SIKA FERROGARD CORROSION INHIBITORS

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SIKA SERVICES AG / TM REFURBISHMENT

BUILDING TRUST

MOTHER NATURE’S RULES

Dig up Iron ore (various oxides)

MOTHER NATURE'S RULES

Spend 1000 kW's of energy to produce steel

MOTHER NATURE’S RULES

Spend the rest of its time converting back to rust (various oxides)

MOTHER NATURE IS GIVEN SOME HELP!!...

CHLORIDE INDUCED CORROSION

CARBONATION INDUCED CORROSION

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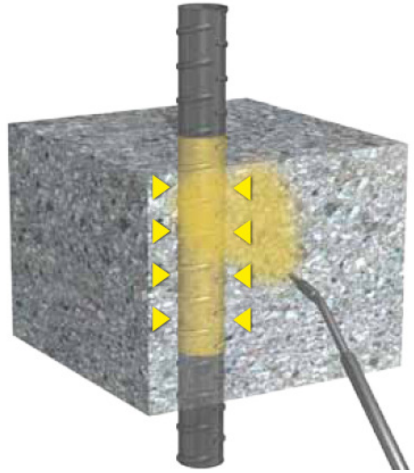

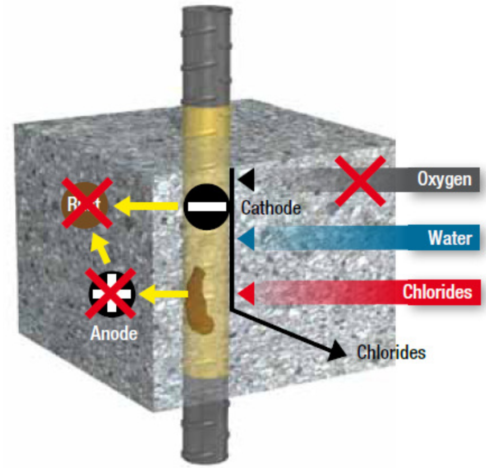

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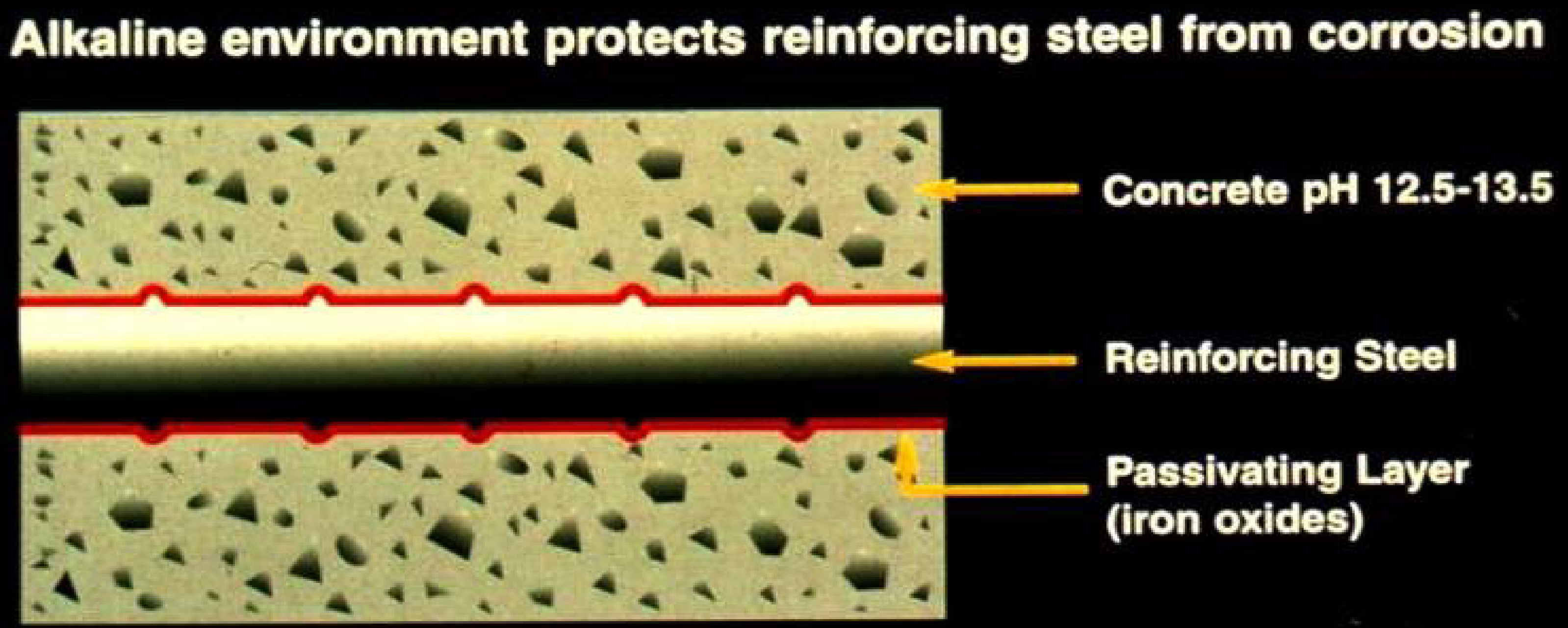
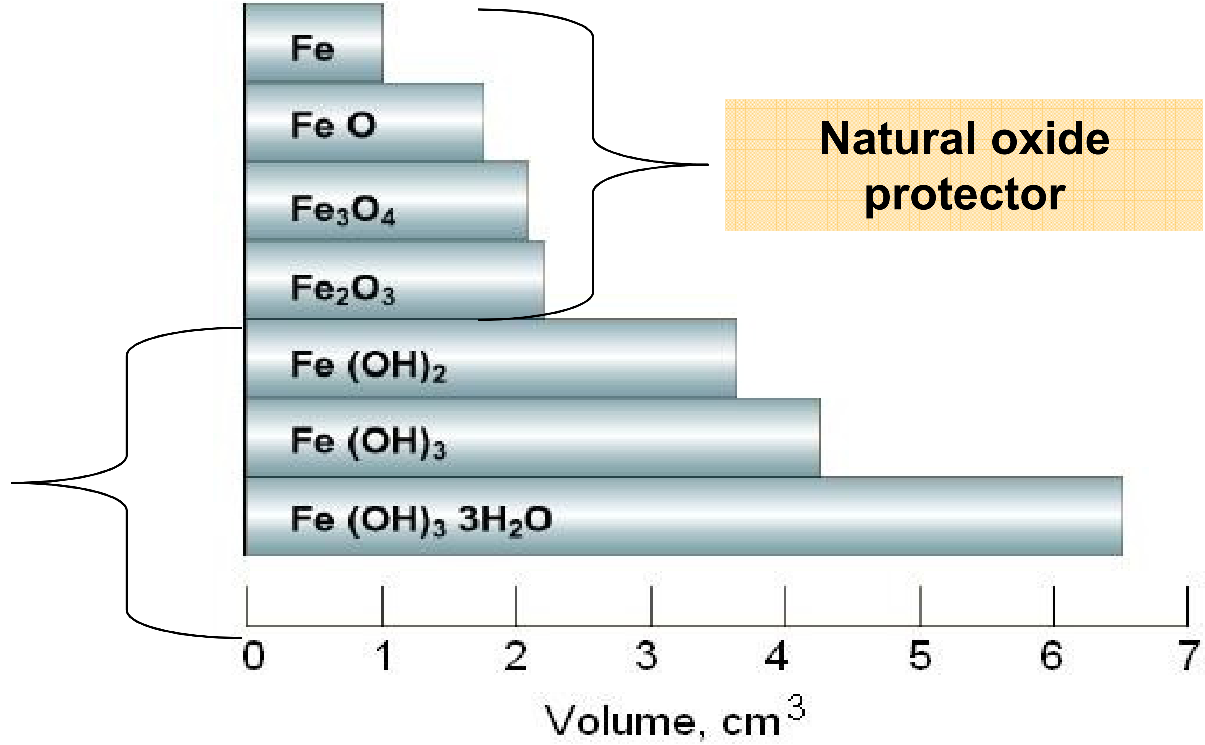
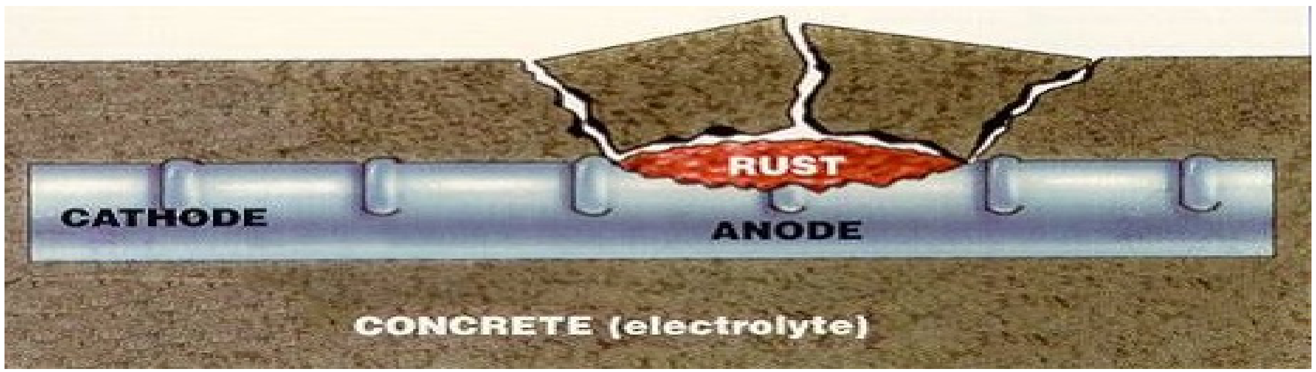
PASSIVATION OF STEEL IN THE CONCRETE



