, SEM and XRD of set cement degradation;
 - Strength and permeability testing after exposure to H₂S / sulfate brines;
 - Special binding materials (for exemple: pozzolanic mixtures, Classe G + silica fume, latex modified systems...)

API Specifications - Sulfate Resistance

- API cement graduation in respect to sulfate resistance:
 - O (ordinary)
 - MSR (moderate sulfate resistance to SO_4)
 - HSR (high sulfate resistance)

H₂SO₄ testing (other organizations)

ASTM C1898-20

- Standard Test Methods For Determining The Chemical Resistance Of Concrete Products To Acid Attack
 - These test methods are intended to evaluate the chemical resistance of cement paste, mortar and concrete materials. This method is loosely based on Test Methods C267, however the solution is more rigorously defined and flexural strength is used. These test methods provide for the determination of changes in the following properties of the test specimens and test medium after exposure of the specimens to the medium:
 - Mass of specimen
 - Appearance of specimen,
 - Appearance of test medium, and
 - Strength of specimens.

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guide and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

 Designation: C1898 – 20

Standard Test Methods for Determining The Chemical Resistance of Concrete Products to Acid Attack¹

This standard is issued under the fixed designation C1898; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last suppressed. A superscript epsilon (ε) indicates an editorial change since the last revision or suppression.

1. Scope

1.1 These test methods are intended to evaluate the chemical resistance of cement paste, mortar and concrete materials. This method is loosely based on Test Methods C267, however the solution is more rigorously defined and flexural strength is used. These test methods provide for the determination of changes in the following properties of the test specimens and test medium after exposure of the specimens to the medium:

1.1.1 Mass of specimen,

1.1.2 Appearance of specimen,

1.1.3 Appearance of test medium, and

1.1.4 Strength of specimens.

1.2 Guide C1894 provides a standard guide for Microbially Induced Corrosion of Concrete (MICC) products. This standard is used for assessing the chemical resistance of nonconcrete products to acid attack caused by MICC; however as described in the guideline document for MICC products the current document only applies for Stage III of corrosion. This document is not intended to be a guideline document for the complete evaluation of MICC nor for assessing the efficacy of antimicrobial additives used to reduce MICC.

1.3 This standard supplements Test Methods C267 to improve the consistency of reported results for acids generated by MICC or other sources.

1.4 This standard does not cover tests in which acidification is achieved by bacterial activity. Testing protocols for bacterial activity are described in Guide C1894.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to alternative units (typically inch-pound units) that are provided for information only and are not considered standard.

1.6 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.7 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guide and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 ASTM Standards:
C14 Specification for Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe
C70/C70M Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C125 Terminology Relating to Concrete and Concrete-Aggregates
C102/C102M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C267 Test Method for Chemical Resistance of Mortars, Grouts, and Monolithic Sealants and Polymer-Concretes
C822 Terminology Relating to Concrete Pipe and Related Products
C904 Terminology Relating to Chemical-Resistant Nonmetallic Materials
C1760/C1760M Practice for Accelerated Curing of Concrete Cylinders
C1894 Guide for Microbially Induced Corrosion of Concrete Products
E4 Practices for Force Verification of Testing Machines

3. Terminology

3.1 Definitions:
3.1.1 For definition of terms used in this standard, refer to Terminology standards C125 and C822.

4. Significance and Use

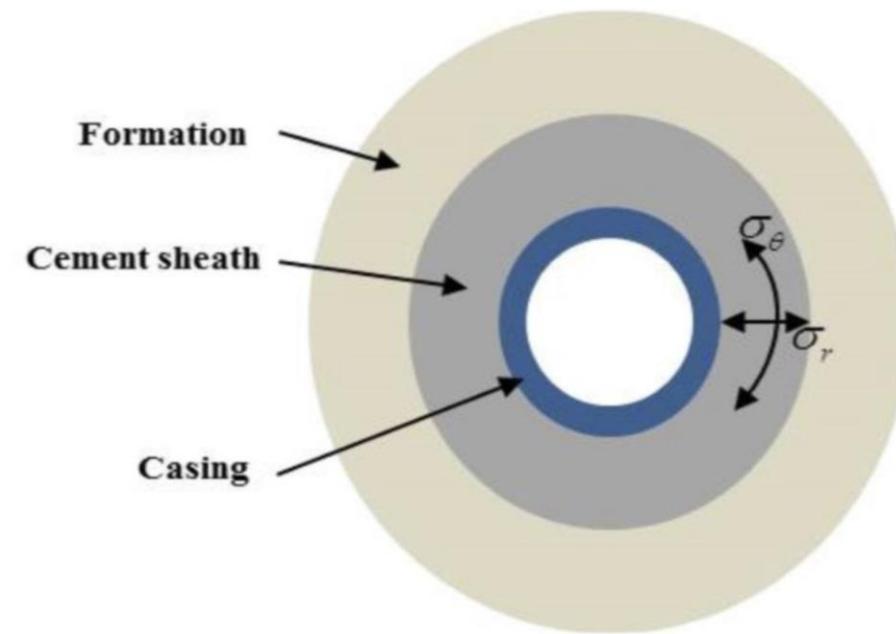
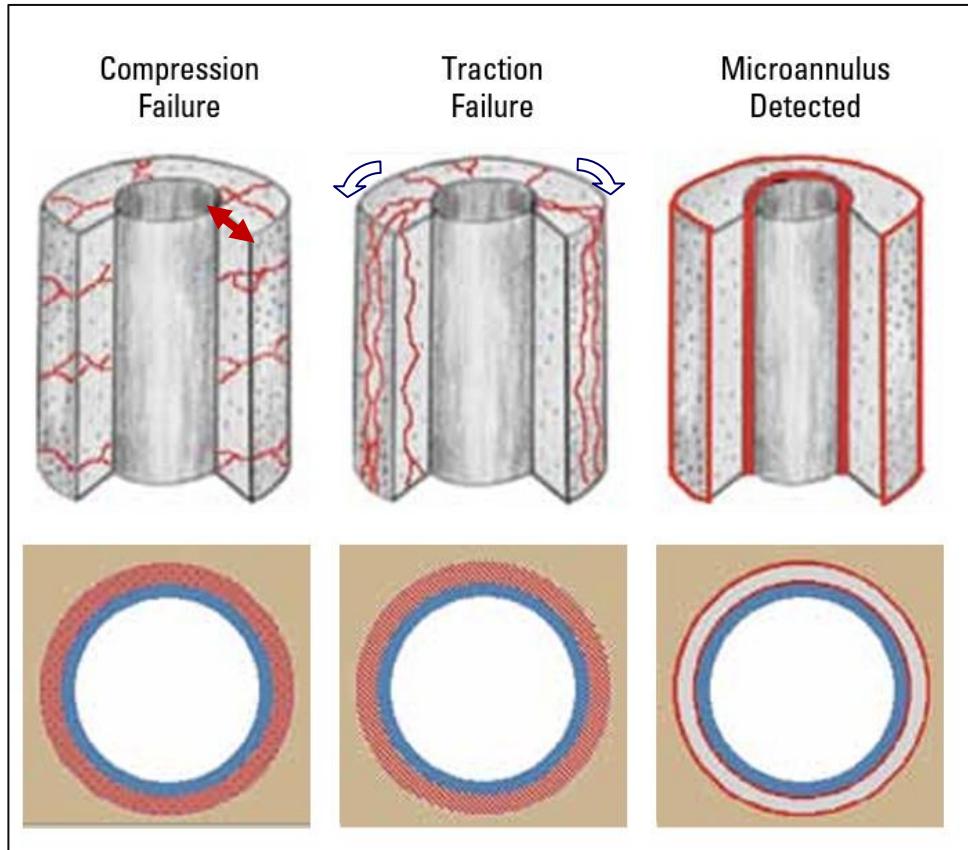
4.1 As described in Guide C1894, the MICC is considered to be a three-stage process with the reduction in pH (Stage I) (for example, 12.5 > pH > 9.0), the establishment of biofilms (which further lowers the pH (Stage II) (for example, 9–10 < pH < 4.0) and eventual deterioration due to biogenic acid exposure (Stage III).

¹ This test method is under the jurisdiction of ASTM Committee C01 on Concrete and in the direct responsibility of Subcommittee C01.09 on Determining the Effects of Biogenic Activities Solid on Concrete Pipe and Structures. Current edition approved May 1, 2020. Previous May 23, 2016. © 2020 ASTM International.

