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Behaviour the Concrete Structures Under the Several Conditions

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Abstract The damaging impact of various chemicals and exposure conditions on concrete materials was investigated, especially in concrete facilities in long time of exploration. This study includes a preliminary analysis of chemically treated water in existing concrete structures, and another after the application of the method and using materials for the structures in future. For repair of existing reinforced structure, new technologies of polymer carbonated materials are used. One of the priorities was to examine the existing concrete structures by using non destructive and destructive methods. After that, based on the results of the analysis, adequate new materials are proposed for the repairs, most commonly new technology polymer carbonated materials, in order to achieve durability of structure elements in using technological processes. Behaviour of the repairing structures was tested using the in situ methods, and especially pull-of test, to verify the adhesion force between the old concrete structures and new applied layer. After the repairing, the concrete structures will be monitored to record the behaviour under the chemical treated water.

Key words: *Reinforced Concrete, Chemical Attack, Repairing, Damages.*

Introduction

Today's concrete is main building material. Modern constructions would be inconceivable without concrete. Our age of globalization requires a stable and fully-functional infrastructure that connects people and markets, and this infrastructure is based on concrete. Global construction every day become higher, bigger and wider and at the same time sets new challenges for materials and technology.

Concrete is wide user material, which is used especially in civil engineering in combination with steel. However, concrete and steel are vulnerable to harmful substances that penetrate into the material by means of moisture. This phenomena cause costly concrete damage due to reinforcement corrosion. The repairing work required to fix the damage is much more expensive than successful prevention with hydrophobic impregnation. Damage to concrete buildings generates costs that run into billions every year.

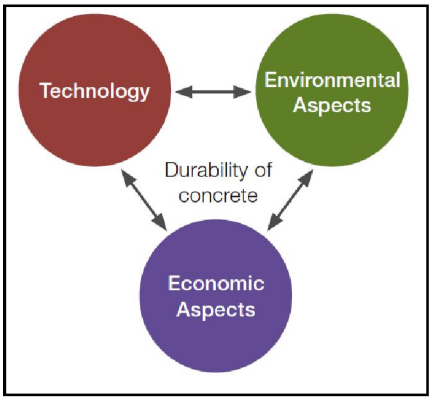

Figure1. Benefits of Durable Concrete (Wacher Chemia AG)

Concrete needs protection by taking preventive measures such as hydrophobic impregnation. Based on to their special penetration effect of hydrophobic impregnation agents, permanently protect concrete against moisture from rain, snow, against road salts and microorganisms and also help in regulation of concrete's water balance. It is estimated that repairing concrete is up to ten times more

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expensive than preventive measures such as hydrophobic impregnation. With new innovative technology for water-repellent treatment of concrete, it is possible to avoid high costs and consumption of energy and resources (Wacher Chemia AG).

Deterioration of concrete by chemical attack

Deterioration processes by chemical attack involve chemical reaction between the aggressive agents in the environment and constituents of cement paste. With a well-hydrated cement paste, the solid phase, composed of relatively insoluble hydrates of calcium such as (C-S-H and CH) exists in a state equilibrium with a high-pH pore fluid. The pH value ranges from 12.5 to 13.5 depending on the concentration of Na^+, K^+ and OH^- ions.

Theoretically, any environment with less than 12.5pH may be branded aggressive because a reduction of the alkalinity of the pore fluid would, eventually, lead to destabilisation of cementations products of hydratation. This means that most industrial and natural waters will be aggressive to Portland-cement-concrete. However, the rate of chemical attack will be a function of the pH of the aggressive fluid and the permeability of concrete.

It should be noted that chemical attacks on concrete manifest themselves into detrimental physical effects, such as increase in the porosity and permeability, decrease in the strength and cracking. The chemical processes can be divided in three subgroups as shown in Figure 2 (Mehta, & Monteiro, 2006).