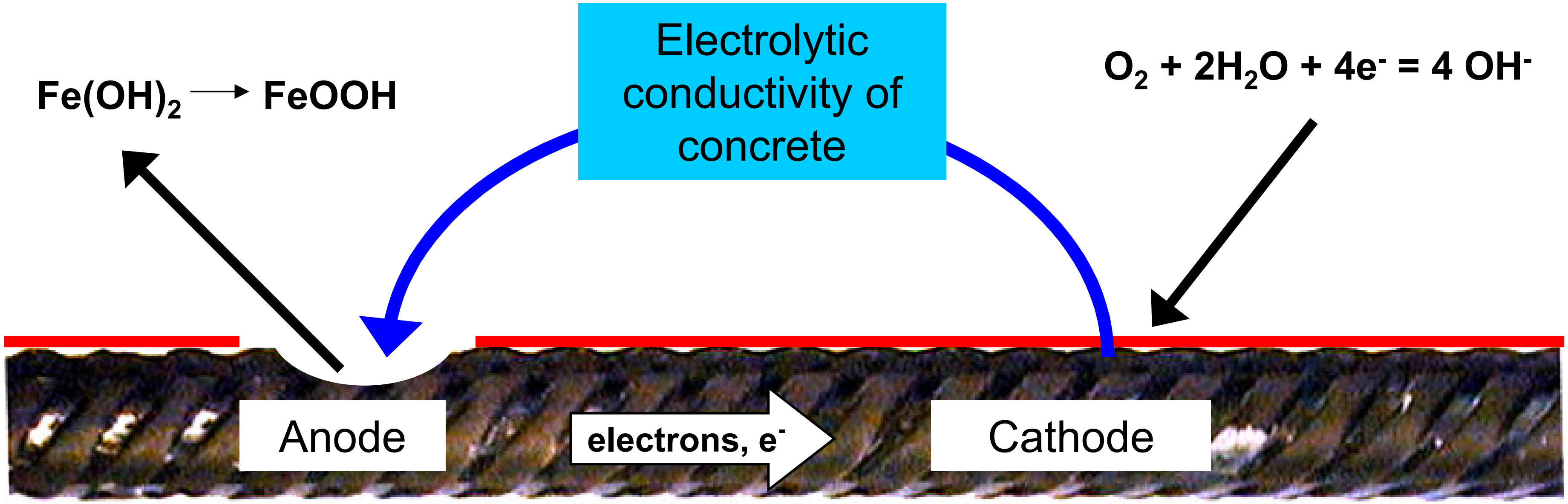
The alkaline environment protects the reinforcement steel from corrosion

