Action of atmospheric agents against reinforced concrete

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Abstract

Increasingly often, concrete is the material of choice for the construction of structures exposed to extreme conditions. As demand for construction in harsh environments increases, so do the desired service live of these structures.

The presence of sulfates in aggressive environments constitutes a large threat to the stability and longevity of reinforced concrete structures because their effects lead to degradation of concrete and corrosion of steel in concrete. Sulfate attack of concrete may lead to cracking, spalling, increased permeability, and strength loss. The purpose of this study is to identify (analyze) these adverse effects and examine the necessary measures to prevent concrete degradation and steel corrosion. This study concludes that the protection of R/c structures from the presence of sulfates in aggressive environments is achieved through careful stability design, engagement of preventive measures and use of additional preventive techniques.

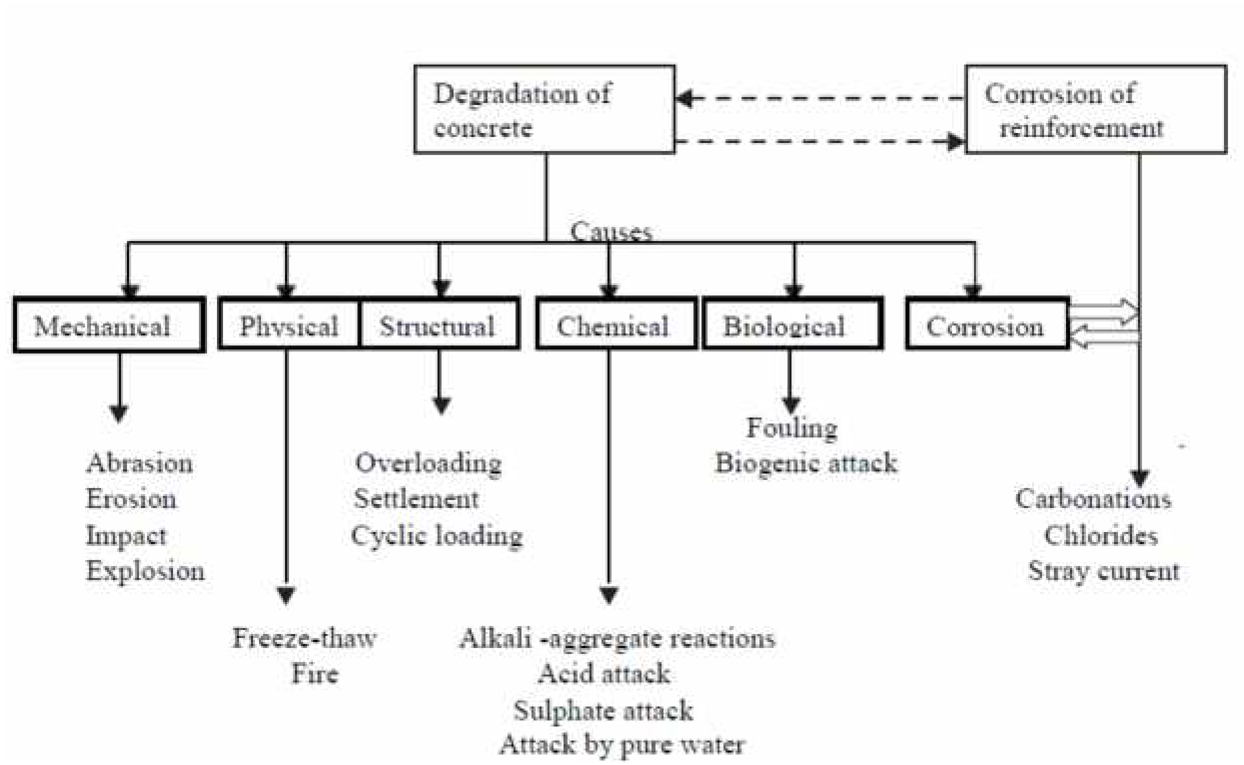
Keywords: *Degradation of concrete, corrosion and durability of reinforced concrete.*

Introduction

Concrete is the material of choice for the construction of structures exposed to extreme conditions whether it be offshore oil platforms in icy water or hazardous waste containment vessels buried in the earth. Typically, concrete structures are designed to perform, with minimal maintenance, 50 to 100 years. Concrete containment vessels, which may be hold chemical and radioactive waste, are designed for 500 year service lives and a desire exists to extend the expected service life to 1000 years.