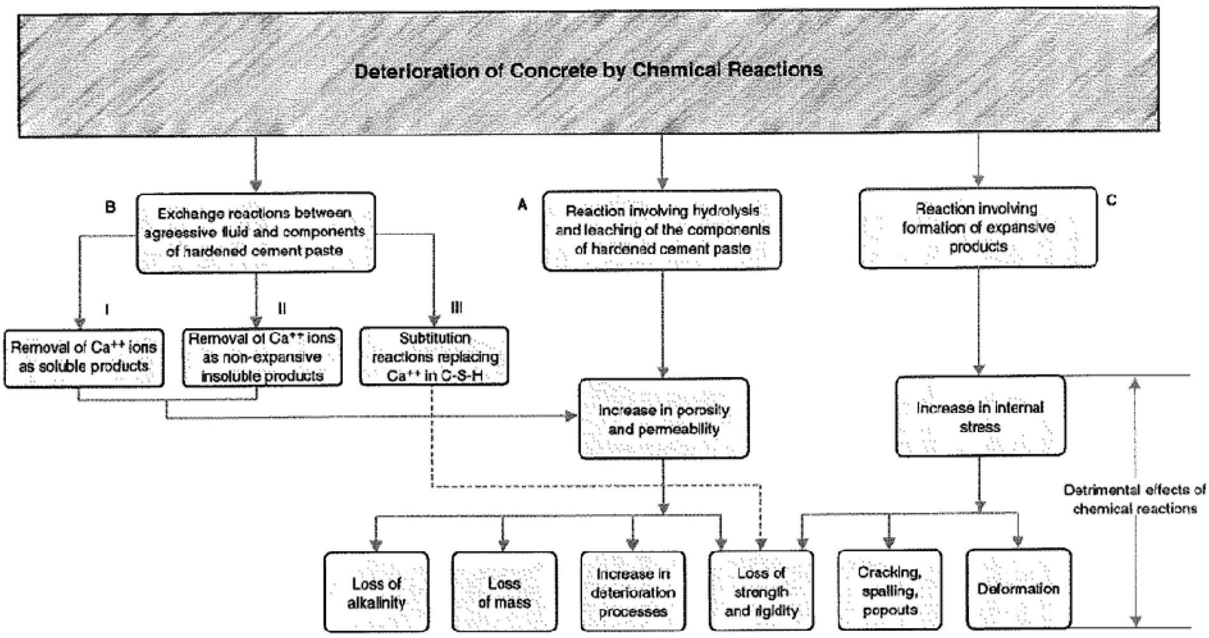

Figure 2. Types of chemical reactions responsible for concrete deterioration. *A: Soft water attack on calcium hydroxide and C-S-H present in hydrated Portland cements; B(I): acidic solution forming soluble calcium compounds such as calcium chloride, calcium sulphate, calcium acetate, or calcium bicarbonate; B(II): solution of oxalic acid and its salts, forming calciumoxalate; B(III): long-term seawater attack weakening the C-S-H by substitution of* Mg^{2+} *for* $Ca^{2+;}$ *C: sulphate attack forming ettringite and gypsum ,alkali-aggregate attack, of steel in concrete, hydration of crystalline MgO and CaO (Mehta & Monteiro, 2006).*

Sulphate Attack

Sulphate attack can manifest in the form of expansion and cracking of concrete, in this way also the permeability and the aggressive water penetrates more easily and accelerates the process of deterioration. Higher concentration of sulphate in groundwater is generally due to the presence of magnesium, sodium and potassium sulphates. Ammonium sulphate is frequently present in agriculture land and water. Also, the water used in concrete cooling towers may also contain a high concentration of sulphate due to evaporation, thus it is common to find deleterious concentrations of sulphate in natural and industrial waters (Mehta & Monteiro, 2006). Delayed ettringite formation is a case of chemical sulphate attack. Ettringite is the mineral name for calcium sulphoaluminate ($3CaO•Al_2 O_3 •3CaSO_4 •32H_2 O$), which is normally found in Portland cement concretes. This phenomenon is not new. It is known to occur when either a gypsum-contaminated aggregate or a cement containing unusually high sulphate content has been use on the concrete production. Ettringite is not a stable phase above 65 ^{0}C, it decomposes to form the monosulphate hydrate if steam-curing temperatures higher than 65 ^{0}C are used in manufacturing process. The sulphate ions released by decomposition of ettringite are absorbed by calcium-silicate hydrate. Later, during the service, when sulphate ions are desorbed, the reformation of ettringite causes expansion and cracking. A diagrammatic representation of holistic approach to DEF related expansion and cracking is shown in Figure 3 (Mehta & Monteiro, 2006).

