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TECHNOLOGICKÉ POSTUPY ZAJIŠŤUJÍCÍ KVALITU BETONOVÝCH KONSTRUKCÍ A ARCHITEKTONICKÝ DESIGN

TECHNOLOGICAL PROCEDURES ENSURING HIGH QUALITY OF CONCRETE CONSTRUCTIONS AND ARCHITECTURAL DESIGN OF STRUCTURES

Summary

Under the term of durability of concrete is, in the first place, understood the service life of the whole building work. This work is affected by the degree of corrosion of concrete, namely of reinforcement. Degradation of concrete is a gradual and permanent erosion of the basic properties of concrete leading to its disintegration. High compressive strength by itself does not guarantee durability. The study into degradation and durability of concrete and building materials and their knowledge provides a fundamental basis for the assessment of constructions. The causes of failure of concrete constructions may be of different types. The greatest is the damage due to corrosion caused by improper technology and non-observance of technological regulations on the site (ca 50 %), the damage due to insufficient reinforcement cover (ca 20 %), the damage caused by an inappropriate design or underestimation of the corrosive environment in which the construction is to fulfil its function (ca 20 %) and concrete permeability (ca 10 %). Here, the quality of the surface zone (layer) of concrete is of utmost importance. This outermost layer – a zone with a thickness of ca 50 mm from the surface of the concrete construction – contributes, in a decisive way, to the service life of the concrete construction. The above-mentioned facts explicitly imply that the only ways leading to the formation of a compact surface layer, which may subsequently fulfil its long-term protective function of concrete reinforcement, are the following: a suitable composition of the concrete mix and adequate placement technology. One of new technologies enhancing formation of a high-quality surface of the concrete construction is application of absorbent textile fibres in formwork. These absorbent inserts allow drainage of excess water from the surface layer thus reducing the w/c ratio in this layer, eliminating the number of air bubbles dragged onto the concrete's surface and further limiting the quantities of fine components of cement milk in this layer. The formwork fitted with absorbent fibre inserts will allow formation of a surface layer that is practically without pores and bubbles whose strength, as compared to classic non-absobent formwork, is higher.

During their operation, concrete constructions are exposed to a number of negative effects of which the most significant are the following: the effects of aggressive gases from the air, the effects of aggressive water and salts, the effects of live load, volume changes due to variable temperature, cumulated frost and internal moisture effects.

They are, in particular, due to climatic effects (temperature fluctuations with the presence of water), but also the effects of high temperature, namely fire. The effects of running water and groundwater on concrete must also be mentioned. All these effects make the service life of concrete shorter.

Souhrn

Pod pojmem trvanlivost betonu se v prvé řadě rozumí životnost celého stavebního díla. Toto dílo je ovlivňováno mírou koroze betonu, zejména výztuže. Degradace betonu je postupné a trvalé narušování základních vlastností betonu, vedoucí k jeho rozpadu. Vysoká pevnost v tlaku sama o sobě trvanlivost nezajišťuje. Studium degradace a trvanlivosti betonu a stavebních materiálů a jejich znalost podává základní podklad pro hodnocení konstrukce. Příčiny poruch betonových konstrukcí mohou být různé. Největší jsou škody způsobené korozí způsobenou špatnou technologií a špatnou technologickou kázní na stavbě (cca 50 %), škody způsobené nedostatečným krytím výztuže (cca 20 %), škody způsobené špatným návrhem resp. podceněním korozního prostředí, ve které má konstrukce plnit svoji funkci (cca 20 %) a propustností betonu (cca 10 %). Zde právě vystupuje do popředí kvalita povrchové zóny (vrstvy) betonu. Tato vrstva – zóna o tloušťce cca 50 mm od povrchu betonové konstrukce se rozhodujícím způsobem podílí na životnosti betonové konstrukce. Z uvedeného jednoznačně vyplývá, že jedině vhodným složením betonové směsi a vhodnou technologií ukládání jsou cesty vedoucí k vytváření hutné povrchové vrstvy, která pak může dlouhodobě plnit svoji roli ochrany betonové konstrukce.

Jednou z nových technologií pro vytváření kvalitního povrchu betonové konstrukce je použití savých tkanin do bednění. Tyto savé vložky umožňují odsátí přebytečné vody z povrchové vrstvy, a tím zajistí snížení vodního součinitele v této vrstvě, omezují množství zavlečených vzduchových bublin na povrchu betonu a dále snižují množství jemných složek cementového mléka v této vrstvě. Savou tkaninou opatřené bednění umožní vytvořit povrchovou vrstvu, která je téměř bez pórů a bublinek a její pevnost je vyšší v porovnání s klasickým nenasákavým bedněním.

Betonové konstrukce jsou během provozu vystaveny působení řady negativních vlivů, z nichž k nejdůležitějším patří: působení agresivních plynů z ovzduší, vliv agresivních vod a solí, vliv nahodilého zatížení, objemové změny od proměnné teploty, účinky kumulovaného působení mrazu a vnitřní vlhkosti.

Jedná se především o povětrnostní vlivy (střídání teplot za přítomnosti vody), ale také vysoké teploty, především účinky požáru. Vliv má i působení tekoucí a spodní vody na beton. Všechny tyto vlivy zkracují životnost betonu.

Klíčová slova: bednění, beton, betonárka, beton vyráběný v centrální betonárně, estetika, trvanlivost betonu, konstrukce, koroze, návrh, oheň, pohledový beton, samozhutnitelný beton, rozptýlená výztuž, technologie, vnější pasivní ochrana, vláknobeton

Keywords: concrete, concrete mixing plant, central-mix concrete, aesthetics, durability of concrete, construction, design, architectural concrete, self-compacting concrete, fibre-reinforced concrete, technology

ISBN

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1. Introduction

- The quality of the surface zone (layer) of concrete contributes, in a decisive way, to its permeability for degrading liquid and gaseous media acting on the concrete construction during the whole of its life cycle. [1]
- A suitable composition of the concrete mix and finishing technology of the surface layer, therefore, must be given special care. One of the latest technologies applied consists is using absorbent textile fabrics (inserts) in formwork. These absorbent inserts allow drainage of excess water from the surface layer thus reducing the water-cement ratio in this layer, eliminate the number of water bubbles dragged onto the concrete surface, and also reduce the amount of fine fractions of cement slurry in this layer. The combination with a high water-cement ratio and successive drying up, in particular, produces shrinkage cracks and colour stains, i.e. visual surface non-homogeneousness of the surface of untreated concrete with no surfacing - fair-face concrete (Fig. 1). The surface layer treated in this way contains hardly any pores and bubbles, and its strength is higher as compared to the method using classic non-absorbent formwork. [4]

Fig. 1 Fair-face concrete surface

2. Durability of concrete

The durability of concrete is one of the most important properties in terms of usability of structural concrete, i.e. its capability of resisting the effects of the environments it is exposed to. The degradation of concrete is a gradual and permanent deterioration of the basic properties of concrete leading to its disintegration. High tensile strength on its own does not guarantee durability. The study into the degradation processes and durability of concrete and building materials and their knowledge provides a fundamental background for the evaluation of constructions.