Sulfates present in soils, groundwater, sea water, decaying organic matter, and industrial effluent surrounding a concrete structure pose a major threat to the long term durability of the concrete exposed to these environments. Sulfate attack of concrete may lead to cracking, spalling, increased permeability, and strength loss. Thus, resistance of concrete to sulfate attack is integral to ensure satisfactory performance over long periods.

-Degradation of concrete structures



1.1-**Mechanical causes early damage of concrete**

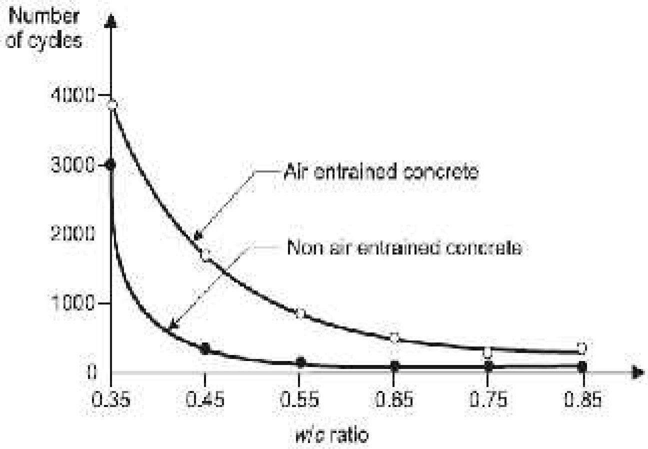
(errors in the design or execution of concrete structures)

→ cracking of concrete due to:

- plastic shrinkage or drying shrinkage
- heat of hydration
- early freezing
- plastic settlement

1.2-Physical causes

Freeze-thaw attack



Prevention:

- reduce capillary porosity (w/c, curing)
- entrained air (air entraining admixture)

1.3- Chemical causes sulphate attack

Mechanism:

1) Penetration of sulphates through the concrete
2) Formation of gypsum:

$$Ca(OH)_2 + SO_4^{=} + H_20 \rightarrow CaSO_4 \cdot 2H_2O$$

3) Formation of ettringite ($C_3A3 \cdot CaSO_4 \cdot 32H_2O$)

Prevention:

- reduce capillary porosity (w/c, curing)
- type of cement: $C_3A\downarrow$, pozzolans (sulphate resisting cements)

Alkali-silica reaction

$Na_2O + H_2O \rightarrow NaOH$ $K_2O + H_2O \rightarrow KOH$

2-Corrosion of steel bars

Solution in the pores:

$Ca(OH)_2$, NaOH, KOH ⇒ pH ≈ 13-14 ⇓ **Passivity**

Conditions of stability of the passive film:

1) pH > 11,5 → Carbonation
2) absence of chlorides → Seawater,De-icing Salts

Other causes:

- stray current
- hydrogen embrittlement (of high strength prestressing steel)

Embrittlement is the loss of ductility of material, making it brittle caused by absorption of hydrogen sulphide