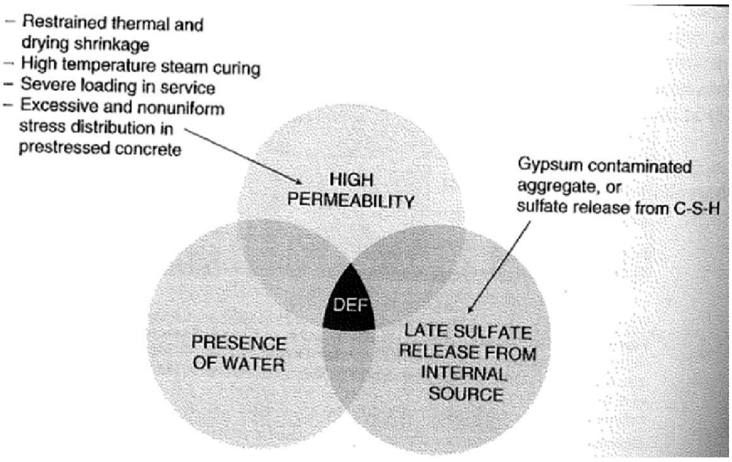

Figure 3. A diagrammatic presentation of holistic approach to DEF related to cracking and expansion (Mehta & Monteiro, 2006)

Deterioration by Corrosion of Steel Reinforcement Concrete

Corrosion can be described as the deterioration of a material, usually a metal, by a chemical or electro chemical reaction within its environment. In this case we are looking at corrosion of steel reinforcement in concrete. When steel is embedded in concrete a passive oxide film forms upon its surface. This film is maintained by the alkaline nature of the concrete (typically in excess of pH 12.6). While this passive film is present, the steel is immune to corrosion and therefore gives stability to a structure. However, when the concrete becomes carbonated the local or global pH of the concrete can fall, causing passivity to be lost and corrosion to occur.

Chloride induced corrosion is also a major problem and can mean the concrete around the steel can still have a high pH, high enough for passivation, but once the chlorides reach the steel they break the passivation layer and corrosion occurs.

A number of everyday contaminants can cause corrosion:

- Airborne chlorides
- Seawater
- Carbon dioxide in the atmosphere
- Sea-dredged aggregates
- Chloride containing admixtures

During the corrosion process, a by-product is formed (rust), which occupies a volume seven times greater than that of the native metal. This volume change causes cracking and eventual spalling of the concrete surface.

Areas prone to corrosion on a marine structure can be categorized into three areas:

- Atmospheric zone. This is reinforced concrete located in the vicinity of the marine environment, but not in direct contact with water; i.e. bridge decks, soffits and beams. These elements often display moderate corrosion rates due to the presence of airborne moisture and chloride.
- Splash and tidal zone. This is the area located on and around the water line and is often classed as semi-submerged; i.e. concrete piles and piers. These elements generally experience the most severe corrosion due to the high moisture, oxygen availability and wet/dry cycling.
- Submerged zone. This is reinforced concrete permanently located underwater, *i.e.* marine piles. These areas can experience lower levels of corrosion due to reduced oxygen levels. However, while corrosion here is less aggressive, submerged areas are at risk from another problem

known as black rust and low water corrosion (Concrete Institute of Australia; Elsner, 2000; Emmons, 1993).

Figure 4 Concrete permanently located underwater, i.e. marine piles (Concrete Institute of Australia)

Selecting a Corrosion Protection Strategy for Concrete Structures

Selecting the appropriate level of corrosion protection is based on many factors such as the level of chloride contamination and carbonation, amount of concrete damage, location of corrosion activity (localized or widespread), the cost and design life of the corrosion protection system, and the expected service life of the structure. The following levels of protection can be used as a guide to decide the most effective strategy.

Corrosion prevention is used to prevent corrosion activity from initiating in contaminated concrete. To mitigate new corrosion activity from occurring around concrete repairs or at other interfaces between new and old concrete such as bridge widening, joint repairs and slab replacements, a simple localized corrosion prevention strategy utilizing with Galvashield® XPT or Galvashield®XP2 embedded galvanic anodes, can extend the life of concrete repairs.

