Technical Manual

CONCRETE FOR WATERTIGHT STRUCTURES

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ADHESIVES • SEALANTS • CHEMICAL PRODUCTS FOR BUILDING

Technical Manual

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1. INTRODUCTION

The aim of this technical manual is to illustrate the technologies and solutions proposed by MAPEI to meet the increasing demand for impermeable concrete.

There are two main reasons why a concrete structure needs to be impermeable:

- to construct hydraulic structures; i.e, structures that will be used to control and direct water (channels, dams, structures to retain and contain water courses, etc.);
- to construct concrete structures with higher durability.

2. REFERENCE NORMS AND STANDARDS

When a concrete structure is designed its nominal service life must be taken into consideration, which varies according to the type of structure. Apart from complying with the requirements of applicable norms and standards, guaranteeing higher durability also means reducing maintenance costs and, therefore, the demand for new infrastructures. In turn, this will lead to lower consumption of raw materials, a reduction in energy consumption and lower CO_2 emissions. That's why we would like to highlight how important it is for designers to specify the level of impermeability of concrete, not only to comply with current standards, but also to have less impact on the environment.

On the basis of current legislation, designers must define the permeability requirements of concrete according to current standards: Eurocode 2 (reference design standards for Technical Construction Norms) and EN 206:2014, with the latter being expressly required by Technical Construction Norms, which means it is legally binding.

When writing Technical Specifications, design engineers must give a detailed description of the base requirements indicated by section 6.2.2

of the standards, but they must also specify the additional requirements listed in section 6.2.3, which expressly mentions resistance to the penetration of water, thereby directly leading to the impermeability of concrete.

3. IMPERMEABLE CONCRETE

The impermeability of a material is its capacity to withstand the passage of fluids. With concrete in particular, this means its capacity to prevent the passage of water within its structure. In fact, constructing impermeable structures is important not only to protect buildings against leaks, but also, and above all, to reduce harmful, aggressive agents to enter and extend the service life of the structure itself.

The entering of water into the pores inside the cementitious matrix, a potential vehicle for aggressive ions, and the passage of gases such as carbon dioxide and oxygen, are the main causes of deterioration in concrete structures.

It is very important, therefore, to define the transport mechanisms that regulate the kinetics of deterioration phenomena.

The following mechanisms may be identified inside concrete:

- diffusion;
- permeation;
- capillary absorption;
- electrophoretic transport.

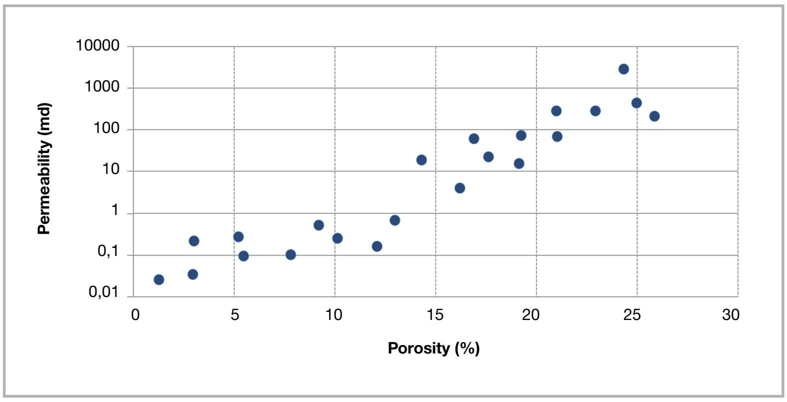
3.1 DIFFUSION

Transport through a porous body by diffusion occurs when there is a concentration gradient. Any solution will tend to move from an area where its concentration is higher towards another area where its concentration is lower. In general, the diffusion of gases tends to occur in pores where

air is present, whereas the diffusion of ions only takes place if the body is saturated with water, or otherwise, by water passing into the pores.
Diffusion within a structure depends on various factors which, in turn, depend on the type of material and its surroundings.
Without going into too much detail about the formulas that regulate stationary flow and non-stationary unidirectional flow, it is worth mentioning that Fick's Laws regulate these processes and are commonly used to estimate the chloride diffusion coefficient of concrete.

3.2 PERMEATION

Transport through a porous body by permeation occurs when a pressure gradient is generated inside the body. Permeability is regulated by Darcy's Law and is defined by a constant K which relates the pressure gradient to flow rate by means of two constants, one based on the characteristics of the fluid and the other on the characteristics of the porous body. Darcy's Law describes so-called *absolute permeability*, i.e. the flow of a single fluid through a porous body. The factors that affect absolute permeability are related to the microscopic structure of the porous body, such as tortuosity and porosity. Even though they express different physical quantities, porosity and permeability in particular are correlated and dependent on each other.



Graph 3.1

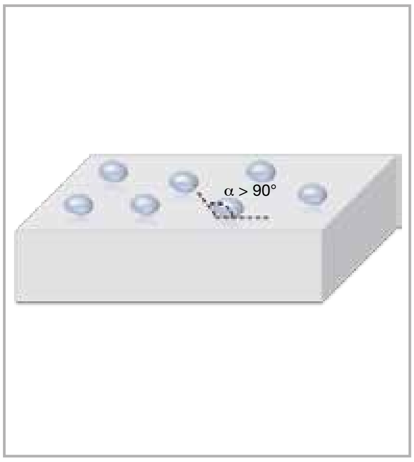


Fig. 3.2 - A hydrophobic body blocks water ingress (α > 90°)

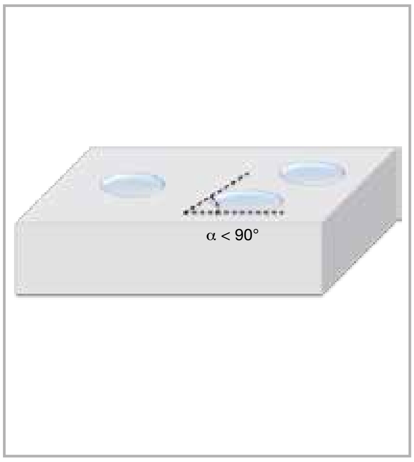


Fig. 3.3 - A non-hydrophobic porous body encourages ingress (α < 90°)

3.3 CAPILLARY ABSORPTION

Transport by capillary action is the phenomenon that regulates the passage of water inside concrete due to the effect of capillary forces. The behaviour of a solid porous body towards water is one of two types: hydrophilic and hydrophobic. In the first case, the water's affinity with the solid body leads to water droplets having a contact angle with the solid surface of less than 90°. In the second case the solid body, due to its intrinsic characteristics or because it has been treated with a special substance, induces water droplets to have a contact angle of more than 90° and its behaviour is known as hydrophobic. Water rising inside capillary pores is a spontaneous action that takes place when there is affinity between water and the porous body; the rising water is pushed by pressure that depends on three variables: the surface tension of the liquid d, the radius of the capillary pore r and the contact angle Φ according to the relationship $P = (2\delta/r)\ cos\Phi$.

