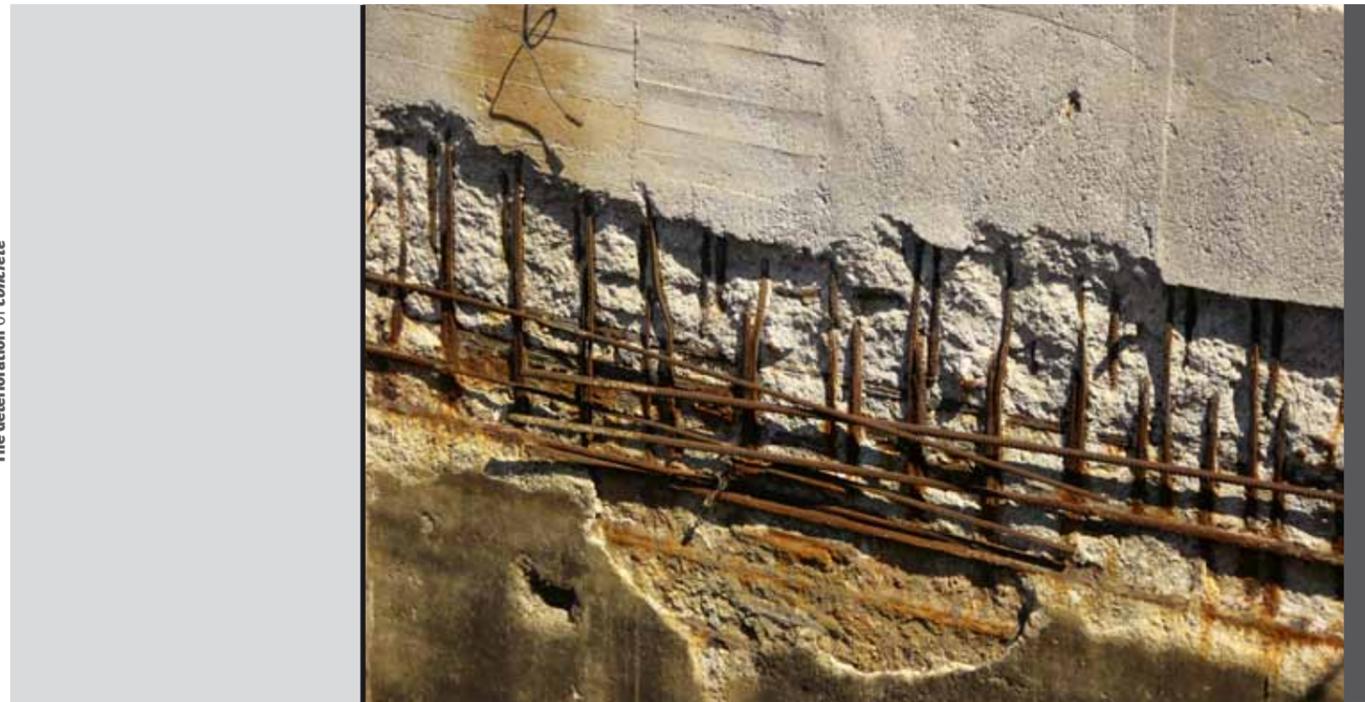


The deterioration of *concrete*

The deterioration of concrete



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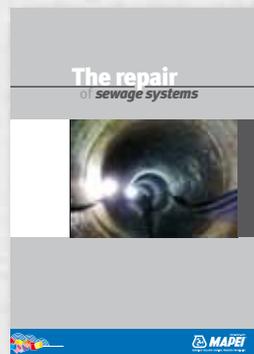
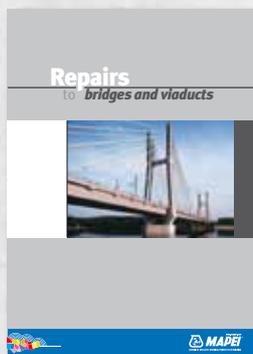
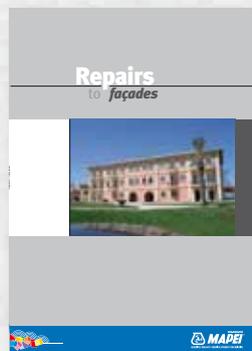
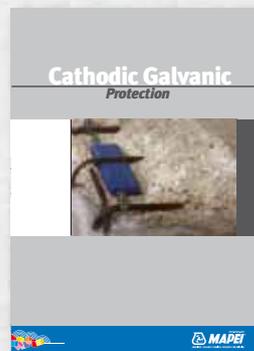
Mapei produces a series of technical manuals so that the subject of the deterioration of concrete may be analysed in depth, and to offer a professional approach to the problems regarding repair work.

The subject of this manual is:

The deterioration of concrete



The other manuals available in the series are:



The manuals are available upon request.

The deterioration of *concrete*

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► 1 | Introduction

The first real construction using concrete is attributed to the Romans, who used a mixture of lime, pozzolan, rubble and water. Examples of famous, imposing Roman construction includes the Pont du Gard viaduct in Nimes (*photo 1*), built around 150 BC, and the even more famous Pantheon (*photo 2*) in Rome, which dates back to the year 27 BC. Such examples give us an idea of the incredible performance characteristics of which this material is capable.