The use of corrosion control systems will either stop on going corrosion activity or provide a significant reduction in the corrosion rate and an increased service life of their habilitated structure. Galvashield® XP2 and XP4 anodes can be used in corrosion control or corrosion prevention applications. Galvashield® CC anodes are used to provide targeted galvanic corrosion control to columns, beams, decks, post-tensioned anchorages and other structures where on-going corrosion activity threatens the service life of the structure. Galvanode® DAS anodes can also be used in concrete overlays, concrete jacketing and other concrete repair applications to provide long lasting galvanic protection.

Cathodic protection provides the highest level of protection and is intended to stop on-going corrosion activity. Impressed current systems such as those that use Ebonex® discrete anodes and Vectorode® catalyzedtitanium anodes utilize an outside power source. For long term performance, these systems should be monitored and maintained. Ebonex anodes are ideal to protect heavily reinforced concrete, thick structural sections such as columns or beams, or steel framed masonry buildings while Vectrode anodes are placed into slots cut into the concrete surface or underneath a concrete overlay. Galvanic systems are typically designed to provide corrosion control or cathodic protection. The systems are self-powered and require less monitoring and maintenancethan ICCP. Galvashield® Jackets are used to protect marine pilings and other structures. Galvanode® DASand Galvanode® DAS Marine anodes can also be used in concrete overlays, concrete jacketing and other concreterepair applications to provide long lasting galvanicprotection.

Corrosion Passivation is provided by electrochemical treatments which are aimed at directly addressing the cause of the corrosion activity. Norcure® Chloride Extraction isused to address chloride contaminated structures such as bridges and parking garages. Norcure® Re-alkalisation is commonly used on carbonated building facades. These systems are installed onto the structure, operated for a short duration, then dismantled and removed leaving the structure in a passive condition. Electrochemical treatments provide many of the long-term corrosion mitigation benefits of cathodic protection systems but without the need for maintenance and monitoring (Concrete Institute of Australia; Elsner, 2000; Emmons, 1993).

Case Study: Effect of Treated Water in Concrete Structures

One of the typical cooling systems is Power Plant near of Prishtina, in one of the part of system is facilities for treated water , were the main domain is using for following steps:

- Clarified water as cooling tower make-up and service water;
- De-mineralized water for heat cycle make-up, equipment cooling system makeup, condensate polishing plant regeneration etc.;
- Filtered and disinfected water for potable water requirement.

The water using for cooling system is treated water in two facilities:

- The treated water in water basins using the coagulant $Fe_2(SO_4)_3$ with polymers in percent of 48%. In this way, the concentration in water will be reduced from 3%-5%;

- The next step will be treated with lime, where by the concentration of hydrated lime is at 90%, such the lime milk with dosage mass 170 mg/L. The treated water will be rotated in reactors and after the homogenization will be used for cooling (Kabashi, at al, 2014]

Concrete Structures under Several Conditions (under Treated Water)

The concrete surface directly under the treated water was damaged on the surface as a result of different conditions. For this reason, an assessment is carried out applying the following steps:

- Visual inspection of structures;
- Examinations of quality of existing concrete;
- Cleaning and treating the surface
- Materials for repairing the structures;
- Applying the methods for repairing;
- Repairs are evaluated through the examinations of structure.

The concrete facilities stage during the inspections is on the conditions presented in Figure 6. The following steps are applied in this analysing and solving the actual protection and repairing the typical concrete structures (Kabashi *at al*, 2014).

Figure 6. The concrete structure during the visual inspection: outside and inside.

Visual Inspection of Existing Structures

The visual inspection resulted in the need to remove the existing additional materials, because the process of damage of concrete surface is ongoing and also leaking water is also visible outside (Kabashi, at al, 2014)

Examinations of Quality of Existing Concrete

To analyze the quality of existing concrete, the authors applied the nondestructive examinations tests, in the first step of the preliminary results. The examinations were done in 20 different points with Hammer Schmidt in the perimeter of the concrete. The received data are presented in Table 1.Based on the results, the quality of concrete allows to apply the repairing methods, including the injection methods and repairing the surface in both sides-inside and outside (Kabashi, at al, 2014).