Capillary rising of the water continues until the capillary pressure and hydrostatic pressure are in equilibrium. The capillary forces increase, therefore, as the size of the pores and the contact angle reduce, which is a function of the viscosity of the fluid and its affinity with the walls of the pores. Capillary absorption is one of the most harmful mechanisms and one of the main causes of deterioration in concrete. Concrete is porous and its extremely complex structure, consisting of numerous interconnecting voids and micro-cracks, is highly exposed to the effects of capillary rising.

3.4 ELECTROPHORETIC TRANSPORT

Another possible transport mechanism in concrete is induced by the difference in potential produced by an electromagnetic field. This electromagnetic field may occur due to corrosion phenomena or to the dispersion of currents from an external source. The difference in potential causes movement of the ions in the solution contained in the capillary pores. This phenomenon is particularly important when chlorides are present, as they are responsible for localised corrosion of steel reinforcement (pitting/spalling).

4. POROSITY

All the transport mechanisms mentioned previously are correlated to the presence of pores and their structure inside the concrete. To this end, it is important that the main types of porosity and their main characteristics are described. Porosity may be classified according to size. IUPAC (*International Union of Pure and Applied Chemistry)* classifies them as follows:

- micropores: d < 2 nm;
- mesopores: 2 < d < 50 nm;
- macropores: d > 50 nm.

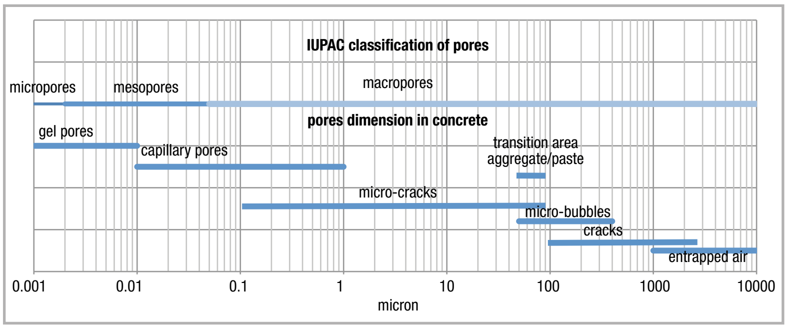


Fig. 4.1

In concrete, on the other hand, the following kind of pores may be identified: gel pores, capillary pores, macropores, cracks and macro-bubbles.

Pores measured in nanometres (1-10 nm) are represented by micro *gel pores* which form the porosity in the C-S-H gel. Colloidal gel is the main component of the cement paste and is what gives it its strength and micro-structure. Micro *gel pores* make up around 28% of the total gel volume, but they have absolutely no influence on the mechanical strength and durability of concrete because they don't allow aggressive agents to pass through.

The capillary pores are generally the size of mesopores and are tipically between 10 and 50 nm, although they may also be up to 300-500 nm and classified, therefore, as macropores.

These are mainly present in the cementitious paste and at the aggregate/

cement paste interface. They may also be interconnected and allow fluids to pass through by means of capillary absorption. The volume of capillary pores reduces with the degree of hydration or with curing and the reduction in the water/cement ratio. Lower capillary porosity improves both the development of mechanical strength and resistance to the ingress of aggressive agents.

Macropores are voids with a diameter of generally more than 50 nm. Macropores mainly consist of larger capillary pores and voids caused by the added or entrapped air.

By encorporated air we mean air that has been introduced both voluntarily by means of chemical admixtures (entrained) or that forms during mixing (entrapped). The air bubbles that form by introducing aerating admixtures are generally spherical and their size is 50-200 μm, they are particularly stable and they improve the durability of concrete during freeze/thaw cycles.

Entrapped air, on the other hand, may have a detrimental effect on the strength of the concrete structure.

5. HOW DO YOU MEASURE PERMEABILITY?

Concrete is generally specified by defining its four main characteristics; exposure class, strength class, consistency class and maximum aggregate diameter. To measure its durability, its resistance to the penetration of aggressive agents will need to be measured. Various methods may be used to carry out this measurement: maximum penetration depth of water under pressure according to EN 12390-8: 2002, determining its coefficient of permeability (K) using Darcy's equation and evaluating capillary absorption according to EN 13057.

5.1 TEST METHOD - PENETRATION DEPTH OF WATER UNDER PRESSURE

The European standard EN 12390-8:2002 specifies a direct measurement of permeability by measuring the penetration depth in mm of water into a concrete sample subjected to water under pressure.

This standard specifies that the concrete sample is cured in a damp chamber for 28 days and then connected to a special instrument and subjected to water at a pressure of 500 ± 50 KPa for 72 ± 2 h. Once the test has been completed, the sample is split perpendicularly to the face on which the water under pressure was applied and, after identifying and tracing the profile of the water, its maximum penetration depth is recorded. Although there is no physical justification, on the basis of deductions from experiments and tests carried out, concrete is considered impermeable if the depth of penetration is less than 20/30 mm.