During their operation, concrete constructions are exposed to a number of negative effects, among which the most significant ones are the following: [6]

- the effects of aggressive gases from the atmosphere
- the effects of aggressive water and salts
- the effects of live load
- volume changes due to temperature fluctuations
- the effects of cumulated frost and inborn moisture activity

The above-mentioned effects are caused by mainly atmospheric (periodic temperature changes with the presence of water) and high temperature action (e.g. fire). The effects of running water and groundwater on concrete must also be taken into account. All these effects make the service life of concrete shorter.

2.1 The effects of atmospheric action

Concrete is adversely affected by repeated freezing and de-freezing of water soaked into concrete. Water changes into ice, increasing its volume by approximately 10 %. As a result of this expansion, tensile stresses arise in the concrete structure impairing the fabric of concrete. A way towards minimizing this effect is aeration by means of air-entraining agents, which will create a defined number of microscopic pores (4 to 7 % of spherical enclosed pores 10 – 300 μm in size) to reduce this expansion. [18]

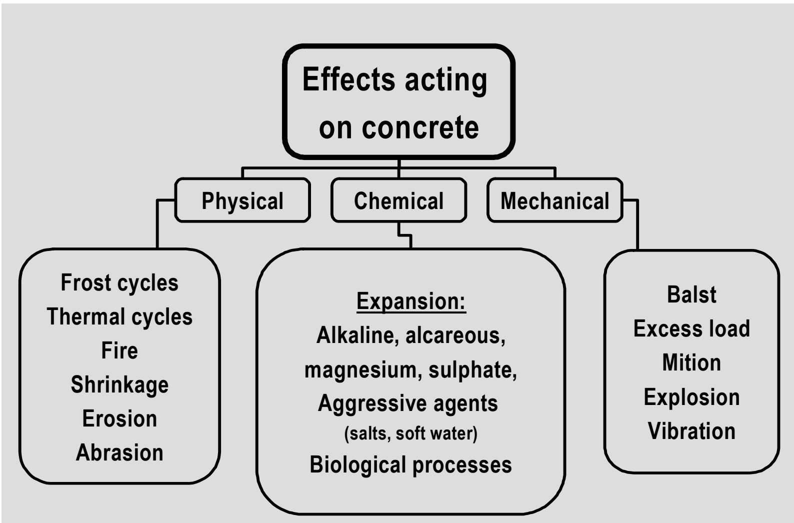


Fig.2 Effectsacting on concrete constructions

2.2 The effects of chemical substances

Chemical substances act on concrete constructions in the form of liquids and gases (Fig. 2).

The intensity of degradation processes affecting concrete constructions depends on the type of chemical substance (salts, acids, gases), its amounts and concentration, exposure time and concrete composition.

2.3 Factors affecting durability of concrete

The durability of concrete is a complex phenomenon affected by the following: [2]

- **the properties of concrete components**
- **the design of concrete formula**
- **concrete production**
- **the properties of the environment acting on concrete during its service life**

3. Production of concrete

A way towards a high-quality concrete construction starts by designing the right concrete formula, continues through ensuring volume homogeneity of fresh concrete thus preventing its separation (segregation, bleeding etc.) and is completed by suitable placement of concrete into the construction, including its appropriate treatment (Fig. 3). The initial basic criterion for concrete production consists in providing an efficient mixing device; this criterion is presently fulfilled by an innovation in the technology of batching plants – a conic mixer (Fig. 4). [15] This mixer guarantees perfect homogenization of concrete mixes, both of small quantities and of highly liquid concrete. [5], [16]

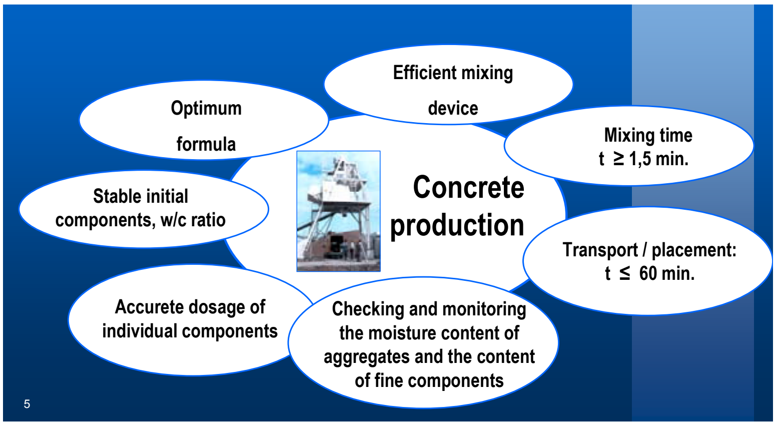


Fig. 3 Optimization of concrete production process

Fig. 4 Conic mixer

The main features of this procedure are the following: [7], [19], [22]

- for one construction use cement of the same strength class, the same mixing properties (CEM I or CEM II/A) coming from the same cement plant
- use aggregates from the same localities, namely aggregates with a grain size of up to 4 mm, of the same grading and grain size composition

- keep to accurate dosage of concrete components (main components ± 3 % of admixtures ± 5 % in keeping with ČSN EN 206-1 standard)
- in hardening regime - strictly follow the rules of concrete treatment
- maintain the same water-cement ratio – the same consistency of fresh concrete (recommended values: consistency S2, cone slump test 90 to 120 mm or spill F2 = ca 500 mm on tapping)
- proportion of fine fraction up to 1 mm – a higher proportion produces smooth concrete surface, increases the amount of mixing water needed and fresh concrete cohesion
- admixtures (plasticizers, air-entraining agents) tested within tests aimed at proving side effects (chemical reactions affecting colour changes on the surface of concrete)
- additives – up to 200 μm in amounts of min. 30 % of the weight of cement (fly ash, limestone, slag, stone dust)

Requirements for separation agents: [17]

- easy and clear separation of concrete from formwork
- optically faultless surfaces (compactness of surface layer, homogeneity in shade, elimination of pore appearance)
- the separator must not react with formwork material
- when it rains – inefficient, sun radiation – higher consumption, frost – emulsion cracking