Integrity Threat : Mechanical Failure

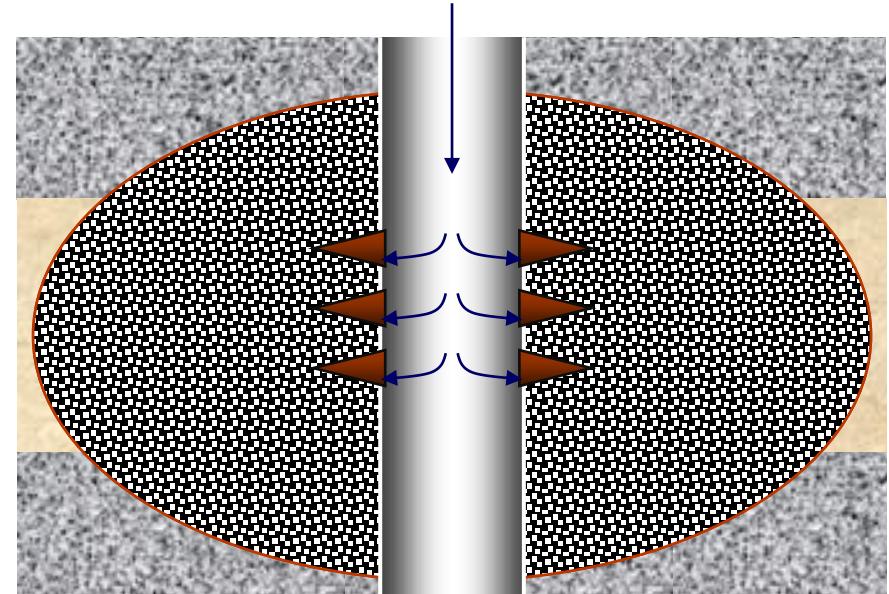
- Effects: Microcracks, debonding, microannulus
- Solutions: Flexible/self-healing cement, FEM analysis

Integrity Threat : Mechanical Failure

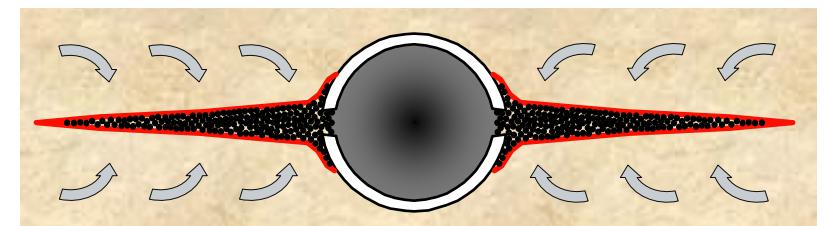


Integrity Threat : Mechanical Failure by Fracturing

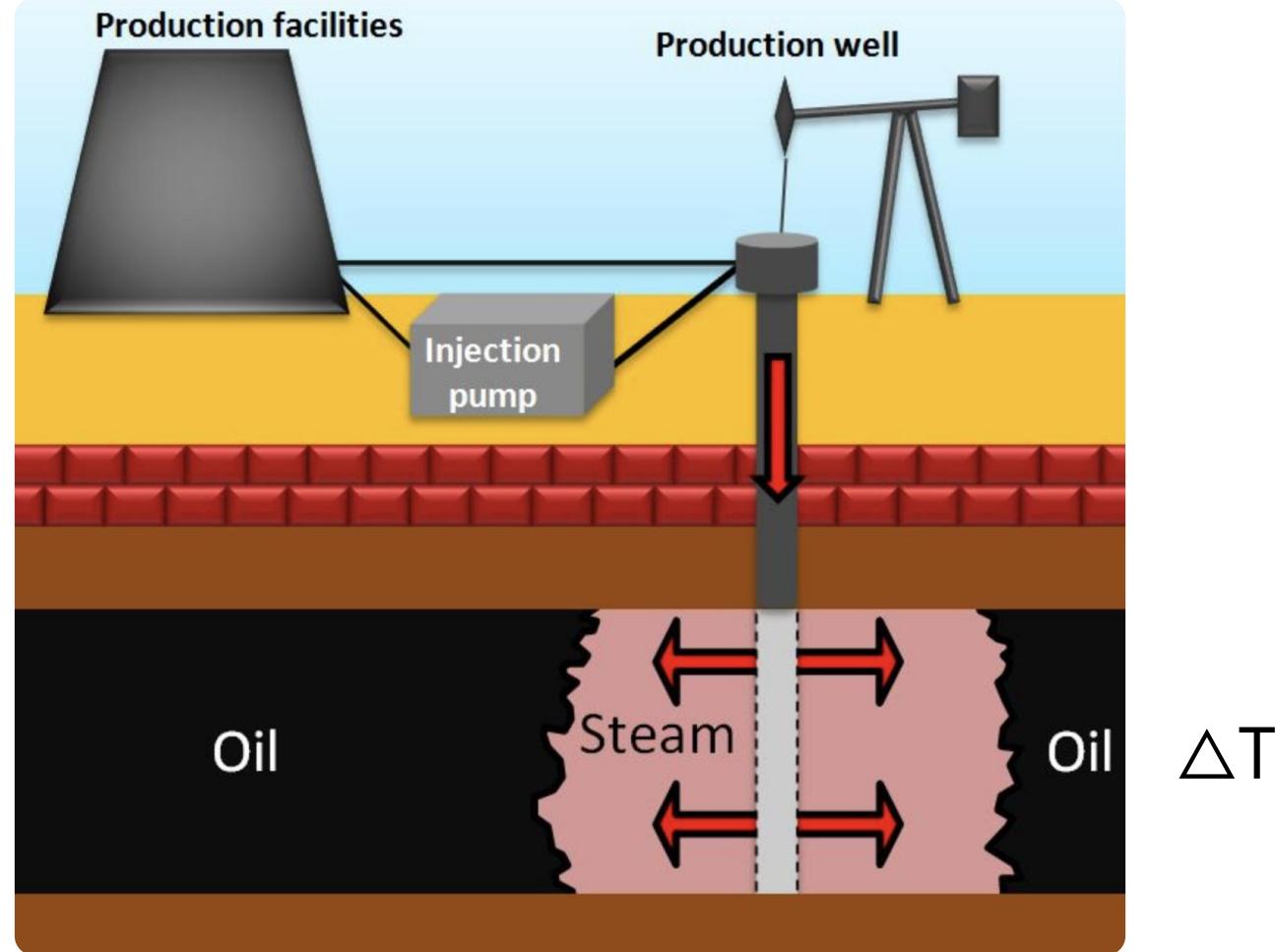
- High rate and high pressure pumping, injecting frac fluids into the formation, creating fractures...
- After the fractures are created, sustaining agents, also called proppants, are pumped in...
- The fracture is filled in by proppants, at the end of the pumping, in order to keep it open and to facilitate fluids from the reservoir to the well.