Consequences of corrosion

Cracking

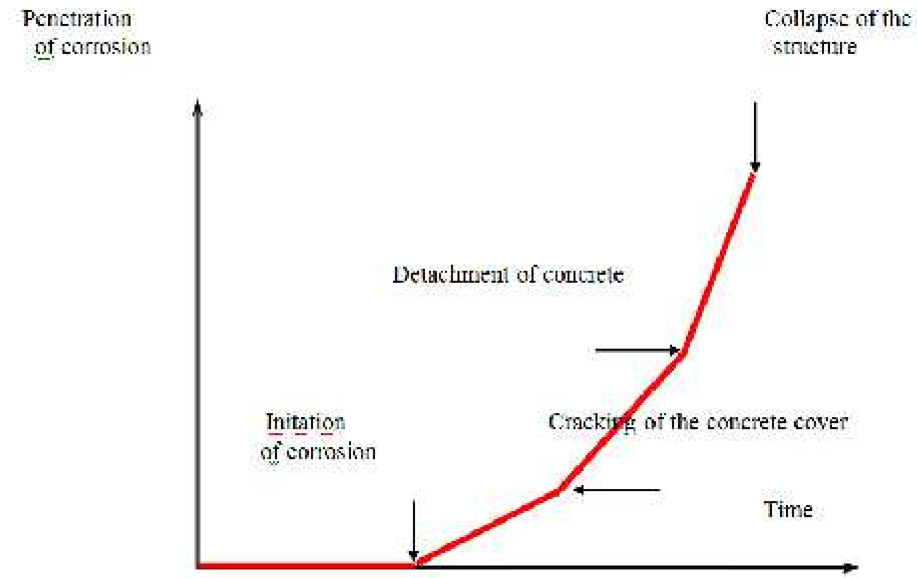
Detachment of concrete cover

Reduction of cross section of rebar

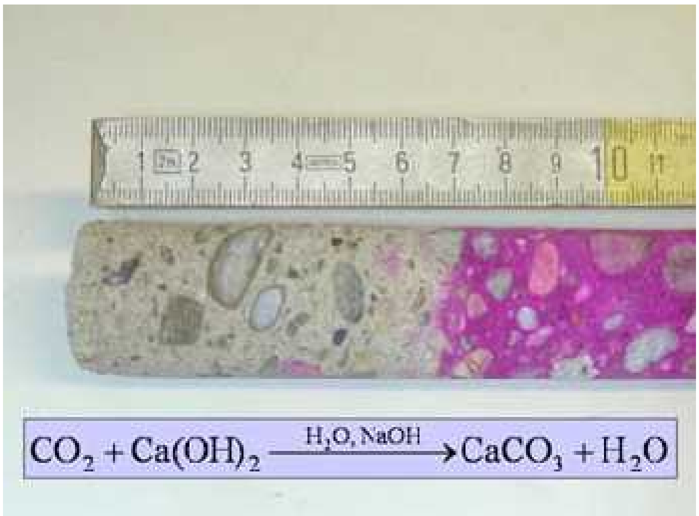
Collapse of the structure

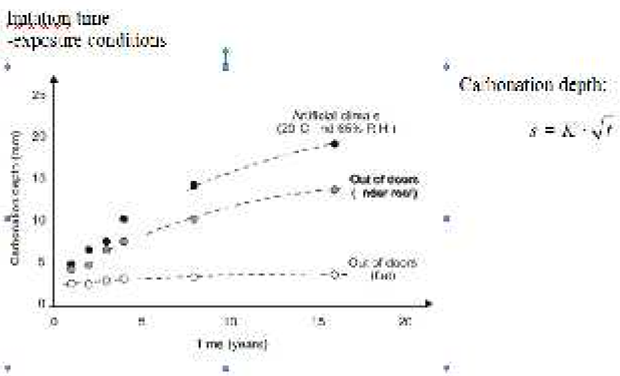
Penetration the of corrosion

Collapse of structur

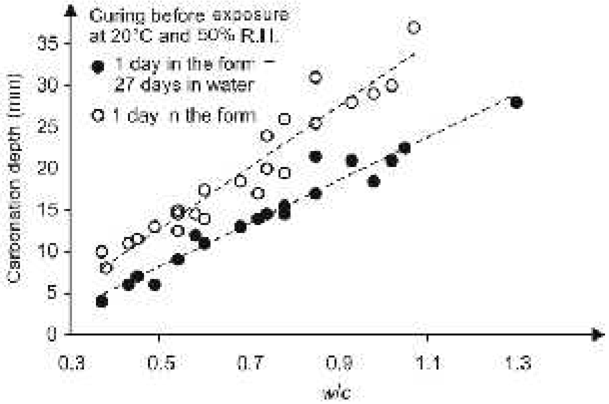


2.1-Carbonation induced corrosion





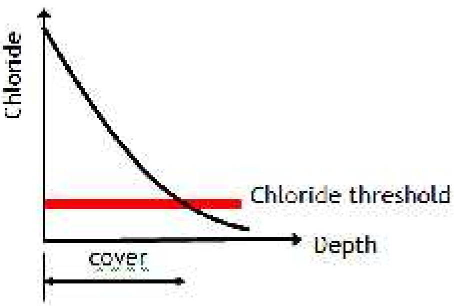
w/c,curing,compaction



-concrete cover thickness

2.2-Chloride induced corrosion

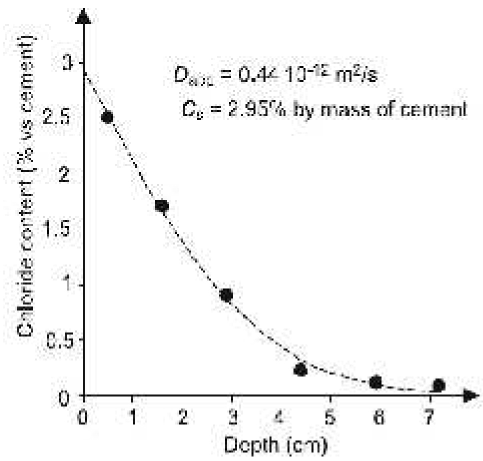
Pitting corrosion may initiate when a critical chloride content (chloride threshold) is reached at the steel surface.