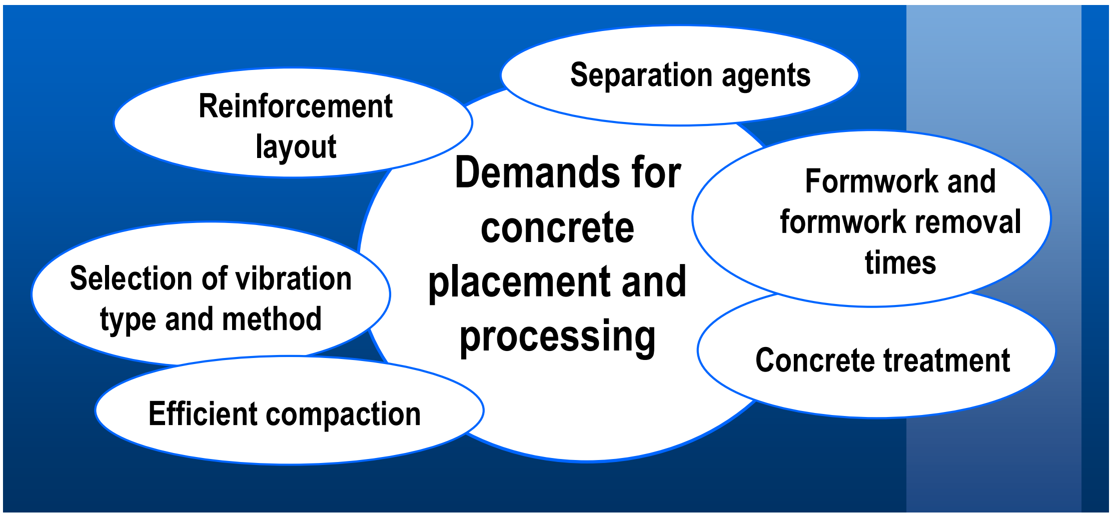


Fig. 5 Factors affecting the quality of hardened concrete in its placement and processing stage (note: consequences of faults shown in Fig. 6)

4. Principles of fault appearance

Primary factors affect the appearance of microcracks during the setting, hardening and ageing of concrete (Fig. 5). They include imperfect compaction or, on the contrary, overcompaction of fresh concrete, the effects related to thermal expansion of concrete and its components and namely the shrinkage of concrete (Fig. 6). [22]

Secondary factors on their own rarely initiate the appearance of microcracks and successive crack development, but support the development of microcracks arising due to the effects of primary factors. They include various types of concrete corrosion, in addition to the frequently discussed alkali-siliceous reaction also sulphate corrosion, frost and salt effects etc. The issue of great concern these days is, in particular, the alkali-siliceous reaction, which, however, will also develop at a more prominent pace in cracked concrete as water may migrate to arising gels, and thanks to microcracks concrete is more brittle. Another problem is sulphate corrosion (note: this is not due to sulphates from the surrounding environment but inborn sulphates).

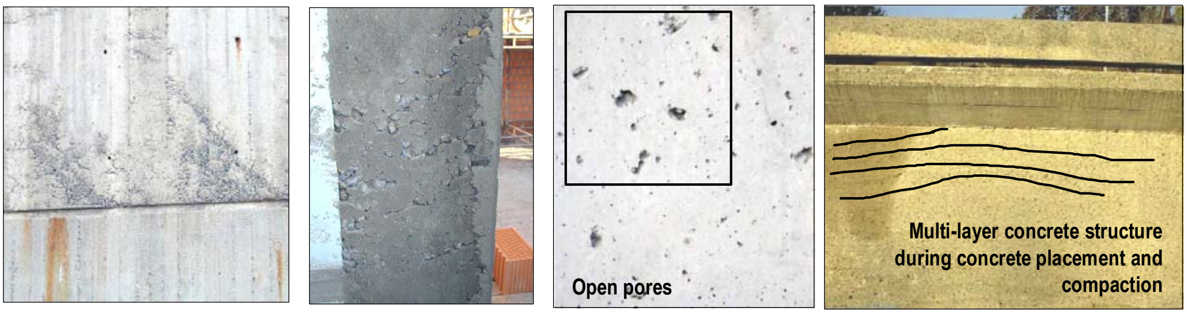


Fig. 6 Faults arising in production, placement and compaction of concrete

5. Concretors´ triangle (Heat – Shrinkage – Strength)

5.1.Heat (hydration)

The growth in strength is inevitably connected with the development of hydration heat and concrete shrinkage (so-called concretors´ Bermuda triangle – quoted in Aïtcin). Strength is our target to which we are ready to sacrifice almost all, but the other two apices must not be forgotten either: **shrinkage** and **hydration heat**.

5.2.Shrinkage

Autogenous shrinkage consists in macroscopic volume changes affected neither by water exchange between concrete and its surrounding environment nor by corrosive processes. Part of cement hydration is chemical shrinkage, which occurs invariably as the volume of cement and water is greater than the volume of hydration products. During hydration, another phenomenon – self-drying - occurs. In fresh concrete, water is gradually consumed for cement hydration.

The water for cement hydration is drawn from larger capillaries. Shrinkage occurs, which is of the same type as shrinkage due to drying on the concrete surface. But concrete, as it is, dries from the inside, and its drying is due to cement hydration, i.e. self-drying is the case. The use of superplasticisers allows reduction of the water-cement ratio below a limit when self-drying starts to be more widely applied. It is known that for hydration of 100 kg of cement, about 23 kg (l) of water is needed. [20] This results from chemical reactions. The fact not considered here, however, is that products with a porous structure arise during this reaction. The pores must be also filled up with water. As a result, the total water-cement ratio required w = 0.38. As soon as the water-cement ratio drops below this value, shrinkage due to self-drying and thus also autogenous shrinkage start to rise significantly. This is also supported by another aspect, which is a very compact consistency of concretes with a low water-cement ratio. [23] Treating water can penetrate inside only very slowly.

If it is applied later, after the concrete has hardened, the surface layers shrink and the capillaries are closed, it cannot penetrate into the cross section core and cannot prevent shrinkage either. Shrinkage of various parts of the cross section showing different intensity, at the same time, produces stresses, which may contribute to the appearance of microcracks. [24]

For this reason, concrete must be treated immediately after compaction, first by preventing the evaporation of mixing water, say only by covering concrete with plastic sheeting, but later the water consumed due to hydration must be replaced. Only after intense hydration is over, concrete may be covered again. Approximately five hours after spraying, the construction must be covered with canvas. The surface cannot be treated with water as this would result in a temperature shock (Fig. 7).