Pressure Cycling

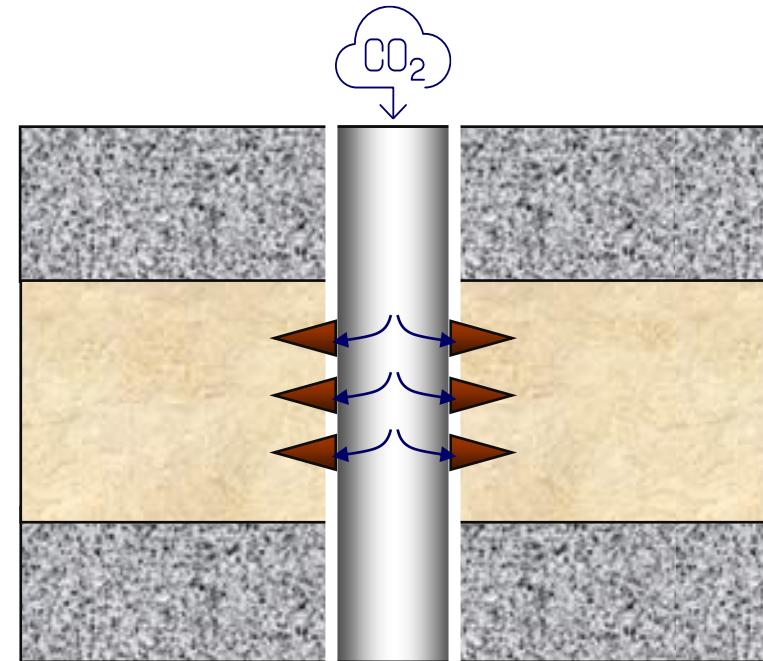


Integrity Threat : Mechanical Failure By Steam Injection

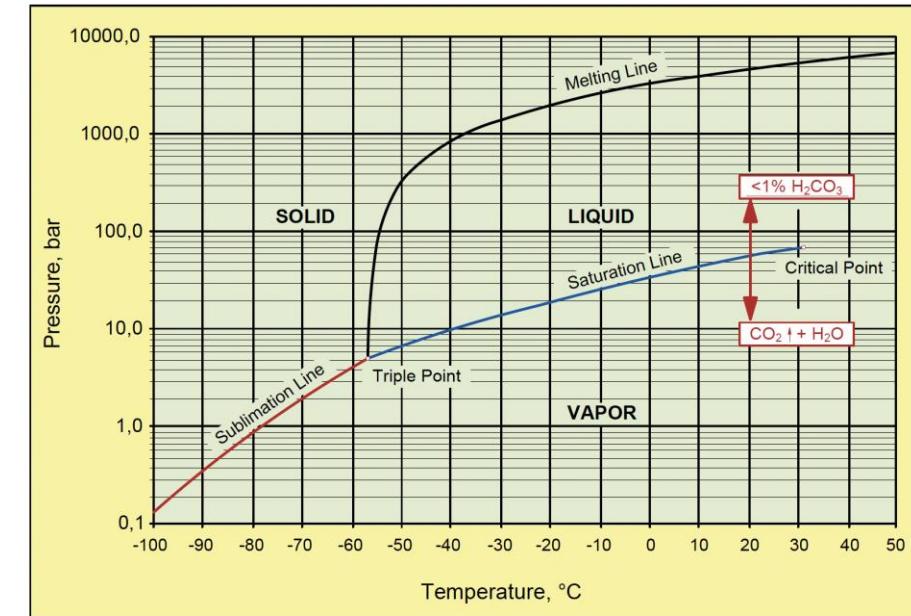
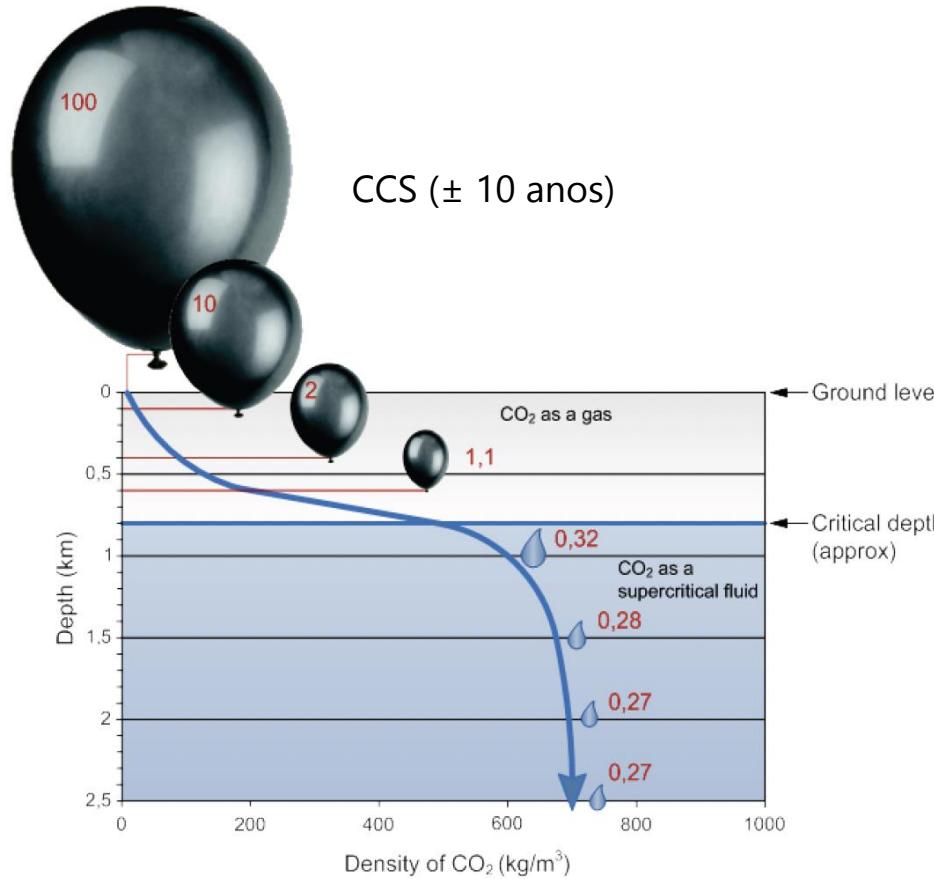


Integrity Threat : Mechanical Failure By CO₂ Injection

- CO₂ injection is a proven EOR technique (\pm 45 years);
- Injected CO₂ reduces oil viscosity and interfacial tension;
- Under high pressure, CO₂ becomes miscible with oil, improving recovery;
- It helps to keep reservoir pressure and improves oil sweep efficiency;
- Recovery increases by 10 to 20% or more in comparison with water injection;
- Captured industrial CO₂ can be reutilized, contributing to carbon management;
- Importance to set cement: wells should keep integrity when exposed to CO₂.

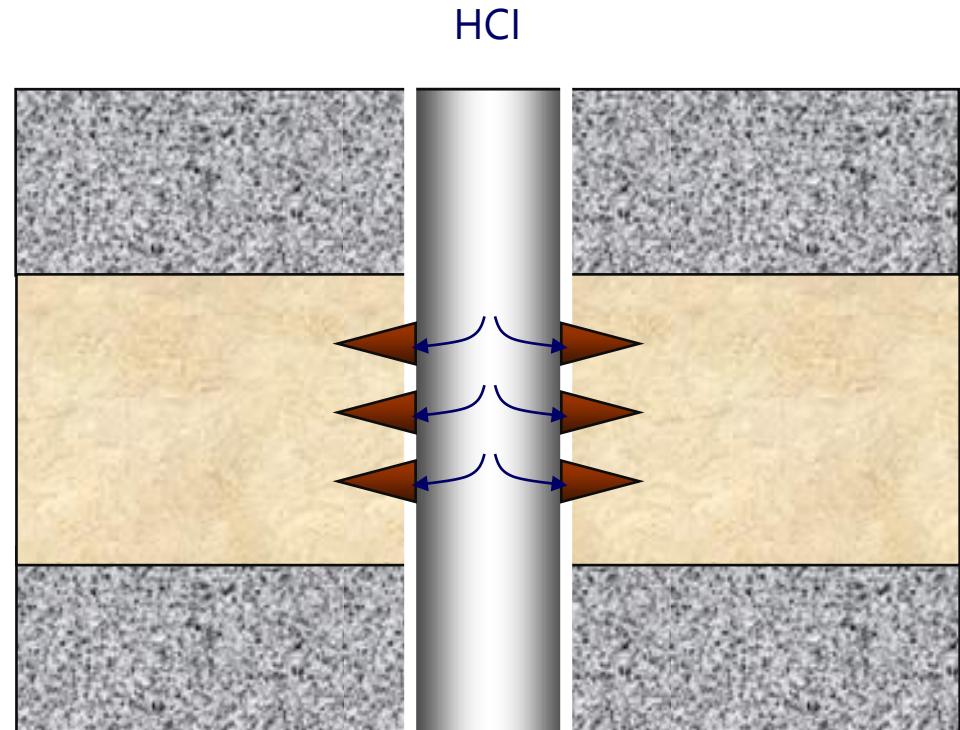


Integrity Threat : Mechanical Failure By CO₂ Injection



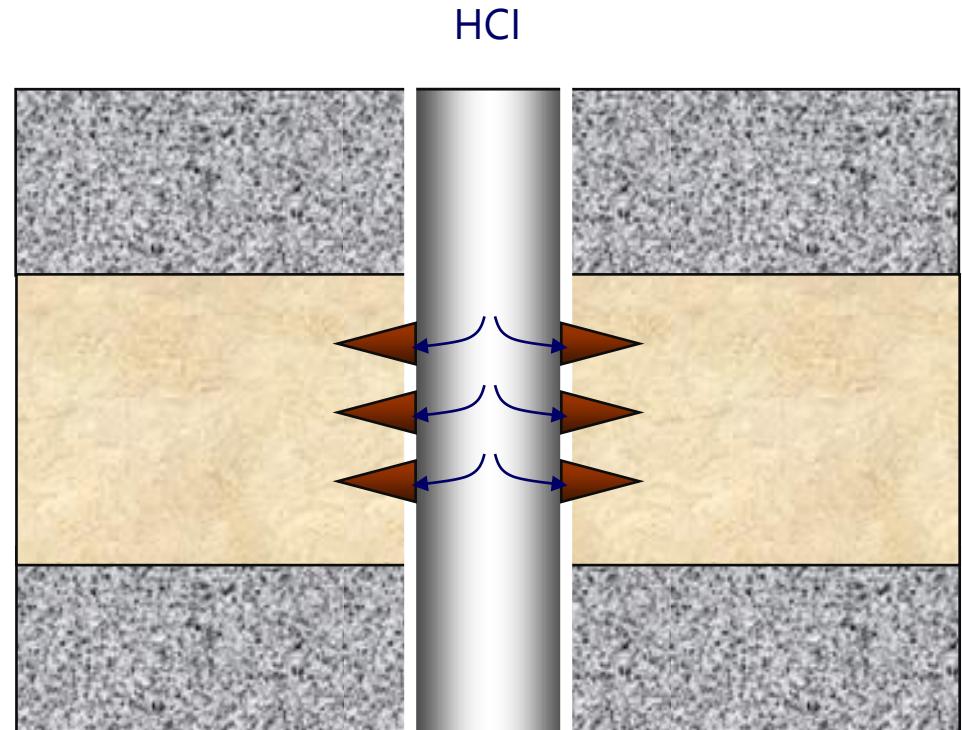
Integrity Threat : Mechanical Failure By Stimulation

- Acid stimulation fluids, especially hydrochloric acid (HCl), can cause serious damage to set cement if they come into contact with it. Here's what happens:
 - Dissolution of Cement Phases
 - HCl aggressively reacts with $\text{Ca}(\text{OH})_2$ and other cement hydrates, such as calcium silicate hydrate (C-S-H), which are key to the strength of set cement.
 - This leads to decalcification, weakening the cement structure.
 - Increase in Porosity and Permeability
 - As acid dissolves cement compounds, it opens up the cement matrix, increasing porosity and permeability.
 - This compromises the sealing capability of the cement, potentially allowing fluid migration along the annulus.



