A NEW NON DESTRUCTIVE PROTOCOL OF MOISTURE DECAY IN REINFORCED CONCRETE

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ABSTRACT

This following contribution is inherent the topic: Management Schemes and Maintenance.

Almost all the concrete buildings are significantly affected by environmental thermo hygrometric variations. On the one hand, the visible effects of the resulting decay are the expression of an already advanced progression of the pathological phenomenon, on the other hand the existing heritage historical-aesthetic value frequently imposes the employment of non, or minimally, destructive testing.

The probabilistic nature of these trials’ results brings about the necessity of developing a surveying protocol that, using various procedures (based on different physical-chemical principles), might limit the uncertainty degree of the results obtained.

This protocol, finding its bases on the theoretical knowledge of the decaying process, provides a reliable answer to the decaying phenomenon’s primer and evolution and to the periodical maintenance intervention.

The surveying scheme is to do a magnetic scan of the surfaces, followed by a series of electrical resistivity measurement.
Subsequently, testing and crossing time measurement of ultrasonic waves will be carried out. Finally, testing with dye toning indicator and without the extrusion of sample material will follow.

Key words: Decay, Concrete, Moisture, Carbonation, NDT.

Introduction

The wearing effect of time that stresses the integrity of buildings and marks on them the traces of decay, testifies the quality, that is to say the durability, of a constructive technology. The concept of quality becomes, in this way, an assumption it is only possible to bet on.

The environmental thermo-hygrometric conditions significantly affect the totality of concrete reinforced buildings, often in a permanent way.

When the decay effects become visible, the progression of the decay mechanism has reached an irreversible stage.

The resulting surface decay is usually interpreted as non influential on the building static safety. This attitude betrays the basic aim of the structural design that assigns each part for the entire dimension –both for concrete and metallic rods – an exclusive and indispensable static role.

It has been useful to search for a survey protocol that might reveal the decaying process, when its effects are not visible and, so, still at the beginning of the mechanism progression. This might prevent from more considerable and irreversible damages or simply lead to plan a monitoring program.

The Decay Mechanism

The high hydraulic capacity of concrete’s chemical components makes it extremely resistant to wetting cycles; water, that in normal conditions is absorbed and released by manufactures, does not alter their chemical and physical order.

If metal bars are present inside the concrete and if the environmental conditions where the building is are aggressive\(^1\), the normal wetting cycles significantly alter the original balance of the concrete mixture.

\(^1\) The highly reactive substances that may be contained in the atmosphere can attack the concrete’s chemical components.
Water, acting as a vehicle, introduces some substances in the deepest layers of the concrete that otherwise will never penetrate it (Trojan’s horse effect). So, chloride compounds or high carbon dioxide concentrations dissolved in the atmosphere may show their reactivity towards the concrete mixture components, upsetting the chemical bounds and forming new compounds.

In this way the carbonation process forms the basis for the premature aging of reinforced concrete manufactures. Atmosphere carbon dioxide, thanks to meteoric water, penetrates the concrete and combines with calcium hydroxide giving birth to corresponding carbonate. Hydroxide is the main responsible for concrete’s highly basic pH and allows this latter to inhibit the oxidation of the metal elements it wraps.

The reaction that leads to the conversion of calcium hydroxide into carbonate renders the mixture poor of its basic component, the pH precipitates in a range of values that, from 12 to 13, go to 9 to 10. As soon as the metal rod comes into contact with water and oxygen, the oxidation phase starts and it leads both to the steel upset and its dilatation. The surface concrete portion, that separates the metal rods from the atmosphere, is so pushed and cast out. Since that moment, the rods suffer from a direct exposure to the environment and their corrosive process becomes extremely rapid and grave, till the exhaustion of the entire reacting iron mass.

The Decay Effects

When in contact with water, every stony substance alters its original colouring. Likewise, also concrete undergoes a generally reversible chromatic alteration when in contact with water.