STEEL CORROSION

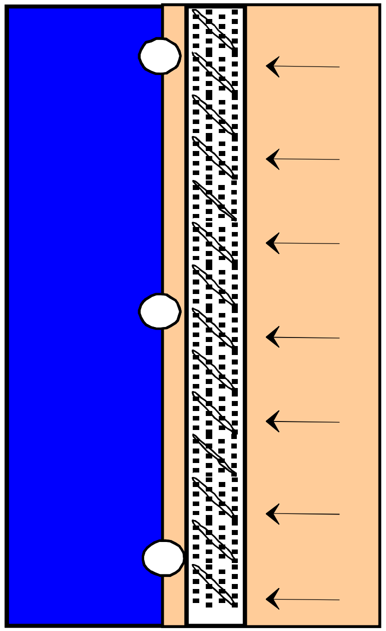




CORROSION CONDITIONS



CORROSION INDUCED BY CARBONATION



Concrete: pH-value approx. 13

Carbonation

<u>Hydrogen carbonate:</u>

$Ca(HCO_3)_2$ pH-value approx. 9.5

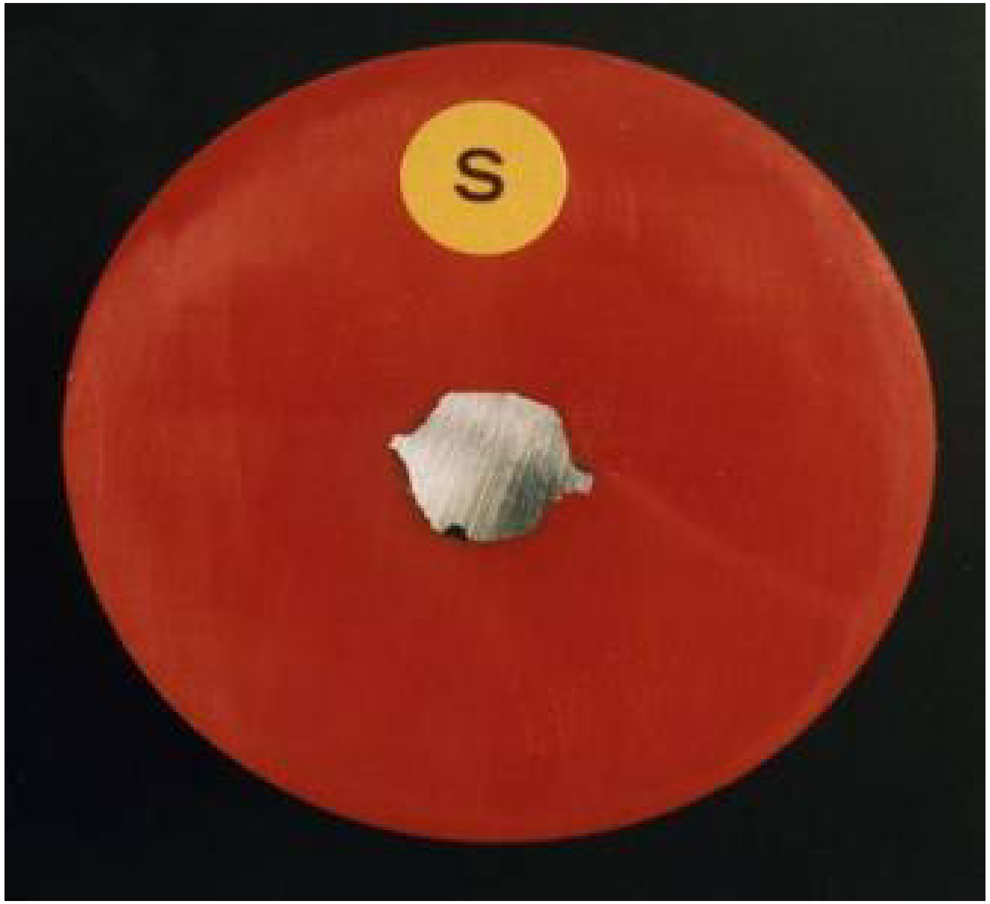
Na(HCO3) pH-value approx. 8.5

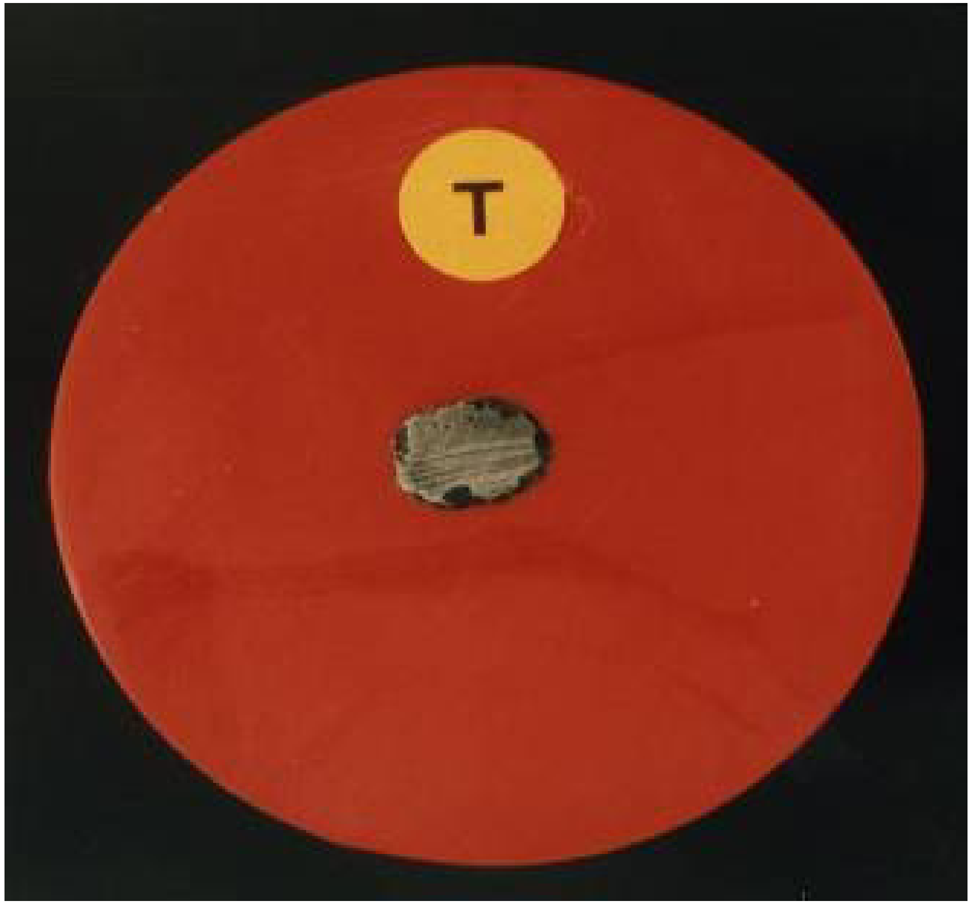
lower pH-value = lower OH^- concentration