Integrity Threat : Mechanical Failure By Stimulation

- Strength Loss
 - Progressive acid attack leads to loss of compressive strength, making the cement sheath unable to withstand pressure or mechanical loads.
- Zonal Isolation Failure
 - Damaged cement can lead to zonal isolation failure, resulting in crossflow between formation layers, gas migration, or sustained casing pressure (SCP).
- Risk of Well Integrity Compromise
 - In severe cases, acid-induced degradation of cement jeopardizes overall well integrity, requiring expensive remediation or re-cementing.



Integrity Threat : Early Gas Migration

- Tests: Static gel strength, thixotropy behavior
- Design: Accelerators, latex, foam, proper centralization

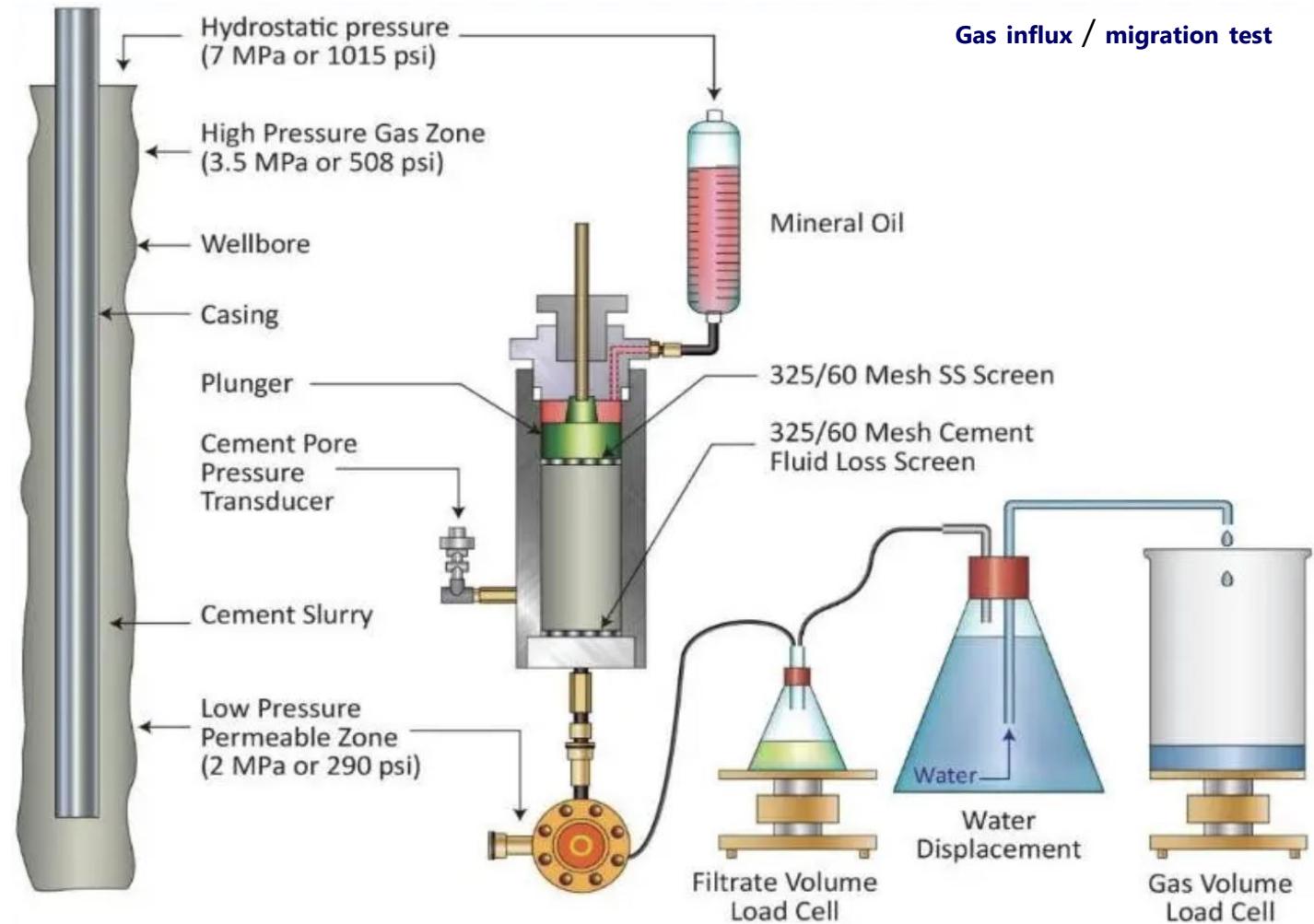


Foam Cement

Integrity Threat : Early Gas Migration



Static Gel Strength Analyzer



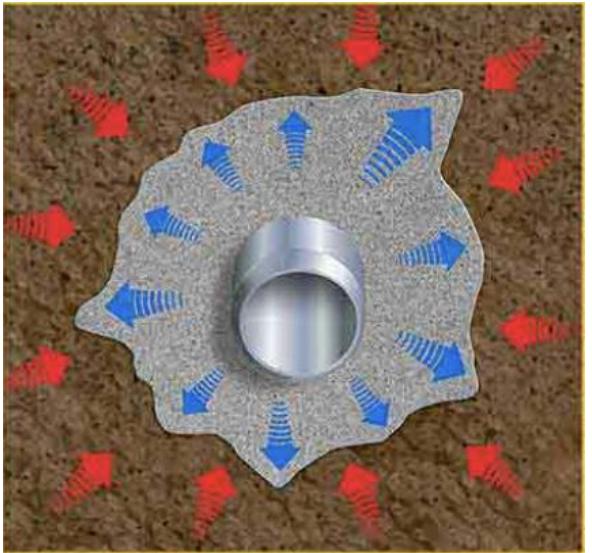
Integrity Threat : Cement Design

- Poorly designed cement jobs may lead to catastrophic failures on well integrity
- Mitigation: the use of simulators, adequate cement systems and mud removal techniques, tailored to well conditions

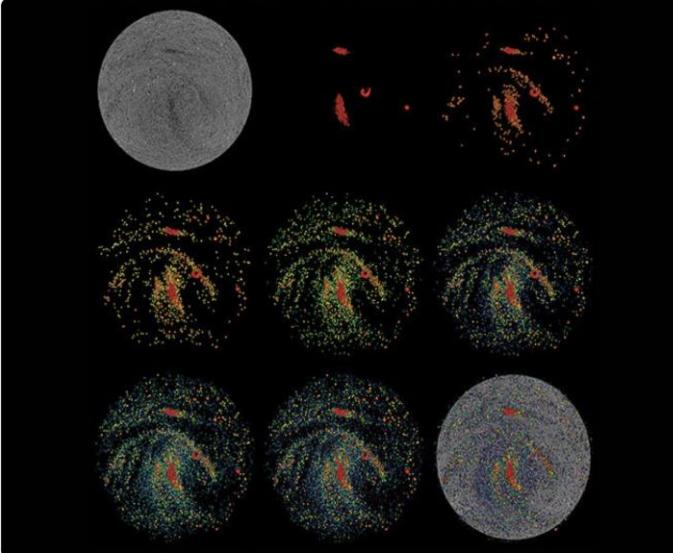
Cement Design

- Expandable systems
- Lightweight/foamed cements
- Self-healing additives
- Compatibility with formations (salt, shale, fractured zones)
- Environmental stewardship (bio-based additives, recycled byproducts, and low-carbon cement alternatives)