Fig. 5.1 - Equipment used to carry out a water penetration test on concrete

5.2 COEFFICIENT OF PERMEABILITY (K)

The method used to determine the coefficient of permeability of concrete using Darcy's equation is described in the document CRD-C 48-92, written by the US Army Corps of Engineers. This is also a direct testing method. The sample of concrete is waterproofed along the sides and the untreated face is exposed to water under a constant pressure of 200 psi (1380 KPa). When the flow is constant, the volume of water that percolates within a set time, and according to the size of the sample, is measured and it is possible to measure the coefficient of permeability (K) using the formula $K = \frac{M}{A\left(\frac{h}{L}\right)}$ where M is flow, A is the surface area of the sample, h is the hydraulic load and L is the length of the sample.

The coefficient of permeability K provides a value that allows you to qualify the concrete and consider it more or less prone to the passage of water and, therefore, classify it as shown in the following table:

TYPE OF CONCRETE	COEFFICIENT K
Fully impermeable	$< 10^{-12}$ m/s
Medium impermeability	10^{-10} to 10^{-12} m/s
Permeable	$> 10^{-10}$ m/s
Mortar	$> 10^{-6}$ m/s

5.3 MEASURING CAPILLARY ABSORPTION

The American standard ASTM C1585 describes how to measure the absorption speed of concrete.

This method is applied to roundshape samples of concrete. The samples are prepared in special moulds or taken using a core sampler and tested to measure their level of absorption as a function of their sampling depth. The samples are cured for 3 days in a dryer at 50°C ± 3°C and then left for 15 days in a sealed container at 23°C ± 2°C before any testing is actually carried out. Once they have been sealed externally and weighed, the samples are immersed in water to a depth of 3 mm and their increase in mass is recorded at set time intervals. The absorption values in $I = \frac{\Delta m}{\frac{A}{d}}$ mm are plotted on a graph as a function of the square root of time (s). The values measured typically form a curve in two parts; the slope of the curve between 0 and 6 hours represents their initial absorption rate, while the slope of the curve between 1 day and 7 days defines their secondary absorption rate.

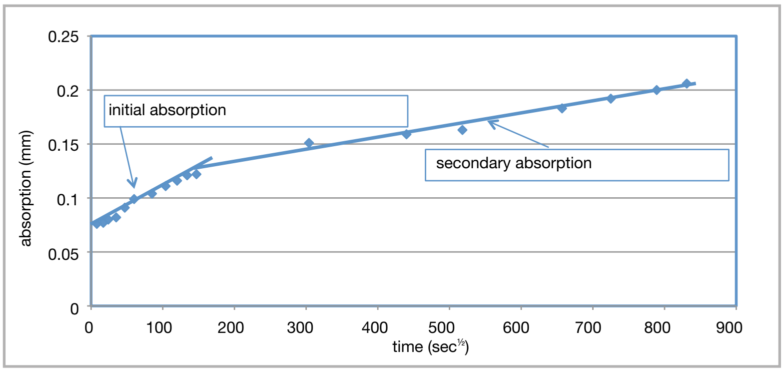


Fig. 5.2

As European standards do not contemplate absorption tests for concrete, reference is usually made to EN 13057 which covers concrete protection and repair systems.
This method specifies curing the samples in a saturated environment according to the method described in EN 196-1 and then holding the samples in a laboratory at 21°C ± 2°C and 60°C ± 10°C for 7 days, or until they reach a constant mass. The samples are then placed on supports sitting on the bottom of a basin of water so that the sample is immersed in the water to a depth of 2 mm ± 1 mm. Capillary absorption is then measured at intervals of time to suit the absorption rate of the sample. The graph showing capillary absorption is always represented by a linear trend that puts water absorption (kg/m^2) as a function of the square root of time. If the sample is saturated due to capillary absorption it is possible to measure its coefficient of resistance R (h/m^2) with the formula $R = \frac{tc}{x^2}$ where tc is the time required to completely saturate the sample and x is the thickness of the sample. The value indicates the depth of water in the sample in a determined period of time and gives an indirect indication of how fine the capillary system of the pores really is. This is, however, a value that may only be measured in materials with a rather high capillary absorption.
Another method used to determine the water absorption rate of a sample at atmospheric pressure, albeit non-harmonised, is described in UNI 7699. The concrete sample, which is either prepared in the laboratory or taken on site with a core drill, is held in an air-conditioned environment (+20°C: 50% RH) until it reaches a constant mass and then subjected to the absorption test.
The test sample is immersed in water so that the upper face sits at least 5 mm above the surface of the water. At intervals of 1, 3, 8 and 24 hours the mass of the sample is measured and the percentage of water absorbed is calculated with respect to the weight of the sample before starting the test. After 24 hours the sample is completely immersed in the water and its absorption rate is measured after 3 and 7 days, or until it reaches a point of

constant mass. The value representing the percentage of water absorbed may be a partial value if compared with the weight of the conditioned sample according to the standard, or a total value if the sample is dried beforehand in a ventilated heater.

5.4 INDIRECT METHODS

Other experiments have been carried out to establish whether certain indirect methods were effective in measuring the permeability of concrete. In particular, attempts were made to establish if there was any correlation between water permeability tests and the RCPT method, which measures the passage of chloride ions inside concrete, but the relationship between the methods is not considered sufficiently accurate.

6. WHAT CAUSES DETERIORATION?

Deterioration in concrete may be triggered by events external to the concrete or from within the concrete itself.

External events are those physical, chemical or mechanical actions triggered by the concrete's surroundings that lead to its premature deterioration:

- physical events: high temperature variations and freeze/thaw cycles;
- chemical events: the presence of gas (CO_2, O_2), sulphates in the ground or other aggressive liquids from industrial processes;
- mechanical events: abrasion and erosion generated by leaching water, the action of cyclical or unexpected loads and natural events.

Deterioration processes triggered by internal events are generally due to the composition and components of the concrete. Internal events are generally caused by poor mix design, imprecise construction features, improper application of the concrete, the use of poor quality materials or the use of mixes that do not meet design specifications.

It is clear that the deterioration of concrete will always be due to a combination of internal and external events and, therefore, the interaction between the quality of the concrete and its surroundings. Permeability and porosity, along with the intensity of actions generated by external events, will be the factors that have the most influence on the durability of the concrete.