➔ Oxides on steel surface not stable

➔ Passivation film becomes porous and permeable

CORROSION INDUCED BY CARBONATION





Steel corrosion speed: ≈ $^{2}/_{100}$ to $^{2}/_{10}$ mm per year

PINHOLE CORROSION INDUCED BY CHLORIDES

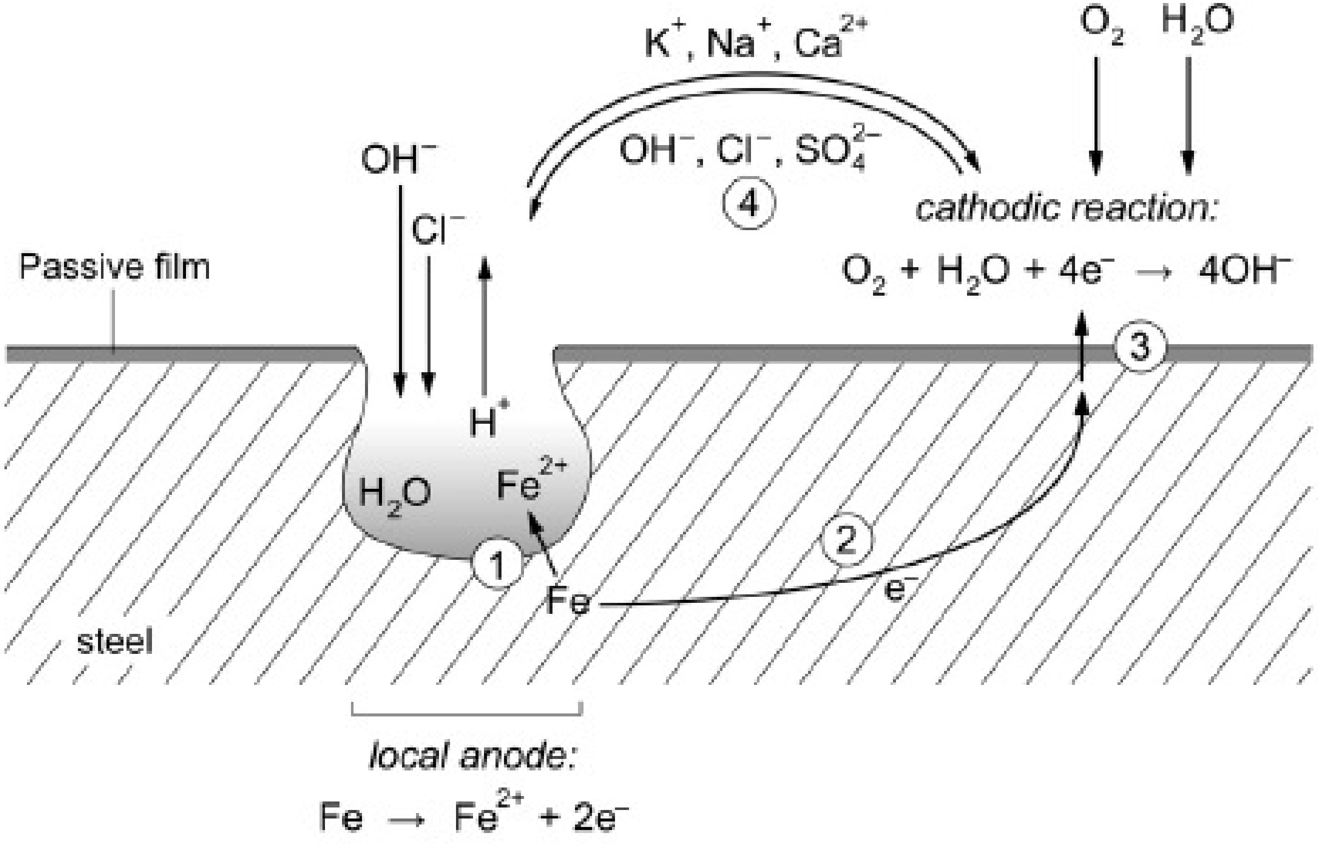


Fig. 2. Schematic illustration of chloride induced pitting corrosion and reaction steps: 1. Anodic iron dissolution; 2. Flow of electrons through metal; 3. Cathodic reduction reaction; 4. Ionic current flow through the electrolyte.

PINHOLE-CORROSION INDUCED BY CHLORIDES

Steel corrosion speed : ≈ 1 to 10 mm per year!!

Steel corrosion speed (by carbonation): ≈ 2/100 to 2/10 mm per year

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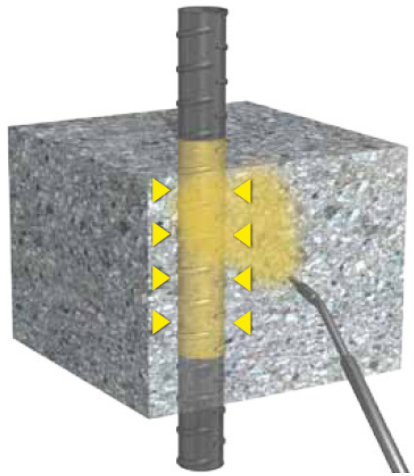

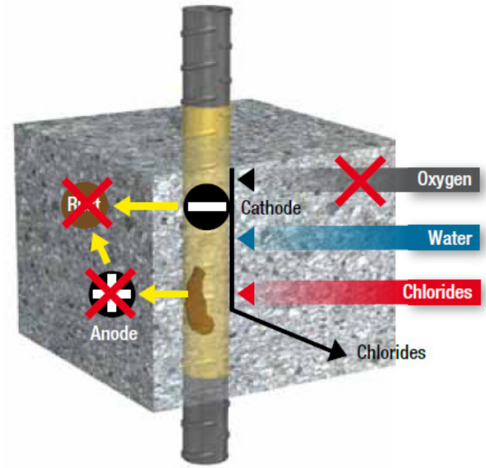

WHAT IS A CORROSION INHIBITOR?