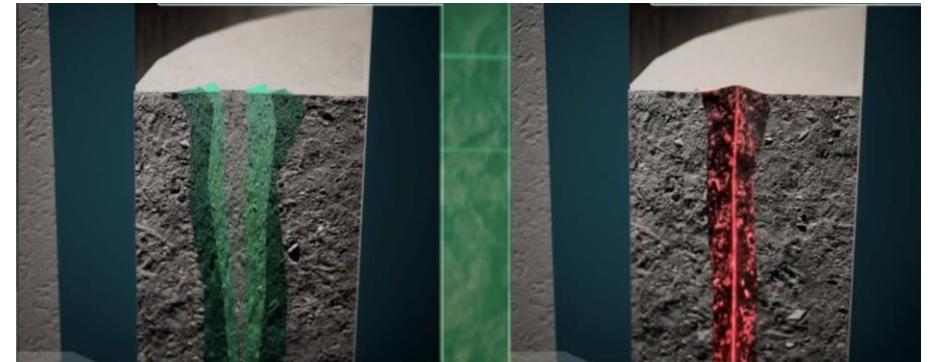
Cement Design



Flexible Cement



Foamed Cement

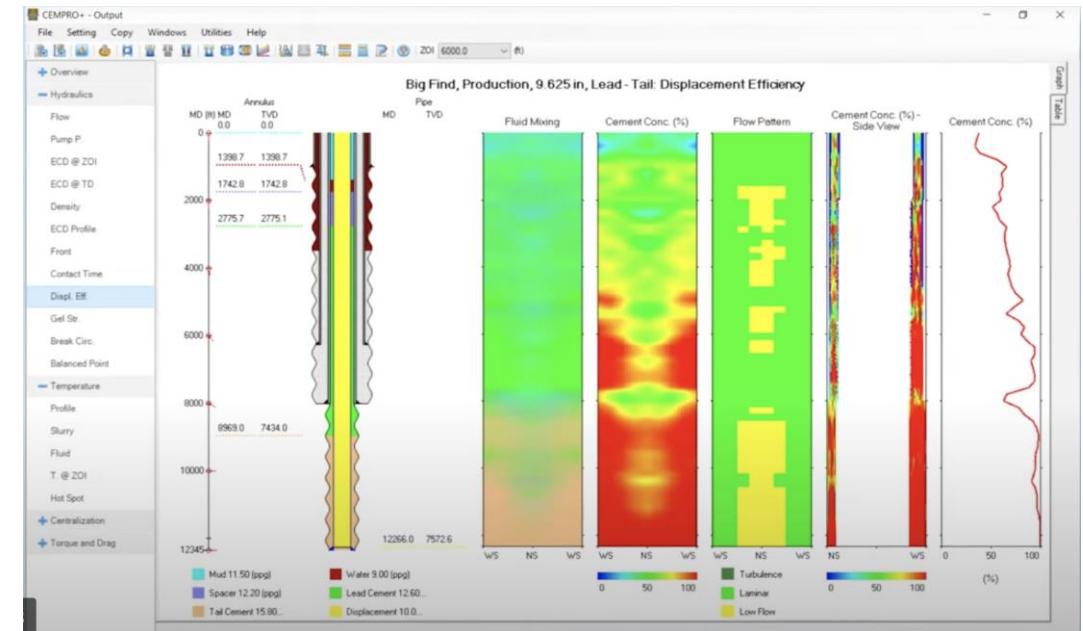


Self-healing Cement

Cement Design Simulators

Sources:

- Service companies;
- Independent specialized software companies.



Cement Design

Composition of high-density cement slurries. Unit wt. %.

180° C

| Density (kg/m ³) | Cement | Water | Fluid Loss Reducer | Retarder | Dispersant | Slica Fume | Mn | Weighting Agent | Slag | Resin |
|------------------------------|--------|-------|--------------------|----------|------------|------------|----|-----------------|------|-------|
| 2.0 | 100 | 41 | 7 | 2.5 | 2 | 35 | 16 | 20 | 8 | |
| 2.1 | 100 | 42 | 7 | 2.5 | 3 | 35 | 32 | 18 | 8 | |
| 2.2 | 100 | 44 | 6 | 2.2 | 4 | 35 | 52 | 18 | 8 | |
| 2.3 | 100 | 45 | 6 | 2 | 4.5 | 35 | 79 | 16 | 10 | |

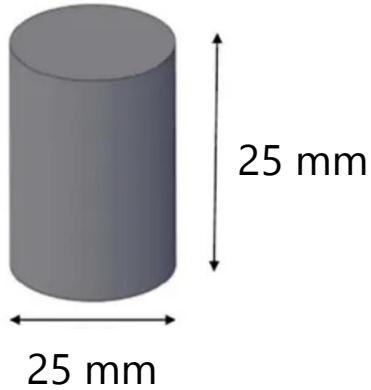
100 mesh: 150µm ; 300 mesh: 48µm

Material which replaces
Portland cement, helping
compaction

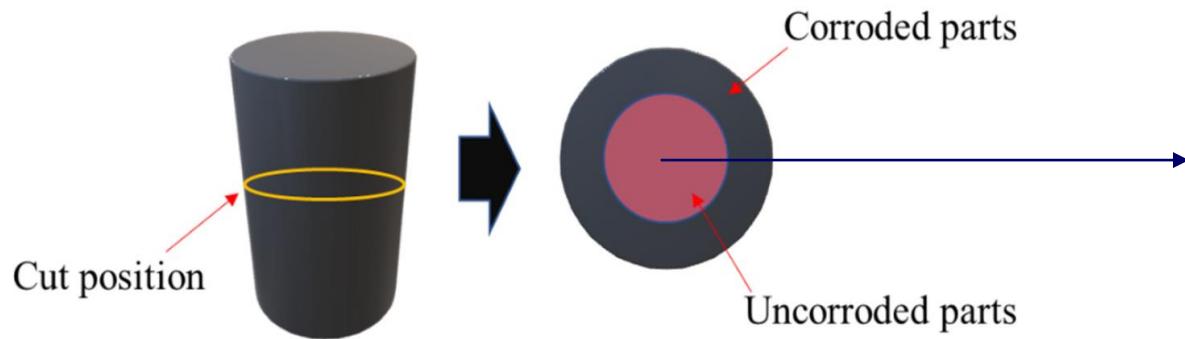
Added material which in high
temperatures, reacts with cement
hydrated silicates to generate
tobermorite and xonotlite,
reducing the ratio of C/S from 2
to 3:1 to approximately 1:1

Material which
protects cement
matrix, mitigating
corrosion

Cement Design



The cement cylinders were retrieved after 7 and 30 days for evaluation



Most integral part = alkaline region (presence of Ca), indicated by phenolphthalein coloration (red)

Cement Design

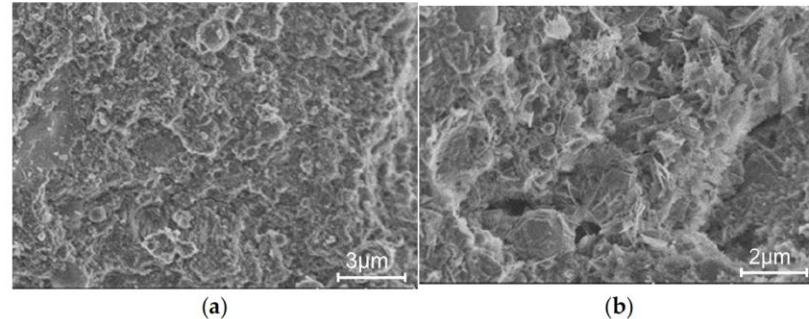


Figure 13. Morphology of 2.0 kg/m^3 cement sample: (a) non-corroded; (b) corroded.