7. HOW CAN YOU REDUCE PERMEABILITY?

In order to reduce permeability, it is important to act on the factors that influence porosity. It is important that not only the size of the pores is measured, but also their shape, concentration and distribution within the system and, above all, to understand if the capillary pores are continuous or discontinuous. The main factors are as follows:

- the characteristics of the cement paste;
- the characteristics of the aggregates;
- the quality of the aggregate/paste Interface;
- the paste/aggregate ratio.

The porosity of the cement paste, or its capillary porosity, reduces progressively with the level of hydration. Whatever the hydration rate of the cement, capillary porosity will remain even when hydration of the cement is complete and the water/cement ratio is higher than 0.38. Increasing the curing time is the only way of guaranteeing an increase in the volume of solid gel sufficient to obstruct the connections between the capillaries. Back in 1959 T.C. Powers indicated the curing time required for various water/cement ratios in order to interrupt the continuity of capillary pores.

WATER/CEMENT RATIO	CURING TIME REQUIRED
0.4	3 days
0.45	7 days
0.5	14 days
0.6	6 months
0.7	1 year
More than 0.7	Unattainable

The aggregates used to make concrete may have completely different origins and be of completely different types. Apart from being influenced by the mineralogical nature of its constituents, the physical characteristics of every type of aggregate are influenced by the structure of the rock, that is, the geometric distribution of the minerals inside the rock. Since it is the structure that determines the porosity of rocks, and since this varies according to the nature of the material, the coefficient of permeability of the rocks will vary considerably.

In general, the quality of the aggregates has little influence on the overall permeability of concrete. Since the cement paste is generally more permeable than the aggregates, whichever route a fluid takes it will tend to pass through the most porous part. Rather than the quality of the aggregates, the characteristics of the cement paste affect the concrete permeability and make it more watertight.

The area of contact between the cementitious paste and the stone aggregates is generally known as the ITZ, or Interfacial Transition Zone. This zone is particularly porous due to the presence of "bleeding" water that accumulates around the aggregates during the compacting phase. The higher presence of water, together with a higher water/cement ratio, determines the formation of higher porosity and more fragile, multi-layered crystals of lime.

The transition zone, therefore, is more exposed to micro-cracking. Stresses generated inside concrete following to drying or thermal shrinkage, or following to the application of loads, cause differential movements between the aggregates and cement paste that lead to the opening of small cracks.

The brittleness of the transition zone will have an effect on the strength and physical properties of the concrete, as well as on its porosity. Only extended damp curing cycles would reduce porosity in the transition zone and strengthen the bond between the aggregates and the cement paste.

8. REDUCING PERMEABILITY

The technologies available to reduce the permeability of concrete deal with the separate or combined use of three different approaches:

Appropriate mix design

Capillary voids are the main cause of permeability in concrete and their formation is connected to the evaporation of water which, as it rises through the cement paste, leaves inter-communicating pores along its path.

The mix design, therefore, must aim at reducing the amount of water added as much as possible in order to minimise the formation of inter-capillary channels.

Permeability tends to increase progressively when the water/cement ratio exceeds 0.55; a ratio lower than this limit, therefore, is always recommended/preferred.

The amount of cement used must be sufficient for the concrete to achieve certain mechanical requirements and to respect the exposition class, but not so much that it causes excessive shrinkage and increases the amount of cracking and potentially heat of hydration.

The quality and its ability to have a positive effect on the workability of concrete, together with a well balanced, graded blend, are the criteria to use when choosing the aggregates. Thanks to their lower specific surface area, aggregates with a high maximum diameter will have an influence on the amount of water required and on the formation of air bubbles, thereby reducing the risk.

Extended curing

Curing is the period of time after the concrete has been laid during which the surrounding temperature and level of humidity must be controlled so that the properties of the concrete develop correctly. A correct curing cycle is fundamental for both the development of the concrete's strength and to improve its characteristics, which in general means its impermeability, volumetric stability, durability and strength integrity.

Curing may be carried out by wetting the exposed surfaces, laying waterproof sheets over the concrete or applying curing agents.

The curing period required to effectively contrast the loss of moisture depends on various factors, such as the type of cement, the quantity of each ingredient in the mix, the surrounding conditions and its exposure to the surroundings. A damp curing cycle for concrete mixes with a relatively low amount of cement and for mass structures must be extended to three weeks or more. Mixes with a high amount of cement, on the other hand, will only need a few days, especially if cement that develops mechanical strength quickly is employed.

Floors and structures with exposed surfaces must be cured for at least 7 days, or until they develop at least 80% of their design strength. Since all the properties of concrete generally improve by damp curing, the curing cycle must be extended for as long as possible.

Permeability reducing admixtures

The classification proposed by the American Concrete Institute in report 212.3 divides permeability reducing admixtures into two main categories: those that improve resistance to water in concrete not subjected to hydrostatic pressure and those, on the other hand, that increase resistance to the penetration of water in concrete subjected to hydrostatic pressure. As a convention, the first type is classified as PRAN (Permeability Reducing

Admixture Nonhydrostatic) and the second type is classified as PRAH (Permeability Reducing Admixture Hydrostatic).

Admixtures in these two categories are made up of a vast range of raw materials: from water-repellent substances such as vegetable oils, derivates of long-chain fatty acids, mineral oils, waxes and bitumen emulsions for hydrophobic admixtures, right up to inert powders or chemically active powders, such as colloidal silicates, for admixtures commonly known as densifiers.

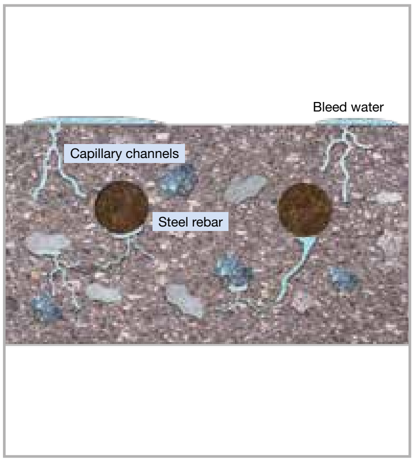
The most widely used hydrophobic admixtures are stearate-based which, by reacting with the lime in the concrete, form a layer of non-soluble calcium stearate on the walls of the pores which reduces permeability by capillary absorption.