In the essay “De Architectura” by the famous writer, architect and engineer Vitruvius, written in

photo 1
Pont du Gard in Nimes
France



around 25 BC, the use of conglomerates, or “opus caementitium” in Latin, defined as a blend of lime, sand and water mixed together with pieces of stone and bricks is discussed. These examples clearly illustrate the antique origins of the material we will try to analyse. In order to discuss “modern” concrete, we must go to the beginning of the 19th century. The binder used in the mix derived from baking earth made up of clay and limestone, at temperatures of up to 1500°C, to form clinker pellets. When mixed with suitable grinding additives and then ground up, it took the name of Portland cement, because of its resemblance to Portland stone.

Concrete used in the modern era is a mixture of water, cement, aggregates and, where required, admixtures (plasticisers, super-plasticisers, etc.), added according to EN 934-2:2002 Standards, which modify its rheology, properties and performance characteristics.

The deterioration of **concrete**

This material does not seem to have any weak points in terms of durability, is made using products which are readily available, has a relatively low cost, is easy to use, etc. However, this is only partially true. For example, concrete has excellent compressive strength, but poor tensile strength. This is why it is reinforced using steel rods to overcome this drawback, but which in turn give rise to other problems, as will be illustrated later. Another fundamental limitation of concrete is that it is very sensitive to the conditions in which it is mixed and



photo 2
The Pantheon in Rome
Italy

applied. These conditions may vary enormously, thus causing other kinds of problems. There are a number of variables which have an effect on the quality of the product, and the lack of attention paid to these variables makes the concrete more vulnerable. In recent years, the ever-increasing need for maintenance and repair interventions on structures has determined a decisive change in how much is spent for repair operations, compared with how much is spent for building new construction.

What is more, the continuous increase of building costs almost always makes repair operations economically more viable, even if deterioration of the structure is at an advanced stage. Even if concrete is well made, if it is installed in an aggressive environment, sooner or later defects which define the deterioration will appear.

► 2| The deterioration of concrete

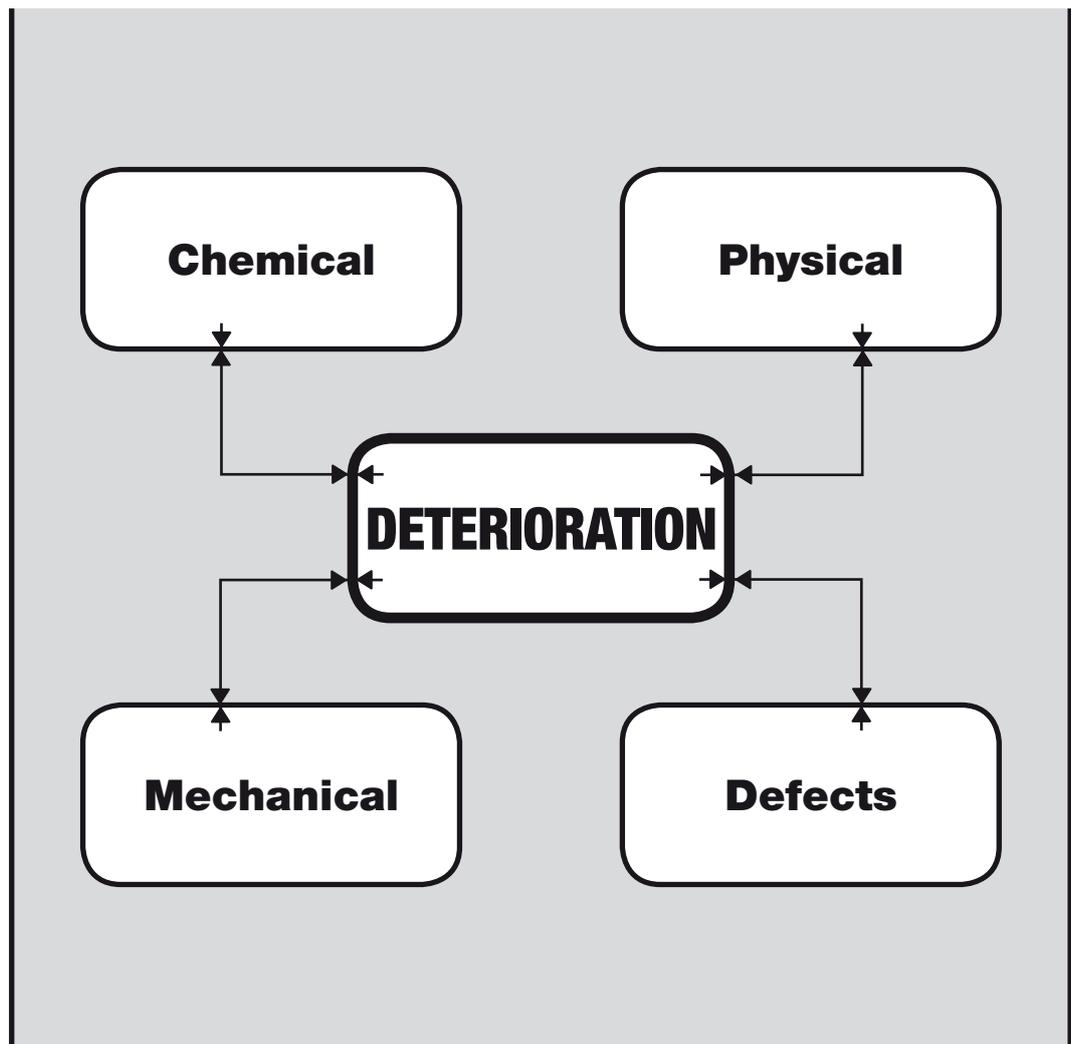
The aim of this manual is to offer a clear explanation of deterioration phenomena in concrete, to connect such phenomena to well-defined causes and to offer valid solutions, in order to help anybody who finds themselves facing difficulties regarding the deterioration of concrete.