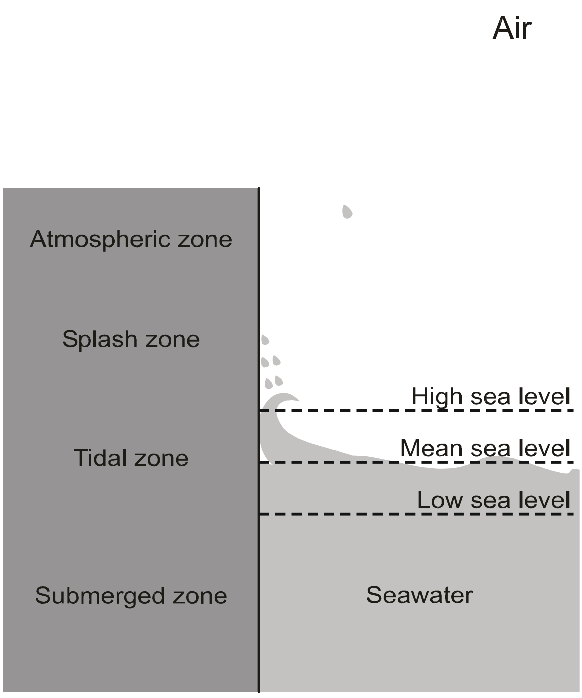
Chloride penetration

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}$$

$$C(x,t) = C_s \left(1 - \mathrm{erf} \frac{x}{2\sqrt{D_{app} \cdot t}}\right)$$



- environmental conditions (microclimate)



- concrete properties:
  - → w/c, curing, compaction
  - → type of cement (blended cement vs portland cement)
- concrete cover thickness

Chloride threshold

It depends on:

- the steel potential (→ moisture content)

- pH of pore solution (→ type of cement)

- voids at the steel surface (→ workability / compaction)

2.3-Corrosion of prestressing steel

1) pre-tensioned structures → concrete cover
2) post-tensioned structures → filling of ducts

Peculiarities:
- low ductility of high strength steel
- risk of hydrogen embrittlement on susceptible steels

Hydrogen Embrittlement, HE

$H^+ + e^- \rightarrow 2H_{ad} \rightarrow H_2$

→ high strength steel (>700 MPa), mainly ferritic

Steps

1-Crack initiation → environments able to initiate a crack → incubation time

→ following local increase in the aggressivity of

the environment (pitting or crevice corrosion)

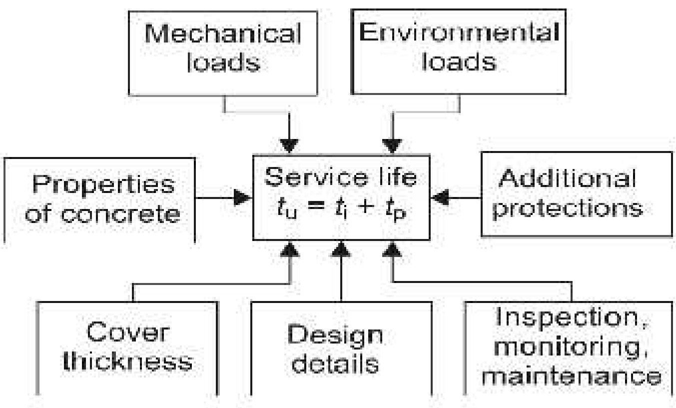
2-Propagation of the crack → combined action of the environment and the applied stress (µm/anno → mm/anno)

3-Durability of RC structures

A structure shall be designed and executed in such a way that it will, during its intended life, with appropriate degrees of reliability and in an economical way

- sustain all actions and influences likely to occur during execution and use, and
- remain fit for the use for which it is required.