Definition corrosion inhibitor

A corrosion inhibitor is a chemical substance that, when added in small concentration to an environment, effectively decreases the corrosion rate or/and delay the onset of corrosion

Inhibitor efficiency

The efficiency of an inhibitor is expressed by a measure of this improvement:

Inhibitor efficiency [%] = $100 \cdot (CR_{uninhibited} - CR_{inhibited}) / CR_{uninhibited}$

where:

$CR_{uninhibited}$ = corrosion rate of the uninhibited system

$CR_{inhibited}$ = corrosion rate of the inhibited system

Excellent corrosion inhibitors show efficiencies >90%

Typical corrosion inhibitor effect: >65%

TERMINOLOGY OF CORROSION INHIBITORS

Active systems

- Chemical reaction between steel and inhibitor resulting in the formation of a protective film
- Adsorption on the steel surface resulting in a protective layer
- Scavenger system – depletion of availability of oxygen (e.g. ammonium bisulfite)

Passive systems

- Inhibition is achieved by reducing chloride ingress (chloride screening)

Passive-active systems

- Combination of the two

TERMINOLOGY OF CORROSION INHIBITORS

Cathodic corrosion inhibitors

- Suppress the cathodic reaction: Cathodic poisons, cathodic precipitates (e.g. zinc oxide, magnesium oxide) and oxygen scavengers.

Anodic corrosion inhibitors

- Suppresses the anodic reaction (e.g. calcium nitrite)

Multifunctional or mixed corrosion inhibitors

- Suppresses both the anodic and cathodic reactions (e.g. amino alcohol)

TERMINOLOGY OF CORROSION INHIBITORS

Anodic corrosion inhibitors – considered as tricky

- Too little of the corrosion inhibitor fails to protect all anodic sites. Therefore, cathode/anode area ratio increases causing increased corrosion at remaining anodic sites.

Cathodic corrosion inhibitors – considered as "safe" corrosion inhibitors

- Reduces corrosion rate at low "dosage"
- Not as efficient as anodic inhibitors

Multifunctional or mixed corrosion inhibitors

- Synergistic effect
- Inhibitor provides protection to both cathodic and anodic sites even at relatively low concentrations

CHLORIDE LEVEL

Chloride State	Indicative Free Chloride Ion at Level at Reinforcement	Possible Consequence
Low	≤ **0.5 %** Chlorides by mass of cement	Corrosion inhibitor potentially viable as a preventive maintenance strategy before any significant active corrosion takes place.
Moderate	≤ **1 %** Chlorides by mass of cement	Corrosion inhibitor may be effective if a satisfactory inhibitor to chloride ion concentration ratio is achieved – much depends on existing degree of corrosion. Protective measures to prevent further chloride build up are recommended in chloride-rich environments.

CHLORIDE LEVEL

Chloride State	**Indicative Free Chloride Ion at Level at Reinforcement**	**Possible Consequence**
High	**1 – 2 %** Chlorides by mass of cement	Corrosion inhibitor dosage level may have to be increased beyond typical manufacturer’s recommendation and additional protective measures required. May take the technique beyond its recommended effectiveness window, introducing higher risk.
Very high	**> 2 %** Chlorides by mass of cement	High dosages of the Corrosion inhibitor are recommended to protect the steel. A durable structure can only be the combination of low chloride migration and the use of inhibitors . Corrosion inhibitor unlikely to be a successful component of the repair strategy.

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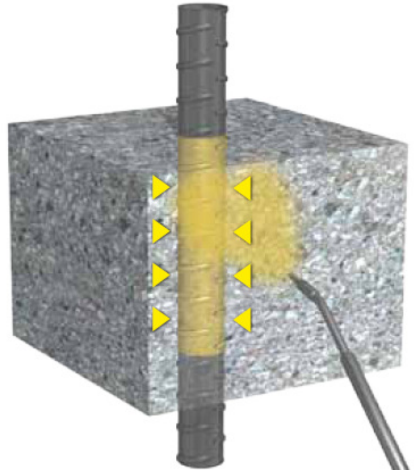

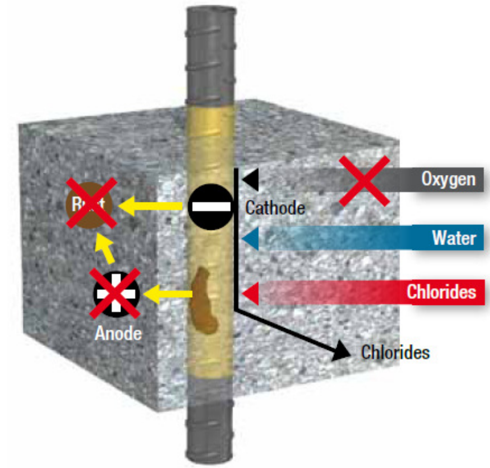

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OPTIONS FOR CORROSION CONTROL

- Properly designed concrete
- Cathodic protection
- Epoxy coated steel
- Galvanised steel
- Stainless steel
- **Corrosion inhibitor Sika FerroGard-901**
- Surface sealer / hydrophobic impregnation