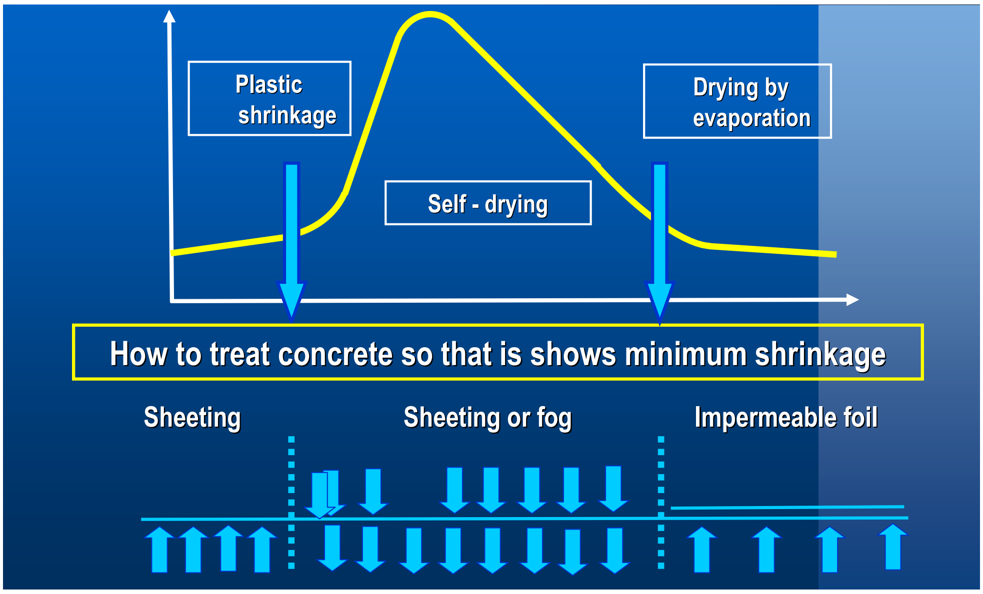


Fig. 7 Concrete treatment cycle after placement into construction

6. The effect of surface treatment of concrete (on its permeability for air)

The quality of the surface layer of concrete contributes in a decisive way to its permeability for degrading liquid and gaseous media in the vicinity of the construction. The composition and finishing technology of the surface layer is presently the subject of special attention. One of the latest technologies applied consists is using textile fabrics or mats fixed directly to formwork. These special textiles allow drainage of excess water from the surface layer thus reducing the water-cement ratio and eliminating the number of water bubbles on the concrete surface. The surface layer treated in this way contains hardly any pores and bubbles, and its strength is higher. [25]

6.1 Absorbent underlay in formwork

The boundary zone of concrete in contact with formwork creates a smooth surface – by increasing the amount of cement (at w/c = 0.6 up to 1.100 kg/m^3 against c = 300 kg/m^3 in the construction core) in comparison to the standard dosage in the concrete construction core.

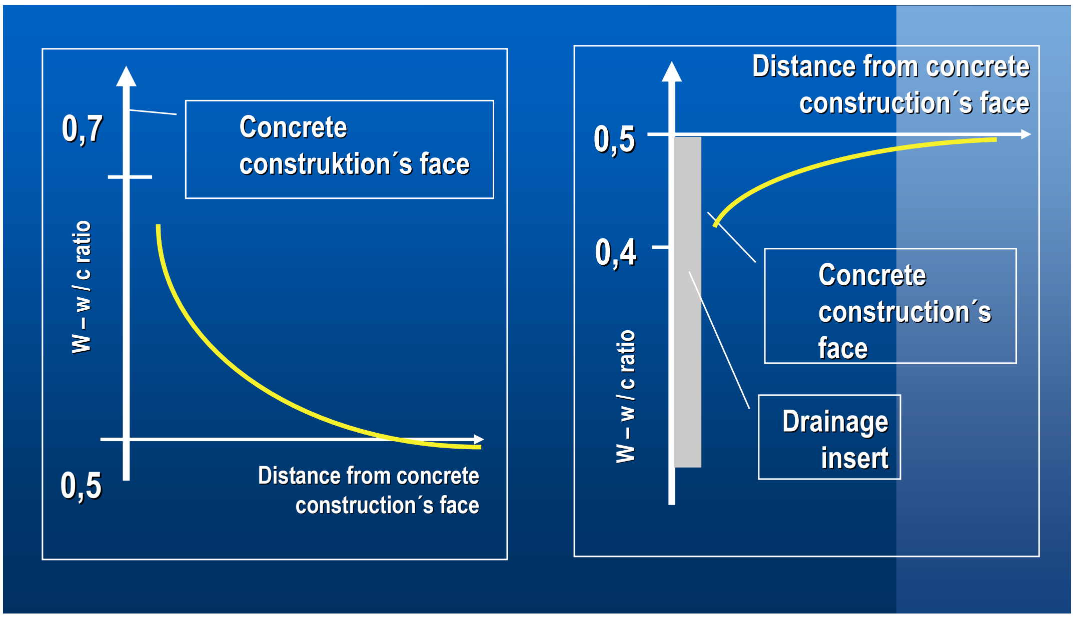
- the zone has a depth of about 1/2 to 2/3 of the dimension of the maximum aggregate grain (i.e. 8 -11 mm for a max. grain of 16 mm)
- these zones show higher shrinkage – the consequence: cracks and local differences in the shade of concrete surface

6.2 The surface layer

The surface layer of the concrete construction (30 to 50 mm) is an important agent affecting its service life. This layer serves as a path for liquid and gaseous substances penetrating into the core of concrete. These substances mostly produce a slightly acid reaction lowering the pH of concrete. Degrading substances pass through the surface layer structure thanks to its permeability or possibly due to diffusion phenomena. This very layer tends to be degraded by microcracks. The surface of concrete is also affected by formwork, the quality of its surface, the formwork removal jig, the technology of concrete placement and compaction. The formwork is mostly water-impermeable, with excess water and enclosed air pressing onto the formwork during compaction, which results in gravel pockets and air voids arising on the interface, and in porous structure of the concrete surface.

Excess water in concrete, which is added to it in order to improve the workability of concrete, is not completely consumed during the hydration process and is evaporated. The resulting porous structure of concrete serves as a path for undesirable liquids and gases entering into the construction. The surface layer of the concrete construction shows, as a rule, poorer quality than its core part, being significantly more damaged. Penetration of aggressive substances may be substantially limited by increasing the compactness of the cover layer of concrete.

Enhancement of this layer by means of raising its compactness preserving its perfect interaction with the construction core consists in applying an absorbent material for formwork and, at the same time, also drainage or coating textile fabrics, which are fixed to the formwork forming a separation layer.
When fresh concrete is placed into formwork, due to of vibration energy air and water are pushed away towards the formwork jacket. Fine pores in the coating sheets allow the seepage of excess water from the concrete surface through the coating. Water seepage encourages the movement of cement particles, which cannot penetrate through pores, and so they concentrate on the coating inside and form a compact cover layer. The result is high concentration of the strongest particles and cement and reduced porosity of the surface layer. Excess water is drained lowering the water/cement ratio value in the surface layer and, on the contrary, the water drained is supplied back into the core to improve the hydration processes (Fig 8).
On the basis of measurement results we may state that the number of visible surface pores is reduced; this presumption may be also applicable for the layer



a) b)

Fig. 8a) w/c ratio time pattern in the surface layer of concrete construction using standard formwork where w/c values towards concrete surface increase

Fig. 8b) w/c ratio time pattern using drainage insert where, on the contrary, excess wate is drained from concrete surface thus reducing w/c ratio in this surface layer with simultaneous saturation with cement, which considerably improves the surface layer of up to20 mm in thickness

situated 20 – 30 mm below the surface of concrete. By comparing water seepage through concrete without and with the use of a separation layer, it was found that the concrete treated in this way shows water seepage to a depth of over 70 mm, while for the concrete with an applied separation layer applied the seepage was ca 15 mm. The above-mentioned makes it clear that the concrete with a separation layer significantly affects the critical zone (layer) of concrete, which influences the durability of concrete.