(EN 1990)

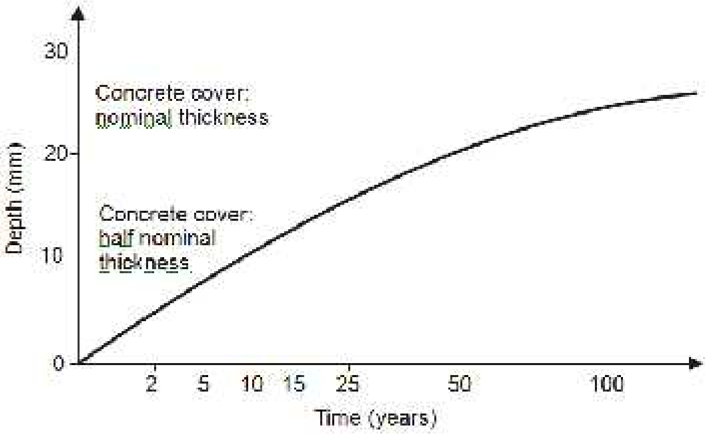


Properties of concrete

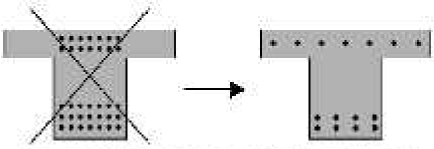
water/cement ratio (water/binder ratio), compressive strength,

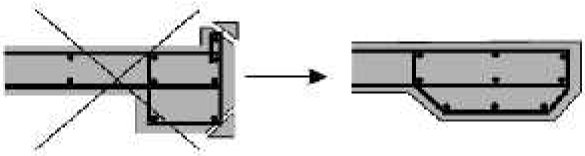
type of cement and mineral additions (GGBS, PFA, SF, ...), workability, drying shrinkage, creep, cracking, use of special concretes (HPC, SCC, LWC, etc.)

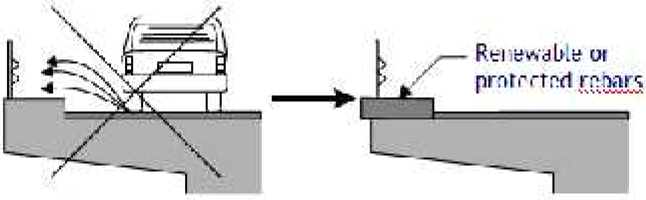
Concrete cover thickness

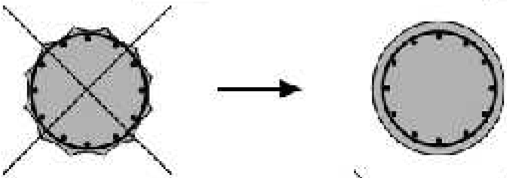


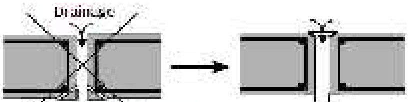
Design details

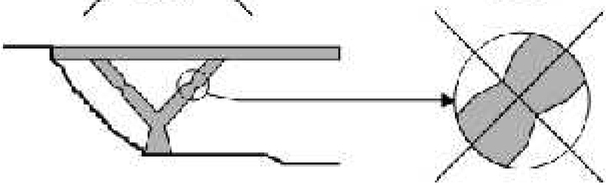








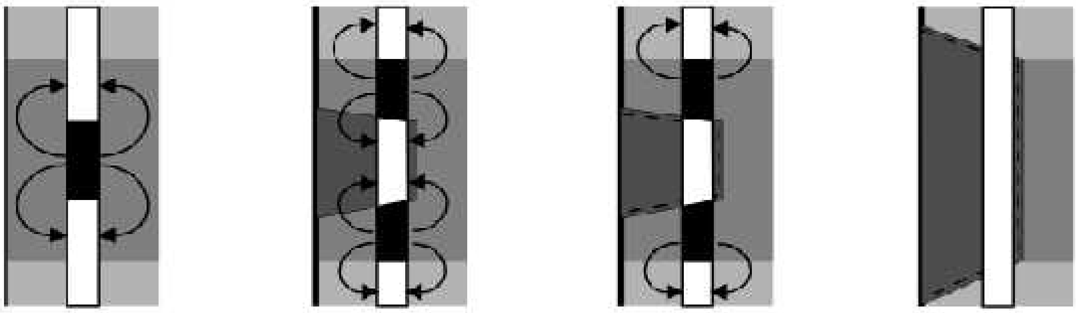




Additional protections

1) Corrosion resistant reinforcement:
   - stainless steel
   - galvanized steel
   - epoxy coated bars
2) Surface treatments of concrete
   - organic coatings
   - hydrophobic treatment
   - cementitious coatings
3) Corrosion inhibitors
4) Cathodic prevention

To increase the durability of intervention can also apply a protective coating or surface which can be used with addition of corrosion inhibitors.