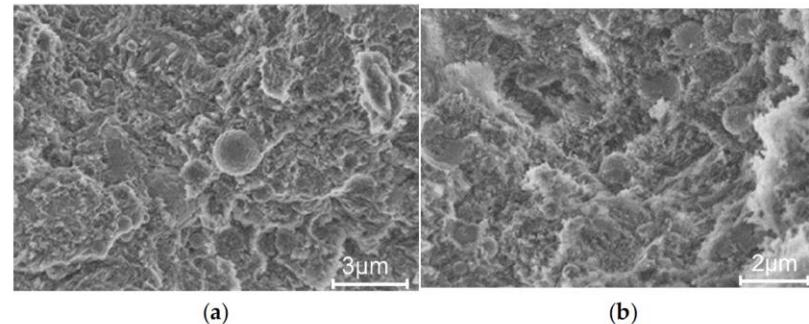
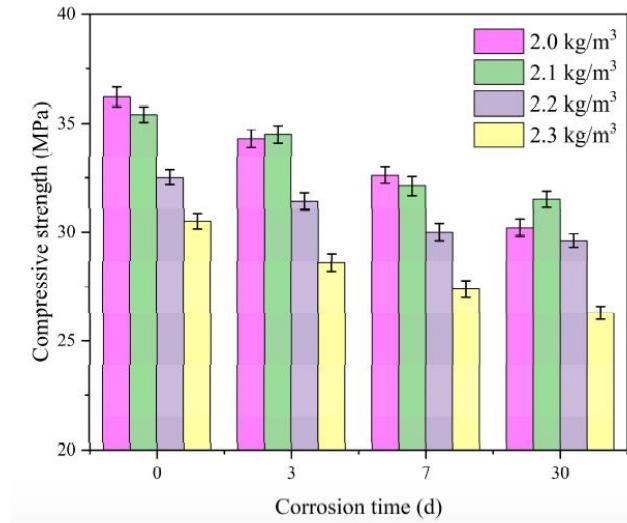
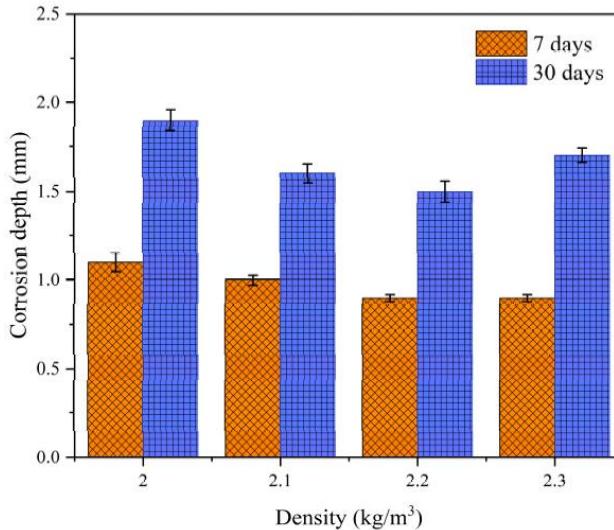
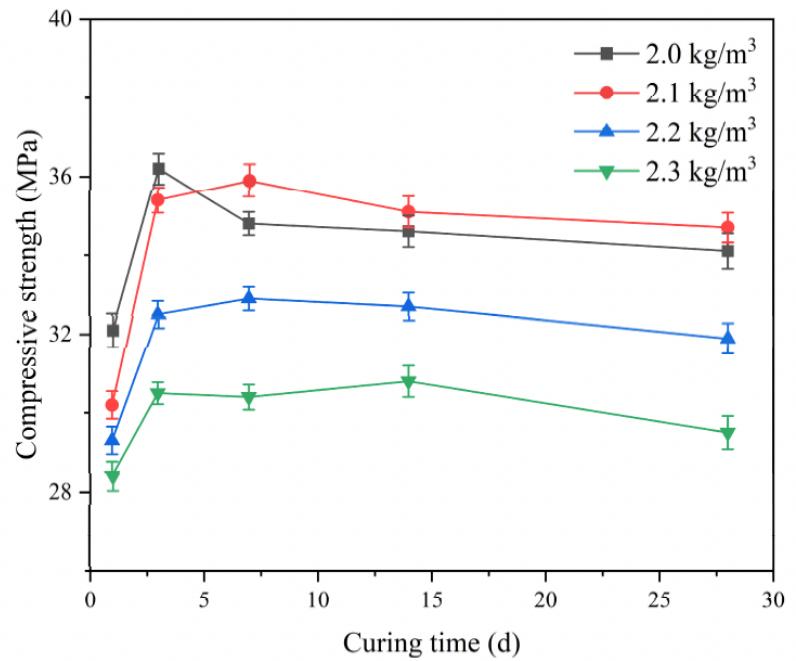


Figure 14. Morphology of 2.3 kg/m^3 cement sample: (a) non-corroded; (b) corroded.

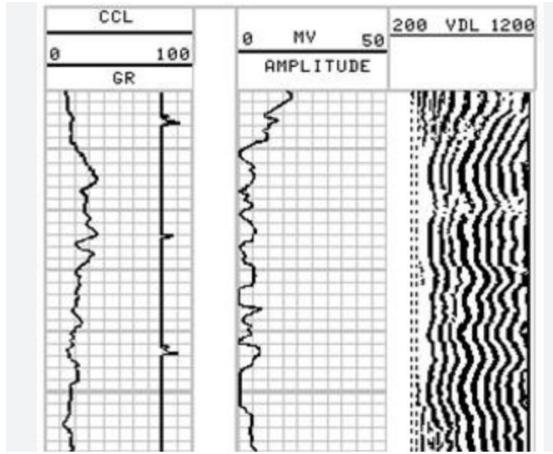
Cement Design



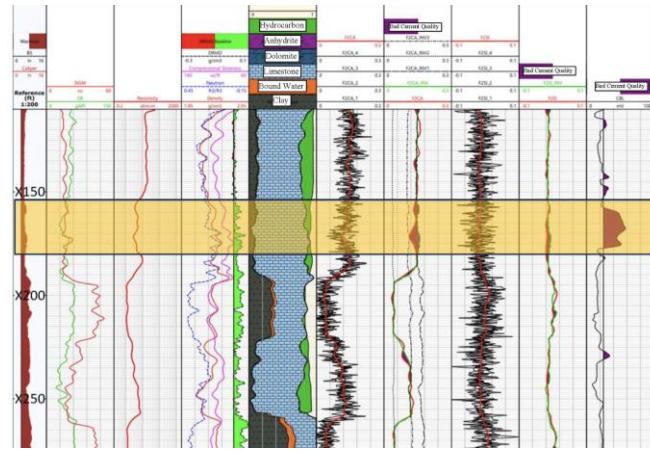
Cement Evaluation Tools Overview

- CBL (Cement Bond Log)
- Ultrasonic (USIT / Isolation Scanner)
- Pulsed Neutron Logs (PNL)
- Fiber Optics (DAS/DTS)
- Temperature & Pressure Surveys