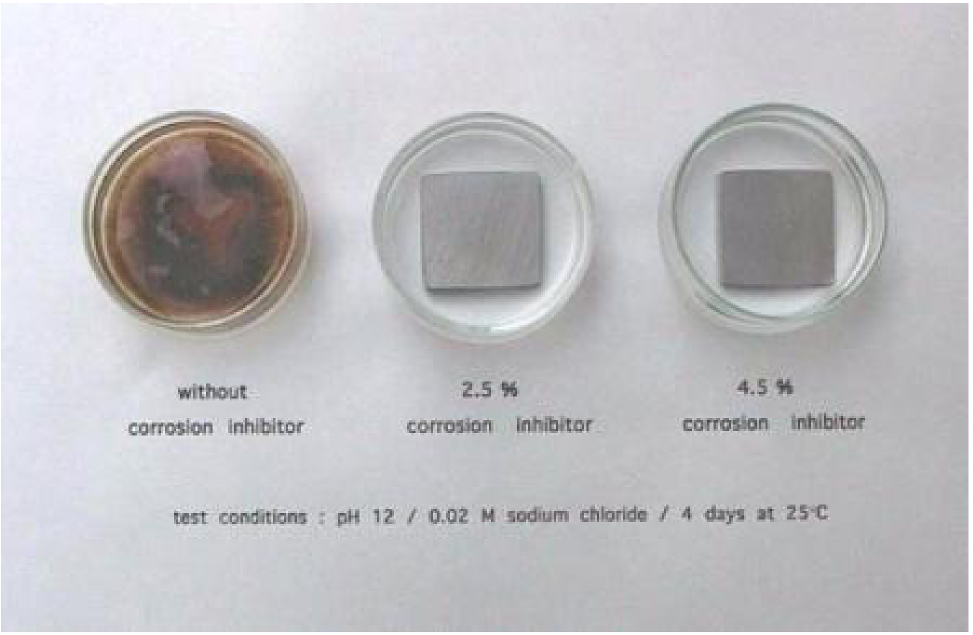
Or combination of the options above

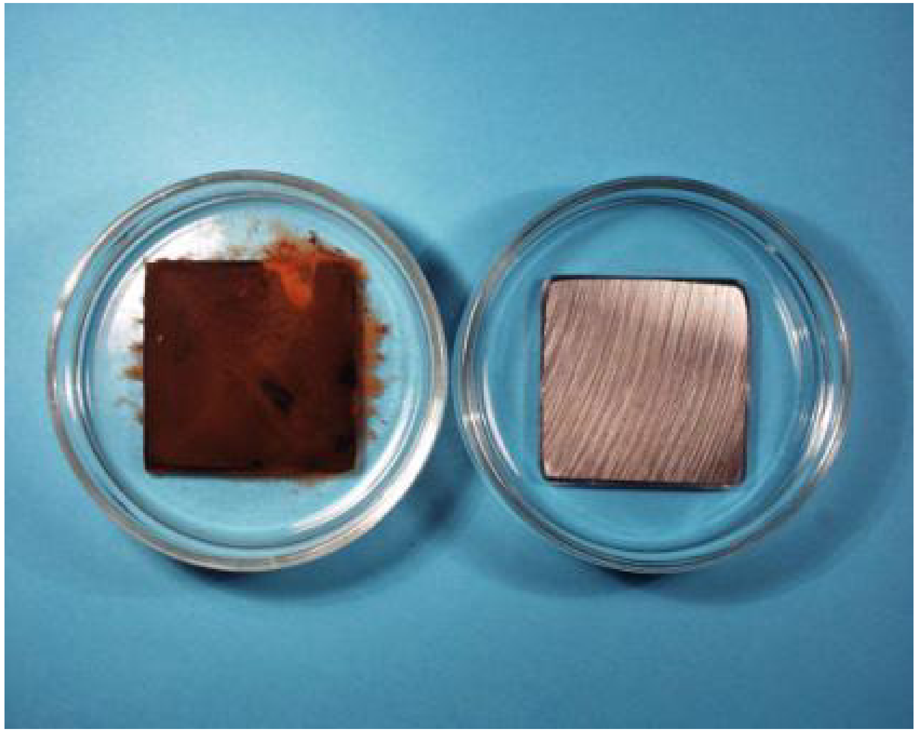
CORROSION INHIBITORS
SIKA FERROGARD

Sika FerroGard-901

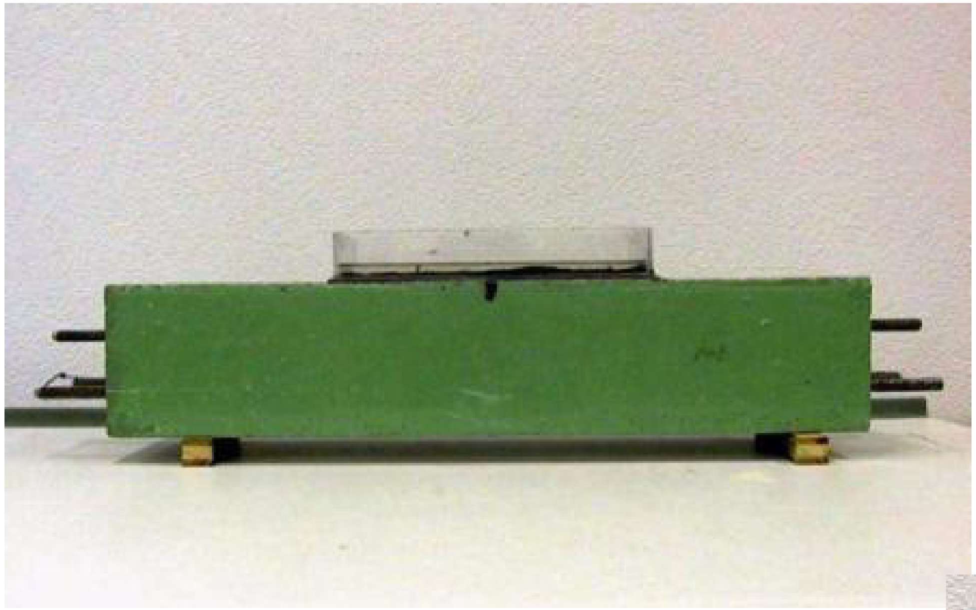
- Reduction of corrosion risk / extending service life of reinforced concrete structures
- No adverse effects when under-dosed
- No or only little influence on fresh and hardened concrete properties
- Environmentally sound / not toxicity rated