6.3 Hydration heat

Immediately after concrete is mixed, not much happens at first: cement does not seem to harden, hydration heat is not produced. This state is soon followed by a reaction period when intensive production of hydration heat occurs and thanks to this concrete is heated. In this way its volume goes up. This expansion acts against hydration shrinkage so that the volume does not change much in fact.

A different situation arises after the maximum temperature is reached, during cooling. Concrete shrinks both due to hydration and due to cooling. This state is the most critical for the appearance of microcracks, and for this reason as well concrete needs to be very carefully treated. Otherwise, its shrinkage exceeds a reasonable limit, and a number of microcracks arise. This negative phenomenon may be made still worse e.g. by large aggregate grains. For aggregates will not shrink, and the shrinking paste around large grains will invariably crack.

An optimum solution for reducing or eliminating the effect of temperature consists in applying two procedures:

1. The design of the construction geometry, and namely the construction technology (selection of working areas, concreting method, placement and processing of fresh concrete, suitable treatment of the construction) aimed at eliminating temperature gradients with a decisive effect on crack development.
2. The design of a suitable composition of concrete (type of binder in terms of hydration heat development, binder quantity, w, suitable admixtures and additives with regard to changes in hydration kinetics etc.)

For the construction of massive in-situ cast constructions, cements with low specific hydration heat must be selected, admixtures with liquefying effects on the concrete mix and retarding its setting must be used. The number of construction joints in the construction should be minimized. Before the start of concreting, a thorough technological and organisational preparation, including sufficient spare capacities, is necessary. While concreting the bottom layers, cleaning of the reinforcement in the upper, not yet concreted part of the construction is necessary.

6.4 The effects of negative temperatures

During the winter season, depending on the depth of frozen ground, active protection and in the case of heavy frosts intensive passive protection is necessary during concreting, or, if allowed by site circumstances, it is better not to concrete at all (Fig. 9). [8], [9], [12]

Active protection procedures: [10]

- consist in raising the cement content, using cements of higher strength class and with faster hydration heat development, reducing the water/cement ratio by using admixtures (plasticisers) and potentially an admixture accelerating concrete hardening
- heating of fresh concrete in the concrete batching plant, in particular by heating the components of fresh concrete before their mixing or by injecting vapour during the mixing time or heating mixed fresh concrete in the batch box before placing it into formwork.

Passive protection procedures: [2]

- fitting the formwork with thermal insulation which will reduce the velocity of fresh concrete cooling
- heating concrete in formwork, which is performed either from the inside of the construction by direct or indirect methods or from the outside of the construction.

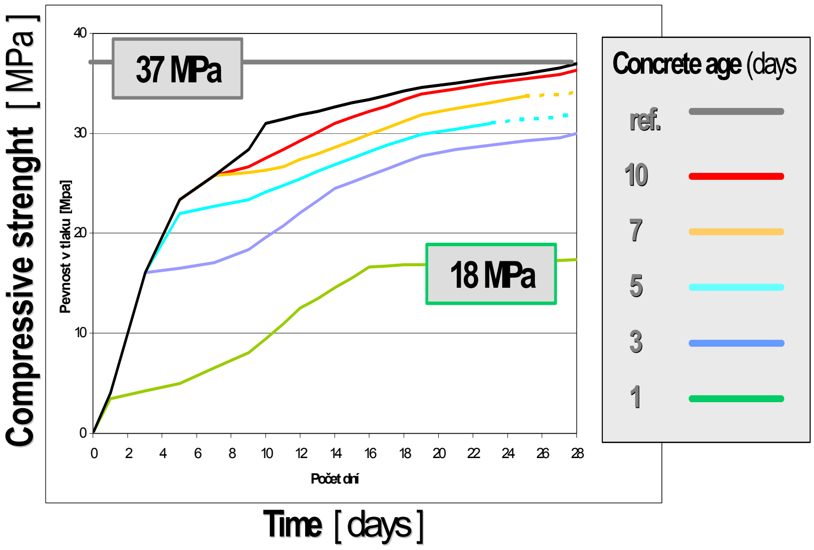


Fig. 9 Compressive strength evolution in concrete in relation to its age from production to placement when it is freezing (1, 3, 5, 7, 10 days and reference sample, which aged under optimum conditions, i.e. at +20 °C). The concrete placed in temperatures below freezing after 24 hours, reached 50% of the reference sample's strength after 28 days from production.

Internal heating:

1) In direct heating, concrete is connected into a circuit as a conductor, and thus it is heated
2) In indirect heating, an insulated heating wire is laid in the formwork before concreting

External heating :

1) By means of infrared radiation, or direct heating using steam or hot air
2) Indirect heating may be applied through formwork or by means of heating mattresses. For these purposes, the formwork must be fitted with electric heating wires on the outside or by conductive rubber strips covered by aluminium sheeting to prevent radiation into the external environment. The latest technical solution is formwork with an electrically conductive surface. [2]

If the concrete construction was exposed to frost effects during the critical time of concrete setting and hardening, ice formation (note: by transition to solid consistency the volume of water grows by 9%) in the structure of concrete would produce hydraulic pressure, and if concrete did not possess sufficient strength, due to tensile stresses local failures in the concrete structure would arise. This would result in reduced strength of concrete (Fig. 9), reduced cohesion of cement stone with the aggregate surface and with steel reinforcement. That is why in its early hardening stage concrete must be protected from the effects of negative temperatures until the time when it reaches the minimum compressive strength, i.e. 5,0 MPa, but also the strength within the limits of 2,5 to 15,0 MPa. [7]

6.5 The effect of dispersed reinforcement

Dispersed reinforcement is a system of random spatial distribution of fibres within the concrete construction. Steel fibres are made of steel plate or wire with a specification for concrete reinforcement. Polypropylene fibres (hereafter referred to as PP) are made of highly pure polypropylene with a specification as admixture into concrete affecting and improving the qualitative parameters of concrete.

As compared to classic reinforcement, the use of steel fibres in concrete slabs increases their rigidity, toughness and strength, eliminating in a significant way, the appearance of shrinkage cracks on its surface.

In the case of polypropylene fibres, there is no further increase in strength, but a significant elimination of microcracks due to shrinkage in the early strength of concrete, surface improvement, elimination of fast drying and thus successive spall of surface grains and reduced plastic settlement of concrete in the vicinity of reinforcement. [22]

Contrary to plain concrete, fibre-reinforced concrete is a material of greater value and toughness. Dispersed reinforcement absorbs mainly tensile stresses and prevents the appearance of microcracks due to concrete shrinkage and

propagation of tensile cracks in the construction, which has a favourable impact on the durability of the concrete construction produced. Dispersed steel reinforcement substantially affects the working diagram of concrete, showing a visible growth in its tensile, but also compressive strength. Steel fibres ensure the fibre-reinforced concrete's deformation ability and its ability of transferring tensile stresses even after the peak tensile strength has been exceeded and cracks have developed. The relative ultimate stretch of fibre-reinforced concrete is greater than that of plain concrete. The growth in tensile strength of fibre-reinforced concrete roughly depends on the volume reinforcement value, and its approximate value may be determined by a calculation. Fibre-reinforced concrete also shows better values for other strength characteristics and has higher non-permeability for water.
Each fibre possesses exactly specified properties from which its efficiency in the resulting composite, such as concrete, is derived. For after high-quality mixing, the fibres will create a three-dimensional structure in the concrete mix. This structure then serves as a basis for the strength behaviour of fibre-reinforced concrete (Table 1).