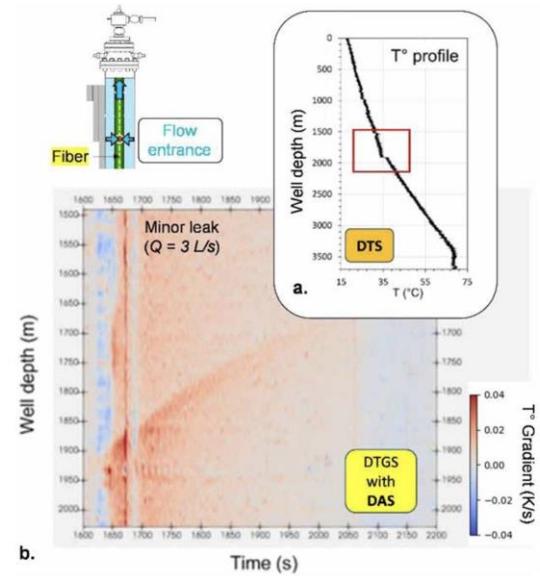
Cement Evaluation Tools Overview



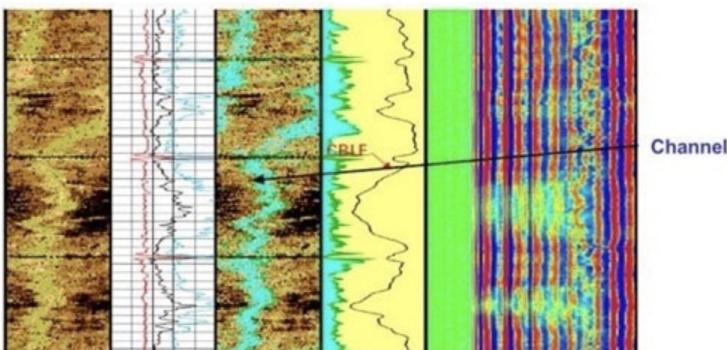
CBL & VDL



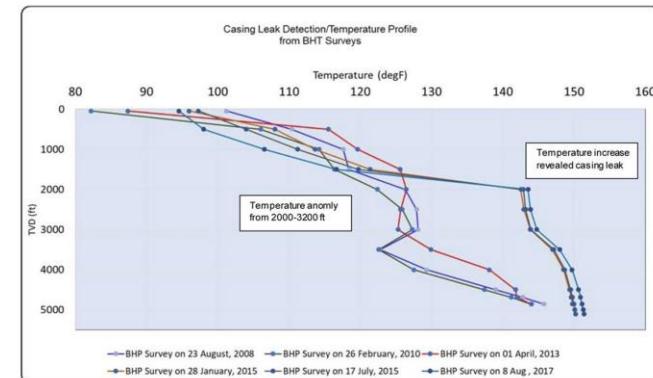
Pulse Neutron Logs



Fiber Optics Sensing



USIT



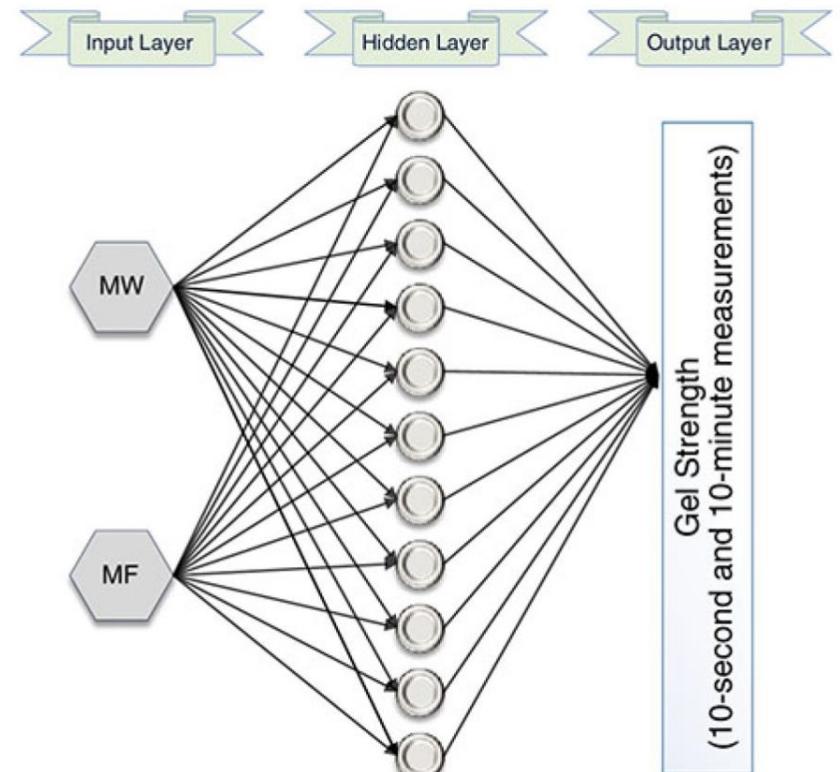
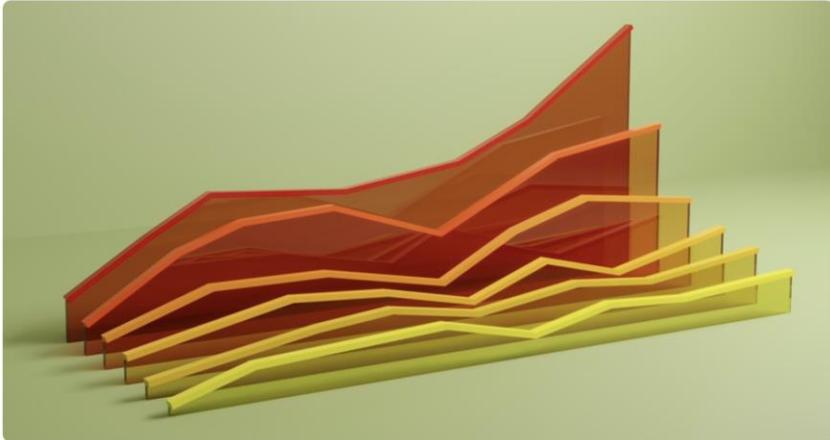
Pressure & Temperature Sureveys

Tool Comparison Table

| Tool | Detect Bond? | Good for Light Cement? | Notes |
|------|------------------|------------------------|----------------------|
| CBL | Yes | No | Good for hard cement |
| VDL | Yes (waveform) | No | Qualitative only |
| USIT | Yes | Yes | Good for gas zones |
| PNL | Indirectly | Yes | Requires base log |
| DAS | Yes (fluid flow) | Yes | Real time detection |

Cement Integrity Monitoring Trends

- Machine learning prediction of isolation failure
- Smart cements (sensing materials, self-healing)
- Permanent downhole sensors



Integration Strategy

- Early Evaluation (while rig is on site)
- Long-Term Surveillance (DTS, casing pressure)
- Life-cycle Integrity Plan

Final Thoughts

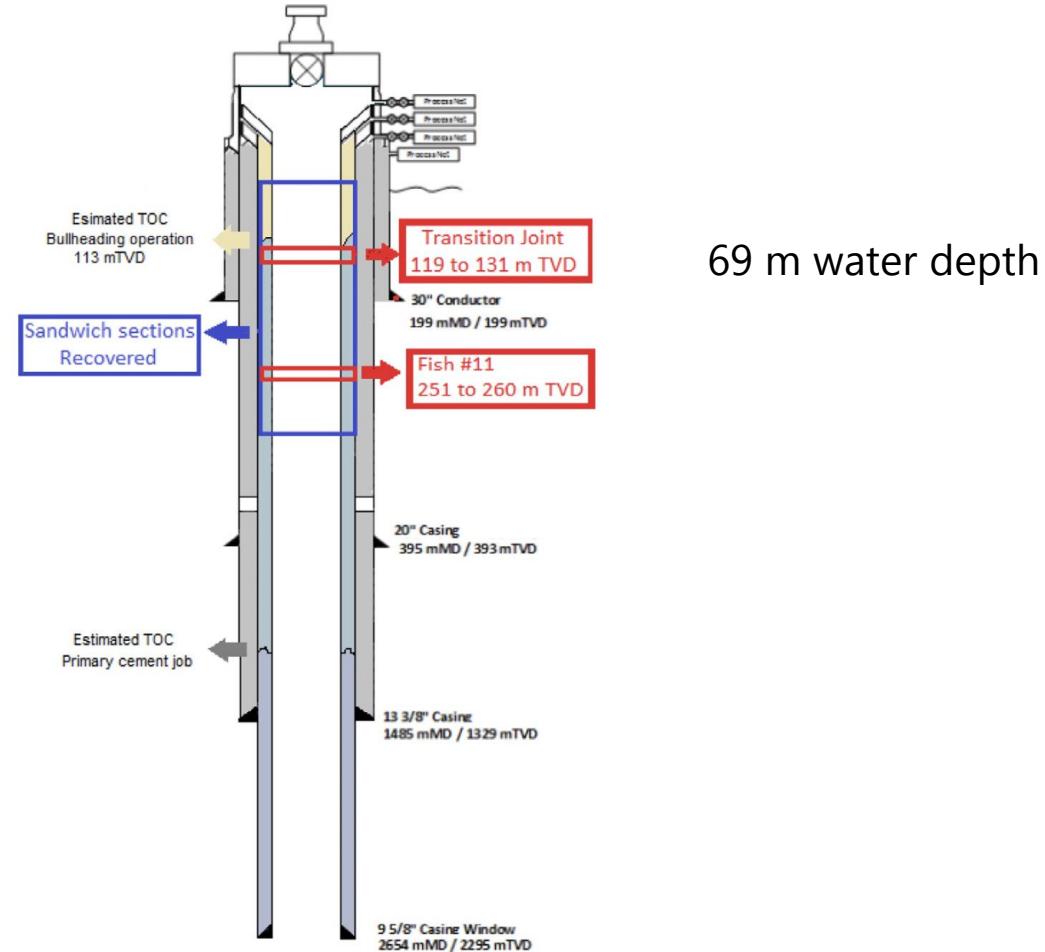
- Evaluation must match design and environment
- Digital tools and smart cements are the future



Thank You!