The use of hydrophobic admixtures depends on the service conditions of the concrete. If water under pressure is not foreseen, the use of hydrophobic admixtures is more than sufficient to solve the problems connected to this phenomenon. Hydrophobic admixtures are generally aimed at the light prefabrication sector, particularly the production of blocks and tiles. Hydrophobic admixtures, however, may also be used for ready-mixed concrete, particularly when used to build walls and for exposed surfaces.

Crystallising admixtures, unlike hydrophobic admixtures, need water to make them react and produce hydrated calcium silicate and other inorganic compounds that precipitate inside the capillary pores and micro-cracks. The crystalline deposits that accumulate inside the capillary pores become an integral part of the concrete mass, reducing its porosity and improving its resistance to the action of water under pressure.

9. MAPEI SOLUTIONS

MAPEI completes its line of products for concrete by offering a series of specific admixtures to help achieve the complete impermeability of



Section of reinforced concrete: the capillary channels represent the preferential route for water (bleeding effect and the accumulation of water are reduced by adding MAPEPLAST SF)

concrete by exploiting the chemical properties of the various components used.

9.1 PORE DENSIFIERS AND FILLERS

MAPEPLAST SF

MAPEPLAST SF is a powdered admixture with pozzolan activity made from densified silica fume. The use of MAPEPLAST SF improves certain advantages in terms of performance for both wet and hardened concrete.

Effects on wet concrete

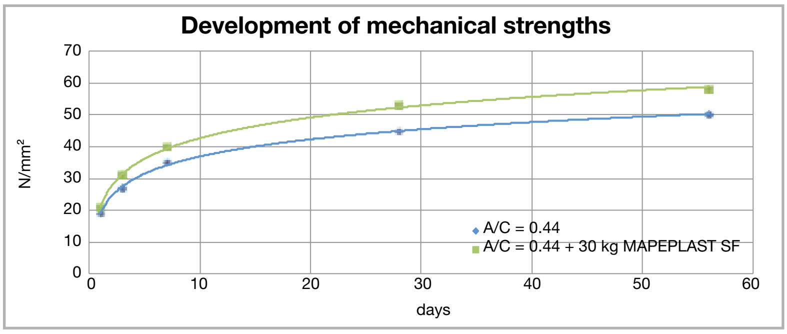
The use of silica fume, in combination with a super-plasticising admixture from the CHRONOS, DYNAMON or MAPEFLUID range, improves the cohesion and rheological properties of the mix, eliminating the risk of bleeding and considerably reducing the risk of segregation during laying operations.

Bleeding occurs when water that has been trapped under the heavier components of the mix rises through the capillary channels. Thanks to its high specific surface area silica fume allows a more compact cementitious paste to be formed, thereby reducing the formation of capillary channels and, therefore, bleeding.

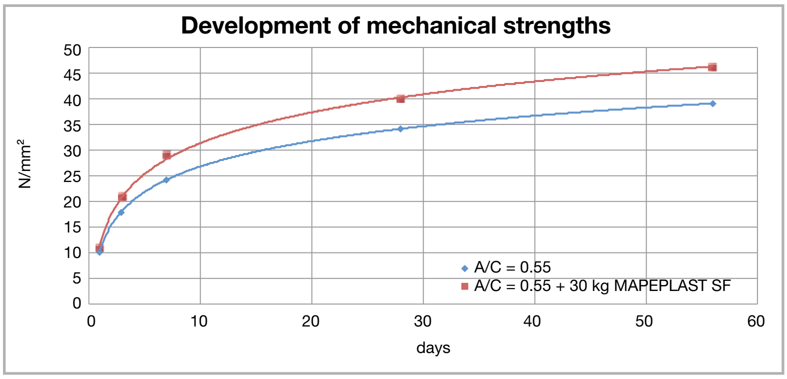
Effects on hardened concrete

There are numerous beneficial effects of MAPEPLAST SF on hardened concrete: improved mechanical properties, such as strength and modulus of elasticity, and a reduction in porosity.

Compared with a reference concrete its strength is higher whatever curing cycle is adopted, but its most beneficial effect occurs after 28 days when the pozzolanic reaction, which is slower, guarantees sufficient development of C-S-H crystals along with a subsequent increase in strength.



Graph 9.2



Graph 9.3

The micro-silicates of MAPEPLAST SF react chemically with the lime produced by the hydration of the cement thus generating calcium hydrosilicates, responsible for the hardening and strength of concrete according to the reaction:

$$\text{Silica Fume} + H_2O + Ca(OH)_2 \rightarrow \textbf{C-S-H}$$

Durability is a property often connected to the level of permeability of concrete. The mechanisms described above allow MAPEPLAST SF to increase the resistance of concrete to the ingress of aggressive agents. MAPEPLAST SF, therefore, may be used to great advantage when you require concrete that is more resistant to:

Chlorides

The presence of chlorides, coming either from sea water or de-icing salts, is seriously damaging because it activates the corrosion process in the steel reinforcement inside concrete. Silica fume is widely used in concrete for exposure classes XS and XD because, it reduces its permeability, thus making much longer for the chlorides to reach the steel reinforcement and then the durability of the concrete is extended considerably.

Sulphates

Even though sulphate attack is mainly due to the chemical nature of the cement, an appropriate mix design, together with the use of silica fume, allows the resistance of concrete to this type of deterioration to be improved.

MAPEPLAST SF reacts with the lime and reduces the total amount of calcium hydroxide available for the sulphate reaction. Furthermore the concrete porosity is progressively reduced so that the ingress into the concrete of the sulphates present in the environment is prevented and the formation of secondary ettringite takes place more hardly.

Chemical agents

Silica fume itself does not improve the resistance to chemical attack but by reducing the permeability and increasing the strength of the concrete, it slows down the process of aggression and extends the interval between maintenance operations.

Alkali-aggregate reaction

MAPEPLAST SF may also be used as a valid option to control, or at least reduce/limit, the damaging effects caused by the expansive reactions between the alkalis in the cement and certain types of reactive aggregates.

Abrasion

Increased strength and lower porosity obtained by using MAPEPLAST SF improves the conglomerate's resistance to abrasion, including when the same type of aggregate is used.