A| Cause

B| Effect

C| Remedy

The cause of deterioration may be divided into four main families:



► 3| **Aggression from chemicals**

3.1| *Aggression by carbon dioxide*

3.2| *Aggression by sulphates*

3.3| *Aggression by chlorides*

3.4| *Alkali-aggregates reaction*

► 3.1| **Aggression by carbon dioxide**

Aggression due to CO_2 may be manifested in two different ways according to the surrounding conditions. In constructions exposed to the atmosphere, carbonatation of concrete takes place, while in hydraulic constructions, there is an occurrence known as leaching which acts upon the cementitious paste. Carbonatation is due to the penetration of CO_2 into the concrete.

This phenomenon consists in the transformation of the lime, which then generates hydration of the cement into calcium carbonate due to the presence of carbon dioxide, the level of which depends on the environment in which the construction is located (the amount of industrial pollution in the area, for example).



photo 3

An example of deterioration caused by carbon dioxide

Healthy concrete has a pH level of more than 13, and in this condition, a passive iron oxide film is formed on the reinforcement rods which insulates them against oxygen and humidity.

If the structure is carbonatated, the pH level in the concrete is reduced to less than pH 9, thus creating a slightly less alkaline environment for the reinforcement rods. When the pH level is less than 11, the passivating film is neutralised, and the rods are exposed to aggression by the oxygen

and humidity which are present in the atmosphere. Under these conditions, a corrosion process of the reinforcement rods initiates, which increases their volume by approximately 6 times their initial volume. The concrete around the reinforcement rods detaches from the rods, and may even be completely pushed out (*photo 3*). Once the concrete has deteriorated, deterioration to the reinforcement rods will progress even more quickly due to the formation of access points for the oxygen and humidity. CO₂ travels from the outside towards the inside of the concrete, and its penetration speed depends heavily on the level of humidity. The transportation speed of carbon dioxide is very high when it is in a gaseous state, that is, in pores full of air, while it is much lower in pores where humidity has collected. Therefore, in those pores saturated with water, the penetration speed will be more or less zero. However, we must remember that in order for carbonatation to take place, the presence of humidity is absolutely essential. The following graph summarises the concept of CO₂ penetration speed as a function of the level of relative humidity of the concrete.

graph 1

Carbonatation speed compared with the % of relative humidity

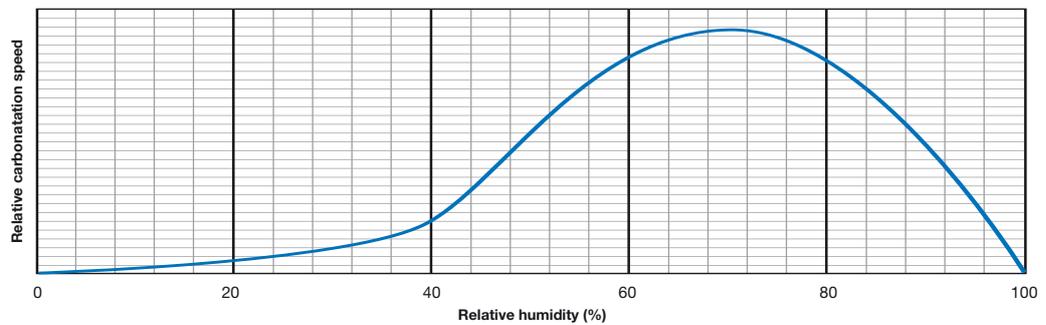


photo 4

Deteriorated structure due to corrosion of the reinforcement rods.



The deterioration of **concrete**

The most dangerous levels of humidity are between 50% and 80%. With values outside this range, the speed decreases until it reaches zero, both in conditions of complete dryness and of total saturation (*graph 1*).

In conclusion, we may state that the occurrence of carbonatation is only damaging for reinforced structures due to the reasons mentioned above, while it is not a determining factor in those structures made using concrete which is not reinforced.

If we observe a concrete construction which is in a condition similar to the one illustrated in photo 4, it is now possible to carry out an initial hypothesis regarding the cause of deterioration. The occurrence of leaching consists in the removal of the cementitious matrix due to the mechanical action of water on the concrete, as may be observed in photo 5. This is further aggravated if the water is particularly acidic due to its content of aggressive carbon dioxide, which is especially present in pure mountain water, by the presence of waste substances given off by industrial processes, or by the presence of sulphuric acid with an organic origin, which develops in waste water in drainage systems.



photo 5

The effect of leaching on a concrete surface.