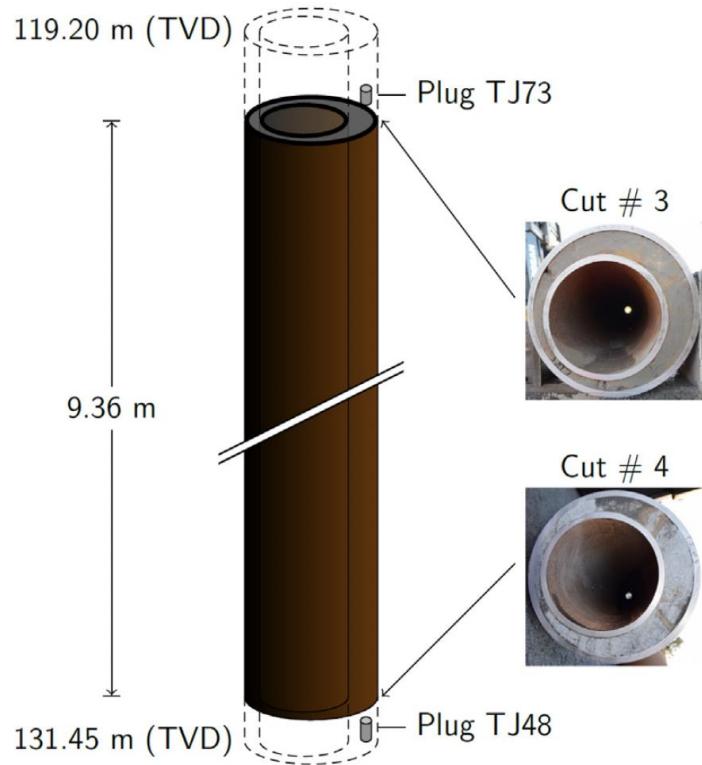


Investigation of well integrity of a 33 years old offshore well in Norway

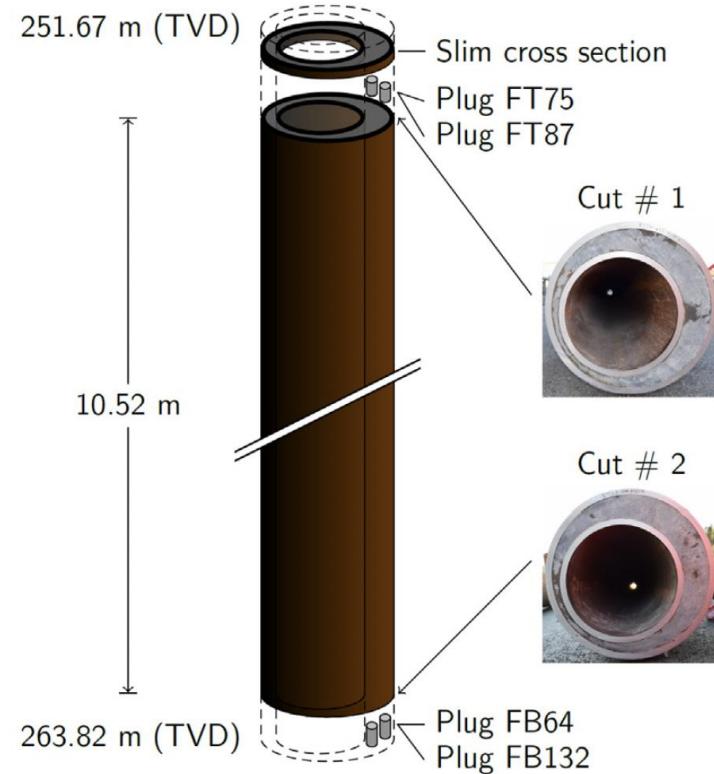


Well design showing the location of sections. In purple the twenty three recovered sections and in red the two sections, our object of study.

Investigation of well integrity of a 33 years old offshore well in Norway



Transition Joint



Fish 11

Fig. 2. Transition Joint and Fish # 11 diagram including pictures of the ends (Bottom and Top).

Investigation of well integrity of a 33 years old offshore well in Norway

Table 1 – Sandwich sections under study

| | Transition Joint | Fish # 11 |
|---------------------|-------------------------|------------------|
| Well depth (m) | 119.2-131-5 | 251.7-263.8 |
| Final length (m) | 9.36 | 10.56 |
| Min. Sand off (m) | 0.01057 | 0.01250 |
| Max. Eccentricity % | 70 | 64 |

Shallow depth (low temperature)

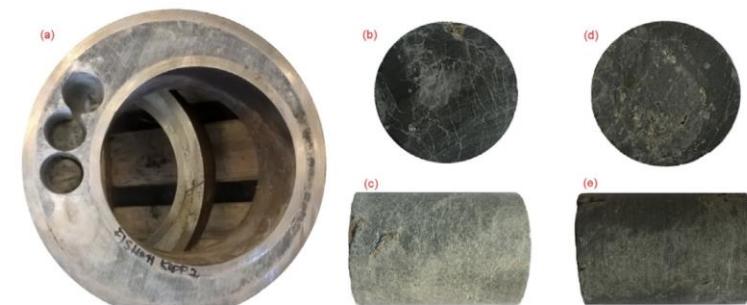
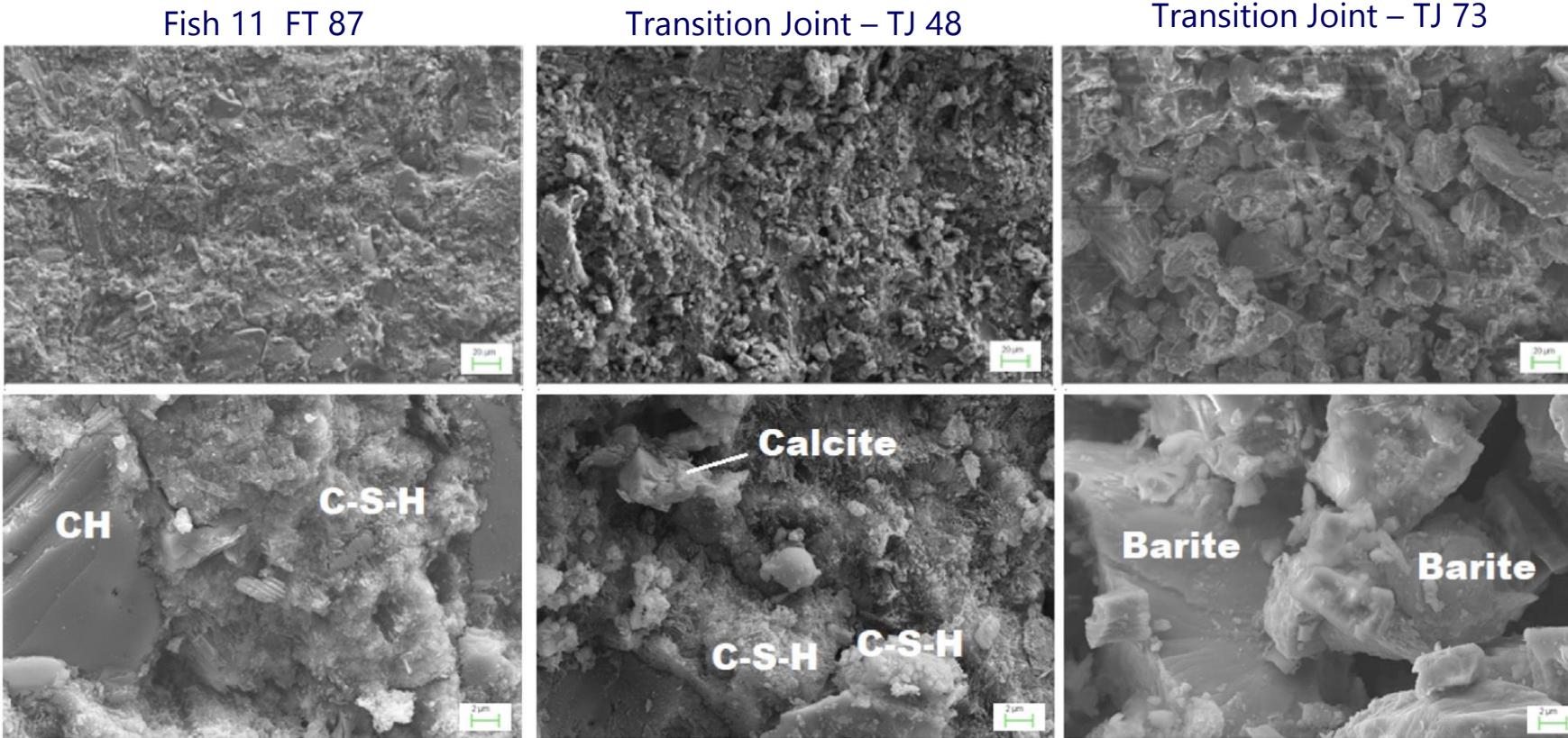


Fig. 3. Core plugs obtained from Fish 11 (Bottom). (a) Drilling of core plugs, (b) FB 64 top view, (c) FB 64 lateral view, (d) FB 132 top view and (e) FB 132 lateral view.

Investigation of well integrity of a 33 years old offshore well in Norway

| Selection name | Core Plug | Petrophysical Properties | | | Mechanical Properties | | Compositional Analysis | | |
|------------------|--------------------------------|--------------------------|------------------|------------------|-----------------------|--------|------------------------|-------------|--------|
| | | Porosity | Permeability | CT scan | E | UCS | SEM-EDS | XRF | XRD |
| Transition Joint | TJ48 TJ73 | ✓ ✓ | ✓ ✓ | ✓ ✓ | ✓ | ✓ | ✓ ✓ | ✓ ✓ | ✓ |
| Fish# 11 | FT75 FT87 FB 64 FB132 | ✓ ✓ ✓ ✓ | ✓ ✓ ✓ ✓ | ✓ ✓ ✓ ✓ | ✓ ✓ | ✓ ✓ | ✓ ✓ | ✓ ✓ ✓ | ✓ ✓ |

Investigation of well integrity of a 33 years old offshore well in Norway



Comparison of SEM Images at magnifications 1.0 kX (upper panels) and 10.0 kX (lower panels) for material extracted from FT87, TJ47 and TJ 73 core plugs.



we are on it