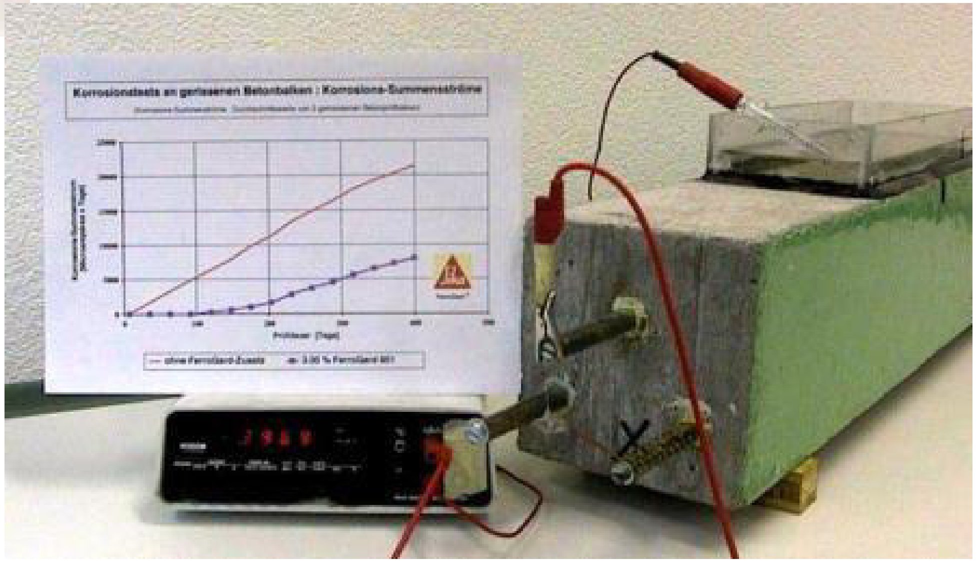
STEEL COUPON CORROSION TEST





CRACKED CONCRETE BEAM CORROSION TEST

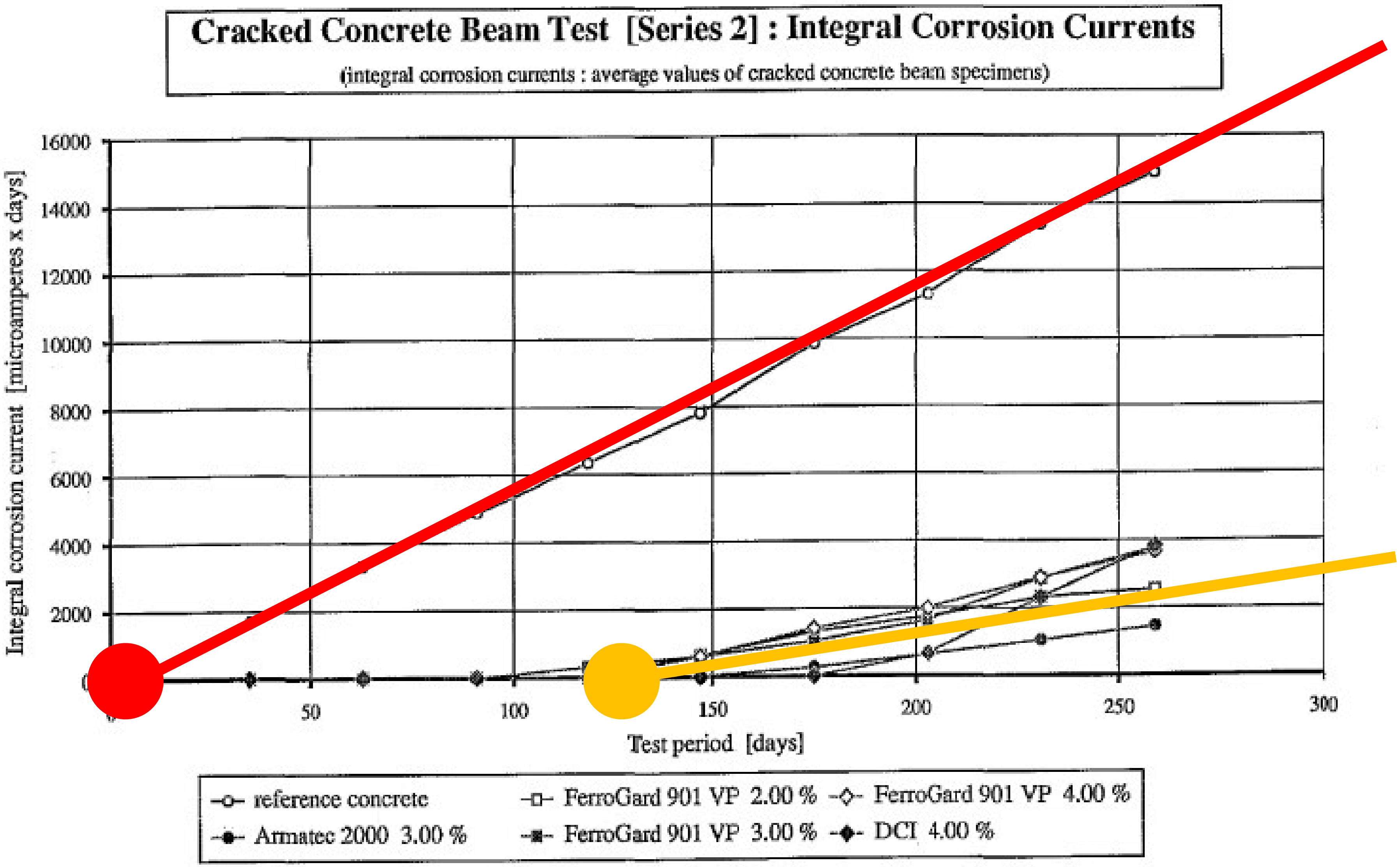




CRACKED CONCRETE BEAM CORROSION TEST

- Beams 150 mm x 150 nun x 750 mm with three embedded rebars 12 mm Ø
- Two rebars are placed 38 mm from the bottom of the beam, the third rebar 43 mm below the top surface of the beam.
- Artificial cracking: 0.25 mm wide shimmed crack
- Cycles: 2 weeks of ponding with a 3.0% sodium chloride solution, followed by 2 weeks of air drying.
- Modeled to simulate a cracked concrete bridge deck, with the top layer of reinforcement directly exposed to sodium chloride solutions through cracks and indirectly by diffusion through the concrete.
- The top rebar is monitored (corrosion potentials silver/silver chloride and voltage measured across a resistor)

CRACKED CONCRETE BEAM CORROSION TEST



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CONCRETE PROPERTIES

- Testing of the influence of Sika FerroGard-901 on fresh concrete properties:
- European wide test series: Mix design EN-104
- **9** Countries, **14** type I and **2** type V cements
- Corrosion inhibitor alone or in combination with **20** important superplasticizers or plasticizers
- Effectiveness of air entrainers on mixes of Sika FerroGard-901 and different superplasticizer
- Freeze-thaw testing

CONCRETE PROPERTIES

Worldwide concrete experiments with corrosion inhibitors based on amino alcohols:

- No to little effect on workability of concrete
- No to little effect on setting times
- No to little effect on 1 day compressive strength
- No effect on 28 days compressive strength
- No effect on air void system
- Air entrainment is assured (freeze-thaw resistance!)