3.1.1| Diagnosis of deterioration due to carbonatation

To verify if deterioration is due to carbonatation, a test method based on the colour of the concrete after treating its surface with a 1% phenolphthalein solution in ethanol (UNI EN 13295:2005) is used. When the solution comes into contact with a material which is not carbonatated, it turns red.

photo 6
Colour test using phenolphthalein



If the material is carbonated, it does not change colour.

With this method, it is also possible to check the depth of carbonatation of the concrete.

An example is illustrated in photo 6, where the depth of carbonatation is approximately 3 cm.

The depth of carbonatation in the reinforced concrete also indicates the entity of the damage.

To repair the damage, the entire thickness of material penetrated by CO_2 around the reinforcement rods must be eliminated.

3.1.2| **Diagnosis of deterioration due to leaching**

In this case, a chemical and thermal analysis, or an analysis using X-ray diffraction, are not suitable to identify leaching. The product of this type of deterioration is calcium bicarbonate which is highly soluble, and the passage of water carries it away and it can not be detected on the surface. A further reason why the above tests are not significant is the fact that the first phase in obtaining calcium bicarbonate is the formation of calcium carbonate, but this is also present in most concrete, in the aggregates or filler materials. Therefore, it would be impossible to establish if it is from one of these elements, or if it had formed due to the effect of aggressive carbon dioxide.

The only method to verify the presence of leaching on concrete is a detailed visual analysis of the surface. If it is deteriorated due to leaching, the aggregates will be visible without the cementitious matrix.

► 3.2| Aggression by sulphates

The most common soluble sulphates in the ground, in water and in industrial processes are calcium and sodium. There are also magnesium sulphates, but these are less common, although they are more destructive. Sulphate ions may be present in water and in the ground, and they may also be found directly in the aggregates as impurities. If the sulphates come from the ground or from the water in contact with the structure, the sulphate ions carried inside the cementitious matrix by water (fundamental for transportation) reacts with the calcium hydroxide to form gypsum.



foto 7/8

An example of a structure damaged by sulphuric aggression

It then reacts with the hydrated calcium aluminates (C-A-H) to form secondary ettringite, which increases in volume and causes delamination, swelling, cracking and detachment (*Photos 7 and 8*). Unlike secondary ettringite, primary ettringite does not damage the concrete, since it is formed by the bond between the anhydrite aluminates and the gypsum added to the cement as a setting regulator. Apart from not being harmful, this type of ettringite is also useful because it creates a barrier around the aluminates and slows down the hydration process.

A further difference between primary and secondary ettringite is that the first type forms almost immediately and uniformly in the casting. These two factors, together with the fact that the concrete is still in a plastic phase, create low expansion stresses which are not, however, harmful. Secondary ettringite, on the other hand, forms a long time after casting, and mainly in the cortex of the concrete (the part penetrated by sulphates), creating high expansion stresses due to the stiffness of the casting.

Another type of sulphate attack occurs in the presence of calcium carbonate at low temperatures (lower than 10°C) and relative humidity above 95%. Under these conditions,

thaumasite is formed which provokes decalcification and the concrete being reduced to pulp. Sulphates may also come from within the concrete, in the form of natural impurities in the aggregates, such as gypsum or anhydrite. The size of the gypsum in the aggregates is higher compared with the gypsum added to the cement for setting, and is therefore less soluble in water. This means that it is not immediately available to form primary ettringite, but will later form secondary ettringite in the cured concrete, causing cracks.

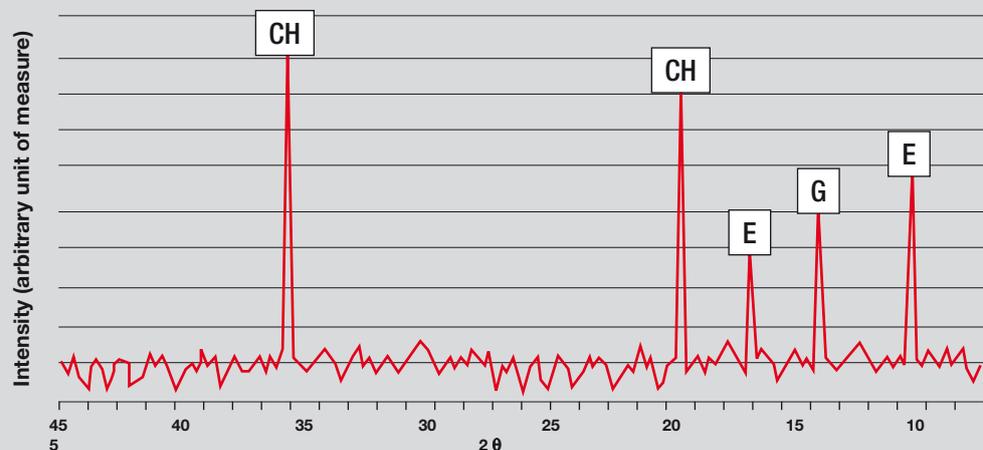
3.2.1| Diagnosis of deterioration due to sulphate attack

To establish whether deterioration of the concrete is due to sulphate attack, chemical analysis is carried out to measure the level of sulphate present. There is normally a small amount of calcium sulphate in the concrete, which is added to the cement during the grinding cycle and acts as a setting regulator. A normal content level in the concrete is around 0.4% to 0.6%. A method to establish if there is ettringite present rather than gypsum, is with an X-ray diffractogram, which picks up the peak values of these substances, as shown in the graph below (photo 9).