MAPEPLAST SF may be added to concrete at various rates, depending on the mechanical performance characteristics you need to achieve. Generally, a rate of between 3% and 8% of the weight of the cement guarantees excellent results.

In special cases the amount added may be increased, but testing has shown that amounts high enough to exceed an SF/CEM ratio of 0.11 does not increase its performance characteristics at the same rate and that its maximum effectiveness may be equally achieved by adding a lower amount.

MAPEPLAST SF is certified according to EN 13263 and, since it is micro-silica, according to Euronorm EN 206 an equivalent K value may be assigned.

Size of K value

The concept of a K value was introduced by European standards so that mineral additives could be used in a concrete mix in addition, or as a partial substitute, to cement to make a concrete with equivalent performance characteristics to a reference concrete. The K concept allows the water/cement ratio to be replaced with a water/effective binder ratio, in which the effective binder is made up of the cement content plus the amount of MAPEPLAST SF multiplied by a coefficient of equivalence. When this method is applied to a pre-set list of cement types, it allows the minimum requirements specified by the exposure classes to be respected without having to carry out any further procedures or durability tests.

When using MAPEPLAST SF the K concept must be applied in certain cases, such as to make sure the minimum cement content specified for exposure classes is achieved, or when used in combination with I type cement or a mix providing it has no silica fume.

When these conditions are met, MAPEPLAST SF guarantees a coefficient of equivalence of 2 with any type of concrete, except for those in exposure classes XC and XF with a water/cement ratio of > 0.45; in such cases the coefficient applied must be reduced to 1.

The K value allows the concept of concrete with equivalent performance characteristics to be introduced, i.e, a concrete that allows a variation in the minimum amount of cement required and the maximum water/cement ratio specified by the exposure class. When the characteristics of the components are known, modifications to the minimum requirements are only allowed when preliminary tests have demonstrated that a mix with mineral additives guarantees that the same results as a specified reference concrete may be achieved.

9.2 PERMEABILITY REDUCING ADMIXTURES

Crystallising admixtures

The technology of making concrete more impermeable by means of a crystallisation process has been adopted for many years and allows the permeability of concrete to be reduced by adding a special admixture to the concrete mix.

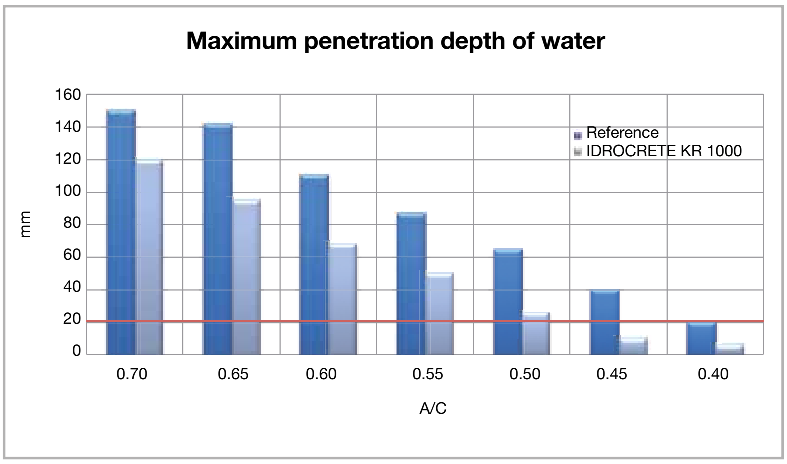
IDROCRETE KR 1000 is a MAPEI admixture with the capacity to make concrete totally impermeable by means of a progressive crystallisation process. When IDROCRETE KR 1000 comes into contact with water, it reacts to form hydrated calcium silicates and other solid precipitates that are deposited inside the capillary pores, becoming an integral part of the concrete mass and improving its resistance to the permeability of water.

Apart from triggering the process through which insoluble crystals are formed, IDROCRETE KR 1000 also provides the nucleation centres required for their growth. The micrometric nuclei represent the point of origin of carbonate and non-soluble hydrosilicate crystals. The effect of these processes is to increase the level of impermeability of concrete.

Concrete made using different water/cement ratios and cured for 28 days in standard conditions behave differently to the penetration of water when subjected to pressure, as shown in figures 9.2, 9.3 and 9.4.

European standard EN 12390-8, which describes the test method, specifies measuring the maximum penetration depth of water inside a test sample after subjecting it to water at a predetermined pressure. Graph 9.5 shows that, as the water/cement ratio reduces, concrete's resistance to the passage of water increases.

The values of resistance to the passage of water increase quite sharply when the crystallising admixture IDROCRETE KR 1000 is added to the mix at a rate of 2% of the weight of cement. The tests carried out show that adding the crystallising admixture is always beneficial in terms of reducing the penetration of water and that it is increasingly beneficial as the water/cement ratio is reduced. It is worth highlighting, however, that there is a limit in the water/cement ratio, below which the structure of the concrete is so closed and compact that any benefit from the crystallising admixture is almost negligible. MAPEI considers this water/cement ratio to be < 0.4 where the maximum penetration of water, including in concrete without the admixture, is lower than the limit where it is considered to be impermeable (20 mm).



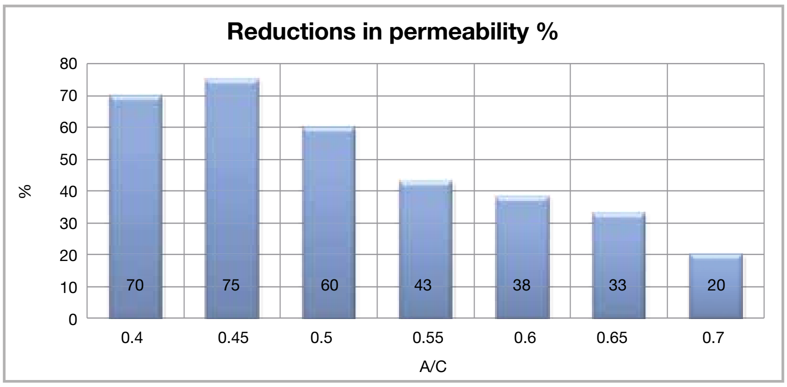
Graph 9.5

Fig. 9.2 - Concrete with a water/cement ratio of 0.6

Fig. 9.3 - Concrete with a water/cement ratio of 0.45

Fig. 9.4 - Concrete with a water/cement ratio of 0.4

Graph 9.6 shows the percentage rate of increase in impermeability as the water/cement ratio is reduced. Using IDROCRETE KR 1000 is most beneficial when the water/cement ratio of concrete is between 0.45 and 0.55. For higher water/cement ratios, and when there is not an adequate, extended curing cycle, there is still a reduction in permeability, but not sufficient to prevent the ingress of water under pressure. When the water/cement ratio is very low, on the other hand, the use of a crystallising admixture will improve its inherent consolidated impermeability.