Cleaning and Treatment of the Surface

The internal surface of concrete was damaged during as a result of 30 years of use and the sedimentation of the lime from treated water. The lime and sulphates are connected fast to the existing concrete and as a result both cleaning methods had to be applied:

- High pressure water for removing the damaged parts;
- Mechanical removal of the damaged part.

The surface before cleaning, during the cleaning and after cleaning is presented in Fig. 6

The surface after the cleaning is treated with primer layer before applying the repairing mortar or layer of mortar (Kabashi *at al*, 2014).

Table 1. Results of the analyses data of the concrete

Pos	Date	Point	X_{min}	X_{max}	s	$X_{average}$	F_{ck} specified compressive strength (N/mm^2)
Wall	>30 y	1-4	41	55	3.6	61	
Wall	>30 y	5-8	34	51	3.7	45.3	
Wall	>30 y	9-12	39	50	3.8	46.1	
Wall	>30 y	13-16	46	54	2.3	50.9	49.2
Wall	>30 y	17-20	34	50	3.7	45.3	
Wall	>30 y	21-24	42	52	2.9	48.1	

Materials for Repairing the Structures

In this case the materials to be used for the repairs are analyzed based on the main properties:

- Behavior of the materials under the treated water;
- Compatibility of materials with existing concrete (quality of concrete);
- Durability of the repairing materials;
- Stopping the leaking of water outside of reactor.

The materials used are from the producer MAPEI-Italy: Primer, Mapefer, Mapegrout T40, Mapelastic, Rexofoam .All the proposal materials meet the requested properties and are approved for repairing. (Kabashi *at.al,* 2014) (Products and Technical Data, Catalogue of Products MAPEI).

Figure 7. Removal of the damaged parts and the cleaned concrete surface inside.

Repairing Methods with Mortar

Mortar Mapegrout T40 in technical specifications has the properties necessary for the wall repairing inside and outside. Medium strength (40 MPa) fibre-reinforced thixotropic mortar is for the repair of concrete. Mapegrout T40 is also recommended for repair working tunnels, canals and water works in general. Mapegrout T40, mixed with about 16% water, forms a very workable mortar with a thixotropic consistency that is easily applied on vertical surfaces without shuttering. Repairs up to 30-35 mm thick in a single coat can be made. To improve open-air curing and further reduce shrinkage, Mapegrout T40 can be mixed with 0.25%by weight of Mapecure SRA, curing agent. Mapegrout T40 meets the minimum requirements of EN 1504-3 standards for R3-class structural mortar. In Fig. 8,a presents the method of repairing surface using the dry methods of preparing mortar and injection method.[Concrete Institute of Australia][Concrete Repair and Maintenance].

Examinations of Repairs on Structures

All activities will be under the EN Standard 1542, and must improve the durability of new repaired structures. One of the requirements in this case is the bond strength between the old concrete and new layer. To verify the bond strength, the authors used the "Pull-of Test Method-EN 1542" and the methodology of examinations and results are presented in Figure 8.b which situation before and after are presented in Figure 9.

Figure 8. a-The injection methods for stopping the water leaking from the reactor and apply the mortar in ready surface **b-**Examinations of bonding strength (Kabashi, at.al, 2014)

Figure 9. Water treatment facilities after repairing (Kabashi at.al, 2014)

Conclusions

Based on the specifications of this project and in general for the repairing works, the authors can conclude:

- The treated water with chemical elements, environmental conditions and the indicative factors caused the damage in concrete structures and the authors' activity is focused for repairing the existing structure;
- The non-permanent assessment and non-permanent inspections, result on the concrete damaged under the specific conditions, such is treated water;
- Selection of repairing materials and methodology of repairs is decided after the analyzing the compatibility of the materials and the existing materials in structures;
- The testing results are satisfactory for this kind of structures and based on the preliminary request;
- The structure is in good conditions after the one year of repairing;
- Using the materials from the same producer is one of the good opportunity, in this case the materials from MAPEI-Italy have very good results

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