a — Initial situation

b — Incorrect restoration because it doesn't eliminate from the surface of reinforcement all concrete with chlorides

c — As b, even if you use a primer insulation

d — Successful recovery because eliminates concrete chlorides

- concrete not attack by chlorides
- concrete with chlorides in content greater than the critical threshold
- concrete recovery
- not part of the corroded coating
- part of corroded reinforcement
- primer adhesive waterproofing
- reinforcement surface

Fig. Schematic illustration of the consequences of the local recovery structure polluted by chlorides.Initial situation (a)restore implemented without completely eliminating the contaminated concrete from the surface of the reinforcement (b,c) after you eliminate it

Exposure classes

1 - No risk of corrosion or attack
2 - Corrosion induced by carbonation
3 - Corrosion induced by chlorides other than from sea water
4 - Corrosion induced by chlorides from sea water
5 - Freeze-thaw attack with or without de-icing agents
6 - Chemical attack

EN 206-1 – Recommended values

1) service life 50 year. 2) CEM I (class 32,5 for strength)

Class of exposure		Max. *w/c*	Min. strength	Min. cem. (kg/m^3)
No risk	*X0*	-	C1 2/15	-
Corrosion due to carbonation	*XC1* (dry/saturated) *XC2* (wet) *XC3* (mod. humidity)	0,65 0,60 0,55 0,50	C2 0/25 C2 5/30 C3	26 0 28 0 28
Corrosi on due to seawater	*XS1* (on the coast) *XS2* (submerged) *XS3* (spray/tidal)	0,50 0,45 0,45	C3 0/37 C3 5/45	30 0 32 0
Corrosion due to chlorides (no seawater)	*XD1* (mod. humidity) *XD2* (humid) *XD3* (wet/dry)	0,55 0,55 0,45	C3 0/37 C3 0/37 C3	30 0 30 0 32

Class of exposure Max.		Min. *w/c*	Min. strength cem. (kg/m³) entrain. air
Freeze- thaw attack	*XF1* (mod.sat.- no salt) *XF2* (mod.sat.- salt) *XF3* (hi.sat.- no salt) *XF4* (hi.sat.- salt)	0,55 0,55 0,50 0,45	C30/37 300 - C25/30 300 4% C25/30 320 4% C30/37 340
Che mical attack	*XA1* (slightly aggr.) *XA2* (moder. aggr.) *XA3* (highly aggr.)	0,55 0,50 0,45	C30/37 300 - C30/37 320 - C35/45

EN 1992-1-1 (Eurocode 2)– Concrete cover thickness

Class of exposure		Minimum thicnkess of the concrete cover (mm)	
		Reinf. Concrete	Prestr. Concrete
No risk	*X 0*	1 0	1 0
Corrosion due to carbonation	*X C1*	1 5	2 5
	XC2, XC3	2 5	3 5
	X C4	3 0	4 0
Corrosion due to chlorides	*XS1, XD1*	3 5	4 5
	XS2, XD2	4 0	5 0
	XS3, XD3	4 5	5 5

Conclusions

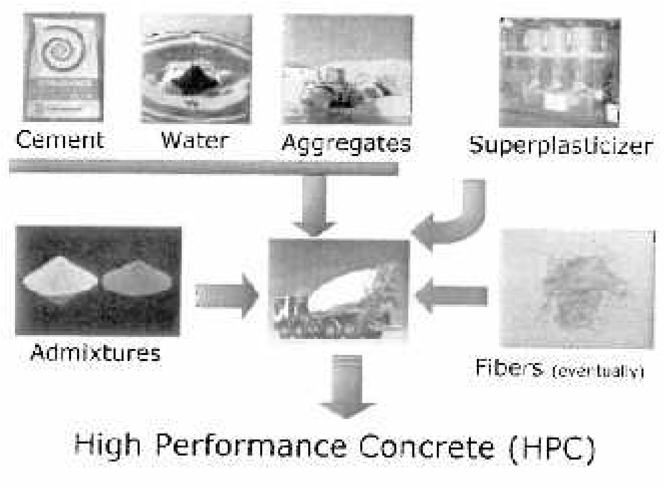
The reduction of the water/cement ratio is necessary but not sufficient to obtain a high quality concrete.

It is essential to consider also: the preparation (mixing), the in site production and the curing of the concrete.

⟹ Mix design ⟹ Admixture
⟹ Technology ⟹ Quality Control

The only way to reduce an external attack (chemical attack) is to reduce porosity and permeability, to reduce penetration of aggressive agents into the concrete.

This limits also the consequence of physical attacks.



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[6] ENV 13670-1, *Execution of concrete structures*, 2000.