Graph 9.6

IDROCRETE KR 1000 will always improve the impermeability of concrete, but bear in mind at all times that it cannot be used to compensate for concrete with a poor mix design or for concrete that has been laid badly. Therefore, to get the best results when using IDROCRETE KR 1000, the concrete mix must be designed correctly by following best practice guidelines and the designer's specifications.

Depending on specific project requirements, IDROCRETE KR 1000 is added at a rate of between 1% and 3% of the weight of the cementitious binder. The product is supplied as a ready-mixed powder and is added to the concrete preferably during the mixing phase. It may also be added on site, but in such cases it is recommended to extend the mixing time sufficiently to make sure the product is completely blended in the mix.

The use of IDROCRETE KR 1000 is recommended for making concrete structures that will be used to contain water such as dams, tunnels, foundations, quays and docks, car-parks, liquid-containment systems, bridges, drains and any other type of structure that requires long-lasting impermeability. Release tests carried out on concrete incorporating IDROCRETE KR 1000 have not indicated the release of harmful levels of hazardous substances and, therefore, the product may be used for structures in contact with drinking water.

Hydrophobic admixtures

Hydrophobic admixtures are salt-based liquid additives that are used to increase concrete's resistance to rising damp.

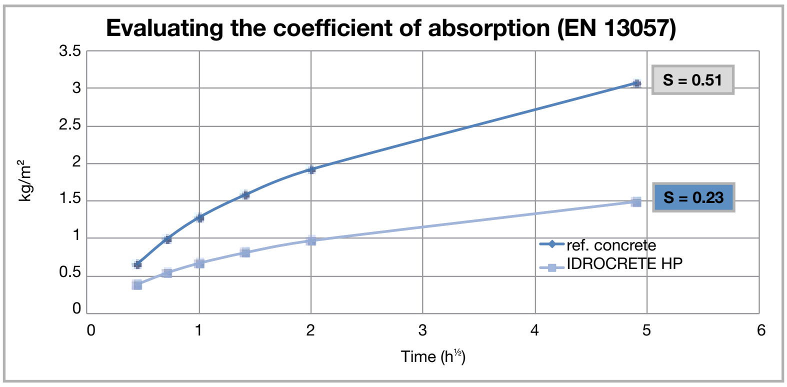
IDROCRETE DM and IDROCRETE S are MAPEI admixtures specifically formulated to protect the surface of concrete from water absorption. IDROCRETE DM and IDROCRETE S are added in mass to concrete to form a thin hydrophobic film around the pores. This technology is not used to fill the capillary pores, but rather to create a water-repellent layer that removes particles of water when they collect on the surface of concrete and form a "droplet effect" on horizontal surfaces.

IDROCRETE admixtures are added at a rate of between 0.2% and 0.6% of the weight of the cement for the more concentrated DM version and at a rate of up to 1.2% for the more diluted S version.

Their hydrophobic effect may allow the ingress of water, including at low pressures, but its beneficial effect on concrete may be quantified by measuring the coefficient of absorption described in the EN 13057 test method.

IDROCRETE HP is the forefather of a new generation of high-efficiency hydrophobic admixtures. 1.5% of IDROCRETE HP drastically reduces the capillary absorption value for any type of concrete. The coefficient of absorption, which represents the slope of the graph that illustrates the amount of water absorbed over time, must have as low a value as possible.

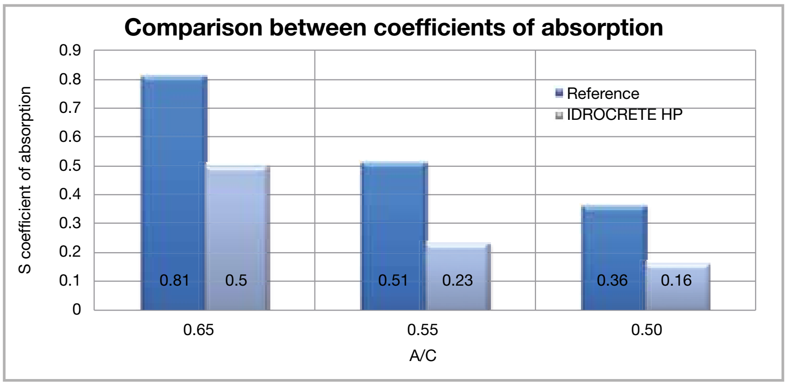
Graph 9.7 shows how the coefficient of absorption of concrete treated with IDROCRETE HP is considerably lower compared with the same concrete without a hydrophobic admixture. A low coefficient of absorption reflects the higher resistance of concrete exposed to critical surroundings for a long period of time.



Graph 9.7

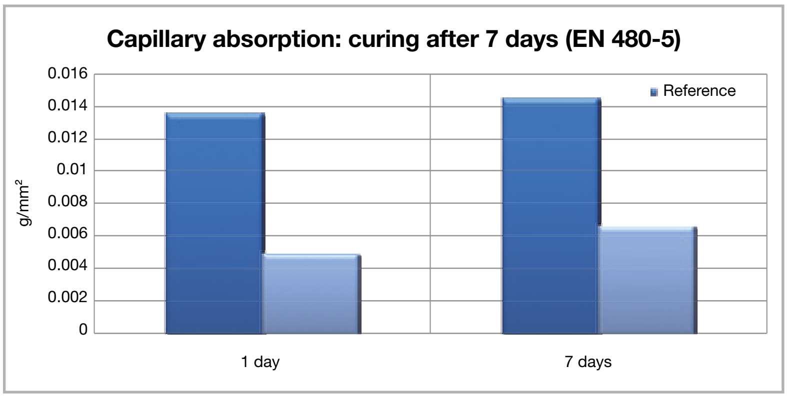
The coefficient of absorption reduces progressively as the water/cement ratio reduces, since the lower number of voids reduces its capacity for capillary lift. Graph 9.8 shows the values for S measured during laboratory tests.