Table 1 *The table summarizes the basic mechanical properties of PP fibres and steel fibres*

Fibre material	Tensile strength [MPa]	Elasticity module [GPa]	Ultimate stretch [%]	Fibre diameter [μm]	Weight [g/m^3]
Polypropylene	200 - 600	4 – 8	8 – 20	10 - 500	0.9
Steel	500 - 1200	170 - 210	1 – 2	100 - 600	7.85

PP fibres are used as an admixture to concrete, mortars, plasters, screeds, binders, asphalts and bitumen mixes in order to eliminate the failures of these materials. In particular, they prevent the appearance of cracks due to plastic shrinkage and settlement. By adding PP fibres into a concrete mix, concrete becomes a material with higher overall toughness and reliability. PP fibres increase the adhesiveness of fresh concrete. In this way, its module of elasticity is improved. All polypropylene fibres are, therefore, always considered as an admixture to concrete aimed at improving its successive properties:

- **reduced stresses due to plastic drying and settlement in the initial stage of concrete setting, and thus elimination of cracking**
- **improved resistance to freezing and thawing**
- **improved shock resistance**
- **improved abrasion resistance**
- **improved fire resistance**
- **improved weather resistance**
- **reduced depth of penetration for water and chemical substances**

- **simple mixing and dosage**
- **simple separation of fibres in concrete thanks to their lubrication**
- **no risks of fibre corrosion**

6.6 The effect of PP on concrete's resistance to high temperatures
After several recent fires in the tunnels, the importance of increased resistance of concrete constructions to high temperatures has become the topic of the day. The whole mechanism of the interaction depends on the construction's moisture content and the effects of high temperature showing a very steep growth (up to +1200 ^{o}C) within a fraction of the time. In the case of using PP fibres simultaneously with steel fibres, such characteristics can be achieved that may, in a significant way, contribute to the reduction or elimination of the damage of constructions due to high temperature effects. [3]

6.7 The effects of high temperature on the concrete construction
Exposure to fire causes non-uniform volume changes at the points exposed to the effects of high temperatures, which results in collapse, buckling and cracking. It must be realized that the temperature gradients are of extreme nature, i.e. in a range of +20 ^{o}C up to +800 ^{o}C or even more. The concrete construction can resists a temperature of +300 ^{o}C, and a temperature of +500 ^{o}C on a short-term basis only, as here the cement already starts to transform into caustic lime and concrete disintegration occurs. For reinforced concrete, the hazard of a loss of steel bearing capacity is around a limit of + 850 ^{o}C. As soon

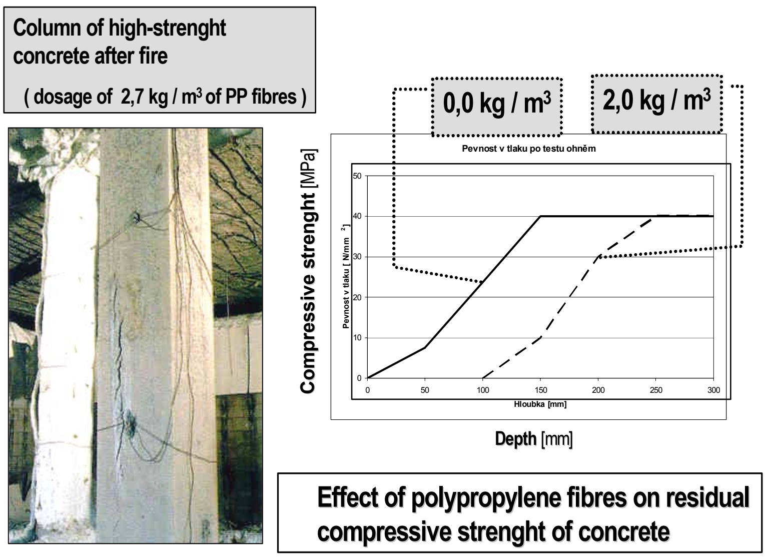


Fig. 10 The effect of PP fibres on residual compressive strength of concrete exposed to fire

as steel reinforcement is exposed by concrete spalling, it expands much faster than the surrounding concrete and loses its adhesion to concrete. The higher the

strength of concrete, the higher the fire resistance of concrete. The present day focus regarding the effects of fire on the properties of load-bearing constructions of steel and reinforced concrete structures is namely on tunnels where the lining must fulfil both technological demands (strength evolution, durability) and the demands for fire safety. As confirmed by the latest research, it is dispersed reinforcement and PP fibres in particular that may significantly improve the fire resistance or behaviour of concrete exposed to fire.
Solution: Elimination of explosive spalling of concrete by using concrete with dispersed reinforcement of polypropylene fibres (with appropriate melting temperature - +180 ^{o}C). By adding 1 kg of PP fibres, the resistance of concrete to explosive spalling of concrete increases. Higher safety occurs at a dosage of ca 2 kg per 1m^3 of concrete, when the effect of PP fibres fully eliminates highly explosive spalling due to fire effects (Fig. 10). [3] Steel fibres do not affect the fire resistance of concrete, and the spalling depth cannot be reduced by steel reinforcement. Short (6 to 12 mm) and thin (18 μm) fibres: By using PP, no structural damage of concrete or steel fibres occurs. No explosive spalling occurs, and as a result repair costs are reduced (the replaced surface layer of the concrete construction is ca 10-20 mm thick).

6.8 Corrosion of concrete

By corrosion of concrete is understood irreversible damage advancing from the surface of the construction. The factors affecting the speed of corrosion may be divided into the factors describing the effects of the aggressive environment and the factors affecting concrete resistance.
The factors characterizing the aggressive environment:

1) the type of aggressive environment given by the nature of prevailing aggressive component
2) the volumes of aggressive component (concentration)
3) physical and mechanical mutual interaction (level fluctuation, mutual interaction of freezing etc.)
4) the temperature of aggressive environment (effect on the kinetics of on-going chemical reactions)

The factors affecting concrete resistance:

1) the chemical and physical composition of cement stone (dependency on the time and conditions of hydration during setting and hardening, on the type of composition and amount of cement, mixing water and admixtures)
2) the porous structure of concrete (affects permeability, absorption capacity, capillary attraction)
3) minimum cross section of the construction
4) the properties of the surface of the concrete construction immediately exposed to the effects of aggressive environment (roughness and potential secondary protection applied in the form of impregnation, coat etc.)