After analysing the samples, their values are compared, and if they are considerably higher than what is considered a normal level (a difference of at least 30%), then deterioration may be considered due to sulphate attack. By carrying out a chemical analysis of a sample, it is possible to define by how much the content is higher than what is considered a normal level. However, the state of deterioration may not be defined, because in this case it is indicated by the formation of products which cause deterioration, such as gypsum, ettringite or thaumasite.

photo 9

X-ray diffraction
(CH:lime; E:ettringite; G:gypsum)



► 3.3| Aggression by chlorides

Aggression by chlorides (*photo 10*) on concrete occurs if it is in contact with environments with a high chloride content, such as seawater or de-icing salts, or if it is prepared using contaminated raw materials. Once the chloride penetrates into the concrete and reaches the reinforcement rods, it eliminates the passivating ferrous oxide film on the rods so that they are



photo 10
Corrosion caused
by chloride attack

exposed to the corrosion process. Penetration starts on the surface and continues into the concrete. Penetration time depends on:

- The concentration of chlorides which come into contact with the surface of the concrete;
- Permeability of the concrete;
- Percentage of humidity present.

Corrosion occurs with a combination of two factors, both of which are required for the process. The presence of chlorides, which depassivate the reinforcement rods, and humidity containing oxygen. For example, a structure completely immersed in seawater will have a higher chloride content. However, the porosity in the concrete will be completely saturated with humidity, and the oxygen will not be able to penetrate. Corrosion of the reinforcement rods will not occur, or will be negligible. If we take into consideration another structure

immersed in seawater, the area most exposed to chloride deterioration is the splash zone, the area which is dry and then wet due to the movement of the waves and high and low tides. De-icing salts spread on road surfaces during the winter penetrate into the structure when it rains causing corrosion and deterioration.

Once the process has started, wherever the structure is located, corrosion is faster because access routes may be found more easily. The concentration of chlorides required to promote corrosion of the reinforcement rods is directly proportional to the pH of the concrete; the higher the alkalinity of the concrete, the higher the concentration of chlorides required to start the process. With reference to this consideration, the phenomenon of deterioration due to carbonatation may be connected to deterioration by chlorides, in that carbonatation lowers the pH of the concrete so that even those areas of the structure with a lower concentration of chlorides will be more vulnerable.

3.3.1 | Diagnosis of deterioration due to attack by chlorides

The presence of chlorides may also be verified by a simple laboratory test by chemical analysis. In this case, chloride of around 0.2% to 0.4% compared with the weight of cement may be considered normal in concrete. If the level is higher, then the chloride has infiltrated into the concrete and has damaged it.

Apart from chemical analysis, there are two other tests which may be carried out:

- Colour test, using fluorescein and silver nitrate (UNI 7928 Standards);
- X-ray diffraction analysis.

The first test consists in spraying a core sample with a solution of fluorescein and silver nitrate. A chemical reaction takes place, and the portion of concrete penetrated by chlorides turns a light pink colour, while the healthy part turns a dark colour. The line which delimits the colour change indicates the thickness of deteriorated concrete, and whether the chlorides have reached the reinforcement rods.

The second test shows the products developed by the chlorides inside the concrete. There are two types of chlorides from de-icing salts, sodium chloride (NaCl) and calcium chloride (CaCl₂). The first type provokes an alkali-aggregate reaction, and pop-out phenomenon in the floor. The second test, which is no longer very widely used, causes the formation of oxychloride, a product which provokes serious deterioration of concrete by removing the cementitious matrix, similar to deterioration due to leaching.

► 3.4| Alkali-aggregates reaction

An alkali-aggregates reaction may cause considerable expansion and serious deterioration of concrete structures. Some types of aggregate, such as those which contain reactive silicon, react with two alkalis contained in the cement, potassium and sodium, or as mentioned in the previous paragraph, with those which come from the surrounding environment in the form of sodium chloride (NaCl) (de-icing salts or seawater). This reaction forms a gel which is highly expansive if exposed to humidity, and the gel creates forces which break the concrete around the aggregates. The alkali-aggregate reaction is a process which takes place slowly and heterogeneously, since it is bound to the composition of the aggregates containing amorphous silicon. The product of the reaction under such conditions are sodium silicates and hydrated potassium, which are very voluminous.

The alkali-aggregates reaction shows up when it starts in the cortex of the concrete, with micro and macro cracks on the surface, or even causing small portions of the concrete above the reactive silicon aggregate to lift (pop-out phenomenon). This phenomenon may be found particularly in industrial floors. Photo 11 illustrates a structure with serious, branch-type cracking, a typical example of deterioration due to an alkali-aggregate reaction. Once the concrete starts deteriorating, a further percentage of humidity will accelerate the reaction process, with the added risk of deterioration due to freeze-thaw cycles.



photo 11
Deterioration due to alkali-
aggregates reaction

3.4.1| Diagnosis of deterioration due to alkali-aggregates reaction

An initial, immediate assessment to detect the presence of an alkali-aggregates reaction is by carrying out a detailed visual check.