When water drags harmful substances into the concrete, after evaporation, the chromatic alteration becomes almost irreversible. The chemical reaction and the degeneration of the original physical condition lead to the progressive formation of micro internal fractures which reach the surface of the reinforced concrete. Because of the direct contact with the atmosphere, the fractures become bigger and bigger in size and, by expanding, make this layer of concrete more porous and crystalline. The corrosion of the metal rods and the resulting increase in volume produce a swelling of the concrete layer adjoining the metallic reinforcement and, ultimately, its expulsion itself (Fig.1 and 2).

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2 Normal steel, if embedded in concrete, behaves like stainless steel because of the high basic pH that surrounds it.
Any intervention on a building, even if simply devoted to a preventive diagnosis of a possible decay mechanism, must follow a precise methodological path. Generally, a fundamental step is represented by the accurate knowledge of the building, from its anamnesis to its technical constructive features.

After a careful visual investigation of the building, taking into account the architectural characteristics that might render some of its parts more subject to the wetting cycles, an infrared thermograding scan is carried out in order to confirm the identification of the areas which are at risk of decay.

Thermography, taking into account the concept of emissivity strictly connected, on its turn, to the surface temperature of a body, will highlight the surfaces that, being at a lower temperature, might present ponding. In these areas, some resistance electrical measurement will be carried out in order to confirm or deny the outcome of the infrared thermograding scan (Figure 3 and 4).
Identified the areas with an excessive amount of surface water – such a condition appears to be more critical if it coincides with the points where the reinforcing bars are embedded – a magnetoscopic scan follows in order to identify the position and the depth of the reinforcing bars housing. These positions are indicated with the use of colored chalk in order to reproduce the trend of the iron rods (Figure 5).

Next to the colored marks, either to verify the presence of micro cracks or to examine the concrete’s state of maintenance, elastic bounce trials (sclerometer testing) are carried out.

If the outcome of the investigation conducted so far outlines the potential primer of the decay mechanism, so the dye toning trial will be carried out in order to determine the depth of the concrete carbonation. This last method, worked out in a new modality of application, will be illustrated in the following paragraph.

Phenolphthalein test as measurement of carbonation depth

Phenolphthalein is a dye toning indicator that allows to identify highly basic pH values through the chromatic alteration of the surfaces it gets into contact with and, specifically, because of its reactivity with calcium hydroxide (Figure 6).

The trial consists in the extraction of a stony material core to be investigated, that after being wet with phenolphthalein in 1% alcohol ethylic solution, shows how pH varies according to the core’s depth.

This extremely effective method, that permits to reuse the same core for other intents, is faulty in being particularly invasive to the manufactures; in this way, it cannot be taken into account when diagnosing historical-aesthetic valuable buildings, being the removal of any minimal parts of theirs legitimately banned.
Besides this significant obstacle, the extraction of sample material remains a complex procedure, both for the employment of cumbersome heavy core barrels (Figure 7) and the use of a conspicuous quantity of water, necessary for the cooling down of the extractor, that has to be dispersed in the place where the extraction is conducted (Figure 8).

![Figure 6](image)

![Figure 7](image)

![Figure 8](image)

It has been developed a new trial method based on the application of phenolphthalein on concrete. It does not need the extraction of any sample material and, at the same time, allows detecting the primer and the depth of carbonation.

It is possible to find here the results of an experiment carried out on a specimen usually employed for the tensile test of tile-concrete floor’s joists, made with a casting of mid-range resistance and with metal reinforcement of modest thickness, but densely distributed.
In a preliminary phase a magnetoscopic scan is conducted in order to trace the metal bars’ position\(^3\).

The points on the sample (from one to three) where the test will be carried out are then selected and marked, trying to avoid the areas with evident anomalies\(^4\).

\(\text{Figure 9} \quad \text{Figure 10} \quad \text{Figure 11}\)

In A (Figure 9) it is made a hole 6 mm in diameter and 6 to 8 mm in depth\(^5\); the powder material expelled (Figure 11) is collected and stored in a dry container. Then, a further check of the depth through a gage is conducted (Figure 10).