Reinforcement corrosion

The durability of reinforced concrete constructions is highly affected by the effect of reinforcement corrosion, which reduces its efficient surface, produces expansion pressures in the concrete cover, which lead to the appearance of cracks and successive spalling, thus resulting in impaired cohesion between the reinforcement and concrete. Anticorrosive protection of reinforcement is given by high alkalinity of concrete (pH = 12.5 to 13.5), by applying a passivating coat on the reinforcement surface. The above-mentioned implies the necessity of preventing the appearance of the causes leading to alkalinity loss in the vicinity of reinforcement. The most frequent cases of reduced alkalinity of the environment below the passivity limit (pH < 9) are due to the effect of soft water or acid rain water, increased contents of CO_2, SO_2 or NO_x in the air and the presence of chlorides in concrete (Fig. 11).

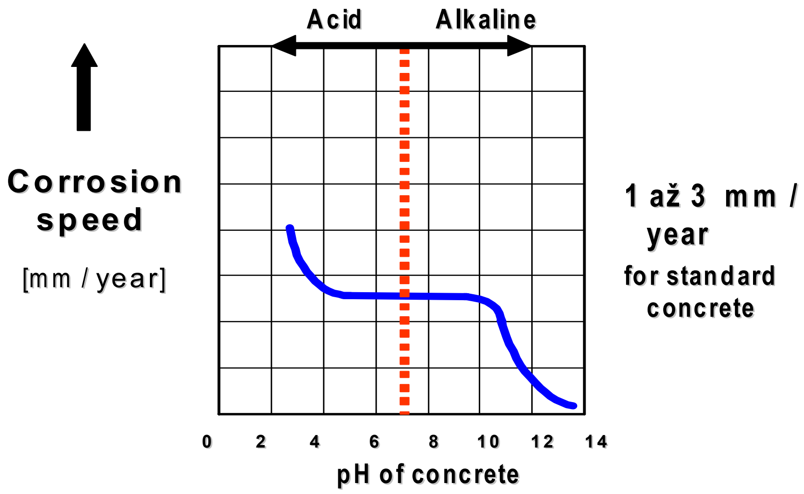


Fig. 11 The effect of pH drop time pattern in concrete - with gradual alkalinity loss in the environment through to effects of aggressive surrounding environment on concrete corrosion

7. Fair-face concrete

Fair-face concrete is the highlight of the surface quality of concrete constructions as it will resist the effects of the external environment retaining the structure's appearance designed by the architect for the whole service life of the structure. That is the reason why high demands are set on the design and placement of fresh concrete of this type, which any other type of concrete would quite naturally deserve, too.

The five fundamental principles for producing high-quality fair-face concrete are the following:

1. For one construction use cement of the same strength class, the same mixing properties (CEM I or CEM II/A) coming from the same cement plant; use aggregates coming from the same localities, namely aggregates with a grain size of up to 4 mm, of the same grading and grain size

composition; keep to accurate dosage of concrete components (main components ± 3% of admixtures ± 5% in keeping with ČSN EN 206-1 standard); in hardening regime - strictly follow the rules of concrete treatment

2. Maintain the same water-cement ratio – the same consistency of fresh concrete (recommended values: consistency S2, cone slump test 90 to 120 mm or spill F2 = ca 500 mm on tapping)
3. The proportion of fine fraction up to 1 mm – higher proportions produce smooth concrete surface, increase the amount of mixing water needed and fresh concrete cohesion (recommended grain content: 0 – 4 mm = 20 %, number of particles up to 0.25 mm including cement = 350 C + 150 K /powder/, i.e. 200 kg/m^3 for max. grain of 16 mm or 460 kg/m^3 for max. grain of 32 mm)
4. Admixtures (plasticizers, air-entraining agents) tested within tests aimed at proving side effects (chemical reactions affecting colour changes on the surface of concrete)
5. Additives – up to 200 µm in amounts of min. 30 % of the weight of cement (fly ash, limestone, slag, stone dust).

7.1 Properties of formwork jacket

The surface of the formwork jacket is one of additional factors which have a significant share in the quality of the surface zone (Fig. 12).

non-absorbent formwork *low-absorbent formwork* *absorbent insert*

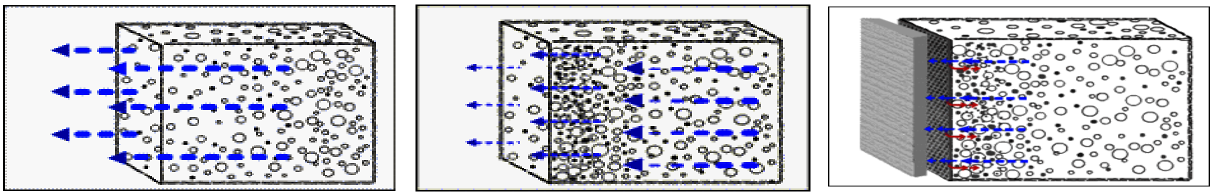


Fig.12 Schematic representation of behaviour of fresh concrete in formwork during placement and compaction, when non-absorption or absorption of the formwork surface affects the surface zone of hardened concrete

Reinforcement and its cover in fair-face concrete

Depending on the type of risk category, the legislation prescribes the thickness of concrete, which protects concrete reinforcement from the effects of the external environment – i.e. by covering the reinforcement. Due to the fact that fair-face concrete is performed by means of the following techniques, it must be mentioned that in the case of disrespect for the technology in terms of providing sufficient reinforcement cover, its reduction may occur, namely in applying the surfacing executed by mechanical methods:

- Textured surface by means of imprint of a matrix inserted in formwork (fig. 14)
- Pigment admixtures in fresh concrete
- Successive surface mechanical treatment (bossing, bush-hammering, scrubbing, scratching, grinding, sandblasting etc.)
- Successive surface coating

Based on practical experience, the following recommendation should be included in the legislative regulations: In designing and successive implementation of fair-face concrete, the prescribed standard value should be increased minimally by 5 to 10 mm (Fig. 13).

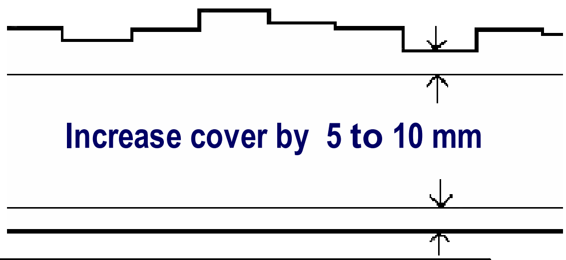
Concrete cover

$$c_{nom} = c_{min} + \Delta c$$

c_{nom} – total concrete cover

c_{min} – minimum dimension

Δc – tolerance for increase



Risk categories	XO	XC1	XC2, XC3	XC4	XD1,XD2,XD3	XS1,XS2,XS3
c_{min}	10	15	25	30	45	45
Δc	10	10	10	10	10	10
c_{nom}	20	25	35	40	55	55

Table in accordance with prepared standard EN 1992-1-1

Fig. 13 For standard environments acting on concrete construction (XC2 and 3) with a recommended cover of 35 mm, the recommended min. value for fair-face concrete should be 45 mm

7.2 Defects of fair-face concrete

During the implementation process of fair-face concrete, a number of problematic phases arise - namely on the level of concrete placement into the construction - that may significantly affect the resulting work despite careful observation of the input factors, such as the appropriate design of the concrete mix and its transport to the site. These are in particular non-homogeneity of compacted concrete – appearance of pores and segregation, and multicolour shades of the concrete surface.