This type of deterioration shows up with cracking in the concrete distributed like a spider's web, with an orderly or less orderly distribution pattern according to the reinforcement rods present. There will also be swelling in conjunction with the cracking, due to the increase in volume. Chemical analysis by means of a colour test using sodium cobaltinitrite is a certain way to identify the presence of a reaction between alkalis and reactive aggregates (amorphous silicon).

This test is used to identify the gel produced by the reaction between alkalis in the cement and the silicon in the aggregates (an American patent). The sodium cobaltinitrite reacts with the K (potassium) in the gel to form a coloured precipitate. Therefore, if there has been a reaction, its colour will change and will turn yellow. To establish whether the aggregates are reactive and, therefore, potentially subject to this phenomenon, a petrographic analysis may be carried out according to UNI EN 932-3 Standards.

Photos 12 and 13 show, respectively, the core sample taken from a structure and the result of the sodium cobaltinitrite analysis to identify the reaction.

photo 12

Core sample taken from a deteriorated structure

photo 13

Colour test using sodium cobaltinitrite



► 4 | **Aggression by physical elements**

- 4.1 | *Freezing and thawing*
- 4.2 | *High temperatures*
- 4.3 | *Shrinkage and cracking*

► 4.1 | **Freezing and thawing**

The effect of ice is negative only in the case of the presence of water at its liquid state inside the concrete. This does not necessarily mean that the concrete must be perfectly dry, but the level of humidity must not be higher than a determined level, known as “critical saturation”.

This means that the amount of water present in the porosity must be lower than this value, so that even when it expands when it turns to ice, it still manages to remain within the pores without creating stresses. However, if the water fills, or almost fills, the entire volume of the pores, when it freezes it will break the concrete because of the pressure it exerts (when water turns to ice, its initial volume increases by 9%).

Also, even if the critical saturation level is not exceeded, the concrete may still be broken due to the presence of water. If we take into consideration the percentage of water present in all the concrete, we do not consider the heterogenous distribution of the water inside the casting.

To overcome this drawback, the percentage in the cortex area is measured, that is, the area where the phenomenon of deterioration due to freeze-thaw cycles initiate (*Photos 14 and 15*).



photo 14
Deterioration due to freezing

photo 15
Deterioration due to freezing



To limit the negative effects of low temperatures, the capillary micro-porosity must be reduced and the presence of macro-porosity encouraged (with a size of between 100 and 300 μm), by adding aerating admixes when preparing the concrete, by keeping the water/cement ratio low and, above all, by using aggregates which do not freeze.

Damage due to freeze-thaw cycles only occurs when there is a combination of the following conditions:

- 1) Low temperatures;
- 2) Absence of macro-porosity.

The type of damage is proportional to:

- The level of porosity;
- The level of saturation by humidity;
- The number of freeze-thaw cycles;
- The amount of air trapped (around 4%-6% for aggregates with a diameter of up to 20-50 mm, and up to 8% for smaller aggregates).

► 4.2| High temperatures

The effect of high temperatures on concrete is destructive. The reinforcement rods resist at temperatures of up to 500°C, while concrete resists at up to 650°C. The function of the concrete around the reinforcement rods in this case is fundamental, in that it slows down propagation of heat. The thicker the concrete, the longer it takes for the reinforcement rods to reach their failure temperature of 500°C.

Fire may provoke many types of damage to concrete, and the damage may also be very serious:

- Even if the reinforcement rods are protected by concrete, when they heat up, their volume increases and they create stresses in the concrete, this may lead to parts of the concrete breaking off.
- Once the reinforcement rods are exposed to fire, they expand much more quickly than the concrete in which they are embedded, causing a loss in adherence and to them being expelled.
- Even if the failure temperature is not reached, the concrete may lose its performance characteristics if it is suddenly cooled down, a condition which usually occurs when fires are extinguished. In this situation, the oxide which forms due to the heat is transformed into lime, which disintegrates the concrete.
- On the face closest to the fire, spalling takes place due to rapid expansion, and some of the aggregates explode and may detach the surrounding concrete, the same result as when humidity is quickly transformed into water vapour, creating small explosions.
- If exposure to fire is prolonged, the reinforcement rods reach their failure temperature and there is a loss in tensile strength, which causes the entire structure to collapse.

The schematic drawing below summarises the various phases of deterioration due to fire.

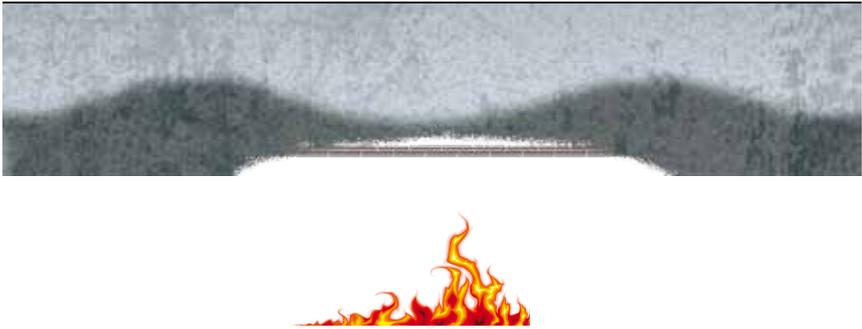
<p>The concrete withstands temperatures of up to 650°C</p>	
<p>The first part to break off is the concrete around the reinforcement, which is fundamental in protecting the rods</p>	
<p>Once the reinforcement rods are exposed, heat propagates more quickly</p>	
<p>If the structure is exposed to fire for a considerable time, the steel also loses its performance characteristics, causing the structure to collapse</p>	