After clearing out the hole with compressed air, a little quantity of phenolphthalein is injected into the bottom of the hole\(^6\) with a common syringe (Figure 12). If calcium hydroxide is present, this will chemically react with phenolphthalein.

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\(^3\) The points are located far from the metal reinforcement. Besides, the carbonation progress intended as chemical process is not influenced by the presence of the reinforcement itself.

\(^4\) It will be excluded the points next to casting seams, porous portions, or coinciding with placing or removing defects.

\(^5\) In order to stop the drilling at the desired depth, a metal crown is applied to the stainless steel tip of the core drill, blocking it at the same distance as the one that we want to impose to the hole.

\(^6\) The trial in examination takes into account vertical holes and this renders the wetting of the bottom part of the hole easier. However, in case of horizontal openings, the employment of the needle allows a correct collocation of the tracer.
After 3-5 minutes the observation phase starts and, in case of modest depth, it can be carried out in normal lightning conditions.

The absence of calcium hydroxide, as a consequence of the carbonation process, involves the lowering of the basic titer and the lack of color of the surface which comes into contact with phenolphthalein.

If this does not happen (figure 13), it is necessary to repeat the test making a deeper hole, in order to investigate the concrete at a major depth (figure 14).

Because of environmental conditions, concrete age and all other variables that affect the process of carbonation, the test outcome might be obtained only after one or two drillings and so in few millimetres, otherwise it is necessary to go on for several centimetres.

The test is to be considered over when on the bottom of the opening the phenolphthalein turns into purple and so the depth of the hole coincides with the extension of the carbonation inside the concrete.
The expelled material, which has been stored, is now mixed to a colourless expansive cement-like binder for the filling up of the holes.

**The Protocol Application**

The diagnosis protocol has been first tested on a series of concrete samples and then on walls.

The survey carried out in laboratory has aimed at verifying the protocol effectiveness through applications on dry samples and then on the same samples after numerous artificial wetting cycles. The answers obtained have coincided with the previsions, showing all the expected variations and highlighting the anomalies caused to the samples.

Although corresponding to the expectations, a more certain answer about the effectiveness of the protocol would have been acquired only through the application of the protocol itself on a real structural element. In this way, the results of a survey conducted on an outer wall of modest dimensions follow hereafter.

A magnetoscopic scan (figure 16) has been carried out on the wall subject of the experiment. This has permitted to trace the position of the reinforcing bars and to identify those more emerging, that is to say those covered by a thinner layer of concrete.

The wall analysed shows visible chromatic alterations (Figure 15) but its modest dimensions and various days of sunlight exposure, that have preceded the one in which the test has been conducted, have made it particularly dry. In this way, the infrared thermograd scans and the resistance electrical measurement (Figure 17) have highlighted only slight anomalies. Differently, the elastic bounce trials (Figure 18) carried out next to the reinforcing bars have pointed out the presence of a series of superficial micro fractures.

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7 Reproducing in laboratory an aging cycle able to generate on a sample the same effects of several years of wetting, is a very complex operation whose result is often uncertain.
The measurement of the carbonation depth has pointed out that the wall is carbonated up to 42 mm in depth (figure 19 and 20). The drilling has not been carried out up to a major depth as, having reached and crossed the symmetry axis – seeing that the wall thickness is 80 mm – it has been possible to affirm that the wall is entirely carbonated. So all the metal rods are at risk – or already in phase – of corrosion.
If the carbonation depth highlighted inside the wall had been inferior to the reinforcement housing’s measurement, the metal bars would not have been at risk of corrosion.

The theoretical knowledge on the progression of carbonation and on the environmental conditions’ influence, have been translated into diagrams that describe the increase of carbonation depth depending on the time and on the above mentioned environmental conditions.

In case of a negative result of the protocol, these theoretical instruments lead to determine the laps of time for the application of the protocol itself and so to work out a monitoring program, to verify the progression of the phenomenon and impose a recovery intervention preventively, defining an effective maintenance plan of the building component.

References