<u>The causes of pore appearance and segregation:</u>

- too fast removal of the internal vibrator's bulb
- compaction from the outside to the core or from top to bottom

- simultaneous usage of external and internal vibrators
- compaction of already setting fresh concrete
- placement of fresh concrete into formwork from great height

The causes of multi-colour surface of concrete:

- simultaneous usage of new and worn out formwork elements
- insufficient formwork rigidity (air intake during compaction)
- insufficient or faulty compaction (e.g. contact of vibrator with formwork)
- small reinforcement cover or rusty steel
- different consistency of fresh concrete or different setting and hardening times

7.3 Standards regulating fair-face concrete
In the Czech Republic, this issue still has not been tackled by the legislation, and therefore there is a necessity for appropriate legislative regulations. (ČSN P ENV 13670-1 Performance of concrete constructions) As for the situation abroad, the problems concerning fair-face concrete refer to the provisions of Austrian and German standards (ÖNORM B 2211, DIN 18217 "Betonflächen und Schalungshaut", DIN 18500 „Betonwerkstein").

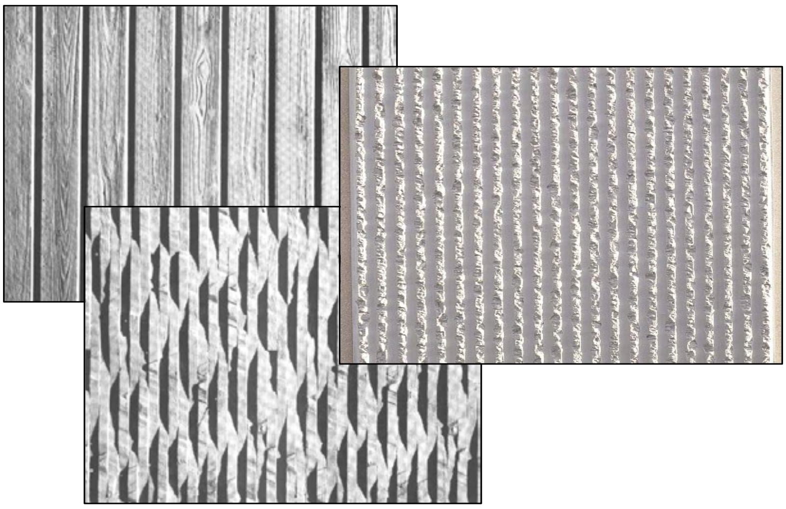


Fig. 14 Fair-face concrete surface texture produced by inserting matrixes into formwork

8. Conclusion

8.1 Summing up of the principles leading to production of durable concrete and to high-quality fair-face concrete. [13], [14]
Concrete with a low water/cement ratio and thus high compressive strength is more vulnerable than concrete with a higher water/cement ratio. It is necessary to eliminate the appearance of microcracks, which due to various impacts –

freezing, dynamic load, ... – grow into cracks allowing easy water transport into concrete thus supporting corrosion processes. In the case of reinforced concrete, the main requirement concerns prevention or considerable slow-down of on-going corrosive processes on the surface of reinforcement.

In order to provide maximum durability of the concrete construction performed the following must be provided:

- frost resistance
- adequate water-tightness
- highest possible volume resistance to temperature and moisture changes
- high diffusion resistance to gas (carbon dioxide or sulphur dioxide) by-passing
- good workability in the widest temperature range
- easy
- cleaning or without susceptibility to surface impurities

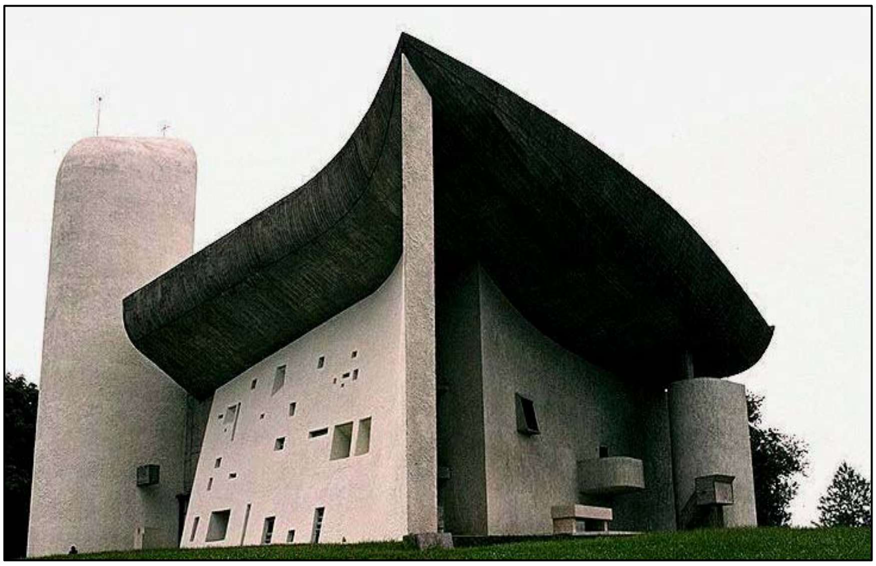


Fig. 15 One of the examples of using fair-face concrete for the entire chapel structure is the chapel designed by Le Corbusiere in France

8.2 The properties of concrete enhancing its durability

- strong
- tough
- water impermeable
- resistant to: - abrasion
  - high temperatures (exposed to temperature changes, concrete and steel behave roughly identically)
- concrete protecting reinforcement from corrosion (tough and with sufficient cover layer)

The causes of main defects – in the design, performance and material with successive failure manifestation:

- Inappropriate design of construction
- Inappropriate design of concrete composition, non-observance of proper mixing proportions of individual components, insufficient compaction, bad spreading of concrete (pouring from great height)
- Insufficient thickness of concrete cover
- Insufficient or faulty water-proofing
- Contamination, unsuitable or reactive aggregates
- Insufficient treatment

Other ways of improving concrete durability:

- Creation of a sufficient efficient barrier between the reinforcing rod and the surface of the construction, which would prevent penetration of water, oxygen, carbon dioxide to reinforcement (concrete carbonation), or sulphur dioxide to concrete (concrete sulphatization) thus maintaining the stable alkaline environment around the reinforcement.
- Cathodic protection [21]
- Direct anti-corrosion protection of reinforcing rods

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Curriculum vitae

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