Table 1

► 4.3| Shrinkage and cracking

This section discusses two types of shrinkage, plastic and hygrometric. Plastic shrinkage occurs during the plastic phase of concrete, when it releases part of the humidity contained within it into the surrounding environment, causing it to contract. Cracking in this case depends on the surrounding conditions when the concrete is cast. When cast into formwork, for obvious reasons, evaporation does not take place, whereas if the concrete is in direct contact with the surrounding environment, evaporation occurs because of the temperature, very low external humidity or strong winds. When plastic shrinkage occurs while the concrete is fresh, micro-cracks may form on the surface. Hygrometric shrinkage is due to the release of humidity into the environment with a low level of R.H. during the entire service life of the structure.

In order to avoid the problems due to plastic shrinkage, precautions must be taken to avoid the water present in the mix evaporating too quickly, which may be done in various ways:

- 1) By laying waterproof sheets on the casting, to block evaporation
- 2) By spraying the entire surface during the first few days after casting
- 3) By applying a protective anti-evaporation filming product on the concrete while still fresh

Since the large majority of hygrometric shrinkage takes place within the first six months of casting, it is impossible to keep it wet for the entire duration. Therefore, we must act upon other factors, such as reducing the water/cement ratio and increasing the inert/cement ratio.

Photos 16 and 17 illustrate examples of cracking in a concrete floor.



photo 16
Cracking in concrete

photo 17
Cracking in concrete
slabs

► 5| Aggression by mechanical elements

5.1| *Abrasion*

5.2| *Impact*

5.3| *Erosion*

5.4| *Cavitation*

► 5.1| Abrasion

If a material is repeatedly struck by particles from a harder body, abrasion takes place. This is due to the friction which the harder powder particles exercise on the surface of the material. It is therefore quite clear that abrasion depends directly on the characteristics of the materials which make up the concrete. As a result, we can improve resistance to abrasion by reducing the water/cement ratio or by sprinkling cement mixed with hard admixes and aggregates on the surface of the concrete.

Factors which influence abrasion resistance:

- Compressive strength;
- Properties of the aggregates;
- Nature of the finishing coat;
- Presence of areas which have been patched up;
- Condition of the surface.

Structures which are particularly prone to this phenomenon include industrial floors, made worse by the continuous passage of vehicles.

Photo 18 shows an example of erosion due to the presence of running water.

photo 18
An example of erosion



► 5.2| Impact

Another form of deterioration due to mechanical elements, is that provoked by impact. A number of considerations must be made in this case, since concrete is a fragile material which, if subject to impacts of a certain intensity, deteriorates and its strength will be reduced. Damage due to impact is not necessarily immediately visible, and in certain cases many impact cycles are required; for example, floor joints subject to the passage of mechanical transport means. In this case, the only way of reducing the effects of deterioration is to prepare concrete which is as strong as possible.



photo 19

An example of the deterioration at the joints

To make concrete more resistant to impact, it can be strengthened using steel fibres, so that the impact energy is distributed more evenly throughout the entire structure.

Photos 19 and 20 show examples of deterioration due to impact on concrete.



photo 20

Deteriorated concrete

► 5.3| Erosion

Erosion is a particular form of wear due to wind, water or ice which provokes the removal of material from the surface. It depends on the speed, the content of hard dust particles and the quality of the concrete. In this case, the only remedy is to take special care when mixing the concrete. The same guidelines as for abrasion should be followed.

► 5.4| Cavitation

Cavitation is a problem where flowing water (> 12 m/s) is present. The high speed of the water, together with an irregular surface where the water flows, provoke turbulence and areas of low pressure, and vortexes will form which erode the substrate. The air bubbles which form in the water flow downstream, and when they run into an area of high pressure, implode and cause a strong impact, resulting in erosion. If the speed of the water is particularly high, erosion due to cavitation may be serious. The occurrence of cavitation may be avoided by laying smooth surfaces without obstacles along the water course.

► 6| Defects

Concrete is a mixture of a number of elements. The way it is prepared depends on each project's single requirements; the higher the requirements, the more delicate the design of the mix will be. The main components are cement, aggregates, water and admixtures. If any of these elements are used incorrectly, one or more weak points in the concrete could develop. If we consider a case where the best products available on the market are used, but due to a lack of experience, or for any of a number of other reasons, they are blended together using incorrect mixing ratios, the result will be the same as if poorer quality products had been used. The quality of the materials used is vitally important, but it is even more crucial that they are mixed together correctly. Photo 21 illustrates an example of the segregation of aggregates due to incorrect preparation and/or casting operations. The most important component is the cement, which must be suitable for the type of application where it is used and its exposition class (this subject will be discussed further in the next sections). Regarding this "ingredient", certain considerations need to be made. Even though this is the element which binds and, therefore, makes sure that the performance levels required are reached, performance will not necessarily be better if the quantity of the cement is higher. It is easy to imagine that the higher

The deterioration of **concrete**



photo 21

Segregation of the aggregates in concrete

the content of cement in a particular mix, the higher the amount of shrinkage of the casting. The aggregates must have a suitable grain size distribution, they must be well dosed between fine parts and larger parts and particularly clean, to avoid foreign objects or impurities affecting their characteristics or, at worse, causing deterioration due to the presence of impurities, as discussed previously.