SIKA FERROGARD-901 SUMMARY

The addition of Sika FerroGard-901 to concrete provides:

- Lower corrosion potentials - less risk of damage
- Larger passive range
- Extended service life of structures
- Delay of onset of corrosion, even in case of cracked concrete
- Reduction of corrosion rate by at least 50 % under severe conditions (cracked beam corrosion tests)
- Same or better performance than nitrite based inhibitors at comparable dosage (in the case of moderate chloride content)
- Environmentally sound
- No negative effects on fresh and hardened concrete properties - no stiffening, no acceleration

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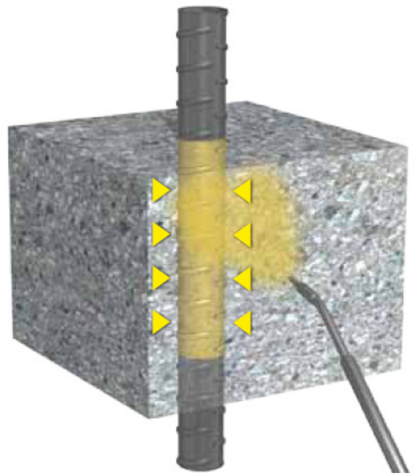
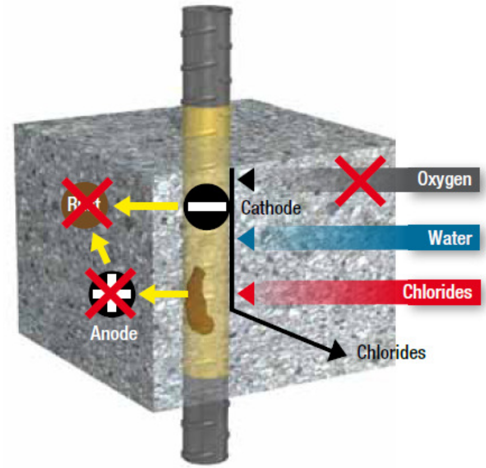




SUMMARY CARBONATION-INDUCED CORROSION

SURFACE-APPLIED CORROSION INHIBITORS:

- Technique at its best:
  - Generally concrete of lower quality (although denser due to the carbonation process)
  - Lower cover
  - Low corrosion rate

ADMIXED CORROSION INHIBITORS:

- Generally not required
  - Too expensive

SUMMARY CHLORIDE INDUCED CORROSION

SURFACE APPLIED INHIBITORS:

- Some limitations:
  - Issue of concrete quality – marine structure using CEM III with low water cement ratio
  - Issue of concrete cover (combined with denser structure)
  - Issue of presence of chloride
  - Issue of rate of corrosion

- Potentially considered if:
  - Lower concrete cover
  - Pro-active maintenance – inhibitor placed before significant amount of chlorides have reached the rebars
  - In renovation; low to medium chloride content at rebar level

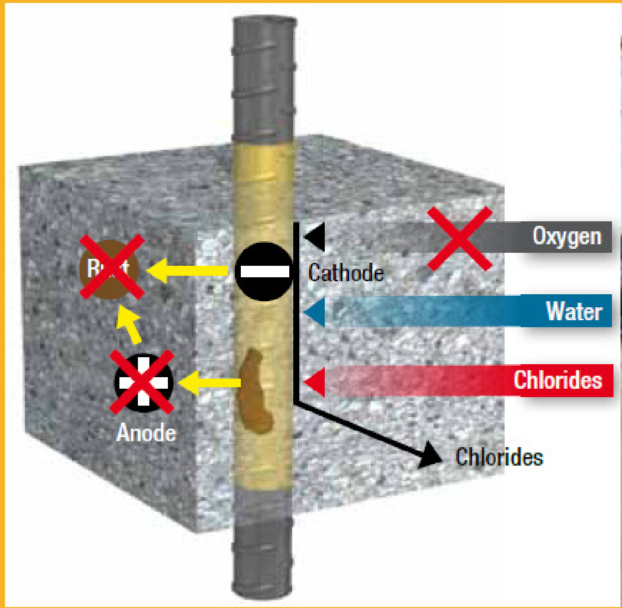
PENETRATION DEPTH TO BE INVESTIGATED

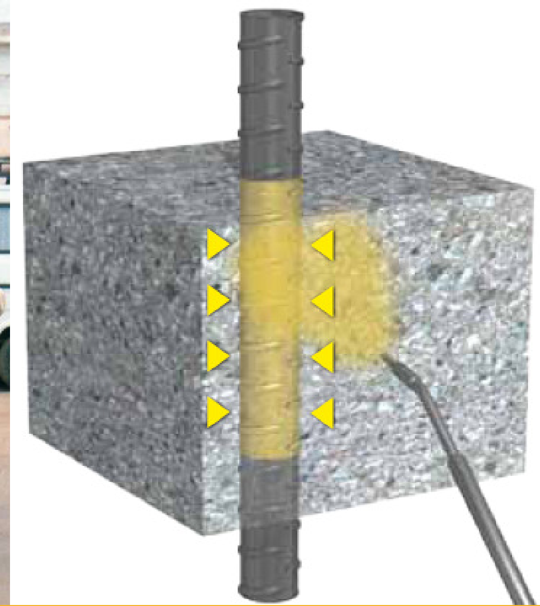
SUMMARY CHLORIDE INDUCED CORROSION

ADMIXED INHIBITOR:

- Calcium nitrite:
  - Good efficiency, especially in the presence of higher chloride concentrations
  - Some health and safety issues in some countries
  - Concrete mix to be adjusted

- Amino alcohol based:
  - Good efficiency in moderate chloride concentration
  - No health and safety issues
  - No adjustment of mix design required



CORROSION INHIBITOR TECHNIQUE CAN BE USED ON MANY DIFFERENT JOB SITES,

But Don’t Overestimate it……!