Adding IDROCRETE HP improves concrete's capacity to not absorb water by up to 50%, or even more; the benefits provided by the hydrophobic admixture increases progressively as the water/cement ratio is reduced.

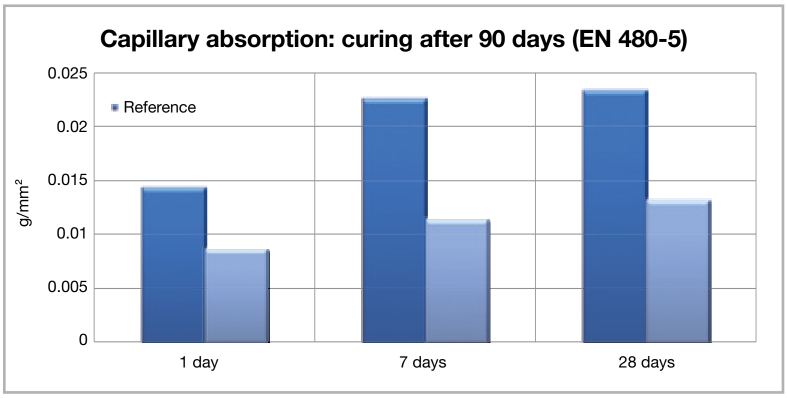


Graph 9.8

IDROCRETE HP also meets the specific requirements of admixtures resistant to water. EN 480-5, which describes the measurement of capillary absorption on test samples of mortar, contemplates carrying out two series of evaluations to measure absorption: the first one after 7 days of curing and the second one after 90 days. The results obtained show that, by adding IDROCRETE HP at a rate of 1.5% of the weight of the cement, absorption of the test mix was 50% lower compared with a control mix after 7 days of curing and 60% lower than the control mix after 90 days of curing.



Graph 9.9



Graph 9.10

The use of IDROCRETE HP, IDROCRETE DM and IDROCRETE S may be highly beneficial to all structures exposed to damp or cyclical wet/dry surroundings, to persistent damp and to sprays of water and improves the resistance of concrete exposed to the action of de-icing salts. IDROCRETE HP, IDROCRETE DM and IDROCRETE S are often used for architectural concrete, pre-fabricated panels, blocks and all those elements and members subjected to the action of water in non-hydrostatic conditions.

Technical specifications for IDROCRETE KR 1000

Making concrete impermeable by crystallising the pores and capillary micro-cracks by adding a crystallising-effect powdered admixture to the concrete mix (such as IDROCRETE KR 1000 by Mapei S.p.A.). The mix must be designed to include the use of quality, non-reactive, assorted aggregates, cement (preferably type I and type II Portland cement), a water/cement ratio of less than 0.5 and an acrylic-based super-plasticiser (such as DYNAMON by Mapei S.p.A.).

When the powdered crystallising admixture is added to the concrete mix, it reacts with the moisture and water contained in the conglomerate to form crystals of calcium silicate which, as they grow, block the capillary pores and improve the impermeability of the concrete.

The crystallising admixture is added into the mixing unit at a rate of 1-3% of the weight of the binder along with the aggregates, cement, water and plasticising admixture and then mixed until it is completely blended.

The concrete obtained with this method will have the following physical and mechanical characteristics:

- density (kg/m^3): > 2300;
- strength class after 28 days (MPa): > C30/37;
- maximum water penetration (UNI EN 12390-8): < 30 mm;
- maximum water penetration (DIN 1048): < 30;
- Darcy coefficient of permeability: < 1.10^{-13} m/1.

The pouring, compacting and finishing methods adopted for concrete admixed with IDROCRETE KR 1000 are the same as those adopted for traditional concrete. The consistency and cohesion of the mix must be such that the concrete may be applied without bleeding or segregation taking place.

Product tests carried out on IDROCRETE KR 1000 by independent laboratories are currently available in the following countries upon request: Austria, Italia, Malaysia, Poland and USA.

Technical specifications for IDROCRETE HP

Making concrete with water-repellent properties. Concrete treated with a hydrophobic admixture (such as IDROCRETE HP) reduces water absorption by up to 50% compared with a control concrete when immersed in water. The impermeabilising effect only occurs in concrete that is not subjected to hydrostatic pressure; the presence of water under pressure does not prevent water penetrating into the treated concrete. Concrete admixed with IDROCRETE HP inhibits the passage of water between the capillary pores in the hardened cement paste and improves concrete's resistance to efflorescence and the passage of water from the outside to the inside, and vice versa. To obtain a better impermeabilising effect, concrete admixed with IDROCRETE HP must also contain a water-reducing admixture (such as DYNAMON, MAPEFLUID or MAPEPLAST by Mapei S.p.A.) to reduce its water/cement ratio. The super-plasticising admixture must be used in combination, but not together, with the mass hydrophobic admixture IDROCRETE HP.

When the mass impermeabilising admixture has hardened in the concrete mix, it reacts with the calcium hydroxide to form a thin, hydrophobic layer on the surface of the pores and reduces permeability through capillary absorption.

The hydrophobic impermeabilising admixture is added at a rate of 0.3% to 0.6% of the weight of the binder into the mixing plant along with the aggregates, cement, water and super-plasticising admixture and then mixed until it is completely blended.

The pouring, compacting and finishing methods adopted for concrete admixed with IDOCRETE HP are the same as those adopted for traditional concrete. The consistency and cohesion of the mix must be such that the concrete may be applied without bleeding or segregation taking place.

Notes:

Technical Manual

CONCRETE FOR WATERTIGHT STRUCTURES

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