When choosing admixtures, it is fundamental that the final characteristics required of the concrete are clearly understood. When mixing the various elements, the water/cement ratio plays a fundamental role, as does the aggregates/cement ratio. Regarding the first ratio, with the same quality of products in the mix, the lower the ratio the better the final results, while for the second ratio, the proportions must be well balanced according to the content of fine parts and larger parts.



photo 22

Exposed reinforcement rods in concrete

In photo 22, apart from the evident segregation of the aggregates, we can also see the exposed reinforcement rods, a symptom of incorrect casting of the concrete. If the reinforcement rods are not protected sufficiently by the concrete, problems due to the penetration of agents which cause deterioration will be provoked more easily.

To summarise the defects in concrete, they may be divided into three main categories:

- Defects due to poor/incorrect design of the mix;
- Defects due to the wrong composition;
- Defects due to incorrect/poor quality installation.

► 7 | **Exposition classes**

The deterioration of concrete may be avoided by taking particular care during the design phase, by carefully considering the environment in which it will be employed. UNI 11104:2004 Standards (Concrete - Specifications, performance, production and conformity - Complementary instructions for the application of EN 206-1) identifies 6 exposition classes, and for each class, indications are given regarding design, preparation and installation of the concrete.

Exposition class	Environment	Structure	Sub-classes
X0	No risk of corrosion or attack	Reinforced and non-reinforced concrete	X0
XC	Corrosion induced by carbonatation	Reinforced concrete	XC1, XC2, XC3, XC4
XD	Corrosion induced by chlorides, except those from seawater	Reinforced concrete	XD1, XD2, XD3
XS	Corrosion induced by chlorides present in seawater	Reinforced concrete	XS1, XS2, XS3
XF	Attack by freeze-thaw cycles with or without de-icing salts	Reinforced and non-reinforced concrete	XF1, XF2, XF3, XF4
XA	Chemical attack	Reinforced and non-reinforced concrete	XA1, XA2, XA3

Table 2

The 6 exposition classes according to UNI 11104 Standards

All the classes and sub-classes are defined and described by the UNI 11104 Standards as follows:

CLASS X0: For concrete without reinforcement or metallic inserts: all exposure conditions except freeze/thaw cycles, or chemical attack.

Concrete with reinforcement or metallic inserts: in very dry environments.

CLASS XC: Corrosion induced by carbonatation.

XC1: Dry or permanently wet

XC2: Wet, rarely dry

XC3: Moderate humidity

XC4: Cycles of dry and wet conditions

CLASS XD: Corrosion induced by chlorides, except those from seawater.

XD1: Moderate humidity

XD2: Wet, rarely dry

XD3: Cycles of dry and wet conditions

CLASS XS: Corrosion induced by chlorides present in seawater.

XS1: Exposure to seawater salts, but not in direct contact with seawater

XS2: Permanently immersed

XS3: Areas exposed to splashes or tides

CLASS XF: Attack by freeze-thaw cycles with or without de-icing salts.

XF1: Moderate saturation with water, without de-icing agents

XF2: Moderate presence of water, with de-icing agents

XF3: High saturation with water, without de-icing agents

XF4: High saturation with water with de-icing agents, or seawater

CLASS XA: Chemical attack by water from the ground and flowing water.

XA1: Environments with low level of chemical aggression

XA2: Environments with moderate level of chemical aggression

XA3: Environments with high level of chemical aggression

In those cases where a given environment includes various exposition classes, as many types of concrete as the different exposition classes should theoretically be prepared. However, from a practical point of view, this solution is not feasible. Therefore, in such conditions, concrete should be prepared according to the worst exposition conditions.

The deterioration of **concrete**

Table 3 contains a summary of the directives for preparing concrete according to their exposition class, and according to UNI 11104 Standards.

table 3

Directives for the preparation of concrete according to UNI 11104 Standards

Class	Sub-class	Max. water/cement	Min. Rck (Mpa)	Min. cement content (kg/m ³)	Thickness of concrete around reinforcement	
					reinf. conc. (mm)	prefab. reinf. conc. (mm)
X0	-	No limit	No limit	No limit	15	20
XC	XC1	0.65	25	300	15	25
	XC2	0.60	30	300	25	35
	XC3	0.55	37	320	25	35
	XC4	0.50	37	340	30	40
XD	XD1	0.55	37	320	45	55
	XD2	0.55	37	340	45	55
	XD3	0.45	45	360	45	55
XS	XS1	0.50	37	340	45	55
	XS2	0.45	45	360	45	55
	XS3	0.45	45	360	45	55
XF	XF1	0.55	37	320	30	40
	XF2	0.55	30	340	45	55
	XF3	0.50	37	340	30	40
	XF4	0.45	30	360	45	55
XA	XA1	0.55	37	320	25	35
	XA2	0.50	37	340	25	35
	XA3	0.45	45	360	25	35

The values for the thickness of the concrete around the reinforcement are as prescribed in EUROCODE 2.

